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Translation

ECONOMICS OF FUELS AND ENERGY TRANSPORTATION

By

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ECONOMICS OF FUELS AND ENERGY TRANSPORTATION

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[Chapters 1-7, pp 159-162 of Chapter 8, Chapters 9 and 10, Conclusions and Bibliography from the book "Economics of Fuels and Energy Transportation" by Serafim Sergeyevich Ushakov and Tatyana Mikhaylovna Borisenko, ed. by Ye. O. Shteyngauz, Izdatel'stvo "Energiya," 5,000 copies, 192 pages]

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Chapter 1. The Role of Transportation in the Energy Complex

[Text] 1.1. Main Trends in Development of the Energy Complex

The scientific and technical revolution--the growth of productive forces and consequently the growth of energy consumption--had an enormous effect on formation of the world's energetics. Worldwide energy consumption increased 3.6-fold during the period 1950-1977 (Table 1.1), and ore consumption increased 5.9-fold, gas consumption increased 7.1-fold, coal consumption increased 1.8-fold, peat consumption increased 1.2-fold, wood consumption increased 1.9-fold and water power consumption increased 3.9-fold. The advances of science made it possible to utilize a new type of fuel--nuclear fuel--and its consumption was equivalent to 360 million tons of comparison fuel in 1977 [30, 71].

The worldwide energy complex and the energy balance are formed under very complex conditions under the influence, on the one hand, of the planned economy of socialist countries, and on the other hand under the influence of the economy of capitalist countries. The nonuniform territorial distribution of resources in countries themselves and the disparity of a fuels raw material base and the needs of countries' economy for energy resources have a significanct effect on the structure of the fuel balance.

Prior to 1973, the energy complex and energy balance of the capitalist countries was formed mainly due to an increase of petroleum use and in some countries of gas use; the fraction of coal usually decreased (Table 1.1). Oil comprised 23.8 percent and 43 percent in 1973 in the worldwide structure of the energy balance, while the fraction of coal decrased from 54.1 to 27.1 percent during this period. This was determined by the discovery of abundant oil fields in the developing countries of the Near East, Africa and South America and by favorable conditions of deposition and low costs for development of the oil fields of the developing countries. One-sided agreements concluded by the oil companies with the governments of the oil exporting countries led to the fact that the petroleum fuel of developing countries was more economical than any other kind even with the transportation

Table 1.1.

(1) Вид топлива и энергии	(2) Энергопотребление, млн. т условного топлива / % к итогу за год					
	1960	1965	1970	1973	1975	1977
(3) Всего	2852 100	5808 100	7580 100	8699 100	8855 100	10 166 100
Нефть (4)	680 23,8	1998 34,6	3058 40,4	3737 43,0	3560 40,3	3981 39,2
Газ (5)	256 9,0	952 16,5	1405 18,5	1664 19,0	1700 19,2	1815 18,9
Уголь (6)	1544 54,1	2166 38,1	2285 30,2	2382 27,1	2506 28,3	2839 27,9
Торф (7)	18 0,6	20 0,3	22 0,3	25 0,3	22 0,2	21 0,2
Дрова (8)	167 5,9	305 4,3	314 4,1	321 3,7	320 3,6	320 3,2
Гидроэнергия (9)	187 6,6	357 6,1	465 6,1	522 6,0	610 6,9	730 7,1
Атомная энергия (10)	— —	10 0,2	31 0,4	77 0,9	137 1,5	360 3,5

Key:

1. Type of fuel and energy
2. Energy consumption, million tons of comparison fuel/percent of annual total
3. Total
4. Oil
5. Gas
6. Coal
7. Peat
8. Wood
9. Water power
10. Atomic energy

costs figured in and at the same time provided high profits to the oil monopolies. Thus, the cost of oil in 1972 comprised 16-25 dollars per ton in the Persian Gulf and the Mediterranean Sea areas, the cost of delivering it by tanker to the United States was approximately 1-2 dollars per ton, the cost of transportation from the port to the petroleum refining plant was approximately 1.3 to 1.5 dollars per ton [96, 97], whereas the cost of producing American oil comprised 88-103 dollars per ton [86, 87].

The economy of a number of capitalist countries was determined largely by the beginning of 1973 by oil supplies: in 1972 the specific weight of imported oil comprised 59 percent in the total energy consumption of Western Europe and 72.6 percent in the energy consumption of Japan. The fraction of imported oil in the energy balance comprised 13.5 percent even in the world's largest oil-producing country--the United States [105]. The orientation of the energy base of capitalist countries toward imported oil made them dependent on OPEC countries,* which could make demands on the largest capitalist countries. The OPEC countries raised the prices for oil: the cost of oil in the Persian Gulf and the Mediterranean Sea areas comprised 100-120 dollars per ton in 1977-1978. This in turn led to the need for a number of capitalist countries to review the entire energy balance from the aspects of the greatest involvement of their own energy resources and development of atomic power engineering.

The result of the 1973 energy crisis was a reduction in the fraction of oil consumption and an increase in coal consumption by 457 million tons of comparison fuel and an increase of power generation by hydroengineering and nuclear power plants (although the specific weight of water power increased from 6.6 percent in 1950 to only 6.9 percent in 1975 and to 7.4 percent in 1977). Rapid growth in the rates of atomic power development have been observed, but its specific weight was still insignificant in 1975, approximately 1.5 percent of worldwide energy consumption, and was only 3.5 percent in 1977.

The energy complex of the socialist countries was formulated in proportion to development of their economy and was not subject to sharp jumps. The energy balance of all the CEMA member countries was formulated through their own energy resources with extensive use of all types of fuels. The specific weight of solid strip-mined fuels is higher in these countries than the worldwide average [14, 68].

The vigorous growth of oil production in the developing countries and the ever increasing consumption of oil andpartially of liquefied gas in industrially developed countries induced vigorous development of maritime shipments of petroleum and pipeline transport of petroleum mainly from the fields to ports, from the ports to oil refining plants and of product pipelines from the plants to consumers. Intracontinental pipeline transport of gas was developed extensively. Very large gas and oil transport systems have now been developed in the United States, the USSR and Western Europe. The total length of the world's major pipelines has reached 680,000 km [30, 97].

Table 1.2.

Вид транспорта (1)	Структура транспорта, %, общего объема перевозок (2)		Вид транспорта	Структура транспорта, % общего объема перевозок	
	(3) СССР	США (4)		СССР	США
Нефть (5)			(10) *Нефтепродукты*		
Трубопроводный (6)	85	75,3	Трубопроводный	10	36,0
Железнодорожный (7)	11	0,2	Железнодорожный	78	2,0
Водный (8)	4	18,2	Водный	12	22,6
Автомобильный (9)	—	6,3	Автомобильный	—	39,4
Итого: (11)	100	100	Итого:	100	100

[Key on following page]

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*OPEC now includes Algeria, Venezuela, Gabon, Indonesia, Iraq, Iran, Qatar, Kuwait, Libya, Nigeria, the United Arab Emirates, Saudi Arabia and Ecuador.

[Key continued from preceding page]:

1. Type of transport
2. Structure of transport, percent of total volume of shipments
3. USSR
4. United States
5. Petroleum
6. Pipeline
7. Rail
8. Water
9. Motor
10. Petroleum products
11. Total

The total freight turnover of all types of intracontinental fuel transport comprised approximately 7 trillion ton-kilometers, which comprises approximately 40 percent of the world's total freight turnover.

The distribution of intracontinental shipments of liquid fuel by types of transport is determined by the specific development of the countries in the USSR and the United States (Table 1.2).

The transport component in the cost of gas in the United States and the USSR is equal to 20-30 and 60-80 percent, respectively, while the transport component of oil is equal to 10-20 and 30-40 percent of its cost. An increase in the fraction of the transport component in the cost of gas and oil should be anticipated in the United States with regard to the need to develop oil and later gas fields in the northern portion of the American continent [76, 96].

A significant fraction of the transport component in the cost of fuels and an increase in the distance of delivery and also the need to construct mainlines under complex and hydrological conditions posed the problem of intensification and more extensive use of scientific and technical progress to transportation. This is an increase of pressure and cooling of gas, an increase of the unit capacity of gas-pumping units and so on in pipeline transport of gas, in railway transport these are various engineering solutions that permit an increase of the carrying capacity of mainlines from 90-100 to 180-200 million tons per year and so on.

The main intercontinental flows of fuels (Figure 1.1) are increasing: the import of oil comprised 1.486 billion tons in 1977, including 582 million tons to Western European countries, 331 million tons to the United States and 237 million tons to Japan [86, 87]. This is also typical for flows of petroleum products; their export from Western European countries comprised 120 million tons, while imports comprised 140 million tons. The import of petroleum products to the United States comprised 88 million tons. During the last few years, oil imports to the United States increased sharply. The total turnover of international marine shipments of petroleum and petroleum products comprised 16.8 trillion ton-kilometers in 1977. Intracontinental shipments of gas and coal are increasing: they comprised 116 billion m^3 and 121 million tons, respectively, in 1977 [81]. Maritime transport of oil costs one-third as much as pipeline transport and the average cost of delivering oil by sea comprises approximately 1.2 dollars per ton for a distance of 4,000 kilometers, while delivery of oil by pipeline comprises 3.6 dollars per ton for a distance of 1,000 km. Consequently, oil consumption is determined only by prices for oil.

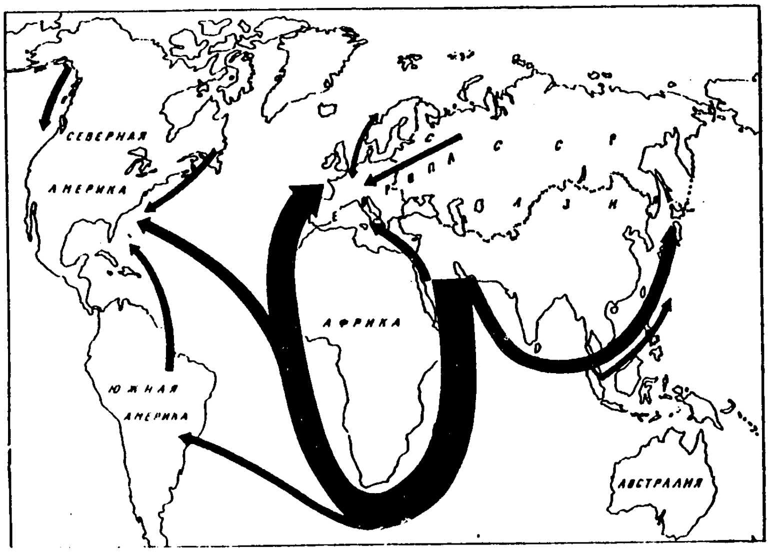

Figure 1.1. Main Intercontinental Flows of Petroleum and Petroleum Products

During the past few years, after nationalization of the oil-producing industry of a number of developing countries and centralized pricing for oil by OPEC member countries, most countries that import oil have implemented measures to replace imported petroleum fuels by more expensive domestic oil, pit and hydrogenous coal and other local fuel resources and are conducting accelerated development of nuclear power. Thus, the shortage of oil and gas in the United States makes it necessary to increase coal production. The increase in the demand for electric power and the slower than anticipated increase in the capacities of nuclear power plants contribute to this (63 AES [Nuclear power plant] were operating in the United States in 1977 at which 10 percent of the total energy was produced, start-up of an additional 75 AES that will provide 20 percent of all generated energy is anticipated by 1985, but this is still 25 percent less than previously planned [70, 71, 105]. According to the latest forecasts, coal production in the United States may reach one billion tons per year in 1985 and 1.3 billion tons per year in 1990 compared to 0.62 billion tons per year in 1976. Moreover, intensive geological prospecting work in Alaska and in the other northern regions of the American continent are now under way in the United States.

Great Britain, Norway, the United States, Venezuela and a number of other countries are conducting intensive geological prospecting work and oil and gas production from offshore fields. The total oil production from offshore fields comprised approximately 540 million tons per year in 1977, including approximately 360 million tons per year by OPEC member countries and 80 million tons per year by the United States. Approximately 210 billion m^3 of natural gas per year was produced from offshore fields in 1977 [81, 97]. Especially intensive operations to exploit offshore gas fields are under way in the English sector of the North Sea.

Intensification of geological prospecting work both on land and at sea made it possible to increase worldwide petroleum reserves by 5 percent by 1977 compared to 1973, gas reserves by 21 percent and coal reserves by 53 percent. At the same time it should be noted that the majority of oil and gas reserves of the capitalist world are located in developing countries. A total of 75 percent of the oil reserves is concentrated in OPEC countries and approximately 60 percent of gas reserves is concentrated in the countries of the Near and Middle East and Africa. The United States has approximately 6 percent of oil reserves and 18 percent of gas reserves and Western Europe has 5 percent of oil reserves and 11.6 percent of gas reserves, whereas the United States, Japan and Western European countries are the largest consumers of energy resources in the capitalist world [97, 105].

The involvement of various types of fuels and atomic power in extensive industrial use and implementation of the enumerated and other programs for this provide the basis to consider the planned trends as long-term trends which will determine in the foreseeable future the general direction in development of worldwide energy management.

Besides extensive development of atomic power, one can expect rapid development of gas production and intercontinental and intracontinental gas transport over long distances. The accelerated development of coal production, primarily by strip mining with transport over relatively long distances, is inevitable since the indicators of nuclear power plants are still less favorable for the near future than those of electric power plants operating on strip-mined coal. Programs have been developed to process bituminous sands, shales and inexpensive strip-mined hydrogenous coal with subsequent transportation of the product (coke, resins, methanol and other chemical products) over considerable distances.

Implementation of the planned programs to improve the structure of the energy balance in different countries requires further development of international transportation systems of different designation, primarily of intracontinental pipeline transport of oil, petroleum products, gas and coal and the products of refining them, of rail and river transport of fuels and also of maritime transport of oil, liquefied gas, coal and products of refining them.

1.2. Fuel Production and Transportation in the USSR

There is a close relationship between the development of a country's economy, fuel production and consumption and development of electric power. During the period from 1960 through 1975, the gross national product increased 2.65-fold, the per capita income increased 2.62-fold, the production of all types of fuel increased 2.61-fold and electric power generation increased 3.52-fold. During the past 25 years the production of all types of fuel has doubled every 9-10 years, while generation of electric power has doubled every 6-7 years. Part of the fuel was exported, primarily to CEMA member countries [69, 72, 73].

Numerous factors affect the growth rates of fuel production and the need for transport facilities to transport it. These are primarily an increase in the volume of industrial and agricultural production, an increase in the power available per worker for labor, technical progress in different sectors of the economy, improvement of the energy balance of individual regions and of the country as a whole, involvement of oil fields remote from consumers in industrial development and other factors [68, 74]. The country's energy consumption (Table 1.3) increased 5.6-fold, oil consumption increased 14.4-fold, gas consumption increased 56.2-fold, coal consumption increased 2.4-fold and water power consumption increased 7.9-fold during the period 1950-1977 under consideration.

The growth of energy consumption in the USSR is 1.6-fold higher than the growth of worldwide energy consumption (Table 1.1) and the growth of oil consumption exceeded the worldwide growth rates of consumption 2.4-fold and of gas consumption 9.5-fold. This indicates the high rates of development of the USSR economy, specifically of the petroleum and gas industry.

Table 1.3.

(1) Виды топлива и энергии	(2) Энергопотребление, млн. т условного топлива / %				
	1950	1960	1970	1975	1977
Всего (3)	318,7 100	716,2 100	1266,2 100	1633,1 100	1785,7 100
Нефть (4)	54,2 16,8	211,8 29,5	502,5 39,5	701,8 42,8	780,5 43,8
Газ (5)	7,3 2,3	54,4 7,6	233,5 18,4	345,7 21,5	410,0 22,9
Уголь (6)	205,7 64,7	373,1 52,0	432,1 34,1	490,4 29,9	486,0 27,2
Торф (7)	14,8 4,6	20,4 2,9	17,7 1,4	16,9 1,0	14,0 0,8
Сланцы (8)	1,3 0,3	4,8 0,7	8,8 0,7	11,7 0,7	11,4 0,6
Дрова (9)	27,9 8,8	28,7 4,0	26,6 2,2	23,8 1,5	24,6 1,4
Гидроэнергия (10)	7,5 2,4	23,4 3,3	44,4 3,5	43,8 2,6	59,2 3,3

Key:
1. Types of fuel and power
2. Energy consumption, million tons of comparison fuel, percent
3. Total
4. Oil
5. Gas
6. Coal
7. Peat
8. Shales
9. Wood
10. Water power

The country's power engineering is being developed under the influence of technical progress to improve production processes and the utilization of energy resources. Thus, the specific fuel consumption with specific calculation per kilowatt-hour of electric power comprised 627 grams at general-purpose electric power plants in 1945, 415 grams in 1965, 348 grams in 1973, 340 grams in 1975 and 334 grams in 1977. Actually, the fuel saving is higher since the specific weight of electric power generation by general-purpose power plants increased simultaneously (by 6.8 percent from 1950 through 1975) and also the specific weight of fuel produced by combination generation at electric and heating plants and central boiler plants was also increased.

Fuel consumption decreased from 35.6 to 8.9 kg of comparison fuel from 1955 through 1975 per 1,000 gross tons-km in railway transport due to replacement of steam traction by electric and diesel locomotives. The total fuel consumption for transport (including intracity) comprises 12-13 percent of the total fuel consumption in the country due to primary development of types of transportation that economize in consumption of energy resources compared to 20-22 percent in the United States and Western European countries.

The replacement of internal combustion engines by diesel engines in agriculture led to a decrease of specific fuel consumption by 30-35 percent.

Technical progress has an enormous effect on fuel utilization, the volume of its consumption and the work of transportation to deliver fuel to consumers. If the specific fuel consumption of 1950 were to be maintained at the modern level of development of the economy, there would be approximately two times more fuel than actually consumed for all needs.

Improving the structure of the country's energy balance by increasing the specific weight of more economical or calorific fuels has an important influence on the consumption of energy resources and the work of transportation. The volume of the energy consumption of fuel and its specific weight in the country's fuel-energy balance are presented in Table 1.3. The fraction of petroleum in the energy balance increased from 16.8 to 43.8 percent and the fraction of gas increased from 2.3 to 22.9 percent during the period under consideration, while the specific weight of coal decreased from 64.7 to 27.2 percent (with an increase of mining it mainly by the open-pit method).

The actual specific weight of petroleum consumption is lower than indicated in Table 1.3 since petroleum and partially gas were exported to CEMA countries.

The main directions in development of the national economy of the USSR for 1976-1980, adopted at the 25th CPSU Congress, provided further development and improvement of the country's energy balance. It is planned to bring oil production (including gas condensate) up to 620-640 million tons (900-930 million tons of comparison fuel), to bring gas up to 400-435 billion m^3 and to bring coal production up to 790-810 million tons [2].

The development of fuel transportation and the fuel's economy are determined by the structure of the energy balance and by the geographic disposition of production and consumption of energy resources. The main consumers of energy resources in the USSR are concentrated in the European USSR and in the Urals. Approximately 80 percent of all consumption went to these regions in 1977; it is expected that approximately 70 percent of energy resources will be consumed in the European USSR and the Urals in the future and that approximately 30 percent will be consumed in Siberia, the Far East and Central Asia. Oil, gas and coal will be exported through the ports of the Black and Baltic Seas and across the country's western borders.

Prior to the late 1960's, the production of energy resources in the European and Asian parts of the country corresponded approximately to consumption. However, this equilibrium was not present by types of fuel. The oil and petroleum products of the Urals-Volga region were transported to Western and Eastern Siberia and to the Far East. A special oil and petroleum pipeline system was developed for this. The pit and coking coals of the Kuzbass and Karaganda were transported by rail or by mixed rail-river traffic to the European regions of the country and were transported by rail to the Urals. The coal of the Ekibastuz basin was transported to the electric power plants of the Urals. Gas from Central Asia was delivered to the Urals through the Bukhara-Urals gas pipeline and gas from Western Siberia was delivered to the Urals through the Igrim-Serov gas pipeline.

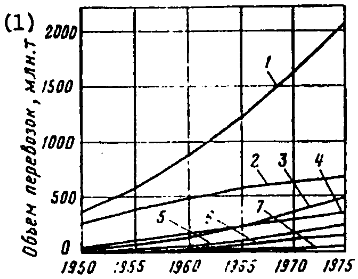

Figure 1.2. Volume of Fuel Shipments by Various Types of Transport: 1--total; 2--coal shipped by rail; 3--oil and petroleum products shipped by rail; 4--oil and petroleum product pipelines; 5--gas pipelines; 6--oil and petroleum products shipped by water; 7--coal shipped by water

Key:
1. Volume of shipments, million tons

Extensive Central Asian-Center-state boundary-Nadym (Medvezh'ye)-Torozhok-Minsk-state boundary and Urengoy-Kazan'-Center and Orenburg-Center gas pipeline systems are being developed during the current decade with regard to the vigorous development of gas production in Central Asia, the Southern Urals, Northern Tyumenskaya Oblast and Orenburg. The Soyuz system has been developed to deliver gas from the Orenburg field to the state boundary and from the Central Ob' field to the regions of Novosibirsk and the Kuzbass. The rapid rates of development of gas production in the Central Ob' region made it possible not only to replace Volga area oil from eastern regions but also to organize delivery of Central Ob' oil to the European regions of the country. Favorable conditions for coal production in the Ekibastuz bains led to its rapid development and made it possible to organize shipments of mass quantities of Ekibastuz coal to the Urals. The volume of fuel shipments by various types of transport during the period 1950-1975 is presented in Figures 1.2 and 1.3, respectively.

By 1975, significant changes had taken place in fuels transportation. Whereas the railroads carried out 85 percent of the total volume of transport work related to providing the country with fuel in 1950, they provided less than 65 percent in 1970, 54 percent in 1975 and 33 percent in 1977. At the same time the specific weight of pipeline transport increased from 5 percent in 1960 to 26 percent in

1970 and 48 percent in 1977, respectively. Oil shipments by sea increased with regard to the rapid development of the northeastern regions and also the increase in the export of oil and petroleum products [55, 56, 59]

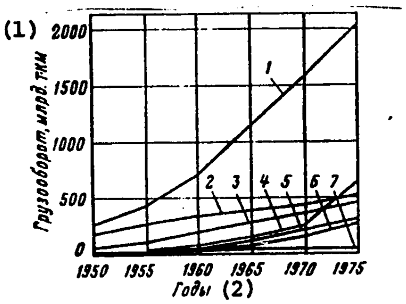

Figure 1.3. Freight Turnover of All Types of Transport in Fuels Shipments. The notations are the same as in Figure 1.2.

Key:

1. Freight turnover, billion tons-km
2. Years

The development of water power played some role in the decrease in the growth rates of the transport load in fuel shipments since most hydroelectric power plants are located in regions with long fuel supply lines. If thermoelectric power plants had been constructed in place of hydroelectric power plants, the need for coal would have increase by approximately 63 million tons in 1975 (with mean specific heat of coal of 5,000 kcal/kg) and the volume of rail shipments of coal would have increased by 95-100 billion tons-km, which comprises 10 percent of the total fuel transportation work of the railroads.

Nuclear power engineering has achieved ever greater development during the past few years. According to the decisions of the 25th CPSU Congress, capacities of 13-15 million kilowatts will be introduced at nuclear power plants during the current five-year plan. Generation will comprise 90-100 billion kilowatt-hours with use of capacities of 6,500-7,000 hours, which will permit replacement of 30-33 million tons of comparison fuel or 42-45 million tons of medium-grade coal of the Ekibastuz or Kuznetsk basins, which would require an increase in the work of rail transport by approximately 3.5 percent.

The role of electric power transmission lines in replacement of energy carriers is still small. All existing electric power transmission lines with voltage of 400 kV or higher could replace transportation of approximately 36 billion ton-km of comparison fuel in 1970 and 56 billion ton-km in 1975, which comprises 2.7 and 3.0 percent, respectively of total fuel transport shipments. The actual saving of transport shipments achieved by using electric power transmission lines is somewhat less than that indicated since some lines performed the functions of linking energy systems to each other and operated in a direction not always coincident with the general direction of fuel transport.

The total volume of fuel transport shipments throughout the USSR is approximately 40 percent. In this case the fraction of freight turnover of fuels in the total freight turnover of the country's transportation system, despite measures adopted to reduce these shipments, is increasing continuously. The freight turnover of fuels comprised 37.3 percent in 1960, 38.2 percent in 1965, approximately 40 percent in 1970, 42.1 percent in 1975 and 44.8 percent in 1977 [30, 55, 56].

For comparison let us point out that the similar index comprises 42-44 percent during the past few years in the United States. If one considers the more uniform distribution of fuel resources in the United States than in the USSR and their proximity to the main consumers and the considerably smaller territory of the United States, one can conclude that the fuel supply of the USSR national economy is at a higher level of organization.

The development of pipeline transport led to some decrease in the fraction of the freight turnover of fuels in the total freight turnover of the country's railroads: 34.7 percent in 1965, 32.7 percent in 1970 and 31.0 percent in 1975. The freight turnover of oil and petroleum products increased from 51.2 billion tons-km in 1960 to 665.8 billion tons-km in 1975. The delivery of commercial gas by pipeline increased from 28.0 to 279.4 billion m^3 during this same period.

Thus, major coal shipments are performed by railway transport via extensive, usually electrified, mainlines, gas and oil and transported by pipelines and petroleum products are transported by rail and pipeline. The distributed transport includes the branched network of pipelines and railroad spur tracks. Motor transport using specialized trucks adopted to deliver petroleum products and coal to small consumers located in rural locales is utilized extensively.

The system of supplying the national economy with energy resources includes storage and distribution bases for solid fuels, oil and petroleum products that provide storage of reserves required to cover the peak consumption and to supply all consumers of the national economy during random interruptions in production and delivery of energy resources.

It should be noted that the established disposition of consumers, primarily of petroleum refining plants, the distribution of shipments and selection of types of transport are not optimum in all cases. Bringing the energy-consuming plants closer to the fuel bases of the country's eastern regions, locating petroleum refining plants closer to the consumer regions and efficient distribution of fuels shipments among types of transport, specifically, development of a more branched network of petroleum product pipelines and switching transport of petroleum products to them from rail and partially motor transport would permit more efficient shipments and would reduce the fraction of transport expenses in delivery of fuel in the total energy expenses and the expenses of the national economy as a whole.

1.3. The Problems of Transport in Formation of an Energy Complex

The volume and distance of transport shipments of energy resources are determined primarily by the level and structure of social production, by the needs for fuel consumption by regions of the country and by the disposition of the main fields of fuel resources. The development of the energy complex and its established structure have an important influence on development of the transport system and its structure (the fraction of the types of transport) (Table 1.4).

Table 1.4.

Показатели (1)	1950	1960	1970	1980 (план) (2)
Топливные ресурсы, млн. т условного топлива (3)	318.2	716,8	1266,2	2050
Увеличение, %, к предыдущему десятилетию (4)	—	226	178	162

Key:

1. Indicators
2. Planned
3. Fuel resources, million tons of comparison fuel
4. Increase, percent, compared to previous decade

It is expected that the future consumption of energy resources will increase with gradual stabilization of fossil fuel production due to improvement in the structure of the electric power balance, an increase of the utilization factor of energy resources by consumers, secondary use of energy resources and other changes that provide an increase in the effectiveness of the country's entire energy management.

The rates of atomic power development are of great significance to reduce fuel transportation shipments. Introduction of Atommash [expansion unknown] places the development of atomic power on a reliable basis.

High rates of development of atomic power are desirable from the viewpoint of relieving transportation from shipping enormous quantities of mineral fuels, provided that the economic indicators of nuclear power plants will be no lower with regard to fulfilling all environmental protection standards than those of electric power plants operating on Kuznetsk, Kansk-Achinsk and Ekibastuz coals (with transport of coal to the consuming regions). In this case an increase of fuel production would be required only for new units at existing electric power plants. Under these conditions all forecasts of energy resource consumption, especialy for the long term, should be regarded as estimate forecasts dependent on the rates of development of atomic power.

Approximate concepts on the main directions of shipping various types of fuel and the role of transport in further improvement of the structure of the country's energy balance can be compiled on the basis of the future needs for mineral fuels according to zones of the country and for the future and proven reserves of natural energy resources.

The main need for energy resources, as indicated above, remains in the European USSR and in the Urals. Depending on the rates of industrial development, primarily of energy-consuming industry in the eastern regions and the rates of development of atomic power in European regions of the USSR, the needs of the western regions of the country for minearl fuels will also fluctuate in the future in the range of 2-2.5 trillion tons of comparison fuel [14, 25]. Approximately 100 million tons of comparison fuel are now mined annually in the European USSR and in the Urals.

A further increase in the level of mineral fuel production in European regions, specifically Donbass coal, is possible in insignificant dimensions with regard to economic effectiveness: essentially by 10-15 percent. The coal of the Moscow (except some mines) and the Pechora basins is the country's most expensive fuel. Further development of coal mining will hardly be justified with the exception of mining the coking coal in the Pechora basin.

Under these conditions an increase of capacities in coal mining in the European USSR is a less feasible direction to improve the structure of the energy balance by this type of fuel and transport of fuel from eastern regions is feasible. Development of oil and gas production in the European regions of the country will depend on discovery of new high-yield fields at great depths or in offshore regions. Known fields are exploited on the basis of existing reserves and rational periods of their exploitation. In the future one can expect depletion of a number of fields and transition to their exploitation with reduced yield. The water power resources in this region will be mainly exhausted with construction of the Nizhnekamskaya and Cheboksary hydroelectric power plants on the Volga river.

All the enumerated factors indicate the need and feasibility of making up the deficit in the energy resources of the European USSR and the Urals by accelerating the construction of nuclear power plants and exploiting the fields of eastern regions with organization of mass transport of fuel from east to west.

The main type of boiler-furnace fuel in this case, along with the nuclear fuel replacing it, will be coal and in some cases gas. Worldwide prices for oil and gas make it feasible to limit their use as fuels in all cases where they can be effectively replaced by economical strip-mined coal. Moreover, oil and gas are a more promising raw material for the chemical industry and a fuel for mobile power stations. Efficient use of these types of fuel is one of the main tasks of improving the country's fuel and energy balance. Therefore, along with increasing oil and gas production and developing extensive transport systems for them, we will be faced in the future with solving the problem of accelerated exploitation of strip-mined coal and of finding methods of transporting it over long distances in the form of fuel or electric power.

The main coal bases of the country's eastern regions are the Kuznetsk, Ekibastuz, Kansk-Achinsk and other basins.

Coal of the Ekibastuz basin is comparatively low-calorie (4,100-4,200 kcal/kg) and has a high ash content, but is now the least expensive hydrogenous coal in the country (2.3-2.5 rubles per ton of comparison fuel) [67, 68]. Comparison of the reduced expenditures for mining, transport and burning of Ekibastuz coal, for example, with Donetsk coal or gas, permits one to conclude that it is feasible to trasnport it over a distance up to 1,500-2,000 km. The capacities of the basin, including the Maykyubenskoye field, are estimated at 120-150 million tons of production annually. Approximately half of this coal production can be used at local electric power plants and can be sent over electric power transmission lines to nearby regions and the country's central regions. The remaining coal must be transported to the Urals and to Central Asia.

The strip-mined coal of the Kuznetsk basin has specific heat of 6,200-6,500 kcal/kg and is also relatively inexpensive (5.5-7.0 rubles per ton of comparison fuel). The coal can be transported both by rail and through coal-slurry pipelines. A total of 350-400 million tons of coal annually can be mined in the basin, including approximately 35-40 percent of coking coal. Based on the need to provide the central regions with fuel, it is feasible to increase mining of the coal of this basin for transport to the west, while the needs of Siberia for energy fuel can be met with coal of the Kansk-Achinsk basin.

The coal reserves in the Kansk-Achinsk basin are extremely large and according to forecasts reach 1.2 trillion tons. The capacities for mining under favorable economic indicators are estimated at 1-1.2 and even 2 billion tons annually [67]. However, these scales of production lead to mining coal at great depths and considerably worsen the economic indicators of production. According to the economic indicators per ton of comparison fuel, this coal is the least expensive--4.0-6.0 rubles of reduced expenditures per ton of comparison fuel--according to projected plans with development of strip mines each producing 40-60 million tons annually. However, this coal is low-calorie (3,300-3,500 kcal/kg), is moisture-saturated (up to 40 percent), has a tendency toward spontaneous combustion and in natural form permits transportation (for example, by rail) over short distances. Methods of concentrating this coal have been developed and tested with production of high-calorie products (semicoke with 6,800-7,000 ckal/kg, resins and so on) that permit transport over long distances by rail and slurry pipelines. Since the large coal reserves of the Kuznetsk and Kansk-Achinsk basins are capable of making up a significant part of the increase of the country's needs for fuel by the year 2000 and can contribute to more efficient utilization of oil and gas, the problem of concentration and transport of it is one of the most timely in the problem of the country's fuel and energy balance.

The main oil and gas fields are concentrated in the West Siberian lowland. The West Siberian industrial complex--the main region for producing these types of fuel, which will be developed, has already been created.

Prior to prospecting the oil fields in the Far East and in the offshore zones of Sakhalin, the oil transport routes of the West Siberian lowland pass to the east and south to meet the needs of all regions located east and south of the Central Ob' region [73, 74]. The presence of predicted oil reserves in the Far East and on Sakhalin determines the approach to selection of transport to deliver oil to these regions from the Central Ob' region. A special pipeline to deliver oil during the next few years if oil reserves are discovered there sufficient to meet local needs may be underloaded in the future. This predetermines the feasibility of organizing oil transport to the east by rail.

The main oil flow from Western Siberia is directed toward the west for the needs of the European USSR and for export needs with delivery of oil by pipeline across the western borders and toward the tanker ports of the Black and Baltic Seas. This flow is stable and large pipeline systems are required for development of it.

During the current five-year plan the West Siberian lowland will become the main gas-producing region in the country. The proven gas reserves in the northern regions of the lowland exceed 70 trillion m^3 [74], which permits development of this region at accelerated rates predetermined by the needs of energy management, the chemical industry and also export needs. Rapid development of gas production requires development of extensive systems for delivery of it to the northwestern regions of the European USSR that are less provided with energy resources, to the central and southern regions with denser population and more developed industry and also the country's western borders for gas transportation for export.

Tyumen' gas flows are now delivered through pipes 1,420 mm in diameter.

The engineering solutions of these mainlines may not be regarded as optimum for a number of reasons, mainly due to the fact that a large number of gas pipelines must be laid and consequently extensive labor and metal expenditures are required. Therefore, problems of increasing the efficiency of the gas pipelines acquire special significance.

The gas from the Orenburg field is sent by an already complex scheme to the country's western regions and for export across the western borders. A pipeline 1,420 mm in diameter, which passes through the USSR, Czechoslovakia and Hungary with branches to other CEMA member countries, has been constructed to transport this gas through the efforts of CEMA countries. The gas of Yakutiya will obviously be sent to the east to meet the needs of Far Eastern regions and also for export by maritime transport.

The general layout of the transport flows of fuel is presented in Figure 1.4.

Along with the enumerated larger transport directions of fuels, transport communications of newly discovered fields with consumers and also with transport mainlines will be developed. Product pipelines need to be developed to create distributed transport of petroleum products from the plants to consumers. Development of product pipeline systems is determined by the disposition of oil-refining plants and their optimum capacity.

The given data show that the national economy is faced with solution of very complex problems on intracontinental transport of energy resources. The first successful steps have already been taken in this direction. Engineering and economic indicators of fuel transport systems (rail and oil and gas pipelines) are usually higher than the corresponding foreign indicators. However, the indicators achieved cannot be regarded as optimum and require a further increase. Advanced transport systems must be developed, engineering and economic problems must be solved and the most efficient types of transport and their combinations must be selected. One must take into account in this case that the level of expenditures for fuel transport and timely solution of problems on fuel support will directly affect the rates and indicators of the effectiveness of developing the country's national economy.

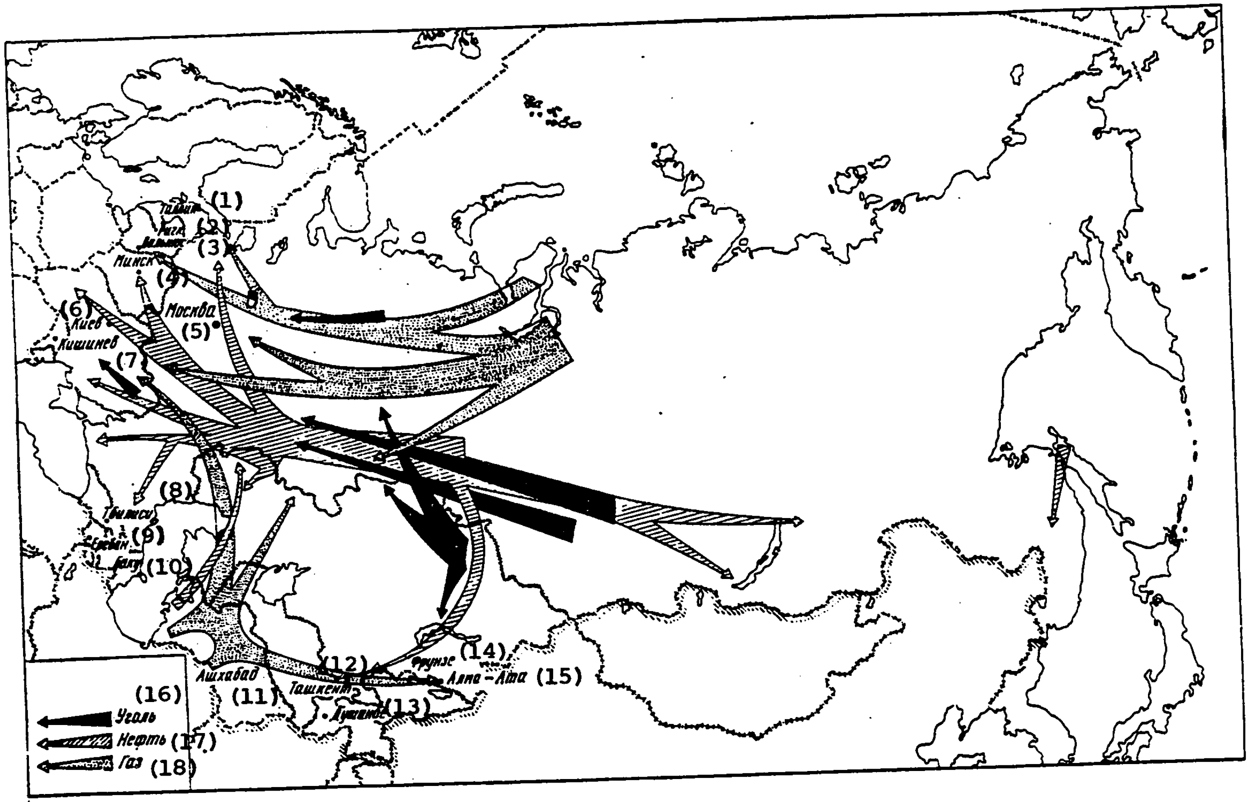

Figure 1.4. Diagram of Main Fuel Flows for the Near Term

[Key on following page]

[Key continued from preceding page]

1. Tallin
2. Riga
3. Vilnius
4. Minsk
5. Moscow
6. Kiev
7. Kishinev
8. Tbilisi
9. Yerevan
10. Baku
11. Ashkhabad
12. Tashkent
13. Dushanbe
14. Frunze
15. Alma-ata
16. Coal
17. Oil
18. Gas

Chapter 2. Methodical Aspects of Determining Transport Expenses

2,1. General Aspects

The diversity of the physical and engineering characteristics of the fuel of different fields, the different engineering and economic indicators of production, the need to take into account the consumer effect (expenditures for combustion), the relatively broad interchangeability of fuel and the possibility of using different types of transport to move it make the problem of formulation of the energy balance as a whole and selection of the most favorable fuel regime of individual consumers exceptionally complicated. The problem is complicated by the need to take into account simultaneously the capabilities of developing fields and of creating one or another transport system within the required deadlines by changing the engineering and economic indicators of production with an increase of the production scales, development of technical progress and a number of other factors.

Different approaches and procedures for taking into account the transport factor in optimizing the energy balance are used at different stages of investigation and planning of the energy balance, depending on the postulated problem and the degree of reliability of information. When developing the basic directions of five-year plans, one relies on the extensive information that permits computer aids in selecting the optimum version of the energy balance and of determining the transport and economic communications for different types of fuel and the need and feasibility of constructing individual transport facilities. Comparison of five-year plans with division by years and annual plans for development of the national economy is based on complete information of the needs of different regions of the country for fuel and energy and on the capacity to produce fuel by fields. This permits development of a completely balanced plan for production and consumption of fuel and for loading and development of transport systems. However, the capability and primarily the deadlines for implementation of different measures on development of existing and assimilation of newly discovered fields and construction of communications lines must be taken into account in this case. A long period (more than 5 years) is usually required to develop large producing and transport facilities with regard to the time required for planning and prospecting work.

When working out future development plans, for example, general schemes for 10-15 years, one relies on less reliable information but in this case there is the possibility of implementing measures that provide serious changes both in the structure of the energy balance with bringing new fields into exploitation and in development of new transport systems. Suggestions based on these developments are taken into account when compiling five-year plans both complete and during subsequent five-year plans as provided for partial or total introduction into exploitation. When working out forecasts for the longer term, there is frequently no reliable information on the conditions for development of the energy economy, especially in proven and confirmed fuel reserves for individual fields, but there is the capability of designating the basic directions of solving problems to improve the structure of the energy balance and consequently of individual types of transport, of taking into account the effectiveness of measures planned for the nearest stages of development and in some cases of advancing proposals on the long-term changes of proportions and shifts in the energy balance and transport. It is obvious in this case that the initial base is the basic directions and general decisions on developing the country's productive forces and primarily of energy-consuming sectors and of their disposition by territory.

At the same time expenditures for transport also have a significant influence on the disposition of the energy-consuming sectors of the national economy.

The disposition of the productive forces and the specialization of regions, as is known, depend on a number of economic, geographic, national and other factors (transport of raw materials and finished products play the far from last role among them). Bringing production closer to energy resources and reducing their transportation expenditures may have a negative or positive effect on the indicators of transporting raw material, semifinished products and finished products. Optimization of the energy balance and development of transport are closely intertwined with the problem of arranging the country's productive forces.

Taking into account the numerous direct and indirect relationships in the national economy during optimization of the energy balance requires complex calculations and makes it necessary to assume a number of provisionalities related to the technique of making calculations and the capabilities of computer equipment and also to variation of the reliability of information for different time levels of calculations. However, one must adhere to a number of common aspects during all assumptions and provisionalities, violation of which would lead to the incompatibility and unreliability of the results of individual calculations and suggestions.

The general aspects may include the following.

1. The community of optimization, as which reduced expenditures required to achieve a given result (increase of production, development of transport shipments and so on) are taken.

2. The energy balance must be optimized and transport must be developed at each stage of working out the plan as an independent section of investigations to optimize the disposition of productive forces, taking as the initial base the already available data on development of the economy of individual regions and their consumption of different types of fuels. The problem of fuel for consumers who permit

replacement of one type of fuel by another is solved by calculations of the energy balance with regard to transport expenses.

3. The engineering and economic calculators of fuel for expansion or development of production in one or another region of the country take into account expenditures for production and transport from the fields, which must be brought into operation, i.e., those usually more remote from the consumer. In calculations on optimization of the sector as a whole, expenditures are usually taken into account by the closing fuel, which leads to some overestimation of the fuel and consequently of the transport component.

4. The indicators of shipping fuel by universal types of transport should be identical to the indicators for shipping other goods. This is determined by the mutual dependence of expenditures for shipments of fuel, raw material, semifinished products and finished products with different versions of the disposition of production. It is natural that these indiators should reflect the shipping conditions (the capacity of the transport facilities used, the level of their utilization, the use of empty runs and so on).

5. The indicators of different types of transport and production should be comparable to each other in calculations on the disposition and development of productive forces. When solving problems of finding the minimum expenses, the nonvariable part of the expenses of industry or transport may be disregarded.

These and a number of other general aspects of engineering and economic calculations are discussion types and are not completely shared by some specialists. However, they are used extensively in practice and serve in the given case as an initial base for calculating fuel (energy) transport expenses.

Let us consider some concepts on determining the transportation expenses for universal types of transport. When compiling five-year plans for development of the energy economy and for disposition of production enterprises, as already indicated, one proceeds in most cases from the real capabilities for development of fuel production in known fields and basins. In working out the plan, calculations are frequently corrected and refined as the capabilities for development of fields or basins and also of transport are determined. These calculations are usually made when the levels and disposition of individual production sectors have still not been finally determined and when there are no complete data on the load of transport directions. Under these conditions all transport indicators can only be approximate since the level of transportation expenses, for example, on rail or pipeline transport, vary significantly as a function of freight traffic volume.

Further stages of calculations to refine the energy balance or to select a fuel for individual consumers require refined indicators of transportation expenses that take into account not only the characteristics of one or another transportation facilities but also the conditions of the stages of their development and the level of loading. Refined indicators of transportation expenses are also required to distribute shipments between the types of transport and to determine expenditures on the closing fuel.

The feasibility of constructing pipelines, electric power transmission lines and specialized loading-unloading facilities in ports and other structures required to develop the increasing shipments of fuels with switching of shipments from one type of transport to another can be substantiated only with consideration of a number of factors that characterize specific conditions for development and functioning of a given transportation facility. These calculations are made with information on the load of individual mainlines and sections, real expenditures to develop one or another types of transportation during the period under consideration with regard to analysis and recovery of potential reserves and an increase of the future carrying capacities of the transportation system.

These concepts led to the conclusion of the need for two types of indicators of transportation expenses:

1) averaged expenses intended for the first stages of optimization of the fuel and energy balance and calculations on the disposition and development of individual sectors of the national economy and other phases when the total load of individual directions of the transportation system for the calculated period is still unknown but calculations are made for the entire mass of "old" and "new" goods, the growth rates of which are close to those typical for a socialist economy;

2) differentiated expenses required to substantiate the distribution of freight loads between different types of transport and primarily to substantiate construction of specialized transportation facilities (pipelines of different designation, electric power transmission lines and so on). These indicators should reflect specific conditions for development of transportation facilities and operation of them.

The first indicators should be worked out for the long term and should be accessible for use by all organizations conducting investigations on optimum development of individual sectors of the economy, including the energy economy; the second indicators can be used by the organization conducting investigations on formation of the country's unified transportation system or by another organization having information on transportation at economic communications and the load of individual sections of the country's transportation system during the periods under consideration.

Main attention is devoted in this book to determining the differentiated economic full-scale indicators of transportation expenditures required for comparison of different types of fuel (energy) transport with regard to specific conditions of their development and also to consideration of methods of technical progress in different types of transportation and their effect on economic and full-scale transportation indicators.

2.2. Methods of Comparing the Versions of Fuel Transport

All problems on determination of the effectiveness of measures directed toward improving universal or specialized types of transportation, on selecting the most efficient of them and also on the feasibility of using essentially new types of transportation reduce to selection of optimum versions.

It is known that development of the national economy, including development of energy resource transportation, can be accomplished by different methods. The main criterion in selection of one or another engineering solution is its economic feasibility, i.e., achieving the minimum reduced national economic expenditures for construction and operation. The optimum version among those compared is regarded as that having minimum reduced expenditures. The version is usually selected with regard to full-scale indicators with similar values of reduced expenditures "in the zone of uncertainty."

The preparedness of scientific and design developments, the possibility of organizing construction organizations within required deadlines according to conditions of material supply and deadlines, the need for accelerated development of the country's lagging regions, climatic conditions, operational reliability under special conditions and so on must be taken into account. However, the main criterion is the minimum reduced national economic expenditures. If a version with increased reduced expenditures is taken for one or another reason, the expenditures must be determined to analyze the losses induced by deviation from the optimum version [28, 29, 33]. It is obvious that the comparability of expenditures and the economic effect of the versions being compared by the time of expenditures and achieving a saving, the prices adopted to express expenditures and the saving, the nature of expenditures and the saving from the viewpoint of simple and expanded reproduction, the range of expenditures included in capital investments and the methods of calculating the cost indicators used to calculate effectiveness and other factors should be adhered to in calculations of economic effectiveness.

All the versions of capital investments being compared should be reduced to a comparable form by all features, except that whose effectiveness is being determined.

The main aspects of comparing the effectiveness of versions have been established by a standard method of determining the economic effectiveness of capital investments and the standard method of the effectiveness of new technology of inventions and innovator proposals [28, 29].

A characteristic feature of developing transportation systems is the step by step increase of capacities, dependent on the growth of freight traffic volume. Capacity may reach very high values for some types of transportation, which is frequently achieved only over a prolonged period calculated in decades. There are usually several methods in this case of increasing capacities and numerous combinations of a step by step increase of the carrying capacities of transportation systems are possible. For example, the carrying capacity of a single-track railroad can be increased by opening up additional sidings, increasing the mass of trains and equipment by more modern means of communication on train traffic, construction of two-track inserts, continuous second tracks and the use of a number of other measures. The carrying capacity of a railroad can be brought up to 60-70 million tons and under specific conditions up to 100 million tons. A step by step increase of the carrying capacity can also be accomplished in river transport, for which corresponding development of ports and locks is required. An increase of the carrying capacity in pipeline transport can be achieved by constructing intermediate compressor or pumping stations and by construction of parallel pipes of different diameter and loopings.

Establishing the deadlines for implementing measures on increasing the carrying capacity and their economic effectiveness requires special attention when solving problems of development of transportation devices. For example, the carrying capacity of a single-track railroad can be brought up to 22-25 million tons annually by opening additional sidings and can be increased even more by using new types of rail cars and freight that permit complete utilization of their load capacity. However, current expenditures increased significantly with this type of loading due to frequent stops of trains. It is economically more feasible to construct two-track and to organize nonstop crossing of trains with freight traffic volume of 20-22 million tons annually, i.e., earlier than is required by conditions of carrying capacity. A similar aspect can also be created in pipeline transport. The carrying capacity of an oil or gas pipeline can be increased compared to that usually achieved by reducing the distance between pumping stations to 40-50 km, but operating expenses increase in this case. It is more feasible to reduce the deadlines for laying a parallel pipeline over the entire length or a section of it.

The characteristic features of transport development also include the fact that different growth rates of freight turnover and different economic effectiveness of individual measures to increase the carrying capacity determine the possibility of developing increasing freight traffic volumes on many types of transport by several methods. These characteristic features of developing transportation facilities make it complicated to find optimum versions when establishing a step by step increase of carrying capacity and consequently of selecting the type of transport to supply different consumers with fuel and also to supply the energy complex. Since the problems related to improvement of transportation factilities, especially for fuels when one is concerned with several interchangeable types of transport, are based on inadequate information and one must introduce a number of assumptions and conditions.

At the same time achieving results that reflect real national economic expenditures with one or another version requires compulsory provision of the variability of calculations of the indicators of transport devices that participate in the comparison. Obviously, expenditures for all facilities, outlays for which can be used in adopting at least one of the versions, must be included in the calculation. This aspect provides the basis to select versions by two methods [32, 33, 59].

The first method assumes calculation of the total expenditures for all facilities included in the comparison. For example, when solving the problem of selecting the type of transportation between some terminals, one must take into account expenditures for all existing transportation systems and those planned for construction in the test area under investigation along which the freight traffic volume can be directed. The given aspect can be illustrated by example of selecting the most feasible version of fuel transport in the test area of a transportation network (Figure 2.1).

Supply of region B with petroleum products can be resolved by one of the following:

1) by construction of a pipeline between the location of the oil-refining plant A and region B;

2) by strengthening the rail line between regions A and B to ship petroleum products from the plan to the oil depot at point B;

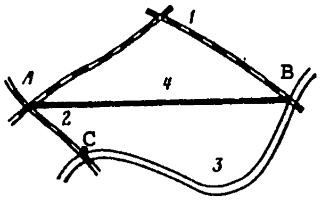

Figure 2.4. Test Area of Transportation Network Under Consideration During Construction of a Product Pipeline: 1--railroad from oil refining plant at terminal A to terminal B; 2--railroad to port; 3--river route; 4--pipeline

3) by organizing shipment of petroleum products between these points in mixed rail-water transport, which requires strengthening of the railroad sections A-C and accordingly of developing a waterway on the leg C-B with construction of tank depots at its destination points and also by completing other work that provides uninterrupted supply of region B with petroleum during the period between navigation seasons.

Adoption of any of three solutions is reflected in the operating indicators of the other two. If, for example, a petroleum product pipeline is constructed, the operating indicators of rail or mixed rail-water transport will be different from those of this transport provided that the fuel flow only be directed along one of them without construction of a petroleum product pipeline. In this case the operating indicators will vary not only for fuels for which the means of transportation is being selected but also for other freight transported in the given case by universal types of transport. Depending on specific conditions (engineering parameters load and so on), the expenditures on these types of transport for the remaining goods may decrease or increase, which is naturally reflected in the indicators of the effectiveness of product pipeline construction from the viewpoint of the national economy as a whole and cannot be taken into account when solving the postulated problem. Accordingly, the total reduced expenses must be determined for each version to determine the optimum solution.

Comparison of the reduced expenditures determined for the case of transporting goods along each of the routes should be the basis for selecting the most economical of them. Experience shows that these calculations are very cumbersome and require information on the loading of existing transport structure now and in the future and on the presence of reserves of carrying capacities and other data.

The second method also assumes comparison of all changes of transportation and related expenditures for all transportation-economic communications of the test areas under consideration, including those along which the flow is not sent in the given version, but may be sent in some other version. However, only the expenditures in the variable part are taken into account. The expenditures which are fixed in all versions are not taken into account. Only the variable expenditures are taken into account that are usually linearly dependent or close to dependent (in a specific range) on the volume of shipments. All calculations are simplified since only specific expenditures are taken into account. The validity of this assumption can be shown on the example of two rail lines.

With the first method, the difference of expenditures a according to the versions being compared, expressed by total expenditures, can be determined by the formula

$$a=P''_1E''_1+P'_2E'_2-(P'_1E'_1+P''_2E''_2), \qquad (2.1)$$

where P_1' and P_2'' are the freight traffic volume (or transport work) on the first line under the initial conditions and with an additional fuel flow, P_2' and P_2'' are the same freight traffic volume on the second line, E_1' and E_2'' are the total specific expenditures on the first line in the initial aspect and with an additional fuel flow and E_2' and E_2'' are the same figures on the second line.

With the second method, i.e., with consideration of only the variable expenditures ΔE for each of the lines being compared that occur with regard to passage of an additional freight flow along it, they can be compared to each other by the formula

$$a=\Delta \text{Э}_1-\Delta \text{Э}_2. \qquad (2.2)$$

It is easy to ascertain that the second method is a modification of the first

$$P'_1E'_1=\text{Э}_1;\ P'_2E'_2=\text{Э}_2; \qquad (2.3)$$

$$P''_1E''_1=\text{Э}_1+\Delta \text{Э}_1; \qquad (2.4)$$

$$P''_2E''_2=\text{Э}_2+\Delta \text{Э}_2. \qquad (2.5)$$

Then

$$a=(\text{Э}'_1+\Delta \text{Э}_1+\text{Э}'_2)-(\text{Э}'_1+\text{Э}'_2+\Delta \text{Э}_2)=\Delta \text{Э}_1-\Delta \text{Э}_2. \qquad (2.6)$$

Thus, determination of the transportation expenditures occurring with regard to the basis of a newly appearing fuel flow, and this is also valid for any goods, by calculation of the total expenditures or their variable part for each test area essentially yields identical results.

The basic principle of comparison is frequently violated in calculations by the first method (for total expenditures) since changes in expenditures on all transportation lines participating in the versions being compared are not taken into account or the variation of specific expenditures occurring with variation of the volume of shipments is not taken into account. As a result the calculated transportation expenditures considerably exceed the actual expenditures, especially on traditional, universal types of transportation. To confirm this conclusion, let us consider the example of determining transportation expenditures to ship coal from station A to an electric power plant if it is located at station B or C located from station A at distances of A - B = 200 km and A - C = 250 km, respectively. Let us assume for clarity that the reduced specific expenditures on the railroad under its existing load are identical over the entire length and comprise 3 kopecks per 10 km. It would seem in this case that expenditures to deliver one ton of fuel to the electric power plant if it is located at station B will be equal to 0.60 ruble and if it is located at station C will be equal to 0.75 ruble.

An increase of expenditures per ton of fuel will comprise 0.15 ruble if the electric power plant is located at point C compared to its location at station B or the expenditures for the entire volume of fuel shipments for the electric power plant will be equal to 450,000 rubles annually. However, this is not true in reality. The specific shipping expenditures on the line with the appearance of an additional freight traffic volume vary and they vary not only to ship coal (the additional freight traffic volume), but also for all other freight shipped on this line. The permanent part of the expenditures will be distributed for a different volume of shipments.

The specific expenditures usually decrease with an increase in the flow of shipped goods if the additional freight traffic volume does not lead to significant overloading of the transportation facilities or to expensive operations to increase carrying capacity. In the given case, based on conditions similar to the average conditions for rail transport, the specific expenditures can be divided into two parts: $E^{post}_{pr} = E^{izm}_{pr} = 0.5\ E_{pr}$, where E^{post}_{pr} is permanent expenditures that can conditionally be taken as independent of the volume of shipments and E^{izm}_{pr} is variable expenditures in proportion to the freight traffic volume.

If six million tons of freight passed through the section prior to construction of the electric power plant and if construction of the electric power plant increased the volume to nine million tons, then this causes an increase of expenditures only in the variable part $E^{izm}_{pr} = 1.5$ kop/10 t-km. With a volume of six million tons, these expenditures comprise 9,000 rubles annually per kilometer and with shipment of coal with total volume of nine million tons it comprises 13,500 rubles. However, the permanent expenses over the entire length of the line remain fixed, equal to 0 5 $E_{pr} = 1.5$ kopecks per 10 t-km or 9,000 rubles per kilometer regardless of whether there is an additional volume of flow for the electric power plant or not. Hence, the specific expenditures E_{pr} comprise 2.5 kopecks per 10 t-km with additional coal for the electric power plant. The total expenditures for shipment of all freight over line A-C then comprise 5.4 million rubles with the electric power plant located at point B and 5.625 million rubles with the power plant located at point C.

An increase of transportation expenses with the electric power plant located at point C rather than at point D will comprise 5.625-5.400 = 0.225 million rubles rather than 0.450 million rubles, as would be the case if the change in the structure of expenditures were not taken into account. We find the same results if we use only the variable specific indicators E^{izm}_{pr}. In the case under consideration, an increase of expenditures to ship coal with regard to the electric power plant being located 50 km from the point of coal production comprises $50 \cdot 3.0 \cdot 10^6 \cdot 0.0015 =$ $= 0.225$ million rubles annually.

The given concepts show the possibility of making calculations for total and supplementary expenditures with regard to all changes occurring in the country's transport network with the considered versions of fuel and other freight traffic volume distribution; determination of expenses for the entire test area with regard to variation of its load requires special attention. It should be stipulated that calculations can be carried out on permanent and variable expenditures and calculations on the variable part of expenditures permit rather accurate accounting of the transportation expenses by versions. At the same time they reflect the real national economic expenses, but do not coincide with existing tariffs, since permanent expenses are also taken into account in the latter. The values calculated for total expenses for individual routes and sections of the transportation network also do not coincide with the tariffs, which are averaged values.

The difference between the real national economic expenses and existing tariffs indicates the impossibility of using tariffs when comparing versions.

When selecting the type of transportation, it is more important to take into account the variation of real national economic expenses by the variable part than to determine them from tariffs, even more so since tariffs change periodically [47].

Errors frequently occur due to incorrect establishment of the level of dependent (variable) and independent (permanent) expenses. Let us assume that a route must be selected to ship one million tons of freight over one of two transportation routes 200 km long with the following characteristics. The dependent expenditures on the first route are equal to 0.2 kop/(t-km) and the independent expenditures are 40,000 rubles/km with a volume of 20 million tons, while the dependent expenditures are equal to 0.1 kop/(t-km) and the independent expenditures are 60,000 rubles/km with volume of 10 million tons on the second route. It is obvious that the additional volume could be carried over the second route where the dependent expenditures are one-half as much. In this case the total expenditures over both routes comprise 30.2 million rubles. However, the total expenses on the first route are lower (0.4 kop/(t-km) compared to 0.7 kop/(t-km)). The total expenses are very frequently the basis for making decisions on the direction of freight traffic volume. There is an increase of total expenditures by 0.2 million rubles, i.e., to 30.4 million rubles, in the give example when additional freight is shipped over the first route with lower total expenditures.

Consequently, when the versions are compared one must determine the increase of expenditures for possible transport versions over all routes on which indicators may vary with the appearance of additional freight traffic volume and as a result of comparison, one must select the more economical route.

In the practice of design and planning of systems development, the economic indicators are always determined for the additional freight traffic volume.

Chapter 3. Rail Transport of Fuels

3.1. The Role of USSR Railroads in Fuel Transportation

During the past 20 years, the engineering and economic indicators have improved considerably on the rail transport of the Soviet Union. Although the length of general-purpose railroads was increased comparatively slowly (by approximately 1,000 km annually), their technical equipping increased rapidly and made it possible to assimilate the increased freight traffic volumes, including fuels. The freight traffic volume of the railroads increased from 602 billion t-km in 1950 to 2.45 trillion t-km in 1970 and 3.33 trillion t-km in 1977. During this time the freight traffic volume of fuels (coal, coke, oil and petroleum products) comprised 34.5, 35.8, 32.8 and 30.9 percent, respectively, of the entire freight turnover. The decrease in the specific weight of fuels was the result of developing pipeline transport and improvement of the country's energy balance [30,55, 56].

The basic direction of technical progress in rail transport that made it possible to sharply increase the freight intensity of the network was redesign of traction (extensive electrification and introduction of diesel traction) with simultaneous replacement of two-axle rail cars with four-axle cars, modernization and strengthening of the upper track structure, means of communications and other components of facilities. The length of electrified railroads increased from 3,000 km in 1950 to 40,500 km in 1977. The most freight intensive, mainly two-track, mainlines were electrified.

Experience showed that electrified mainlines with modern technical equipping assimilate freight traffic volumes up to 100 million tons or more, including fuels of approximately 40-60 million tons annually, and operate rather reliable and economically. All this made it possible to improve the engineering and economic indicators: the cost of shipments was reduced from 4.86 kopecks per 10 t-km in 1950 to 2.48 kopecks in 1975. This reduction in the cost of shipments made it possible to significantly reduce national economic expenditures for transportation of coal from the eastern basins and to expand the boundaries of their effective use. The coal of the Kuznetsk basin began to be delivered west of the Urals, to the Volga region and in some cases to the Center.

The effect of variation of the engineering and economic indicators on expansion of the coal transportation area and formation of the energy balance can also be considered in the experience of the United States.

A number of measures has been implemented on the coal-hauling railroads of the United States that made it possible to significantly improve the engineering and economic indicators of this type of transportation. They primarily include:

the use of specialized gondolas with capacity of 91 tons that provide rapid unloading of coal without manual cleaning;

the use of remote locomotive (diesel) control equipment located among cars from the pilot locomotive, which made it possible to drive a train with mass up to 20,000 tons or more;

organization of special "shuttle" coal trains formed up between large mines or coal-collection stations and large electric power plants according to a strict schedule, which makes it possible for the electric power plants to operate without cumbersome stores of fuel;

organization of coal-collecting stations in coal basins to which coal is delivered from small mines and where "shuttle" trains are formed up.

All these measures made it possible to considerably reduce expenditures for crew payment and as a result to reduce tariffs. Variation of expenditures for production and transport of coal is obvious from the data presented in Table 3.1.

A decrease of prices for coal and improvement of the regularity of delivery to the electric power plants led to the fact that this type of fuel was in some cases competitive with oil and gas. In combination with electric power transmission lines (with the electric power plant being located outside populated regions), a reduction in cost of coal transportation made it possible to expand the sphere of use of coal fuel [70, 71].

Thus, improvement of rail shipments of coal induced a number of far-reaching consequences in the field of development of both energy capacities and of the fuel industry and in the final analysis in the structure of the fuel and energy balance.

During the past few years, with regard to the energy crisis, the process of further development of power engineering with rail shipment of coal is being developed, and, judging by data from the literature, will also be developed in the future.

According to forecasts of the National Petroleum Council of the United States, coal consumption will increase from 544 million tons in 1974 to 890 million to 1.09 billion tons (metric tons) in 1985. During this time the coal consumption by electric power plants will increase from 350 to 590-635 million tons, respectively.

Table 3.1.

(1) Показатели	(2) Затраты, долл/т		
	до 1966 г. (3)	(4) после реорганизации	
		для крупных шахт (5)	для мелких шахт (6)
Добыча угля в шахтах (7)	4,41	4,41	4,96
Транспорт по магистрали (8)	3,86	2,20	2,20
Транспорт до углесборочных станций и перегрузки (9.)	—	—	0,67
Всего (10)	8,27	6,61	7,83

Key:

1. Indicators
2. Expenditures, dollars/ton
3. Prior to 1966
4. After reorganization
5. For large mines
6. For small mines
7. Coal production in mines
8. Transport over mainline
9. Transport to coal-assembly stations and transloading
10. Total

It is planned to use rail shipments usually by block trains to ship coal where there is no possibility of using water transportation. Despite the extensive development of water shipments, 65 percent of the coal mined in the country was shipped by rail in the United States in 1974. Since the fields most favorable for mining are located far from rivers, the fraction of rail shipments will increase in the future. Only the development of pipeline transport of coal may affect the growth rates of coal shipments. However, even if all the available programs for development of coal pipelines are fulfilled (up to 8,000 km), the volume of coal shipments by railroads will increase significantly.

A large part of the measures implemented by United States railroads (block trains, coal-collecting stations, the high level of using rolling stock, an increase of train mass and so on) was implemented earlier to one degree or another on the railroads of the Soviet Union.

Further improvement of fuel shipments and improvement of their engineering and economic indicators on domestic railroads have their own characteristic features that follow mainly from the high loading of the railroad network. Assimilation of newly occurring shipments usually requires not only corresponding supplementation of the rolling stock pool but also an increase of carrying capacity and in some cases construction of new rail lines.

It should be noted in this case that an increase of carrying capacity of a number of rail routes is complicated by their high load in which construction work requires prolonged periods and increased expenditures. However, despite these difficulties, the role of rail transport in formation of the country's fuel and energy balance will increase for conditions of the Soviet Union [55, 56].

The reduced expenditures for coal in most regions of the European USSR for long-distance Kuznetsk and concentrated Kansk-Achinsk coal are lower than the cost of coal from the Donetsk, Pechora and Moscow basins. Imported coal is similar in many regions by reduced expenditures to those for gas fuel of the northern fields of Western Siberia with regard to the saving from improving the consumption conditions at electric power plants. Therefore, one should expect a further increase of coal shipments from the east to the west and primarily for production purposes: coke, semicoke, concentrates for coking, special grades of energy coal (lump semicoke and high-quality briquettes for domestic needs) and energy coal for heating and electric power plants and in some regions of the country to supply power to condensation electric power plants, especially those operating in the semipeak mode of the load schedule.

Rail transport occupies the leading position in shipment of petroleum products, only approximately half the petroleum products can be pumped over petroleum product pipelines. Mazut, oils and a number of grades of light petroleum products of increased quality or those produced in small quantities and at oil refining plants remote from consumers will be transported mainly by rail transport.

Despite the fact that the fraction of fuels in the total general-purpose rail shipments will be gradually reduced (34.5 percent in 1965, 31.5-32 percent in 1975 and 28-29.5 percent in 1980), the actual volume of fuels increased by approximately 15 percent during the five-year period from 1965 to 1970 and it increased by 18-20 percent during the five-year period from 1971 to 1975, and a further increase of shipments is anticipated during the current five-year plan. The fraction of fuel shipments in the more remote future will continue to decrease, but the rate of this decrease is now difficult to imagine. This will depend on the structure of the fuel and energy balance, the scale of oil and gas production, the ratio of expenditures to production and transport, the rates of development of nuclear power engineering, involvement of large masses of Kuznetsk and Kansk-Achinsk coal and the fuel and energy balance of the European regions and the Urals and development of pipeline transport of coal fuel or development of long-distance electric power transmission lines.

The given data indicate the need for further improvement of the hardware and organization of shipment of fuels on railroads.

3.2. Basic Directions for Development of Railroads

Analysis of the prospects for development of the Soviet Union and its transportation system leads to the conclusion that rail transport will remain the main type of freight transport in the foreseeable future for long and medium distances for most freight, except oil and partially of petroleum products. Despite switching a number of goods to specialized types of transport and despite accelerated development of more high-speed and convenient passenger traffic, the work of the railroads will increase, although at lower rates.

The change in loading of the railroad network is of special interest under these conditions to judge the effect of shipping fuels on the development of railroads. The freight intensity (freight turnover per unit length) of individual sections of the railroad network is extremely nonuniform and on some lines exceeds 60 million tons-km/(km·year) in one direction, but the total length of sections with this load is insignificant. The length of lines with load from 40 to 60 million t-km/(km-year) in the loaded direction is also low. The optimum freight intensity of two-track railroads with modern hardware is at the level of 50-90 million t-km/(km-year) in the loaded direction depending on the structure of the freight turnover, the length of the receiving-dispatching tracks and the dimensions of passenger traffic. A number of loaded sections and routes operates rather reliably with freight intensity exceeding 70 million t-km/(km-year) in the loaded direction and with rather intensive passenger traffic. As already pointed out, there are sections of railroads where the freight intensity reaches approximately 100 million tons-km/(km-year). However, parallel railroads constructed to relieve them are sometimes not fully loaded. Therefore, the railroad network can be developed by construction to assimilate additional shipments for increasing the carrying capacity on individual routes or sections of railroad and also to supplement the rolling stock fleet.

One must also take into account in this case the general nature of variation of the load of railroads: the freight traffic volumes in the loaded direction remain relatively stable only on an insignificant part of the network of single-track (7-12 percent) and double-track (3-5 percent) lines, while a continuous increase of shipments of all freight occurs on the remaining length of the railroad network.

There may be two methods of increasing the carrying capacity of railroad routes: making the railroad network denser by construction of new routes parallel to existing routes and converting to mainlining--development of mainlines with very high carrying capacity and inexpensive shipments on the basis of existing railroads. Development of domestic rail transport confirmed the fruition of ideas of mainlining proposed earlier by the GOELRO [State Commission for the Electrification of Russia] plan as the basic direction for development of transportation [3].

Analysis shows that there is the possibility on all main rail routes parallel to existing loaded mainlines to develop new railroad routes with high carrying capacity by constructing individual missing sections of relatively short length and construction of second tracking on existing single-track sections included in the mainline being created. An exception are regions of the Far East and the Urals-Center where the Baykal-Amur Mainline Railroad is under construction.

Under these conditions the problems of fuels shipment faced by railway transport can be divided into two types.

The first type of problem is development of a relatively slow increase of coal shipments and shipments of petroleum products. This problem arises if a further improvement of the energy balance of the European regions and the Urals occurs due to development of nuclear power, an increase in the specific weight of gas fuel and extensive development of pipeline and other specialized types of energy transportation (coal pipelines and electric power transmission lines), then an increase in the volume of coal shipments from the eastern basins by rail will be relatively slow and will not exceed 130-150 million tons annually in the foreseeable future. In this case concentration of coal volumes on individual routes may be no more, for example, than 20 million tons and it may reach 60-80 million tons on each route from the Ekibastuz and Kuznetsk basins [2, 72, 73]. This transportation support may be achieved by increasing the carrying capacity of the existing railroad network, by improving the rolling stock, by rearrangement of single-track railroads to two-track railroads with conversion of them to large mainlines and by developing new routes by improving the configuration of the network.

The second type of problem is to deliver large amounts (for example, more than 180-200 million tons annually) of coal from the Kuznets, Kansk-Achinsk (concentrated) and other eastern basins to the Urals and to the European USSR, i.e., an energy complex will be developed by extensive involvement of the coal of eastern regions. This is possible with development of a special large-capacity mainline. A specialized mainline can be developed on the basis of a railroad by restructuring a number of sections and fundamental reconstruction of lines already constructed.

A characteristic feature of railroads is the capability of increasing their carrying capacity by increasing the mass of trains and by increasing their number. Thus, the carrying capacity for a single-track railroad was established at 12-36 pairs of trains per day with length of the receiving-dispatching tracks of 850 or 1,050 meters. The carrying capacity will be brought up to 180 pairs of trains per day, i.e., will be increased 5.7-17-fold, with double-track railroad mainline with modern communications devices that provide a succession of trains at intervals of 8 minutes. Even higher carrying capacities are achieved on short, primarily suburban sections. At the same time, the mass of a train can be increased by lengthening the receiving-dispatching tracks and introducing rolling stock with increased load per meter of length.

In practice the carrying capacity of a railroad constructed according to specifications of category I (3-5 million tons annually) can be brought up to 80-100 million tons annually in the loaded direction with subsequent development.

The use of eight-axle gondolas and tank cars is possible in the future for shipping fuels, which will make it possible to increase the carrying capacity of double-track electrified mainlines by an additional 30-35 percent and to bring it up to 120-130 million tons annually with length of receiving-dispatching tracks of approximately 1,050 meters [59, 60].

The effective carrying capacity of a railroad section or route determined by existing hardware and also by the number of pairs of passenger trains and volume of shipments to service local consumers and the possible carrying capacity which can be achieved with complete development of the railroad to a double-track mainline with modern hardware that provides passage of 144-180 pairs of trains of a parallel schedule should be distinguished. However, this carrying capacity permitted by permanent devices with corresponding support with rolling stock is not optimum. The optimum carrying capacity is somewhat lower than the possible capacity with complete use of permanent devices. The presence of a reserve that provides high operating indicators and operating stability of the route is required to achieve minimum transportation expenses.

The problem of passing an additional flow of fuels and other freight over one or another section or route of a railroad network with existing hardware and the number of rolling stock is solved on the basis of the effective reserves and other conditions and is related to problems of operational planning. Consideration of routes and indicators of conversion from the actual to the possible carrying capacity and the use of this increase to ship fuels is of great interest for analyzing the engineering and economic indicators of fuel transport.

3.3. Methods of Increasing the Carrying Capacity of Railroads

a) The Mass of Trains

As is known, the mass of a train is determined by the length of the receiving-dispatching tracks, the load capacity of rail cars and the level of their utilization. Electric and diesel traction makes it possible to achieve any tractive force and capacity by sectioning with control from the front locomotive section. Therefore, trains of any mass formed up according to the length of the receiving-dispatching tracks of stations can essentially be made up. During the past decades practically all basic directions of the railroad network were reconstructed and the receiving-dispatching tracks were lengthened to 850 meters and on some routes to 1,050 meters. Therefore, the reserves for increasing the mass of trains by a further lengthening of receiving-dispatching tracks have essentially been exhausted.

When constructed new rail mainlines, the length of the receiving-dispatching tracks can be any length. There is positive experience in laying out a mainline under valley conditions of terrain with the possibility of lengthening the receiving-dispatching tracks to 1,700 meters. The use of station tracks of this length on railroads constructed under less favorable conditions causes an increase in construction cost, but is also possible. Preliminary developments showed the possibility of developing a mainline with access of trains on it with double length of 2 X 850 or 2 X 1,050 meters. However, trains of this length can be used only in construction of a new railroad or fundamental reconstruction of existing, primarily single-track railroads.

Improving the parameters of coal gondolas and tank cars may provide large reserves for increasing the carrying capacity. Shipment of coal or petroleum products in eight-axle cars, especially those constructed according to dimensions 1-T, increases the running load per meter of train length from 5.8 to 8 and even 8.5 t-f/m, i.e., by 38-45 percent (Table 3.2). The fuel-carrying capacity of railroads accordingly increases without increasing the number of pairs of coal or tank-car trains [20, 21].

Restrictions on overall dimensions and the strength of artificial structures (bridges and overpasses) prevent a further increase of the load capacity of rail cars or rather of load per meter of train length. Eight-axle rail cars with dimension T carrying a load of more than 9 t-s per meter of length will be able to be operated in the near future only on closed routes.

Improving the stock of gondolas to ship coal and tank cars, besides increasing the carrying capacity, should also solve two other problems: reducing coal losses during shipment and increasing the operating reliability of the rail car stock and consequently of railroads as a whole.

Coal losses now comprise up to 1.5 tons for each gondola with capacity of 60 tons or up to 20 percent of the transported coal. When coal is transported only from

Table 3.2.

(1) Число осей	(2) Габарит	(3) Грузоподъемность, т	(4) Тара, т	(5) Объем кузова или котла цистерны, м³	(6) Длина по осям автосцепки, м	(7) Погонная нагрузка, тс/м	(8) Удельный объем, м³/т
(9) *Полувагоны с глухим полом*							
6	1-T	95	30,0	107,0	16,4	7,60	1,11
6	T	95	31,5	116,0	15,7	8,05	1,23
6	T	97	28,7	116,4	14,0	9,0	1,2
8	1-T	127	41,5	138,0	19,8	8,5	1,08
8	T	132	40,0	155,0	19,1	9,0	1,18
8	T	128	39,9	153,6	18,7	9,0	1,2
(10) *Цистерны*							
6	O-T	90	38,0	99,0	16,0	8,0	1,10
6	T	90	35,6	100,0	14,0	9,0	1,10
8	1-T	120	48,0	136,8	21,1	8,0	1,12
8	T	120	48,0	146,0	16,4	10,2	1,2
8	T*	128	48,0	153,6	18,0	9,78	1,2

*Design developed for Baykal-Amur Mainline Railroad

Key:

1. Number of axles
2. Overall dimensions
3. Load capacity, tons
4. Tare, tons
5. Volume of body or boiler of tank car, m^3
6. Length of automatic coupler along axles, meters
7. Running load, t-f/m
8. Specific volume, m^3/t
9. Gondolas with blind floor
10. Tank cars

the Kuznetsk basin, more than 2.5 million tons of coal is lost annually and the nonproductive expenses throughout the country as a whole due to coal losses reach several tens of millions of rubles [60].

The main causes for coal losses are gaps in the body (and doors and unloading hatches) and loading gondolas from the "top." Therefore, reducing coal losses by covering it with mastic, spraying it with oil and packing the surface of the coal with rollers does not eliminate the main causes.

As can be seen from the data of Table 3.3, calculated for average distance of coal shipment, the minimum losses due to wind occur when gondolas are loaded to the level of the sides or higher up to 100 mm. However, with existing gondolas, this loading leads to significant losses due to incomplete utilization of load capacity.

The volume of a gondola body constructed according to dimension 1-T, is increased by approximately 12 percent, which makes it possible to load coal into the car without a "cap" and at the same time to improve the running load of the car.

Eight-axle gondolas constructed according to dimension T with false floor and specific body volume of 1.18-1.20 m^3/t have good indicators. They completely eliminate losses due to coal spilling through leaks in hatches and removal of fine coal fractions due to wind when gondolas are loaded with a "cap." However, these gondolas will find application only on individual routes in the near future.

Table 3.3.

(1) Высота шапки, мм	(2) Загрузка вагона, т	(3) Недогрузка, т	(4) Потери от недогрузки вагона, руб.	(5) Потери угля от выдувания		Высота шапки, мм	Загрузка вагона, т	Недогрузка, т	Потери от недогрузки вагона, руб.	Потери угля от выдувания	
				(6) т	(7) руб.					т	руб.
600	64,1	0	--	2,50	21,30	100	58,2	8,9	10,89	0,21	1,78
500	63,5	0,6	1,05	2,10	15,50	0	55,2	8,9	16,91	0,22	1,82
400	62,4	1,7	3,01	1,52	12,90	—100	52,2	11,9	23,30	0,70	5,95
300	61,6	2,5	4,48	0,92	7,80	—200	49,3	14,8	30,22	0,91	7,70
200	59,9	4,2	7,62	0,60	5,09						

Key:

1. Height of cap, mm
2. Load of rail car, tons
3. Underloading, tons
4. Losses due to underloading of rail car, rubles
5. Coal losses due to wind
6. Tons
7. Rubles

Investigations of the designs of large-capacity tank cars for the Baykal-Amur Mainline showed that the internal diameter of the cylindrical part of the body must be increased to 3,400 mm to increase the engineering and economic efficiency of tank cars. Efficient use of dimension T and the optimum parameters of tank cars will provide a decrease of reduced expenditures by 8.5-9 percent and will permit an increase of the carrying capacity of the mainline by 26-27 percent [19].

Thus, the basic directions for further improving the hardware of railroads in fuel shipment are convergent to dimension 1-T and subsequently to dimension T and improvement of the parameters of loading capacities.

Extensive use of eight-axle gondolas and tank cars of dimension 1-T and subsequently of dimension T may be regarded as the most effective direction of assimilating the increasing fuel volumes with minimum expenditures for development of permanent devices: capital investments are required only for construction and adaptation of loading devices (rail car tipping devices and unloading tracks) and energy supply devices on some sections with electric traction.

b) The Carrying Capacity of Railroad Sections

A characteristic feature of rail transport is the possibility of step by step development of carrying capacity usually accomplished as needed. The approximate values of the carrying capacity of railroads at the main phases of technical equipping are presented in Table 3.4.

An increase of carrying capacity above 144-180 pairs of trains is possible by constructing additional main tracks or reducing the traffic interval of trains. However, this concentration of shipments on a single mainline is unfeasible and used only on short suburban sections.

Table 3.4.

(1) Этапы развития железнодорожного участка	(2) Расчетные размеры движения пары поездов параллельного графика в сутки	(3) Капиталовложения для перехода к следующему этапу пропускной способности, тыс. руб.	
		на 1 км эксплуатационной длины (4)	(5) на 1 пару поездов
(6) Однопутная железная дорога с тепловозной тягой, полуавтоматической блокировкой и разъездами первой очереди	10—12	—	—
Открытие разъездов второй очереди (7)	18—24	10,0	0,8—1,2
Открытие всех разъездов (8) . . .	36—42	20,0	1,4—1,7
Строительство двухпутных вставок, автоблокировки и диспетчерской централизации при тепловозной тяге (9)	60—70	200	6,5—7,2
Строительство сплошных вторых путей с автоблокировкой при тепловозной тяге и интервале движения поездов 10 мин . . . . (10)	144	370	3,3—4,0
Электрификация тяги на двухпутной линии и доведение интервалов движения поездов до 8 мин . . . (11)	180	140	3,9—4,0

Notes: 1. Expenditures for electrification and construction of two-track inserts and double tracking are partially repaid and those on sections with intensive traffic are fully repaid by a saving of operating expenses.

2. Expenditures for construction of double tracking are given for the case of laying them on a single-track line.

Key:

1. Stages in development of a railroad section.
2. Calculated dimensions of traffic of a pair of trains of a parallel schedule per day
3. Capital investments for conversion to the next phase of carrying capacity, thousand rubles
4. Per kilometer of operating length
5. Per pair of trains
6. Single-track railroad with diesel traction, semiautomatic blocking and sidings of first unit
7. Opening of sidings of second unit
8. Opening of all sidings
9. Construction of two-track inserts, automatic blocking and centralized traffic control with diesel traction
10. Construction of continuous double tracking with automatic blocking with diesel traction and 10-minute interval of train traffic
11. Electrification of traction on two-track line and bringing train traffic intervals up to 8 minutes

It is obvious from the data of Table 3.4 that the least capital investments are required with opening of additional sidings on single-track railroads. After this possibility has been exhausted, the most effective is construction of double tracking and construction of two-track inserts may frequently be adequate for the initial period. Construction of double tracking now and in the near future is the basic direction for increasing the carrying capacity of railroads.

As the number of train pairs increases, losses to their passing and crossing due to delays of trains for repair of track and the contact system increase and losses with random interruptions of traffic due to external factors (snow removal, damage of devices by floods, damage to energy supply devices by lightning and so on) and also as a result of random breaks of track and breakdowns of rolling stock increase sharply. The higher the utilization factor of carrying capacity, the longer the time required to introduce train traffic to a normal schedule and the higher the delays of rolling stock and economic losses. The optimum carrying capacity is considerably below the calculated capacity.

A schedule of variation of expenditures related to train delays on a two-track railroad with electric traction having high passenger train traffic intensity and low linear load of freight cars (lightweight freight) is shown as an illustration in Figure 3.1. For the given case the minimum transport expenses occur with freight traffic volume in the loaded direction of approximately 40 million tons. Expenditures begin to increase sharply with a further increase of volume and it becomes feasible to carry out reconstruction work on the section under consideration or on a parallel route and to switch part of the freight traffic volume to it. With average scope of passenger traffic (15-20 pairs of trains per day) and average linear load of the train, the optimum load level of two-track railroads occurs with freight traffic volume of approximately 60-90 million tons annually. With higher loading, the operation of railroads becomes unstable: slight disruptions lead to prolonged interruptions in traffic, mass lateness of passenger trains, delays in movement of freight, maneuverability is lost and specific expenditures increase.

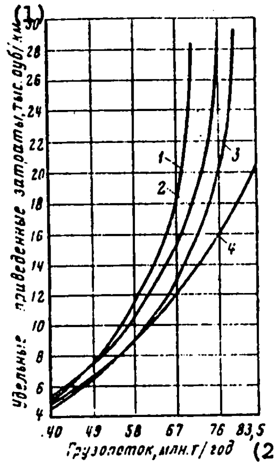

Figure 3.1. Nature of Variation of Reduced Expenditures on Two-Track Railroad with Increase of Freight Turnover: 1--10-minute interval of trains travelling in the same direction with length of receiving-dispatching tracks of 850 meters; 2--10-minute interval with length of receiving-dispatching tracks of 1,050 meters; 3--8-minute interval of trains travelling in same direction with length of receiving-dispatching tracks of 850 meters; 4--8-minute interval with length of receiving-dispatching tracks of 1,050 meters.

Key:

1. Specific reduced expenditures, thousand rubles/km
2. Freight traffic volume, million tons/year

The optimum load level is shifted toward large freight traffic volumes with a high specific weight of fuels and consequently with heavier trains, since this is primarily determined by the number of pairs of return trains and the level of utilization of carrying capacities.

Railroads operate stably with handling of 100-110 pairs of freight and passenger trains per day and with high specific weight of fuels, providing shipment of up to 80-100 million tons annually in the freight direction. The optimum carrying capacity is increased even more with eight-axle gondolas when the number of train pairs with fuels is 30-40 percent lower than with four-axle gondolas. With handling of 120-140 pairs of trains per day, sections of even relatively short length, with the exception of short suburban sections, operate rather stably and are usually relieved of their load due to switching of the train flow to parallel routes or due to construction of relief lines.

One can assume handling of 30-36 pairs of trains per day for single-track railroads with diesel traction under optimum loading, depending on the disposition of individual terminals and the characteristics of the other elements of technical equipping. The maximum carrying capacity of single-track rail sections during shipment of diverse freight and the average load for the system per rail car axle reaches 20-22 million tons with passage of 10-15 pairs of passenger trains per day. However, the operating and engineering and economic indicators with this load are low, for example, section speed comprises 50-60 percent of route speed and in some cases is even lower. Losses due to delays of trains are so significant that it becomes economically feasible to construct two-track inserts or double tracking.

When constructing single-track railroads especially to ship fuels with low passenger traffic intensity, especially when handling eight-axle rail cars, the carrying capacity of a single-track railroad can be increased to 30-35 million tons annually.

It should be noted that different measures to increase the carrying capacity of single-track railroads affect in different ways the operating indicators and shipping costs. Construction of double tracking and two-track inserts reduces the number of stops for train crossing and the length of these stops. Construction of additional sidings and electrification of single-track sections, despite the possibility of a further increase of traffic intensity, on the contrary lead to an increase in the number of stops [66, 19, 18].

Under average conditions, the optimum results (minimum one-time and current expenses over a prolonged period) are achieved when a single-track railroad is developed with semiautomatic blocking in the following sequence: opening of all sidings, lengthening of the receiving-dispatching tracks to 850 or 1,050 meters depending on the length of the receiving-dispatching tracks over the entire route or test area, construction of two-track inserts with equipping the section with automatic blocking and centralized traffic control, construction of continuous double tracking with the interval of trains travelling in the same direction brought up to 10 minutes, electrification of the route, reduction of the interval to eight minutes and finally construction of an additional main track in a parallel direction or construction of a parallel relief railroad.

This sequence may be different depending on the growth rates of shipments and the track profile. Electrification of a single-track railroad and introduction of a partially packet schedule of train traffic if this permits postponement of expenditures for construction of double tracking for a sufficiently long period, are feasible with slow growth rates of shipments on a loaded single-track line, especially with heavy profile when construction of double tracking requires large capital investments.

Two-track inserts and double tracking can be constructed on these sections after electrification and as the carrying capacity of a single-track railroad is exhausted. Continuous double tracking can be constructed immediately on routes with rapid growth rate of shipments and intensity of passenger traffic and diesel locomotives can be replaced with electric locomotives with a further increase of shipments.

Electrification of two-track railroad mainlines permits a reduction in the interval of trains travelling in the same direction to 7-8 minutes (compared to approximately 10 minutes with diesel traction) and permits an increase of carrying capacity to 30 percent or by 20-30 million tons in the freight direction. This increase of carrying capacity is achieved due to the high output of electric locomotives and their capability of achieving considerably higher accelerations than with diesel locomotives. This makes it possible to increase the traffic speed on waysides and especially at station entrances and to reduce the interval of trains travelling in the same direction without reconstruction of station entrances and signalling devices, centralized traffic control and blocking. This type of traction may be regarded as the main one for freight-intensive mainlines with regard to the other advantages of electric traction such as power supply from electric power plants operating on nuclear energy or coal and the absence of air pollution.

Transportation of relatively low fuel volumes (several million tons annually) is essentially possible on most two-track lines and on part of single-track lines. However, additional fuel volumes may require introduction of double tracking or two-track inserts on many loaded single-track sections, while admission of additional volumes of even 2-3 million tons may be impossible on some sections without implementing considerable reconstruction measures.

c) Coupling of Trains

Coal is shipped by rail in the United States by "coupled" trains have a mass 2-3 times greater than trains ordinarily handled.

Coupling of trains, i.e., coupling two trains and putting the second locomotive in the middle of the train, is used on USSR railroads as a temporary measure to increase the carrying capacity of individual sections. Development of remote control apparatus for locomotives in the center of a train from the pilot locomotive permits an increase of the length and mass of the train [58, 59].

The use of coupled trains may provide an increase of carrying capacity to 60-80 percent, i.e., approximately the same as construction of two-track inserts.

The engineering and economic indicators when using coupled trains with regard to construction of sidings and waysides and expenditures for development of the line are close to the corresponding indicators with construction of two-track inserts. At the same time, the circulation of rolling stock deteriorates somewhat with coupled trains compared to an ordinary single-track line due to the additional idle time during "coupling" and "uncoupling" and the circulation of rolling stock is considerably improved with two-track inserts due to the nonstop crossing of trains. The saving of operating expenses achieved with elimination of train stops at intermediate stations makes it feasible to construct two-track inserts with loading less than that in which introduction of "coupled" trains is required. The use of coupled trains on single-track sections should be regarded as a temporary measure effective for the period of constructing double tracking or two-track inserts or for conducting other operations.

The use of coupled trains as a method of further increasing the carrying capacity of two-track routes with lengthening of receiving-dispatching tracks at part or at all intermediate and preterminal stations and development of carrying capacities of preterminal waysides may require lower expenditures than construction of a parallel railroad. However, this organization of traffic, besides development and finishing of a locomotive remote control system, requires fundamental rearrangement of most stations and also of terminal and section stations to service the increased number of coupled trains without uncoupling them. Work on rearrangement of stations should be carried out under intensive traffic conditions, which is related to great difficulties and requires long deadlines. This rearrangement is essentially reconstruction of a loaded two-track railroad into a super mainline.

3.4. Development of a Specialized Railroad Mainline

Investigations and research were carried out during the early 1920's to develop a specialized mainline or the Donbass-Moscow-Leningrad super mainline. Investigations of a special route with flat grades (4 percent), with large curve radiuses and other parameters that provide handling of heavily loaded trains [60], were carried out on the Moscow-Donbass route. Laying of up to three main tracks of normal gauge was provided in this case. The super mainline was designed to supply the Leningrad, central industrial and northern regions with coal from the Donetsk basin instead of imported coal delivered to these regions from England prior to the Great October Socialist Revolution. The problem of a universal reduction of transportation expenses by increasing shipments, specialization of the route in mass shipment of freight of the same type and high technical equipping was posed in this case.

The problem of equipping the mainline with very high carrying capacity from Kuzbass to the west with track gauge up to 3 meters was considered after World War II. Discovery of unique coal fields in Siberia again raised the question of the need to study the engineering capability and economic feasibility of developing a specialized railroad mainline to ship coal to the Urals and the European USSR.

Based on the investigations, one can formulate the main aspects of developing a specialized mainline.

The points of fuel consumption (electric power plants, metallurgical plants and so on) are usually located on an existing railway system.

Connecting the pilot station of this mainline to individual mines and concentration enterprises will also be accomplished through a general-purpose railway system and partially through the sidings of enterprises. A specialized mainline cannot be isolated from the operation of the remaining part of a railway system. Consequently, the rail car fleet should have the capability of being handled not only through the mainline but through existing railroads. This predetermines the gauge, linear load per meter of rail car length, axle load and requirements on automatic brakes and automatic coupling.

Rail cars designed for handling on a specialized mainline should be calculated by brake and automatic coupling characteristics to operate in trains formed up to operate on other sections of a railway system.

Development of specialized rolling stock, for example, by dimension T, with increased axle loads and unit length, is possible with large consumers (of coal). This rolling stock can be handled in closed routes and sections where it travels from the loading points to the mainline and from the mainline to the consumers should be brought into agreement with the characteristics of this rolling stock.

A high carrying capacity of the mainline and reduction of transportation expenses can be achieved primarily by increasing the mass of trains. With locomotive traction of 120 t-f, the possible mass of trains and their length on sections with different calculated grade with locomotives at the head of the train are presented in Table 3.5.

Table 3.5.

(1) Уклон, °/₀₀	(2) Масса поезда, т		(5) Длина поезда с локомотивом, м, при нагрузке на 1 м	
	брутто(3)	(4) нетто	9 т (6)	8 т
4	21 400	16 200	2450	2750
6	15 800	12 000	1830	2060
8	12 500	9500	1460	1630

Key:

1. Grade, percent
2. Mass of train, tons
3. Gross
4. Net
5. Length of train with locomotive, meters, with load per meter
6. Tons

It follows from the data of Table 3.5 that handling of trains with mass of 15,000 tons with length of 1,800-2,000 meters by a single locomotive is possible with a grade of 6 percent. Reducing the grade to 4 percent permits the train mass to be brought up to 20,000 tons with length of 2,500 meters. If one takes into account that trains usually have a standard length of 850 or 1,050 meters, the mainline can have a length of receiving-dispatching tracks of 1,700 meters and a train mass up to 14,500 tons or 2,100 meters and train mass up to 18,000 tons. Consequently, the mainline should have a grade of not more than 6 percent with length of the receiving-dispatching tracks of 1,700 meters and a 4 percent grade with track length of 2,100 meters.

The grade can be increased when using several locomotives with remote control from the front locomotive. However, this arrangement is undesirable since it complicates the operating work.

The experience of operating loaded two-track railroads of great length shows that stable operation is possible with 10-minute interval of trains travelling in the same direction with handling of 100-110 pairs of trains per day. A specialized mainline will service the transport needs of adjacent regions. Section, built-up, local, passenger and farm trains will travel on it. Moreover, the interval of travel in the same direction can hardly be less than 11-12 minutes according to conditions of train passage through station entrances. This leads to a reduction in the number of coal block trains to 70-90. The carrying capacity with train mass of 18,000 tons is increased 1.2-fold compared to a train mass of 14,500 tons. Trains which travel at speeds different from coal trains should be diverted to parallel routes [60].

Rails with volumetric hardening in which wear resistance was increased twofold compared to rails of unhardened steel have now become widely distributed. Continuous replacement of these rails is required after mileage up to one million gross ton-km, i.e., every 3-4 years for a loaded specialized mainline.

Investigations are now being conducted to further increase the wear resistance of rails by adding alloying additives and by different hardening of individual parts of the rail. It is expected that the resistance of these rails will be additionally raised 1.5-2.0-fold and accordingly the service life will be increased. It must be noted that rails removed from a mainline will be laid on railroads with low traffic intensity for a service life up to 10-20 years.

High operating reliability of all elements of the system should be provided when developing a mainline of especially high carrying capacity. This requirement is decisive to ensure uninterrupted operation of this transportation system.

A high-capacity mainline to deliver coal from the country's eastern regions can be developed on the basis of Central Siberian Mainline from Achinsk to the Volga region in the area of Pugachevsk by corresponding lengthening and development of a station and all the management of the mainline. A specialized mainline should be capable of handling trains consisting of eight-axle gondolas with total mass of 15,000 tons with length of receiving-dispatching tracks of 1,700-2,100 meters.

Development of yet another mainline from the Kansk-Achinsk and Kuznetsk basins to the European USSR may be required in the future if it is necessary to deliver an even greater quantity of eastern coal to the Urals, Volga region and the European regions of the country. This problem requires scientific research work and engineering and economic substantiation.

3.5. The Engineering and Economic Indicators of Railway Transportation

The following aspects must be taken into account when determining the engineering and economic indicators of shipping fuels by rail.

1. The railroad system for additional fuel volumes should be developed with regard to maintaining the potential reserves for subsequent assimilation of other freight shipments. Consequently, the engineering and economic indicators of fuel shipment must be determined with regard to expenditures to recover the potential reserves of the railway system.

2. The engineering and economic indicators of shipping various types of freight depend on their physical properties, which primarily predetermine the use of the freight capacity of rolling stock, and on the load per meter of train. Under these conditions comparison of railroads to other types of transportation by mean indicators may lead to serious errors; therefore, indicators that more accurately characterize the shipment of fuels must be determined for future types of rolling stock.

3. Expenditures for rail shipments vary significantly with regard to the use of empty runs of trains. Coal gondolas can be used upon return to the station of dispatch to ship metal, timber, containers and a number of other types of freight and oil tank cars can be used to ship mazut and in some cases certain light petroleum products. However, the specific weight of gondolas and especially of tank cars loaded in empty routes is relatively low and decreases as the fuel volume increases, since the return route of coal volumes from the Kuznetsk, Karaganda and Donetsk basins to the west coincides with the volumes of timber and in some cases of ore. Under these conditions an increase of coal volume from the eastern basins to the Urals and to the European USSR and from the Donbass to the western regions of the Ukraine leads to a corresponding increase of empty runs of trains in the opposite direction.

Analysis shows that the capabilities of using tank cars to ship petroleum products in the same direction will be reduced as the number of oil refining plants increases and with more uniform disposition of them throughout the country. Therefore, when considering the engineering and economic indicators of shipping large volumes of fuels, preferably superimposed on already existing volumes, one can proceed approximately from the condition of returning gondolas and tank cars empty from the unloading points to the loading points and all expenditures may be related to shipment of fuels in the freight direction.

4. All expenditures for acquisition of rail cars, tank cars, electric locomotives, diesel locomotives and construction of devices required to service them (depots, repair yards and station tracks of different designation and so on) must be taken into account.

Indicators that are general for all freight are suitable to determine the optimum structure of the energy balance during the first phases of calculations, especially when determining the transportation and economic ties when great accuracy is not required.

All characteristic features of developing specific sections of railroads must be taken into account with more accurate calculations of transportation expenses, i.e., in all cases when calculations are a substantiation for specific engineering solutions and errors that reduce the reliability of the information obtained may lead to national economic losses.

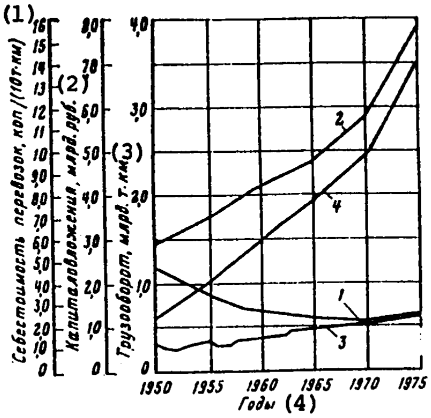

Figure 3.2. Actual Expenditures for Rail Shipments: 1--shipping cost; 2--total annual operating expenses for freight shipments; 3--capital investments to assimilate freight shipments; 4--freight turnover

Key:

1. Shipping cost, kopecks/10 t-km	3. Freight turnover, billion t-km
2. Capital investments, billion rubles	4. Years

During the past few years the engineering and economic indicators of railway transportation have improved significantly (Figure 3.2). The cost of freight shipments was reduced from 4.861 kopecks per 10 t-km in 1950 to 2.478 kopecks per 10 t-km in 1975, i.e., by one-half. However, some increase of expenditures from 2.341 kopecks per 10 t-km to 2.478 kopecks occurred during the past five years. A reduction in the rates of reducing shipping costs and even some increase of them during the past few years was the result of operating a number of railroad sections under nonoptimum conditions.

Operating expenses increased from 2.9 to 8.025 billion rubles or by 5.075 billion rubles during the period 1950-1975 with an increase of freight shipments from 602 billion to 3.236 trillion t-km, i.e., by 2.634 trillion t-km [30]. Assimilation of the increase of shipments required approximately 1.93 kopecks per 10 t-km and in this case the highest rates of reducing shipping cost were achieved during the period from 1950 through 1956 when the specific weight of new types of traction was still low. This indicates that improving the use of permanent devices to reduce shipping costs plays an important role. During the past few years when the rates of reducing shipping costs slowed down (for example, from 1965 through 1975) expenditures to assimilate additional shipments comprised 2.60 kopecks per 10 t-km, while they comprised 2.55 kopecks during the five-year period from 1971 to 1976. It is obvious from these data that the typical operating expenditures to assimilate increasing shipments will be 2.5-2.6 kopecks per 10 t-km [55].

The average annual capital investments related to an increase of freight shipments (Figure 3.2) comprise an average of 8.7 kopecks per 10 t-km for the entire period under consideration and 10 kopecks during the period 1970-1975, which is explained by replacement of steam traction with electric and diesel traction, from removal of two-axle and partially of four-axle rail cars from operation that do not meet modern requirements. This led to an increase in the rates of reduction of shipping costs. Reconstruction of traction led to a significant increase of carrying capacity due to an increase of train mass, an increase of traffic speeds and uninterrupted operation of railroads.

At the same time intensification of rail transport led to the fact that reserves were reduced sharply on a number of railroad sections, i.e., expenditures to develop mainlines were lower than required.

The basic directions for increasing the carrying capacity of railroads in the future are construction of double tracking and two-track inserts with corresponding development of terminals and also development of new routes parallel to specially loaded routes using available dead-end and other low-loaded sections of railroads. Implementing the indicated measures requires higher specific capital investments than reconstruction of traction.

The engineering and economic indicators of fuel transportation, especially on routes with mass volumes of coal and petroleum products, are significantly more favorable than the average indicators throughout the system as a result of using trains of increased mass and of moving them without handling at classification yards. The average gross mass of a train was approximately 2,500 tons throughout the railway system in 1975 and that of coal trains was approximatly 4,000 tons. Shipping fuels in six- and eight-axle gondolas and tank cars with linear load up to 8-9 t-f/m makes it possible to increase the train mass with fixed length of receiving-dispatching tracks and consequently permits an increase of load capacity by 35-40 percent without increasing the carrying capacity of waysides and stations. Specific expenditures to increase the carrying capacity of sections and stations are reduced accordingly.

Analysis of further development of rail transport leads to the fact that one can expect in the near future an increase in the mean specific capital investments, however, they will comprise 12-14 kopecks per 10 t-km (in prices introduced on 1 July 1967) for fuels with regard to the extensive use of eight-axle gondolas and tank cars. Operating expenses will be reduced and a figure of 2.0-2.3 kopecks per 10 t-km will be used for conditions of mass fuel shipments. Under these conditions the mean reduced expenses to assimilate newly occurring fuel shipments in eight-axle rolling stock will be 3.2-3.7 kopecks with coefficient of the effectiveness of capital investments of 0.1 and up to 4.0 kopecks with coefficient of effectiveness of 0.15. The given indicators do not include the cost of existing basic stocks and current expenses to maintain them since the latter do not vary from the rates of development of railway transport.

Table 3.6.

(1) Начальный грузопоток, млн. т/год	(2) Категории строительства			Начальный грузопоток, млн. т/год	Категория строительства		
	II	III	IV		II	III	IV
5	350	430	482	15	417	484	540
10	392	452	507	20	445	512	578

Key:

1. Initial freight traffic volume, million tons per year
2. Category of construction

The given mean indicators vary significantly for some sections and routes depending on the level of technical equipping, the use of carrying capacity, the track profile, the distance of freight shipment and a number of other important factors.

When determining the engineering and economic indicators of fuel transportation by rail, two general cases must be distinguished:

construction mainly for shipment of fuels of new railroad sections (for example, approaches to coal basins and specialized mainlines);

an increase of carrying capacity of existing railroads to assimilate shipments of additional fuels.

The specific expenditures, thousand rubles per kilometer, for construction of a single-track railroad under different conditions of construction and with the calculated freight traffic volume using diesel traction are presented in Table 3.6 [48].

Capital investments for construction of a two-track railroad can be determined as the sum of expenditures to construct a single-track railroad and the expenditures to construct double tracking. The specific capital investments for acquisition of freight gondolas and tank cars in the freight direction are presented in Figure 3.3 for single-track railway lines and with different difficulties of track profile with length of station tracks of 850 and 1,050 meters using diesel traction. Similar data are presented in Figure 3.4 for two-track sections using diesel traction and in Figure 3.5 for electric traction (determined for tank cars). A factor of 0.9 must be introduced when they are used to determine expenditures for gondolas. The indicators should be doubled to take into account the empty return of gondolas and tank cars in the opposite direction.

Data on the specific operating expenses to move loaded cars on single-track railroads with diesel traction are presented in Figure 3.6 and data for two-track railroads with electric and diesel traction are presented in Figure 3.7. The expenditures for shipping an empty car comprise 60-70 percent depending on the load of rolling stock in the freight direction typical for fuels. Thus, this coefficient is 1.62 when using freight capacity to 100 percent, 1.68 with freight capacity at 80 percent and 1.69 with freight capacity at 70 percent. The expenditures should

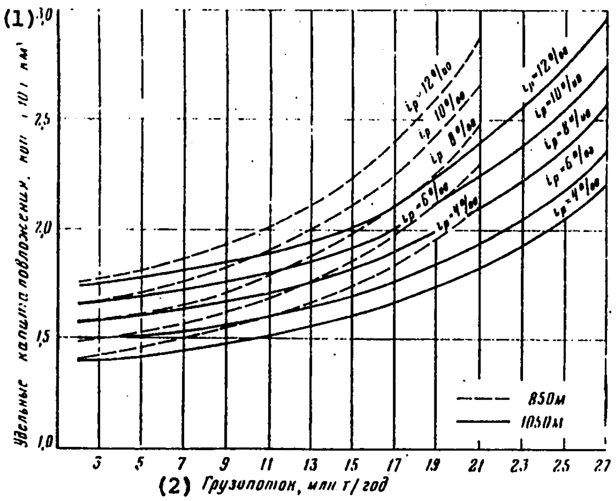

Figure 3.3. Specific Capital Investments in Rolling Stock for Single-Track Railroad with Diesel Traction and with Different Length of Receiving-Dispatching Tracks

Key:
1. Specific capital investments, kopecks per 10 t-km
2. Freight traffic volume, million tons annually

be multiplied by the correct coefficient to determine the total shipping expenses. When shipping freight with incomplete use of freight capacity, a coefficient equal to 1.2 for operating expenses and a coefficient of 1.25 for capital investments must be introduced for freight capacity of 80 percent; the figures are 1.25 and 1.40, respectively, for freight capacity of 70 percent. The operating expenditures, thousand rubles per kilometer, for maintenance of permanent facilities for traffic operation are presented in Table 3.7.

Calculations of the variation of specific reduced expenditures to ship fuels over a specialized single- and two-track railroad depending on their load (Figures 3.8 and 3.9) showed that specific capital investments in permanent devices decrease rapidly as shipments increase. Capital investments in rolling stock with an increase of section loading increase somewhat. An increase in the level of using the carrying capacity leads to an increase of idle times, a reduction of the section speed factor and deterioration in the use of rolling stock. The expenditures related to movement of trains also increase as load increases for the same reasons. In short, the reduced expenditures for a single-track railroad with diesel traction having ruling grade of 8 percent and length of receiving-dispatching tracks of 1,050 meters decrease to a load on the order of 30 million tons in the freight direction. It should be noted that these calculations do not take into account the increase of idle times and expenditures due to various complications in operating activity. These expenditures are very significant at high section load levels.

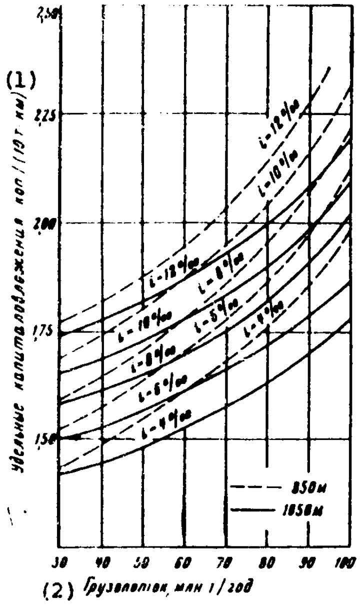

Figure 3.4. Specific Capital Investments in Rolling Stock for Two-Track Railroad with Diesel Traction with Different Length of Receiving-Dispatching Tracks

Key:
1. Specific capital investments, kopecks per 10 t-km
2. Freight traffic volume, million tons annually

Table 3.7.

(1) Вид тяги	(2) Грузонапряженность в грузовом направлении, млн. т·км/км				
	10	20	40	60	80
Однопутная железная дорога:(3)					
тепловозная тяга (4)	95	113	—	—	—
электрическая тяга (5)	119	138	—	—	—
Двухпутная железная дорога:(6)					
электрическая тяга (5)	—	206	237	269	278
тепловая тяга (4)	—	157	186	203	215

Key:
1. Type of traction
2. Freight intensity in loaded direction, million t-km/km
3. Single-track railroad
4. Diesel traction
5. Electric traction
6. Two-track railroad

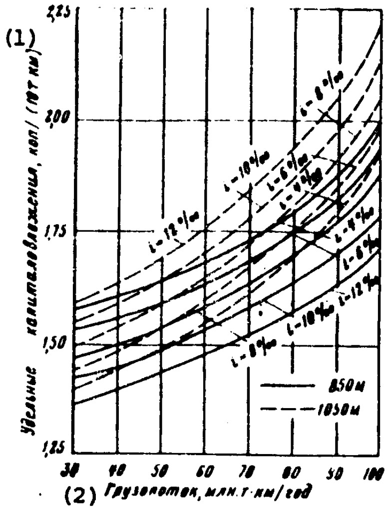

Figure 3.5. Specific Capital Investments in Rolling Stock for Two-Track Railroad with Electric Traction with Different Length of Receiving-Dispatching Tracks

Key:
1. Specific capital investments, kopecks per 10 t-km
2. Freight traffic volume, million tons annually

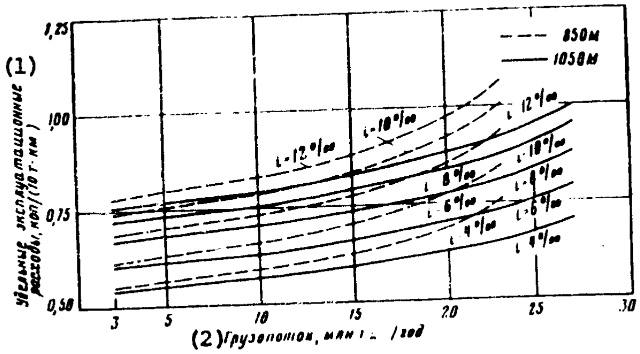

Figure 3.6. Specific Operating Expenses Dependent on Scope of Traffic on Single-Track Railroads with Diesel Traction with Different Length of Receiving-Dispatching Tracks

Key:
1. Specific operating expenses, kopecks per 10 t-km
2. Freight traffic volume, million tons per year

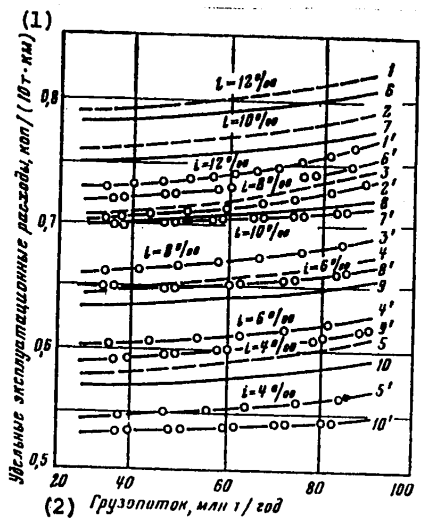

Figure 3.7. Specific Operating Expenses Dependent on Scope of Traffic on Two-Track Railroads with Electric and Diesel Traction with Different Length of Receiving-Dispatching Tracks:
1, 2, 3, 4 and 5--with grades of 12, 10, 8, 6 and 4 percent, respectively, and with length of receiving-dispatching tracks of 850 meters and with diesel traction; 1', 2', 3', 4' and 5'--O—— O--with the same grades using electric traction; 6, 7, 8, 9 and 10-- ——-- --with the same grades with length of receiving-dispatching tracks of 1,050 meters and with diesel traction; 6', 7', 8', 9' and 10'-- ——OO——OO--with same grades using electric traction

Key:
1. Specific operating expenses, kopecks per 10 t-km
2. Freight traffic volume, million tons per year

The optimum loads of a single-track railroad mainline are at the level on the order of 25 million tons annually with regard to expenditures of complicating operation, with length of receiving-dispatching tracks of 1,050 meters and handling of existing four-axle cars with primary volume of coal freight.

The optimum load capacity of two-track railroad sections comprises 80-90 million tons under the same conditions (see Figure 3.9). These values are determined for operation of a railroad with relatively modest scope of passenger traffic--10-20 percent of the number of pairs of freight trains. The optimum load capacity is somewhat lower than that indicated on sections with higher scope of passenger train traffic.

It should be noted that a railroad mainline should have carrying capacity reserves not only to provide irregular shipments but also to eliminate various traffic interruptions when providing normal operation. Losses of carrying capacity due to failures of track, rail cars and locomotives reach 25 trains when handling 60

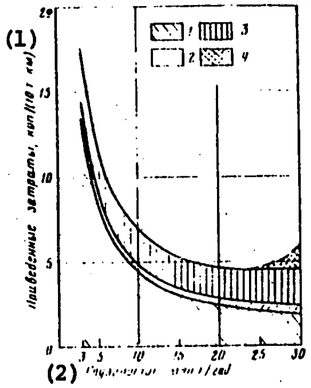

Figure 3.8. Reduced Expenditures for Single-Track Railroad with Different Load: 1--reduced capital investments in permanent devices; 2--reduced capital investments in rolling stock; 3--operating expenses; 4--losses due to unplanned expenses due to operation in nonoptimum mode

Key:
1. Reduced expenditures, kopecks per 10 t-km
2. Freight traffic volume, million tons annually

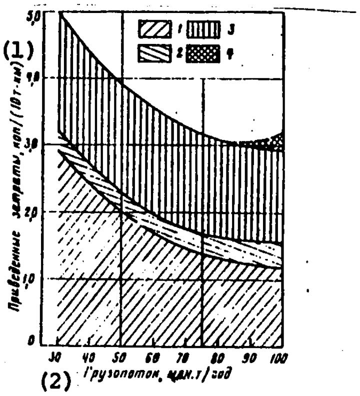

Figure 3.9. Reduced Expenditures for Two-Track Railroad with Different Loading. The notations are the same as in Figure 3.8

Key:
1. Reduced expenditures, kopecks per 10 t-km
2. Freight traffic volume, million tons annually

pairs of freight trains and 40 pairs of trains per day when handling 100 pairs of freight trains for a two-track railroad with passage of 20 pairs of passenger trains [66]. Thus, up to 90-100 pairs of freight trains can be handled with regard to the required carrying capacity reserve on a two-track railroad mainline with eight-minute interval between trains in the same direction, which can ensure shipment of approximately 100-110 million tons of freight with medium train mass of approximately 5,000 tons.

The saturation of track with trains affects the operating stability of the railroad. Thus, with filling of a track equal to 0.005, which corresponds to the 24-hour scope of traffic of 66 pairs of freight trains, the losses in speed comprise 3.2 km/hr and with filling of 0.075 or 100 pairs of trains, the losses are 5.2 km/hr. Section speed drops especially sharply with filling greater than 0.075 and if the filling is on the order of 0.08-0.1 (one train per 10-12 km of track) a railroad line of great length loses the required maneuverability, which results in prolonged delays of trains.

The given data indicate the need to have a specific carrying capacity reserve of railroads that ensures their stable operation and ensures that optimum economic indicators will be achieved.

The expenditures for the initial-final operations comprise an average of 2.5-6.0 rubles per 10 tons of freight and signficantly affect transportation expenses with short and medium shipping distances. Their value depends on the conditions of dispatch and receipt of freight by the consignee [60]. The following gradations of reduced expenses for initial-final operations can be established approximately for fuel shipping conditions:

dispatch of coal or liquid-cargo block trains formed up on the train tracks of enterprises and delivery by block train to the consignee--2.5-3.0 rubles per 10 tons;

dispatch of coal or petroleum products in block trains and delivery to consignees by individual gondolas or by small groups of gondolas (tank cars)--4.0-4.5 rubles per 10 tons;

dispatch and delivery in individual cars or groups of cars (tank cars)--5-6 rubles per 10 tons. Capital investments comprise 33-35 percent in this case.

Expenditures for initial-final operations are presented in Table 3.8 as a function of the distance of freight shipments.

In many cases, for example, when selecting versions of the location of electric power plants and other fuel consumers or oil refining plants with variable loading or unloading level, the expenditures for initial-final operations remain fixed and cannot be taken into account without a loss to the accuracy of comparative calculations. However, in other cases, for example, when determining the transportation component in expenditures to develop one or another energy object, when selecting the type of fuel when expenditures for initial-final operations are different, they must be taken into account especially with short and medium shipping distances.

Consequently, typical values of reduced expenditures for shipping fuels on newly constructed single-track lines with optimum loading and shipping distance of approximately 1,000 km will be approximately 5.0 kopecks per 10 ton-km and those on two-track railroads will be approximately 3.0-3.2 kopecks per 10 tons-km.

Table 3.8.

(1) Начально-конечные операции	(2) Затраты, коп/(10 т·км), при расстоянии, км						
	25	50	100	250	500	1000	2000
Прием и отправление маршрутами(3)	12,0	6,0	3,0	1,2	0,6	0,3	0,15
Прием маршрутами, сдача отдельными группами или наоборот (4). .	18,0	9,0	4,5	1,8	0,9	0,45	0,23
Прием и отправление отдельными вагонами или группами вагонов(5)	24,0	12,0	6,0	2,4	1,2	0,6	0,3

Key:

1. Initial-final operations
2. Expenditures, kopecks per 10 tons-km, at distance, km
3. Reception and dispatch in block trains
4. Reception in block trains and dispatch in individual groups or vice versa
5. Reception and dispatch in individual rail cars or groups of rail cars

The economic indicators in development of existing railroads, i.e., when the additional fuel or other freight traffic volume is superimposed on an existing railroad, are significantly better in some cases since the flow can be realized on some sections by using existing reserves of carrying capacity, restoration of which may be required only in the remote future.

These calculations for fuel delivery to large consumers are carried out on the basis of the following concepts [18, 19]:

expenditures to increase the carrying capacities of waysides of one or another section were determined as the sum of expenditures for development (step by step) of a given line or a parallel railroad if the volume must be switched to it;

expenditures for development of railroad management or so-called "intraphase" capital investments, were taken from average system indicators since the greater part of these expenditures is unrelated to specific sections (development of repair yards, enterprises of highway significance and so on);

capital investments to acquire rolling stock required to ship the additional freight were determined with regard to changes in the use of rolling stock engaged in shipment of freight already being shipped;

expenditures for maintenance of newly constructed permanent devices were taken into account;

expenditures related to movement of additional trains were determined with regard to the change in operating and economic indicators for shipment of "old" freight.

In this case the entire increase of expenses was related to the additional volume due to which expenditures assimilate it were frequently above the average.

Determination of the engineering and economic indicators caused by superposition of an additional freight traffic volume on an existing railroad requires consideration of a number of operating features and development of railway transport. A diagram of the variation of step by step strengthening of a railroad section with the appearance of an additional freight traffic volume is shown in Figure 3.10. As can be seen, superposition of an additional freight traffic volume brings these phases closer to an increase of the carrying capacity of the section.

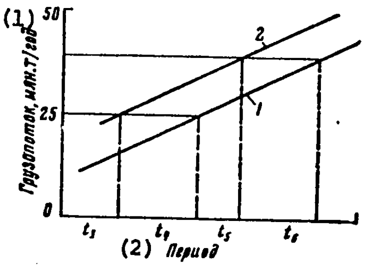

Figure 3.10. Diagram of Phase Strengthening of Carrying Capacities of Railroad Sections: 1--freight traffic volume; 2--additional coal volume for electric power plants; t_3--deadline for construction of two-track inserts with additional volume; t_4--deadline for construction of two-track inserts without additional volume; t_5--deadline for construction of second tracking with out additional volume; t_6--deadline for construction of second tracking with additional volumes

Key:

1. Freight traffic volume, million tons annually
2. Period

Under these conditions, capital investments for phase strengthening caused by superposition of an additional volume can be determined by the formula:

$$K_{\text{доп}}=\left(\frac{K_1}{(1+E_{\text{пр}})^{t_1}}+\ldots+\frac{K_n}{(1+E_{\text{пр}})^{t_n}}\right)-\left(\frac{K'_1}{(1+E_{\text{пр}})^{t'_1}}+\ldots+\frac{K'_n}{(1+E_{\text{пр}})^{t'_n}}\right),$$

where K_1, K_2, ..., K_n are capital investments for the corresponding phases of strengthening the carrying capacities, t_1, t_2, ..., t_n are the deadlines for implementing the corresponding phases of strengthening without an additional freight traffic volume and t'_1, t'_2, ..., t'_n are the deadlines with superposition of an additional freight traffic volume. The load of railroad sections, million tons annually, with a surplus of which measures can be implemented to increase carrying capacity, is presented in Table 3.9.

Table 3.9.

(1) Развитие железнодорожного участка	(2) Тепловозная тяга		(3) Электрическая тяга	
	(4) Длина приемо-отправочных путей, м			
	850	1050	850	1050
Открытие разъездов второй очереди (5) . . .	8—10	10—12	—	—
Строительство двухпутных вставок (50—55% протяженности) (6)	20—22	24—26	24—26	26—28
Строительство сплошных вторых путей (7) . .	32—34	36—40	36—40	40—44
Перевод на электрическую тягу (8)	30—40	30—40	—	—
Строительство второго пути на параллельном (9) железнодорожном направлении или строительство разгружающей железной дороги .	70—75	80—90	75—80	90—100

Key:

1. Development of railroad section
2. Diesel traction
3. Electric traction
4. Length of receiving-dispatching tracks, meters
5. Openings of sidings of second unit
6. Construction of two-track inserts (50-55 percent of length)
7. Construction of continuous double tracking
8. Conversion to electric traction
9. Construction of double-tracking on parallel rail route or construction of relief railroad

These indicators are related to railroad sections with average scope of passenger traffic (the number of pairs of passenger trains is 15-20 percent of the total freight traffic volumes) and with sufficiently high indicators of utilizing the freight capacity of rail cars typical for railroads with primary freight traffic volume of raw materials.

Capital investments for construction of two-track inserts and double tracking, thousand rubles/km, are presented in Table 3.10 as a function of the anticipated freight traffic volume and construction conditions.

The cost of electrifying one kilometer of railroad on direction current is equal to 85,000-100,000 rubles for single-track sections and 120,000-140,000 rubles for two-track sections depending on the anticipated freight traffic volume. Electrification on alternating current requires 20-25 percent fewer expenditures.

The reduced normal expenditures for construction provide that the minimum work required to convert to the next phase of increasing the carrying capacity of railroads and of assimilating shipments anticipated for the fifth year of operation of the line and on the part of structures and during the second year of operation according to existing norms for railroad planning will be carried out.

The indicators do not take into account expenditures for development of classification yards and other work to strengthen the repair base, development of depots and other work required to assimilate shipments during the period between the next phases. According to current data, these expenditures comprise 2.0-2.5 kopecks

Table 3.10.

(1) Показатели	(2) Категория трудности¹ строительства			Показатели	Категория трудности¹ строительства		
	II	III	IV		II	III	IV
(3) *Строительство двухпутных вставок (50% протяженности) при грузопотоке 30 млн. т*				(6) *Строительство сплошных вторых путей при грузопотоке 60 млн. т*			
(4) Тепловозная тяга . .	194	215	247	Тепловозная тяга . .	343	367	415
(5) Электрическая тяга	218	240	260	Электрическая тяга	368	397	447

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[1] Sections with volume of excavation work of 25,000 m^3 per kilometer are related to construction category II, those with excavation at 26,000-35,000 m^3 per kilometer are related to construction category III and those with excavation of 36,000-45,000 m^3 are related to category IV [48].

Key:

1. Indicators
2. Category of construction difficulty
3. Construction of two-track inserts (50 percent of length) with freight traffic volume of 30 million tons
4. Diesel traction
5. Electric traction
6. Construction of continuous double tracking with freight traffic volume of 60 million tons

per10 tons-km of additional shipments. Expenditures to construct large bridges (more than 100 meters long) and tunnels were not taken into account. This work should be taken into account separately.

When railroads are constructed in regions where construction of tunnels is not required, the additional expenditures can be taken as equal to 10-20 percent of the cost of the railroad or the cost of constructing double tracking indicated in Table 3.10.

One should bear in mind that all the indicators are presented for the first phase and consideration of coefficients whose values are given above for construction of new railroads must be taken into account for other phases. This is true of constructing railroads in the middle belt. They are up to 25 percent higher in the northern regions of the European USSR and up to 40 percent higher in regions of the eastern USSR. The cost of constructing a kilometer of railroad reaches 1.0-1.2 million rubles per km in northern swampy regions and 2.5-3.0 million rubles per kilometer in mountainous regions of the northeast. Capital investments to construct double tracking and two-track inserts under complex mountainous conditions and in suburban sections of large cities also reach 800,000 to one million rubles per kilometer.

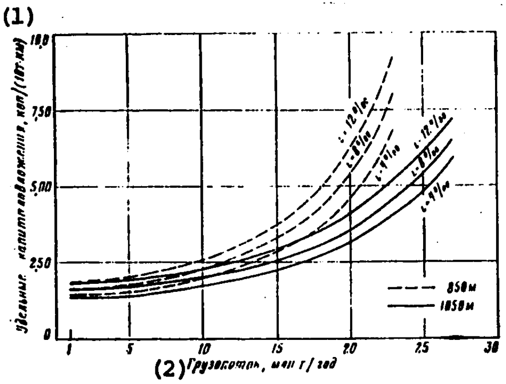

Figure 3.11. Specific Capital Investments in Rolling Stock with Assimilation of Additional Volume on Single-Track Railroad With Different Length of Receiving-Dispatching Tracks

Key:
1. Specific capital investments, kopecks per 10 tons-km
2. Freight traffic volume, million tons annually

The specific capital investments in rolling stock for a single-track railroad with diesel traction, related to the additional volume, are shown in Figure 3.11. When this graph and the graphs of specific capital investments given below for two-track railroads and graphs of specific operating expenses are used, one must take into account that the specific indicators should be taken for half the sum of the volumes prior to superposition of the additional volume (the initial volume) and after superposition of the additional volume. Indicators for a volume of 55 million tons annually will be a typical value with an initial volume of 50 million tons annually in the freight direction on a two-track railroad and with additional volume of 10 million tons annually. Similar indicators for two-track railroads are presented in Figure 3.12. As when determining the expenditures for the average indicators, one must take into account the empty run by introducing a factor of 2.0 and correcting for the use of the load capacity of rolling stock.

When determining capital investments to ship coal in gondolas, one must introduce a factor of 0.9 that takes into account their lower cost. Data for specific capital investments presented in Figures 3.3, 3.4, 3.11 and 3.12 can be used for future conditions when one can orient onself to handling of eight-axle gondolas and tank cars. The tare factors of four- and eight-axle gondolas and tank cars are similar. Consequently, when organizing serial production of eight-axle rolling stock, its cost per ton of freight capacity should also be close to the cost of four-axle gondolas and tank cars.

When using these graphs, one should take into account that the typical capital investments shown on the graphs are related to a range of 2.0 million tons on single-track and 5.0 million tons on two-track sections. Thus, if an additional volume of two million tons annually is superimposed on an existing volume of 17

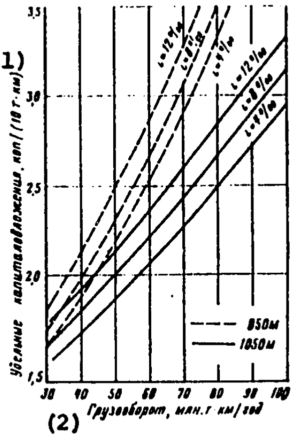

Figure 3.12. Specific Capital Investments in Rolling Stock When Assimilating Additional Volume on Two-Track Railroad with Different Length of Receiving-Dispatching Tracks

Key:
1. Specific capital investments, kopecks per 10 tons-km
2. Freight traffic volume, million tons annually

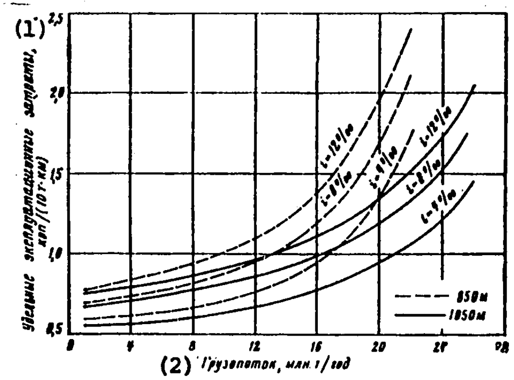

Figure 3.13. Specific Operating Expenses Dependent on Freight Traffic Volume When Assimilating Shipment of Additional Freight on Single-Track Sections with Different Length of Receiving-Dispatching Tracks

Key:
1. Specific operating expenses, kopecks per 10 tons-km
2. Freight traffic volume, million tons annually

million tons on a single-track railroad section with diesel traction and length of receiving-dispatching tracks, the specific capital investments will comprise 5.1 kopecks per 10 tons-km at a ruling grade of 10 percent and 6.5 kopecks per 10 tons-km for the next two million tons. Comparison of the functions presented in Figure 3.11, where the mean indicators are given, to the functions in Figure 3.3 shows that acquisition of rolling stock to assimilate additional freight traffic volume on single-track railraods requires considerably greater capital investments than the average. This is explained by relating expenditures caused by the deterioration of operating indicators of rolling stock involved in shipment and freight shipped earlier to the additional volume. Assimilation of an additional freight traffic volume on single-track railroads may require capital investments 2.5-3.0 times higher than the average in some cases. Expenditures on two-track sections where an increase in the volume of shipments causes no sharp deterioration of operating indicators increase mainly due to an increase in the number of passings of freight trains by passenger trains and the expenditures on acquisition of rolling stock to assimilate the additional volume exceed the average expenditures to a lesser degree. The specific operating expenses that depend on freight traffic volume when assimilating shipment of additional freight on an existing railroad can be determined for single-track sections and diesel traction from the graphs presented in Figure 3.13 and can be determined for two-track railroads from the graphs presented in Figure 3.14.

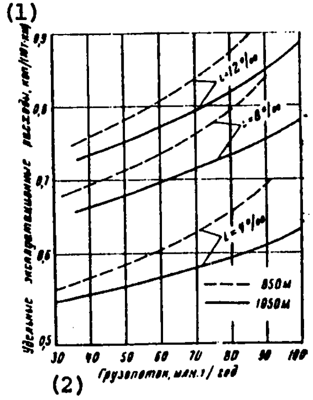

Figure 3.14. Specific Operating Expenses Dependent on Freight Traffic Volume with Assimilation of Shipments of Additional Freight on Two-Track Sections with Electric Traction with Different Length of Receiving-Dispatching Tracks

Key:

1. Specific operating expenses, kopecks per 10 tons-km
2. Freight traffic volume, million tons annually

When using these graphs, one should be guided by the same rules as when determining the specific capital investments, i.e., one should take into account the indicators shown on the graph for half the sum of the initial and additional volumes. Expenditures for return of empty tank cars or gondolas must be taken into account by the factors presented above when determining the mean specific operating expenditures.

An example of determining expenditures is considered below to illustrate the use of the graphs.

It is required to determine transportation expenses when solving the problem of locating a thermoelectric power plant with coal consumption of approximately 6.0 million tons annually.

According to the conditions of development of the power system, water supply, environmental protection and other factors, the electric power plant can be located in two regions whose rail communications with the coal basin should be provided from different directions and their characteristics are presented in Table 3.11.

Table 3.11.

Участок железной дороги (1)	Длина, км (2)	Число главных путей (3)	Руководящий уклон, ‰ (4)	Исходный грузопоток, млн. т (5)	Перспективные темпы роста грузопотока, млн. т (6)
Вариант I, электрическая тяга (7)					
А—Б	210	2	4,0	55,0	2,0
Б—В	630	2	4,0	65,0	1,5
Вариант II, тепловозная тяга (8)					
А—Г	250	2	8,0	50,0	2,0
Г—Д	580	1	8,0	15,0	1,0

Key:

1. Railroad section
2. Length, km
3. Number of main tracks
4. Ruling grade, percent
5. Initial freight traffic volume, million tons
6. Future growth rates of freight traffic volume, million tons
7. Version 1, electric traction
8. Version 2, diesel traction

If one takes into account that the shipper is a strip mine with high productivity of loading devices and the consumer is a large electric power plant, coal shipment can be organized in shipper block trains and they will be loaded on the sidings of enterprises. The coal volume is superimposed on the already existing coal volume at which part of the gondolas should be empties in the opposite direction. Consequently, the gondolas in the opposite direction from the additional volume for the electric power plant under consideration may not be loaded and all expenses to acquire and move them should be related to shipment of coal in the freight direction.

The additional operating expenditures caused by shipment over the directions of coal volume of 6.0 million tons annually under consideration are presented in Table 3.12 (Figures 3.13 and 3.14). The additional operating expenditures to maintain permanent devices for traffic and initial-final operation are presented in Table 3.13. Capital investments to acquire rolling stock (gondolas and locomotives) are determined from the indicators presented in Figures 3.11 and 3.12 with reduction of them by a factor of 0.9 (Table 3.14), which takes into account the lower cost of gondolas than is indicated in the graphs for tank cars. Capital investments to develop the carrying capacity are determined as approximation of the phases of strengthening railroads caused by superposition of the additional freight traffic volume.

Table 3.12.

(1) Участок	(2) Удельные дополнительные затраты, коп/(10 т·км)	(3) Коэффициент на порожний пробег	(4) Коэффициент на заработную плату	(5) Коэффициент к затратам на электроэнергию	(6) Всего затрат, коп/(10 т·км)	(7) Всего дополнительных затрат по участку, тыс. руб.
(8) *Вариант I*						
А—Б	0,567	1,62	1,05	1,03	0,99	1180
Б—В	0,571	1,62	1,05	1,03	0,99	3540
(9) Итого по варианту I:						4720
(10) *Вариант II*						
А—Г	0,558	1,62	1,05	1,03	0,93	1400
Г—Д	0,750	1,62	1,05	1,03	1,31	4540
(11) Итого по варианту II:						6940

Key:
1. Section
2. Specific additional expenditures, kopecks per 10 tons-km
3. Coefficient for empty run
4. Coefficient for wages
5. Coefficient to expenditures for electric power
6. Total expenditures, kopecks per 10 tons-km
7. Total additional expenditures for section, thousand rubles
8. Version 1
9. Total for version 1
10. Version 2
11. Total for version 2

Table 3.13.

(1) Участок	(2) Удельные затраты на содержание постоянных устройств, коп/(10 т·км)		(3) Дополнительные эксплуатационные расходы, тыс. руб. в год		(6) Всего расходов, тыс. руб/год
	(4) по движенческой операции	(5) по начально-конечной операции	по движенческой операции	по начально-конечной операции	
(7) *Вариант I*					
А—Б	0,06	18	76	118	194
Б—В	0,06	18	237	118	355
(8) Итого по варианту I:					549
(9) *Вариант II*					
А—Г	0,06	18	90	118	208
Г—Д	0,19	18	660	118	778
(10) Итого по варианту II:					986

[Key on following page]

[Key continued from preceding page]

1. Section
2. Specific expenditures to maintain permanent devices, kopecks per 10 tons-km
3. Additional operating expenses, thousand rubles annually
4. For traffic operation
5. For initial-final operation
6. Total expenses, thousand rubles annually
7. Version 1
8. Total for version 1
9. Version 2
10. Total for version 2

Table 3.14.

(1) Участок	(2) Удельные дополнительные затраты, коп/(10 т·км)	(3) Коэффициент на порожний пробег	(4) Всего затрат, коп/(10 т·км)	(5) Всего дополнительных затрат, тыс. руб.
		(6) *Вариант I*		
А—Б	2,03	2,0	3,65	4600
Б—В	2,23	2,0	4,02	15 200
	(7) Итого по варианту I:			19 800
		(8) *Вариант II*		
А—Г	1,93	2,0	3,47	5200
Г—Д	3,3	2,0	5,95	20 600
	Итого по варианту II: (9)			25 800

Key:

1. Section
2. Specific additional expenditures, kopecks per 10 tons-km
3. Coefficient for empty run
4. Total expenditures, kopecks per 10 tons-km
5. Total additional expenditures, thousand rubles
6. Version 1
7. Total for version 1
8. Version 2
9. Total for version 2

A possible variant of strengthening two-track sections A-B-C and A-D may be construction of a third main track on the route under consideration or of a second main track on a parallel single-track route. In the latter case, a continuous main track may be constructed depending on the growth rates of freight traffic volumes in two directions or two-track inserts may be constructed during the first phase and a continuous main track may then be constructed to fill the carrying capacity. If there is no reliable information on the growth rates of freight traffic volume for the future, the most expensive version--construction of a continuous main track--is used.

Strengthening of a second-track section with regard to comparatively low growth rates of freight traffic volume that existed during past years and anticipated in the future is used by construction of two-track inserts during the first phase with the carrying capacity being grought up to approximately 36 million tons annually in the freight direction and with the capacities of a single-track line with two-track inserts already exhausted and construction of double-tracking during the second phase.

Intraphase capital investments are assumed to be constant for the entire calculated period. The deadline for assimilating them to provide for an additional freight traffic volume is conditionally related to the moment that it appears, i.e., without regard to removal of expenditures.

Calculation of capital expenditures to strengthen the carrying capacity are presented in Table 3.15.

Table 3.15

Показатели (1)	(2) Вариант I	(3) Вариант II
Эксплуатационные расходы, тыс руб (4)		
по продвижению поездов (5)	4720	6940
по содержанию постоянных устройств (6)	519	986
Итого (7)	5269	7926
Капиталовложения, тыс. руб : (8)		
на приобретение подвижного состава (9)	19 800	25 800
на усиление пропускных способностей перегонов и узлов (10)	35 700	82 100
Итого:	55 500	107 900
Приведенные затраты на освоение перевозок угля, млн. руб. (11)	11,8	18,7
Удельные затраты, коп/(10 т·км) (12)	2,18	3,12

Note. Capital investments in development of permanent devices related to initial-final operations were not allocated separately in the calculations since they are contained in the averaged norm for intraphase development of railway management.

Key:

1. Indicators
2. Version 1
3. Version 2
4. Operating expenses, thousand rubles
5. To move trains
6. To maintain permanent devices
7. Total
8. Capital investments, thousand rubles
9. To acquire rolling stock
10. To strengthen carrying capacities of waysides and terminals
11. Reduced expenditures to assimilate coal shipments, million rubles
12. specific expenditures, kopecks per 10 tons-km

The total expenditures to assimilate a coal volume of 6.0 million tons with the versions of electric power plant location under consideration are the following:

The shipping expendituresón two-track sections having significant carrying capacity reserves comprise approximately 2.2 kopecks per 10 tons-km, i.e., they are significantly lower than the tariff rates (3.3 kopecks per 10 tons-km).

These expenditures are higher than the tariff rates on single-track sections and they comrpise approixmately 4.2 kopecks per 10 tons-km for section D-8 and 3.12 kopecks per 10 ton-km for the route as a whole, i.e., they are at the level of existing tariffs.

This example confirms that the use of average system indicators or tariffs when compiling the versions for location of electric power plants and other energy-consuming facilities and also when selecting the types of transport, may lead to significant errors that distort the real picture of effectiveness of one or another version. Approximate calculations must at least be made, for example, for the consolidated data presented above.

3.6. Full-Scale Indicators of Rail Shipments

a) Labor Productivity

During the past decade a increased volume of shipments was carried out with stable numbers of workers with regard to technical reconstruction in railway transportation and improvement of operational work.

The contingent involved directly in railroad operation is usually taken into account when determining the labor productivity of railway transport workers. For comparing the various types of fuel transportation, it is also more correct to relate workers involved in all types of transportation equipment repair in shipments and at the same time the numbers of workers involved in passenger travel must be excluded.

It is accepted that labor productivity is calculated per reduced ton-kilometer and one passenger-kilometer is taken as equal to one net ton-kilometer of freight shipments. In fact, the laboriousness of one passenger-kilometer is several times higher than one ton-kilometer of freight shipments. According to the existing method of determining labor productivity, an average of 11-12 percent of operating personnel throughout the system is related to passenger travel. It is more correct in the first approximation to use the distribution of workers in proportion to the train-kilometer, i.e., to relate 27-28 percent of all workers to passenger travel. This approach is more accurate although it does not reflect the real situation. The numbers of train crews of passenger trains, especially long-distance trains (with conductors for each rail car), is much higher than the number of freight train crews. At the same time a freight train performs much greater ton-kilometer work than a passenger train in passenger-kilometers.

Consequently, with this correction the numbers of workers involved in transport related to freight shipments will be somewhat exaggerated.

The numbers of workers and average labor productivity on general-purpose railroads in freight shipments are presented in Table 3.16 [55].

Table 3.16.

(1) Годы	(2) Численность работников, занятых на перевозках, тыс. чел.	Из них может быть условно отнесено на грузовые перевозки, (3) тыс. чел.	Грузооборот железнодорожного транспорта, (4) млрд. т·км	Производительность одного работника, занятого на грузовых перевозках, тыс. т·км (5)
1960	2011	1440	1504,2	1045
1965	1977	1420	1950,2	1372
1968	1968	1410	2274,8	1615
1970	1997	1425	2494,7	1750
1975	2070	1475	3236,5	2190
1977	2097	1490	3327,7	2240

Key:

1. Years
2. Number of workers involved in shipments, thousand persons
3. Those that can be conditionally related to freight shipments, thousand persons
4. Freight turnover of rail transport, billion tons-km
5. Productivity of one worker involved in freight shipments, thousand tons-km

Thus, the typical annual labor productivity of a single worker in freight shipments can now be calculated at 2.2 million tons-km or approximately 0.8 man-hours per thousand tons-km.

For the future one can proceed from a reduction of the laboriousness of rail shipments of fuel by heavy block trains to 0.6-0.7 man-hours on single-track railroads and 0.4-0.6 man-hours per thousand ton-km on mainline railroads.

Appoximate calculations of the numbers of workers for a specialized mainline with high productivity show that the laboriousness of shipments with a volume of 200-250 million tons annually and with future technical equipping will comprise 0.3-0.4 man-hours per thousand ton-km. The results of calculations of the variation in labor productivity are presented in Figure 3.15 as a function of freight intensity.

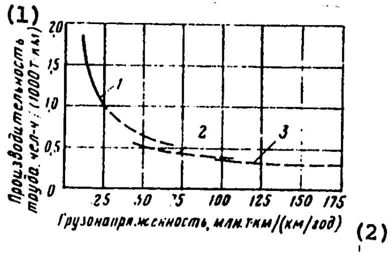

Figure 3.15. Variation of Labor Productivity in Rail Transportation as a Function of Freight Intensity: 1--average conditions; 2--for coal and liquid-carrying trains on ordinary mainlines; 3--for large-mass coal trains on specialized mainlines

Key:

1. Labor productivity, man-hr per 1,000 tons-km
2. Freight intensity, million tons-km/(km/year)

b) Energy Indicators

The consumption of electic power or diesel fuel for rail shipments depends on many factors: the type of traction, the profile and layout of the line, organizationof traffic, the degree of utilization of rolling stock and so on. Report data on electric power consumption on the buses of traction substations or of diesel fuel by diesel locomotives may not be regarded as comparable since they do not take into account the fuel expenditures for production and preparation for consumption by railroad traction equipment. An estimate of the fuel consumption for shipments can be gained from the country's fule-energy balance if one takes into account the expenditures for fuel production, refining it to a form consumed by locomotives and also the losses occurring at all stages of refining. If one proceeds from this prerequisite, then when calculating expenditures of energy resources for freight shipment by rail, besides energy expenditures to overcome the natural resistance of motion and grades, one must take into account the following factors [54, 60].

With electric traction one must take into account fuel consumption for the electric power plant's own needs, losses in electric power transmission lines, consumption for fuel production and transport to electric power plants and losses during transportation and storage.

With diesel traction one must take into account fuel consumption for oil production, transportation to the oil refining plants and for production of diesel fuel, losses for transportation to depots and losses at all phases of refining.

The actual mean network data on electric power and fuel consumption with electric and diesel traction on general-purpose railroads and the averaged losses of energy resources at different stages of refining and transport are presented in Table 3.17. An average of 8.0-8.5 kg of comparison fuel must be expended to ship one ton of freight a distance of 1,000 km, which comprises approximately 0.7 percent of the fuel hauled by railroads for oil and petroleum products and 1.1-1.3 percent for medium-heat coal (5,500-6,000 kcal/kg). There may be significant deviations from these mean data under specific shipping conditions.

Fuel or electric power consumption increases sharply with an increase in the percentage of empty runs. A further increase of fuel shipments can essentially be accomplished, as already pointed out, with return of rail and tank cars without a load, which leads to an increase of specific energy consumption. At the same time the use of roller bearings in modern tank cars and gondolas leads to some reduction of specific fuel consumption. The specific fuel or electric power consumption is significantly dependent on the railroad profile, the number of main tracks in the use of carrying, i.e., the number of train stops and the idle time of locomotives in trains.

The effect of a permanent reduction of specific fuel consumption at electric power plants and the expanded use of alternating current traction of trains, which provices reduced electric power losses in the contact system, affect the improvement of indicators of energy resource utilization on railroads with electric traction. There are significant reserves for reducing diesel fuel consumption with diesel traction by improvement of diesels. The specific electric power and diesel fuel

Table 3.17.

(1) Показатели	(2) Электрическая тяга	(3) Тепловозная тяга
(4) Расход электроэнергии на шинах высокого напряжения тяговых подстанций, кВт·ч, или дизельного топлива, кг условного топлива, на 10 000 т·км брутто	127,0	30,6
То же на 1000 т·км нетто (5)	223,0	68,5*
Расход топлива на выработку 1 кВт·ч электроэнергии, отпущенной потребителям (6)	0,340	—
Расход топлива на добычу, транспортировку, переработку и потери при его хранении, % (7)	5—10	15—20**
Полный расход энергоресурсов на железнодорожные перевозки, кг условного топлива, на 1000 т·км (8)	8,0—8,4	8,0—8,4

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*The increased fuel consumption indicators are explained by the fact that fuel consumption for shunting and auxiliary work performed by diesel locomotives on sections with electric and diesel traction is related to the net measurement of 1,000 ton-km.

**Including fuel expenditures for refining diesel fuel of sulphur to the requirements of locomotive diesels.

Key:

1. Indicators
2. Electric traction
3. Diesel traction
4. Electric power consumption on high-voltage buses of traction substations, kW·hr, or of diesel fuel, kg of comparison fuel, per 10,000 gross tons-km
5. The same per 1,000 net tons-km
6. Fuel consumption to generate 1 kW·hr of electric power sent to consumers
7. Fuel consumption for production, transportation, refining and storage losses, percent
8. Total energy resource consumption for rail shipments, kg of comparison fuel, per 1,000 ton-km

consumption (per 10,000 net tons-km) on railroad sections of different characteristics with 100 percent empty run of gondolas and tank cars is presented in Table 3.18. The specific fuel and electric power consumption increase sharply (up to twofold) depending on the difficulty of the track profile--essentially on the terrain relief (Figure 3.16).

The type of traction as a comparatively insignificant effect on energy consumption. When electric traction is powered from future large electric power plants operating on coal with fuel consumption of 0.310-0.320 grams per kW·hr of power delivered to the consumer or with development of nuclear power, electric traction is more desirable than diesel traction both in energy resource consumption and especially in the saving of liquid fuel.

Thus, the basic directions for reducting energy resource consumption for rail shipments are concentration of shipments on two-track mainlines with favorable track

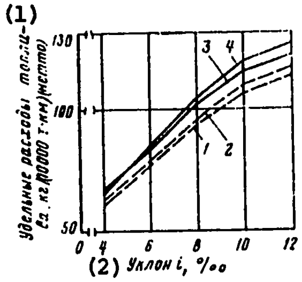


Figure 3.16. Fuel Expenditures for Coal or Oil (Petroleum Product) Shipments by Rail with Different Difficulty of Track Profile with 100 Percent Empty Return of Rolling Stock: ---- --electric traction; —— --diesel traction; 1 and 3--single-track sections, train mass of 3,000-4,000 tons; 2 and 4--two-track sections, train mass of 6,000-8,000 tons

Key:

1. Specific fuel consumption, kg per 10,000 net tons-km
2. Grade i, percent

profile, supplying power to electrified railroads from economical electric power plants operating on solid fuel or nuclear power and with diesel traction, using modern diesels with low specific fuel consumption on diesel locomotives; the typical fuel expenditures on shipments with regard to losses at different phases of refining with 100 percent empty run of rail cars and tank cars are 10-12 kg of comparison fuel on railroads of all regions of the country except Western Siberia and northern Kazakhstan and it is 7-8 kg of comparison fuel per 1,000 net tons-km on railroads of Western Siberia and Kazakhstan with flat track profile.

Table 3.18.

(1) Характеристика дороги	(2) Масса поезда, т	Удельный расход электроэнергии или топлива при расчетном подъеме, °/оо (3)				
		4	6	8	10	12
(4) Электрическая тяга, кВт·ч						
Двухпутная или однопутная малозагруженная (5)	3000—4000	185	226	271	306	342
То же (5)	6000—8000	180	221	264	296	320
Загруженная однопутная (6)	3000—4000	225	270	316	350	372
То же (6)	6000—8000	193	238	290	328	352
(7) Тепловозная тяга, кг условного топлива						
Двухпутная или однопутная малозагруженная (5)	3000—4000	63,3	79,0	96,0	109,1	117,0
То же (5)	6000—8000	61,8	77,5	94,0	105,6	112,5
Загруженная однопутная (6)	3000—4000	66,2	83,5	101,5	114,7	121,2
То же (6)	6000—8000	64,7	85,1	103,6	118,2	126,0

[Key on following page]

[Key continued from preceding page]:

1. Railroad characteristics
2. Train mass, tons
3. Specific electric power or fuel consumption with calculated grade, percent
4. Electric traction, kW·hr
5. Two-track or one-track low-freight
6. Single-track loaded
7. Diesel traction, kg of comparison fuel

c) Metal Consumption

Determination of the metal consumption of rail shipments encounters a number of methodical difficulties. The metal allocated to rail transport is consumed for:

construction of additional rail cars and locomotives;

increasing the length of main and station tracks;

repair of rolling stock (rail cars and locomotives) and other railroad equipment;

replacement of worn rails and other parts of the upper track structure--switches, rail bracing, manufacture of reinforced concrete crossties instead of wooden crossties and so on;

supplying railroads with new equipment (electrification, more improved communications equipment and so on).

Investigations made it possible to establish the following indicators of the metal consumption of rail freight shipments: 18-20 kg/(t·km/year) (net) to assimilate shipments and 0.9-1.0 kg/(t·km/year) (net) to restore worn-out components.

The first indicator is the amount of metal supplied to transportation to increase shipments: additional rail cars, metal to strengthen the carrying capacity of railroads and so on and the second indicator is compensation for wear of metal: replacement of rails, wheels, brakeshoes and manufacture of various spare parts consumed during repair of main equipment.

These indicators are average for shipments of all freight. The indicators will be close to those presented in shipment of fuels by ordinary trains with empty return of rail cars or tank cars since a reduction of metal consumption achieved by improvement of freight capacity is compensated for by an increase of the empty run of gondolas or tank cars.

The metal consumption of the types of transport over a prolonged period is sometimes calculated as the total metal expenditures during the service life, i.e., by not less than during 25-30 years, to compare the types of transport (rail and pipeline) to different indicators of initial investments of metal and its annual consumption. It is more correct to take into account the time factor when calculating metal consumption by reduction of metal consumed for repair to the year of an increase of shipments, for example, by a formula similar for reduction of capital investments at different times. With this approach the consumption of metal per 1,000 tons-km of increase of annual shipments performed over a prolonged time period with indicators of the use of rolling stock typical for the system as a whole will comprise 26-30 kg as a function of the reduction coefficient. The conditionality of this approach is obvious. However, it more correctly reflects the essence of the phenomenon from economic aspects than simple summation of metal consumption for shipments over a number of years or underestimation of it to restore basic stocks and for repair needs.

Chapter 4. Gas Transport

4.1. Gas Pipeline Transport Systems in the USSR and Abroad

Natural gas is one of the most effective types of fuel. Gas consumers even with identical cost of one ton of comparison fuel of gas and coal achieve an additional saving from improvement of burning conditions, which can be estimated from 3 to 18 rubles, and in some cases even higher. The greatest svaing is achieved when gas fuel is consumed at large electric power plants and the lowest saving is achieved in small furnaces and household devices and also when gas is used as a raw material of the chemical industry.

The enormous advantage of gas fuel is the high degree of its combustion and the insignificant noxious discharges into the atmosphere, which makes the use of it extremely desirable at enterprises located in cities.

The high efficiency of gas fuel use, especially in high-temperature production processes, at enterprises located in large cities and for household needs, i.e., in those spheres where it produces the highest consumer saving, can be judged by the rapid development of gas fuel imports by industrially developed countries over pipelines of great length and maritime transport in a liquefied state with expenditures that considerably exceed those to produce other types of fuel in the same fuel equivalent.

The high economy of gas fuel provides the basis to assume that one of the basic directions for improving our country's energy balance should be an increase in the specific weight and efficiency of using gas fuel. The use of gas in the national economy made it possible not only to increase the growth rates of the country's economy and product quality but in many cases to sharply improve the ecological conditions of cities. Not only the geological reserves and production conditions that determine expenditures for production but transport indicators as well affect the specific weight of gas fuel in the country's fuel balance.

The gas transport system of the USSR is now an interrelated complex of fields, major pipelines, gas depots and distributing pipelines. The gas transport system of the USSR is inferior only to that of the United States in the amount of gas delivered to consumers.

Development of the gas transport system was begun in 1946 with construction of the first Saratov-Moscow major gas pipeline 300 mm in diameter. The Dashava-Kiev and Kokhtla-Yara-Leningrad gas pipelines 400-500 mm in diameter were then constructed. Gas pipelines began to be put into operation at especially rapid rates in 1956 with regard to discovery of the Shebelinskoye, Stavropol'skoye and Krasnodarskoye fields and the fields of Central Asia. The Northern Caucasus-Center four-pipe gas transport system approximately 2,000 km long and with productivity of 42 billion m^3 annually and the Bukhara-Urals system that established the beginning of the gas fields of Central Asia into the fuel economy of the Urals and the European USSR was developed.

Construction of a large gas transport system from the four Central Asian-Center pipelines was begun in the 1960's. Development of the Western Siberian fields was begun in 1971 and the Urengoy--Nadym-Punga--Perm'--Izhevsk--Kazan'--Gor'kiy and other gas pipelines were constructed. The country's gas transport system has recently been developing at especially rapid rates [30]. The rates of development of gas pipeline transport can be judged from the data presented in Table 4.1.

Development of the gas industry is now characterized by intensive introduction of fields of the northern regions of the West Siberian lowland and the Orenburg and Central Asian fields into exploitation and a rapid increase of the distance of gas transport. The accelerated development of gas production leads to a systematic increase of its fraction in the country's fuel-energy balance.

The country's unified gas transport system has now been formed already, including regional and functional major gas pipeline systems [60, 62, 63]. The Central Asia-Center system permits delivery of approximately 56 billion m^3/year of gas from the Central Asian fields to the European USSR. The length of the system is 3,070 km and it consists of two pipes 1,220 mm in diameter and one pipe 1,020 mm in diameter, designed for a pressure of 56 kgf/cm^2, and one pipe 1,420 mm in diameter designed for a pressure of 75 kgf/cm^2. The system delivers gas to the Central, Volga and Urals systems. The northern regions of Tyumenskaya Oblast-Ukhta-Torzhok is transferring approximately 20 billion m^3 of gas annually to the Torzhok region through the rapidly developing system. The length of the system is 2,850 km. A new gas pipeline system of the northern rayons of Tyumenskaya Oblast-Punga-Perm'-Center is being formed, approximately 18 billion m^3 of gas annually is delivered to Yel'ets through a section of the gas pipeline and approximately 80 billion m^3 of gas annually will be delivered by 1980. The largest Urengoy-Chelyabinsk gas transport system and further to the rayons of the Volga area is being laid in Tyumenskaya Oblast. Approximately 60 billion m^3 of gas annually will be delivered through this mainline. The Orenburg-State border gas pipelines 2,750 km long are

Table 4.1.

Показатели (1)	1965	1970	1975	1977
Товарный газ, млрд. м^3/год (2)	112,1	170,5	250,6	300,2
Протяженность, тыс. км (3)	41,8	67,5	99,2	104,6
Грузооборот, млрд. м^3·км (4)	70,2	164,2	337,3	437,1
Средняя дальность транспортировки, км (5)	626	963	1345	1456
Грузонапряженность, млрд. м^3·км/км (6)	1,68	2,43	3,4	4,17

Key:

1. Indicators
2. Commercial gas, billion m^3/year
3. Length, thousand km
4. Freight turnover, billion m^3·km
5. Average transport distance, km
6. Freight intensity, billion m^3·km/km

being developed mainly to supply the southern regions of the Ukraine with gas and to deliver gas for export. One of the gas pipelines 1,420 mm in diameter is being constructed in cooperation with CEMA member countries. The Northern Caucasus system is the main one for gas distribution of the Northern Caucasus fields to consumers and partially for delivery to Donbass regions. The Central Asian system delivers gas to the regions of Uzbekistan, Tadzhikistan, Kazakhstan and Kirgiziya from the fields of Central Asia and by import from Afghanistan. The Transcaucasus system provides consumers of Georgia, Armenia and Azerbaijan and also regions of the Northern Caucasus with gas, i.e., the gas of local fields and also imported gas from Iran is distributed through it.

The Central system distributes gas from the fields of Central Asia, Western Siberia and the Eastern Ukraine and transfers gas to other regions. The Eastern Ukraine system supplies the Eastern Ukraine with gas and transports gas to the west [61]. Gas is delivered to consumers of Lithuania, Latvia, Belorussia, the Ukraine and for export through the western system. The Volga system is used to distribute Central Asian and Siberian gas to consumers of the Volga region. The Urals system is ringed with the Central, Volga and Central Asia-Center system. The gas of Siberian fields is connected to it. It is used to distribute gas in the Urals.

Along with the major gas pipeline system, a branched distributing system that supplies gas to most any large populated points of the European USSR, the Urals and partially to Central Asia has been developed in the USSR. The specific weight of the length of the distributing networks in the total length of the gas pipelines in the USSR comprises approximately 30 percent. This is less than in the United States and European countries, which is explained primarily by the higher concentration of gas consumption [60]. It should be noted that it is now planned to increase the specific weight of gas consumed for production and municipal-domestic needs in the USSR, which leads to accelerated development of separating systems [63].

The desire to increase the carrying capacities of large mainlines and to change the structure of consumption increased the demands on the reliability of gas supply, which in turn required that measures be implemented to develop a reserve

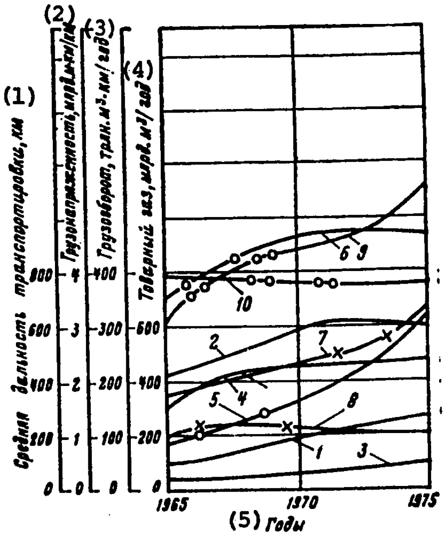


Figure 4.1. Indicators of Gas Pipeline Transport Development: 1--commercial gas of the USSR; 2--commercial gas of the United States; 3--length of gas pipelines in the USSR; 4--length of gas pipelines in the United States; 5--freight turnover of USSR gas pipelines; 6--freight turnover of United States gas pipelines; 7--freight intensity of USSR gas pipelines; 8--freight intensity of United States gas pipelines; 9--average length of transportation in the USSR; 10--average length of transportation in the United States

Key:

1. Average length of transportation, km
2. Freight intensity, billion m·km/km
3. Freight turnover, m^3·km/year
4. Commercial gas, billion m^3/year
5. Years

system and to cover the peak gas consumption of consumers by another type of fuel and to develop an underground storage system. There are now gas depots with active volume of 34 billion m^3 [62].

The total indicators for development of gas transport systems in the USSR and the United States are presented in Figure 4.1 [30, 97].

The transport system of the USSR gas industry in the volume of gas delivery, length of the major network, the use of large-diameter pipes, the freight intensity of mainlines and a number of other indicators emerged in second place in the world after the United States.

Gas pipeline transport in the USSR was developed at rapid rates with improvement of the engineering and economic indicators, which made it possible to achieve favorable results despite the increase in the distance of gas transportation and shifting of production to regions with unfavorable climatic and hydrogeological conditions. This was the result of extensive use of the advances of scientific and technical progress and primarily of the use of large-diameter pipes and conversion to a pressure of 75 kgf/cm^2. Moreover, the gas pipeline transport of our country is being developed under conditions of good support with resources.

A characteristic feature of the development of the gas industry in the United States is a gradual decrease of gas production and consequently of transport by explored and proven reserves. Production by proven reserves decreased from 17.6 to 11.0 years from 1965 through 1973. If the gas reserves on the north slope of Alaska are excluded, production is at the level of 9-10 years and this naturally restrains the development of the hardware and technology of gas transport in the United States.

As can be seen from Figure 4.1, the freight turnover of gas pipelines in the USSR was approximately 80 percent of the corresponding indicator of the United States in 1975. The development of highly productive gas pipelines in the USSR made it possible to bring the freight intensity up to 3.4 billion m^3·km/km, unlike the freight intensity equal to 0.92 billion m^3·km/km in the United States.

Pipeline transport of gas is practically unchanged for gas delivery under the conditions of any continent. However, loading of pipelines for their service life must be provided for effective operation, which is ensured only with the presence of the corresponding reserves.

The gas pipeline transport of the United States has been developed under conditions of low effectiveness of geological prospecting work for gas. Thus, capital investments in development of the entire gas supply system of the United States comprised 1.935 billion dollars in 1965, which provided an increase of production of 35 billion m^3. Capital investments reached 3.0 trillion dollars in 1973 and provided an increase of production by only 3.0 billion m^3/year. The major expenditures were required to maintain production at the achieved level.

According to preliminary data, approximately 50 percent of the consumed gas in 1990 in the United States will be gas produced in the region north of the 48th parallel or exported in the liquefied state by maritime transport. The problem of constructing a number of major gas pipelines from the northern regions is being discussed widely in this regard. The problem of delivering gas from fields located on the north slope of Alaska is being discussed. A version of combined gas transport by the gas pipeline from Prudhoe Bay to Valdez is being considered, in which construction of a liquefaction plant and further transport to the west coast of the United States in tankers is planned, and a version of gas delivery completely by land over a gas pipeline route parallel to the trans-Alaskan pipeline to Fairbanks and then to Calgary, from which one branch will go to Chicago and the other to San Francisco, is being considered. The total length of the gas pipeline is 7,700 km of pipes 1,220 mm in diameter. The total cost of construction is estimated at 10 billion dollars.

A number of versions for construction of the gas pipeline from fields discovered on the Arctic islands of Canada--the second expected significant resource base of natural gas on the American continent--have been advanced [97].

As can be seen, further development of the gas industry of the United States by exploitation of the gas fields in the Arctic regions of Canada and Alaska requires very complex engineering solutions to develop transport systems and consequently requires high capital investments.

The structure of gas consumption in the USSR and United States differ sharply. Thus, gas consumption by electric power plants comprises approximately 25 percent, consumption by industry comprises approximately 70 percent and consumption by municipal-domestic consumers comprises approximately 5 percent in the USSR, while the fraction of the same consumers is approximately 15, 60 and 25 percent, respectively, in the United States.

The structure of consumption also determined the characteristic feature of the gas industry in the United States: extensive development of means for compensating for irregular consumption and equalization of the load of mainlines, especialy those of great length. The total productivity of means to compensate for irregular gas consumption was approximately 1.64 billion m^3/day during the winter of 1975-1976 with average daily gas delivery of 1.8 billion m^3 by pipeline companies. Thus, compensation supply of gas comprises approximately 50 percent of the total and 1.3 billion m^3 goes to underground depots, 0.13 billion m^3 goes to propane-air units and 0.2 billion m^3 goes to liquiefied natural gas units.

Conditions in the United States permit the use of depleted oil and gas fields and also other similar structures located near large gas consuming regions for creation of gas depots. There were 386 underground gas depots in the United States in 1976, of which 302 were created in depleted gas pools, 18 were in gas-oil pools, 7 were in oil pools, 53 were in water-bearing beds, 5 were in salt domes and one was in a mine shaft with total active gas volume of 143 billion m^3. The increase in the role of units for gas storage in the liquefied state merits attention. There are 57 liquefied natural gas units used to cover peak loads in the United States and Canada.

One of the main problems of further development of the fuel balance in the USSR is improvement of the gas consuming structure: a decrease in the volume of gas delivered to low-qualified consumers. This should lead to development of a large distributing network and an increase in the means of regulation and reserve of the gas supply.

The socialist countries of Europe mainly receive gas by import from the USSR. Gas deliveries from the USSR have been increasing during the past few years and the gas supply of these countries is achieving ever wider development.

The Orenburg-State border gas pipeline was constructed through the common efforts of a number of countries and a branched network of major gas pipelines has now been developed on the basis of their own fields in the socialist countries and that delivered from the USSR (Table 4.2).

Beginning in 1967, major gas pipeline transport in Western European countries began to be developed. The main natural resource base of the gas pipelines are the fields in the Netherlands and in the offshore fields of the North Sea. But since the resource base of Western European countries is rather limited, gas is imported from the USSR, Algeria and other countries [77].

Table 4.2.

(1) Страна	(2) Протяженность газопроводов, тыс. км				Страна	Протяженность газопроводов, тыс. км			
	1965	1970	1975	1977		1965	1970	1975	1977
Венгрия (3)	0,8	1,7	2,4	2,8	Румыния (6) . .	—	6,4	7,1	7,4
ГДР (4)	—	12,3	13,5	13,9	Чехословакия (7)	—	6,7	8,4	8,7
Польша (5) . . .	—	5,4	5,9	5,9	Югославия (8) . .	—	0,8	1,0	1,3

Key:

1. Country
2. Length of gas pipelines, thousand kilometers
3. Hungary
4. German Democratic Republic
5. Poland
6. Rumania
7. Czechoslovakia
8. Yugoslavia

The Ekifisk-Emden (German Federal Republic) with length of 433 km consisting of pipes 900 mm in diameter was put into operation in 1975. Gas pipelines were laid from the North Sea fields to a number of countries: the Brent-Scotland field with length of 480 km consisting of pipes 900 mm in diameter, the K-13--Norway field 120 km long with 900-mm diameter pipes, the Isk-Frigg--Norway field 160 km long with 900 mm diameter pipes and a number of others. Gas pipeline systems are being constructed which will deliver gas from the North Sea fields to England, the Netherlands, West Germany, Norway and to other countries. The gas pipelines will be under water at a depth of 120 meters or more. The problem of constructing a trans-Scandinavian pipeline system for pumping natural gas from the fields of the Norway sector of the North Sea is being considered.

The main gas pipeline system of Western Europe is the trans-European gas pipeline which supplies West Germany, Switzerland and Italy with gas. The length of the gas pipeline is 1,100 km and the carrying capacity of the first unit is 10 billion m^3 of gas. The gas pipeline passes through the Alpine zone in Switzerland, where it crosses the mountains through 11 tunnels with total length of 32 km [77]. One of the large branches of the trans-European gas pipeline is that going to Brussels and then to Paris.

The largest gas pipeline system for gas transportation from the USSR to European countries is the gas pipeline passing through Czechoslovakia, Austria and then to Italy.

A project for construction of a trans-Mediterranean gas pipeline linking Algeria and Italy is being developed. Gas will be delivered through the gas pipeline from the Hassi-R'mel field to Cape Bone on the coast of Tunisia and then through the Gulf of Tunis to Sicily and then across the Gulf of Messina to La Spezia (Italy). The length of the gas pipeline is approximately 2,600 km [88].

The length of the major gas pipelines of the systems of West European countries is presented in Table 4.3 [77, 78]. The distributing systems of a number of countries exceed the development of mainlines 2-5-fold, i.e., gas is mainly delivered for municipal-domestic needs.

Table 4.3.

(1) Страны Западной Европы	(2) Протяженность газопроводов, тыс. км				Страны Западной Европы	Протяженность газопроводов, тыс. км			
	1965	1970	1975	1977		1965	1970	1975	1977
Франция (3)	13,8	16,4	19,2	19,9	Дания (8)	0,3	—	0,3	0,3
ФРГ (4).	19,9	22,4	29,4	32,1	Нидерланды (9). .	5,1	9,0	12,7	12,7
Италия (5). . . .	5,5	8,7	13,3	13,5	Швеция (10) . .	0,3	0,4	0,4	0,4
Австрия (6) . . .	1,3	1,5	2,1	2,3	Швейцария (11) .	0,8	1,4	2,1	2,1
Бельгия (7.). . .	3,6	2,1	3,0	3,1					

Key:

1. Western European countries
2. Length of gas pipelines, thousand kilometers
3. France
4. West Germany
5. Italy
6. Austria
7. Belgium
8. Denmark
9. Netherlands
10. Sweden
11. Switzerland

Thus, a rather branched system of gas pipelines is being formed in Western European countries, primarily in West Germany and France, with relatively low productivity and with maximum pipe diameter of 1,000 mm and productivity up to 10 billion m^3/year.

4.2. The Engineering and Economic Indicators of Major Gas Pipelines

The modern level of engineering of the major gas pipelines in the USSR can be characterized by the use of pipes 1,220 mm in diameter at pressure of 57-75 kgf/cm^2 with carrying capacity of 15-16 and 20-22 billion m^3, respectively, and pipes 1,420 mm in diameter at pressure of 75 kgf/cm^2 with carrying capacity of approximately 28-30 billion m^3/year and by extensive use of centrifugal blowers, primarily with gas turbine drive with rating of 6,000 and 10,000 kW and formation of multi-pipeline systems with junctions that provide relatively high degree of operational reliability. The structure of the gas pipeline system in the USSR is shown in Table 4.4 in percent of the total length by pipe diameters.

Table 4.4. Percent of Total Length

(1) Диаметр, мм	1965	1970	1975	1977	Диаметр. мм	1965	1970	1975	1977
1420	—	—	3,7	5,8	1020	17,8	23,5	20,6	19,7
1220	—	5,7	15,6	16,9	820 и пр. (2)	82,2	70,8	60,1	57,6

Key:

1. Diameter, mm
2. 820 and so on

As can be seen from the table of Table 4.5, almost half the gas pipelines is constructed of pipes more than 820 mm in diameter. Only 16 percent of gas pipelines in the United States have been developed from large-diameter pipe [36, 62].

Straight-seam large-diameter steel pipe is usually employed for major gas pipelines in the USSR (Table 4.5).

Part of the pipes 1,420 mm in diameter is imported. However, the cost of imported pipe is relatively high [38]. Obviously, the specific weight of imported pipe will decrease gradually in the future. The planned high rates of development of the gas industry with involvement of fields of the northern regions of Western Siberia with gas transportation distance of 3,000 km or more predetermine the rapid development of the need for pipes and development of a guiding gas pipeline system to provide numerous consumers with gas.

Table 4.5.

(1) Показатели	(2) Диаметр труб, мм					
	1020	1220	1220	1220	1420	1420
Толщина (3) стенки, мм	10—14	12—15,2	11—15	10,5—12,5	16,5—19,5	17,5—20,5
Испытательное (4) давление, кгс/см²	66—100	65—82,7	65—90,4	70	90—100	90—100
Предел прочности, кгс/мм² (5)	57	52	57	60	60	56
Предел текучести, кгс/мм² (6)	36	36	40	42	42	42
Относительное удлинение, % (7)	20	20	19	20	20	20
Ударная вязкость, кгс/см², при: (8)						
(9) минус 40°C	3	3	3	5	6	3
(9) минус 60°C	—	—	—	—	5	3,5

Key:
1. Indicators
2. Pipe diameter, mm
3. Wall thickness, mm
4. Test pressure, kgf/cm^2
5. Ultimate strength, kgf/mm^2
6. Yield point, kgf/mm^2
7. Relative elongation, percent
8. Impact strength, kgf/cm^2, at:
9. Minus

The most widely distributed type of pumping units in the USSR are now gas-turbine units with unit capacity of 4,000-10,000 kW. In 1975, 2,100 gas-pumping units with total rating of 8.2 million kW were operating on the gas pipelines in the USSR. The structure of the stock of pumping units is presented in Table 4.6 [38].

In 1975, 4,029 gas-pumping units with total rating of 6.0 million kW were operating on the gas pipelines of the United States. Moreover, the structure of the stock was the following in percent: 68.1 reciprocating units, 21.7 gas turbine units, 5.3 electric drive units, 4.2 with aviation drive and 0.7 percent with steam turbine drive. As can be seen, the compressor stations of United States gas pipelines are equipped with less modern machines and lower unit rating than those of USSR gas pipelines.

Table 4.6.

Тип агрегата (1)	Единичная мощность, (2) МВт	(3) Общая мощность, тыс. кВт	Структура, (4) % общей мощности
Газотурбинный(5)	6 и ниже (8)	3640	44,4
Газотурбинный	9—10	2080	25,4
Электроприводной (6)	4—5	1665	20,2
Газомоторный (7)	4 и ниже	825	10,0

Key:

1. Type of unit
2. Unit rating, MW
3. Total rating, thousand kW
4. Structure, percent of total rating
5. Gas turbine
6. Electric drive
7. Gas-motor
8. And below

The use of pipe 1,020, 1,220 and 1,420 mm in diameter at working pressure up to 75 kgf/cm^2 made it possible to achieve favorable engineering and economic indicators of gas transport (Table 4.7). Construction of gas pipelines, especially in northern regions, showed that the adopted transport technology and methods of construction require further improvement, primarily on gas cooling. Gas transportation at temperatures of 50-30°C may lead to disruption of the hydrogeological conditions, specifically to the routes turning into swamps.

Table 4.7.

(1) Показатели	(2) Диаметр, мм		
	1020	1220	1420
Пропускная способность, млрд. м^3/год(3)	16—18	19—22	28—30
Металлозатраты, т/(млрд. м^3/км) (4)	20,2	19,5	18,1
Энергозатраты, тыс. кВт·ч/(млрд. м^3·км) (5)	200	180	120
Центральные районы (6)			
Капиталовложения, тыс. руб/(млрд. м^3·км) (7)	17,5	16,8	12,4
Эксплуатационные затраты, (8) тыс. руб/(млрд. м^3·км)	2,46	2,29	2,25
Приведенные затраты, тыс. руб/(млрд. м^3·км) (9)	4,56	4,31	3,74
(10) *Северные районы*			
Капиталовложения, тыс. руб/(млрд. м^3·км) (7)	35,4	34,5	24,9
Эксплуатационные затраты, (8) тыс. руб/(млрд. м^3·км)	3,44	3,20	3,26
Приведенные затраты, тыс. руб/(млрд. м^3·км)(9)	7,70	7,36	6,24

Key:

1. Indicators
2. Diameter, mm
3. Carrying capacity, billion m^3/year
4. Metal expenditures, tons/(billion m^3/km)

[Key continued on following page]

[Key continued from preceding page]:

5. Energy expenditures, thousand kW·hr/(billion m^3·km)
6. Central regions
7. Capital investments, thousand rubles/(billion m^3·km)
8. Operating expenses, thousand rubles/(billion m^3·km)
9. Reduced expenditures, thousand rubles/(billion m^3·km)
10. Northern regions

The main engineering and economic indicators for development of gas pipeline transport in the USSR during the period 1965-1977 are presented in Table 4.8 [62].

Despite the fact that construction of major gas pipelines from the northern regions of Tyumenskaya Oblast is being carried out under severe conditions (the gas pipeline routes pass through swampy terrain and through sections with permafrost soils) and that expenditures for construction increased 1.8-2.0-fold compared to expenditures in the country's central regions, stabilization of the specific capital investments and cost of transport work is being observed. This has been achieved primarily by extensive introduction of large-diameter pipes and an increase of working pressure. Labor productivity was increased by an increase of unit capacities and as a result the specific weight of expenditures for wages was reduced somewhat.

Table 4.8.

Показатели (1)	1965	1970	1975	1977
Удельные капиталовложения, (2) тыс. руб/(млрд. $м^3$·км)	24,3	32,1	21,0	28,0
Фондоотдача по объему грузооборота, (3) тыс. $м^3$·км/руб.	31,4	34,0	34,8	35,1
Эксплуатационные расходы, млн. руб/год (4) .	173,4	346,2	740,0	959
Себестоимость, тыс. руб/(млрд. $м^3$·км) (5) . .	2,46	2,11	2,19	2,20

Key:
1. Indicators
2. Specific capital investments, thousand rubles/(billion m^3·km)
3. Fund recovery by volume of freight turnover, thousand m^3·km/ruble
4. Operating expenses, million rubles/year)
5. Cost, thousand rubles/(billion m^3·km)

Energy expenditures increased sharply during the period 1965-1977. The extensive construction of compressor stations carried out during this period and caused by an increase in the distance of gas delivery and by an increase of intensification of pipe utilization was felt here. Review of prices for electric power and gas also led to an increase of energy expenditures. Prior to 1967 gas for the needs of pipelines was paid for by prices corresponding to expenditures for production in the fields and for transport to the compressor station. The change in the structure of operating expenses, rubles/(million m^3·km) is presented in Table 4.9.

The distribution of operating expenses for the part dependent and independent of the volume of work is of special interest.

Table 4.9.

Структура расходов (1)	1965	1975
Заработная плата (2)	0,35	0,27
Начисления на заработную плату (3)	0,03	0,02
Материалы-реагенты (4)	0,03	0,09
Энергетические затраты, включая потери газа (5)	0,59	0,62
Амортизационные отчисления (6)	1,10	0,93
Прочие расходы (7)	0,36	0,26
Итого: (8)	2,46	2,19

Key:

1. Structure of expenses
2. Wages
3. Wage bonuses
4. Reagent materials
5. Energy expenditures, including gas losses
6. Depreciation deductions
7. Miscellaneous expenses
8. Total

Expenses not dependent on the volume of work are constant at the given technical equipping of the gas pipeline, despite fluctuations in the load. According to approximate calculations, dependent expenses comprise approximately 25 percent of the total operating expenses. Depreciation deductions are also not dependent on the volume of work. As a result only about 10 percent of all the reduced expenditures are dependent on the volume of work. These ratios indicate the high economic effectiveness of maximum loading of the carrying capacity of gas pipelines primarily by reducing the coefficient of irregular gas delivery.

Under these conditions an increase of the utilization factor of carrying capacity of gas pipelines must be considered as one of the decisive measures for further improvement of the economic indicators of gas pipelines.

The direction adopted in the Soviet Union to reduce irregular gas consumption through regulation has already made it possible to reduce the needs to 0.87-0.88 of the average annual needs during the summer months and to increase consumption to 1.18-1.19 of average annual consumption during the winter. However, there are still large reserves for further improving the load of pipelines by increasing the specific weight of gas expended by regulating consumers and especially by construction of depots at consumption points. The latter measure is also required to provide a reliable gas supply.

Pipeline transport of gas is an energy- and metal-consuming type of transport. Energy expenditures per unit of freight turnover are approximately 4-5 times greater than during rail transport. In conditional calculation, they comprised 480 tons/(billion $m^3 \cdot km$) in 1965, 464 in 1970 and 504 tons/(billion $m^3 \cdot km$) in 1975.

The reduction of specific metal expenditures per unit of freight turnover is followed from 81.6 tons/(billion $m^3 \cdot km$) in 1965 to 56.9 tons/(billion $m^3 \cdot km$) in 1975, which made it possible to compensate for the increase of metal consumption per unit of delivered gas with regard to the significant increase in the transportation distance. The distance of gas delivery increased from 626 to 1,345 km during the period 1965-1975, i.e., 1.96-fold, while the specific metal expenditures per unit of delivered gas increased from 51.1 to 71.3 tons/million m^3, i.e., by only 39 percent. This was achieved mainly by using large-diameter pipes and by increasing the working pressure with a simultaneous increase of metal quality (see Table 4.7).

However, a lag in construction of compressor stations is being observed for some gas pipelines, which led to a decrease of gas pipeline productivity and consequently to deterioriation of their engineering and economic indicators, including specific metal expenditures. Large reserves for a further reduction of specific metal consumption are hidden in an increase of the quality of pipe metal.

The number of maintenance personnel in transport increased 1.9-fold during the period 1965-1975, which is explained by the rapid rates of development of the gas industry, while labor productivity per transport worker increased from 3.44 to 9.15 billion $m^3 \cdot km$ during this same period, i.e., 2.6-fold. Significant reserves for reducing the number of maintenance personnel and for increasing labor productivity are to be found primarily in increasing the operating reliability of equipment and in correct organization of repair at centralized enterprises, extensive automation of control, accounting and fiscal reporting. An increase of labor productivity can be achieved by maintenance personnel being qualified in several occupations.

Thus, high results have been achieved during the past few years in development of the gas transport system of the USSR. Fulfillment of the decisions of the 25th CPSU Congress on accelerated development of the gas industry will lead to the fact that gas production will reach 400-435 billion m^3 in 1980, i.e., it will increase 1.45-fold compared to 1965.

4.3. Basic Directions for Development of Gas Pipeline Transport in the USSR

a) Main Problems.

The main problems of developing gas pipeline transport are [2]:

creation and development of super large gas pipelines of high productivity and distance of gas delivery of 3,000-4,000 km from the fields of the northern regions of Tyumenskaya Oblast to the European USSR;

construction of gas pipelines from medium and small fields with limited yield to consumers or for connection to a common pipeline system;

development of a branched major distributing system that links the yields from the main gas-producing regions to a local distributing system that provides gas delivery from mainlines to large consumers or groups of smaller consumers.

The fields of the northern regions of Tyumenskaya Oblast are distinguished by relatively favorable mining-geological conditions for drilling and high yield of wells. All these factors lead to the fact that, despite the severe climatic conditions, the presence of permafrost and swampiness of the area of the fields, gas production in these regions is profitable. Therefore, the gas reserves of the northern regions of the West Siberian lowland and the Yamal peninsula are regarded in the foreseeable future as one of the country's main fuel bases [41].

The gas fields of the northern regions of the USSR are now a source of increasing gas production and of providing the country with more qualified fuel. The main consumers of the gas are the regions of the European USSR and the Urals. Part of the gas is delivered for export across the western borders. The distance of gas transport from the northern regions of Tyumenskaya Oblast to consumers comprises and average of 3,000 km and in some cases even more. Expenditures for mainline and branched transport under these conditions reach 60-80 percent of the total cost of consumer gas [41].

These conditions make the problem of gas transport from the northern regions of Tyumenskaya Oblast one of the main problems of formulation of the energy balance, that predetermines to a significant degree the development of the country's economy [25]. In this case the problem should be regarded as a long-range problem and the use of both hardware already available and planned for use in the future and more modern productive engineering solutions subject to development in the near future should find application in solving it.

The main characteristic of gas transport systems is the rigid connection of the transport process to production and consumption of fuel: variation of production or consumption is immediately felt in transport, changing its parameters, and consequently changing the engineering and economic indicators. This characteristic of gas pipeline systems must be taken into account in planning, i.e., selecting the parameters and phases of development of systems is not a problem of transport alone but is part of the problem to develop an effective structure of the country's energy balance.

Moreover, a rigid internal production relationship is inherent to pipeline systems, including gas pipeline systems, which makes them dynamic, increases the requirements on their systems reliability and expands the methods of creating reserves and regulating them. There is the possibility of cycling the systems, creating intersystem jumpers and implementation of other measures that increase the efficiency of this system.

General concepts on formation can be advanced according to the problems of developing the country's gas transport system.

b) Long-Distance Gas Transportation Systems

Capital investments and metal and equipment expenditures to develop long-distance gas transportation are so high that they determine a special approach to selection of their capacity and load according to operating time.

The depreciation period of gas pipelines has been established at 30 years. The service life of a gas pipeline may also be higher than the depreciation life with sufficiently high-quality insulation and improved protection of pipe metal against corrosion by electrical engineering methods. Consequently, as complete use as possible of capacity during the entire operating period should be provided to increase the efficiency of long-distance pipeline systems. Moreover, design and development of gas pipelines are carried out in most cases under conditions of incomplete information. There is a number of specific factors for gas pipelines that are difficult to take into account during design.

Geological study of a region is usually inadequate. Even if the proven reserves of discovered fields turn out to be reliable, there are several indefinite factors in this case.

Fields with economically effective conditions of exploitation may be discovered in the future near fields or along the route of the gas pipeline, which changes the volume of the gas to be transported and requires implementation of redesign measures (laying of a parallel pipe, loops and so on) that affect the change in the operating conditions of the gas pipeline. However, these suggestions, even with the presence of predicted reserves, are not sufficiently substantiated and cannot be taken into account during design.

If there are data on reserves, even if they are quite reliable, the parameters for exploitation of a field for the entire period of operation and especially for the period of decreasing production, i.e., when gas sampling will decrease with regard to the drop of bed pressure and the reduced yield of wells, cannot be established with sufficient accuracy during planning. It is known that the rates of decrease of gas production for individual fields and sampling of it during this period depend on numerous geological features of the field. The methods of intensification of gas sampling not yet known during planning can also not be taken into account.

These factors that determine the conditions for exploitation of fields make the initial information for calculation of a gas pipeline in many cases condition to a significant degree. Even if one proceeds with total reliability of proven reserves of fields and schemes for exploitation of them adopted by the plan, loading the gas pipeline to full capacity cannot be provided even in this case with the onset of decreasing production. To determine the productivity of the gas pipeline, gas production is usually taken at the rate of 5 percent of extracted gas reserves. However, the total volume of gas delivered over the entire operating period will be considerably less in this case than was determined by calculation, based on uniform loading during the entire period of operation. Consequently, the actual specific expenditures may be considerably higher than calculated in a number of cases. The periods of development of a field and of increasing the carrying capacity of a gas pipeline to design capacity and preparation of consumers to receive the gas must also be taken into account. The actual periods of developing the design capacity of gas pipelines are shown in Figure 4.2. The length of the period of assimilation of the design capacity during the last period comprises 2-3 years for one-pipe gas pipelines; this period is increased for pipelines having several parallel pipes. However, it usually does not exceed the indicated period for a single pipe.

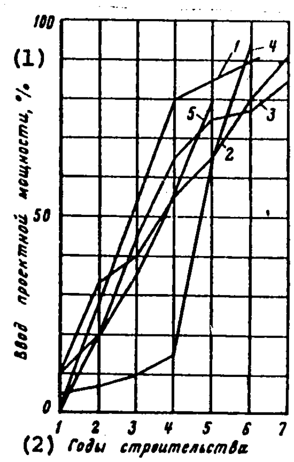


Figure 4.2. Assimilation of Design Capacity of Gas Pipelines: 1--Bukhara-Urals (two pipes); 2--Central Asia-Center (four pipes); 3--Ukhta-Torzhok (two pipes); 4--Nizhnyaya Tura-Center (two pipes); 5--norther regions of Tyumenskaya Oblast-Tura (four pipes)

Key:
1. Introduction of design capacity, percent   2. Years of construction

Development of local gas consumers must be taken into account when selecting the calculated productivity of a gas pipeline. The volumes of local consumption and the growth rates are extremely different for individual regions and fields.

Maintenance of gas pipeline productivity for a prolonged period at the planned level is possible if this factor is taken into account during design or when new fields are connected to it and also when gas pipelines from more remote fields are connected to the system.

Underestimation of this factor may lead to the fact that gas pipelines delivering gas from fields that have already entered the decreasing production phase begin to operate with incomplete loading and deteriorated indicators.

Gas pipeline systems should be calculated on the basis of proved reserves with calculation of their operation at total loading during the entire or the greater part of the depreciation period in order that these systems operate during the decreasing production phase with a gradual decrease of working pressure and that they be maintained in the operating state by relaying or switching off individual, more corrosion-damaged sections (with multipipe systems) and other measures.

Formation of multipipe gas transport systems, especially from the larger northern fields, and selection of the number of developed pipes and the production parameters of gas transport should rely on careful analysis of prospected and proven reserves and the conditions for exploitation of gas fields.

Economic investigations on optimization of the highest steady gas delivery, depending on the extracted reserves and the modes (strategies) of the gas transportation system, were conducted in a perennial profile for specific total expenditures, which were calculated as the sum of the annual capital investments K_{ijn} and operating expenses C_{ijn} reduced to the first year of operation of the gas transportation system:

$$\sum_{(n)} \frac{K_{ijn} + C_{ijn}}{(1+E)^n},$$

where n is the number of years of construction and operation beginning with the first year and E_n is the reduction factor.

The freight turnover A_{ijn} was also reduced in similar fashion to the first year:

$$\sum_{(n)} \frac{A_{ijn}}{(1+E)^n}.$$

The specific reduced expenditures, corresponding to each of the strategies for development and functioning of the gas transportation system, can be represented in the following manner:

$$\Pi_{ij} = \frac{\sum\limits_{(n)} \frac{K_{ijn} + C_{ijn}}{(1+E)^n}}{\sum\limits_{(n)} \frac{A_{ijn}}{(1+E)^n}}.$$

The perennial operating conditions of a gas transportation system and its economic indicators were calculated by different versions with the highest gas delivery variable in a range given in percent of the extracted reserves. The depreciation period of gas pipelines was taken as equal to n_a, years. The time the gas pipelines were brought to condition n_o and the period of stationary mode of gas pipelines n_{st} were taken by version. A reduction of gas delivery is typical for the latter years, i.e., the utilization factor of developed transport capacities decreases. The calculations were carried out for identical total gas yield by versions during the entire operating period of gas pipelines.

The mathematical postulation of the problem can be represented in the following manner: there is a finite number of scenarios of perennial operating conditions of a gas transportation system

$$A = \{A_1, A_2, \ldots, A_n\},$$

which accordingly provide a number of versions of gas yield

$$B = \{B_1, B_2, \ldots, B_n\}$$

and to which corresponds a number of solutions for the highest steady gas yield

$$Q=\{Q_1, Q_2, \ldots, Q_n\}.$$

A matrix of the specific reduced expenditures $\|\Pi_{ijk}\| (i=\overline{1, n};\ j=\overline{1, n};\ k=\overline{1, n})$ was compiled for the optimization solution. The expenditures permit selection of a minimax strategy for development of transport with mean value of payoff (with regard to specific reduced expenditures for construction and operation). The best (economically effective) strategy is then that to which will correspond

$$v=\min\max\Pi_{ijk}.$$

The results of calculations made by the considered method for gas pipelines of different length and different conditions of construction are presented below.

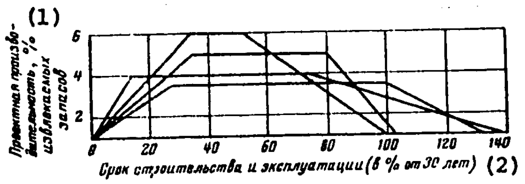


Figure 4.3. Diagrams of Operating Modes of Transportation Systems With Different Calculated Gas Yields from Fields

Key:
1. Planned productivity, percent of extracted reserves
2. Period of construction and operation (in percent of 30 years)

Different levels of the planned productivity of a gas pipeline, which comprises from 2 to 6 percent of extracted reserves (Figure 4.3), was considered for all conditions of the route.

The following propositions were used in the calculations (Figure 4.4):

1--the fields are located in the European USSR and the length of the gas pipeline route is 500-700 km;

2--the fields are located in the Urals and Central Asia and the length of the pipelines is 1,500-2,000 km;

3--the gas pipelines are laid from the fields of the northern Tyumenskaya Oblast with length of 2,500-3,000 km without permafrost sections;

4--the gas pipelines are laid from fields located north of the Arctic Circle when the route partially passes through permafrost conditions and has a length of approximately 3,000 km.

As can be seen, the planned productivity of a gas pipeline of approximately 5 percent of the extracted reserves is close to optimum for pipelines from a field in

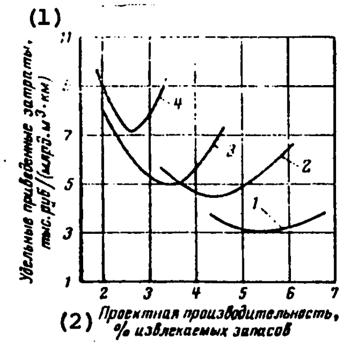


Figure 4.4. Variation of Reduced Expenditures for Transport as a Function of Gas Yield for Different Locations of Fields and Passage of Gas Pipeline Routes

Key:
1. Specific reduced expenditures, thousand rubles/(billion m^3·km)
2. Planned productivity, percent of extracted reserves

the European USSR. However, gas pipeline productivity of 4.5 percent of extracted reserves is more feasible with pipeline lengths of 1,500-2,000 km. A calculated productivity of 3.5 and even 2.5 percent of extracted reserves, respectively, can be taken for construction of heavy and unusually long gas pipelines in order to ensure continuous operation of the pipelines over a prolonged period. It should be noted that complication of construction conditions and an increase of the gas pipeline route not only worsens the economic indicators but also constricts the zone of optimum solutions. If a short pipeline laid under favorable conditions is characterized by a sloping optimum of gas yield levels on the graph (1 in Figure 4.4), then a long pipeline and especially one laid under unfavorable conditions is characterized by a clearly marked optimum level of gas yield (4 in Figure 4.4) that provides normal operation of the pipeline at the calculated load.

This indicates the need to investigate the scope of yield as one of the factors determining the effectiveness of gas pipeline systems of great length and also forces one to approach very carefully the selection of the calculated productivity of gas pipelines. Moreover, it becomes obvious that one must proceed from real conditions with regard to the period of assimilation when yield will increase gradually to the calculated value and with regard to the operating period of the system under conditions of decreasing yield of fields if other fields in this region are not prospected, rather than from conditions of a uniform gas yield for the entire operating life of the gas pipeline when selecting the parameters of the pipeline and when establishing the wholesale prices for gas.

c) Major Gas Pipelines of Short Length

A number of conditions that increase the reliability and maneuverability of the gas supply of nearby regions must be taken into account to provide high engineering and economic indicators of gas supply for the national economy when establishing the productivity of gas pipelines of short length that connect fields with relatively modest reserves to the country's overall gas-supply system.

Fields located near consumer centers can be used as regulators to cover the peak loads, with regard to which the maximum level of gas production may be very high, while the mean annual load of a pipeline will be lower than that possible with constant year-round consumption. Fields can be used as gas depots to cover peak loads as reserves are depleted.

Forced exploitation of fields which are not quite advantageous for the sector economy of the gas industry may be required to provide the rates of development of the country's economy. In this case the problem of using fields located in the gas-consuming regions as regulators to cover the peak loads with regard to more uniform and high load of major gas pipelines of great length merits special attention. Major gas pipelines in turn should be designed for high load during a short period, after which they can be used as gas depots required to equalize irregular consumption and interruptions of gas supply during emergency situations.

If the short operating life of these gas pipelines under full load is taken into account, they can be designed to operate in the forced mode.

Thus, when a gas pipeline is operating in the calculated mode for 4 years and producing 22-25 billion m^3 of gas annually, two pipes 1,020 mm in diameter can be laid with spacing of 90-100 km between compressor stations instead of three pipes and spacing of 130-140 km, as would be the case during operation of a gas pipeline for a prolonged period in the calculated mode. The system of two pipes permits a reduction of total expenditures by 40 percent over a period of 15-20 years compared to a system of three gas pipelines.

It is obvious that selection of the parameters and operating modes of systems requires detailed analysis of their load during the entire operating period for each specific case. Orientation toward production of 5 percent of proven reserves and calculation of all parameters of the system based on this production during prolonged operation may lead to unsubstantiated losses.

d) Extractions from Major Gas Pipelines

Major branching gas pipelines that deliver gas from major systems to individual consumers are characterized by a gradual increase of gas delivery as the industry of a region is developed; there may be periods of accelerated growth caused by startup of a some large gas consumer or a slowdown in the rates of an increase of consumption due to introduction of enterprises that operate on another type of fuel and there may be other reasons. However, one may assume in the first approximation for these pipelines that there is approximately uniform growth of productivity in time with rates typical for one or another region.

When working out the basic directions for development of a country's economy, data on the need of large economic regions (oblasts) are found in the first approximation. Only extrapolation of the consumption indicators is practically possible for the more remote period, which may yield only approximate results. However, they are adequate in many cases to select the basic parameters of these gas pipelines. The engineering and economic indicators of different versions of a pipeline system that delivers gas from a major gas pipeline to industrial centers where an increase of gas consumption by an average of 0.5 and 1.0 billion m^3/year is expected and where the carrying capacity of existing pipelines has been essentially exhausted, are presented in Table 4.10.

Gas delivery to these regions will reach 15 and 30 billion m^3/year, respectively, over a calculated period of 30 years. Gas delivery may be solved by several versions of laying different diameter pipes. The results of calculation are presented for several typical versions with conditional pipeline length of 500 km.

Table 4.10.

(1) Варианты трубопроводной системы	(2) Темпы роста потока газа, млрд. м³/год							
	0,5				1,0			
	(3) Диаметр газопровода, мм	(4) Пропускная способность, млрд. м³/год	(5) Приведенные затраты¹, %	(6) Металлозатраты, %	Диаметр газопровода, мм	Пропускная способность, млрд. м³/год	Приведенные затраты¹, %	Металлозатраты, %
Однониточный трубопровод² . (7) . . .	1220	15,0—16,0	100	100	1440	30,0	100	100
Двухниточный с постройкой второй (8) нитки через 15 лет	820	7,0—7,5	$\frac{92}{89}$	118	1220	15,0	$\frac{90}{88}$	108
Трехниточный с постройкой каждой (9) нитки через 10 лет	720	4,5—5,0	$\frac{87}{73}$	160	1020	9,5—10,0	$\frac{83}{80}$	114
Четырехниточный с постройкой каждой (10) нитки через 7—8 лет	—	—	—	—	820	7,0—7,5	$\frac{80}{78}$	127

[1] In the numerator with reduction factor of 0.12 and in the denominator with factor of 0.15.

[2] Pipeline pressure of 75 kgf/cm^2 and pressure of remaining pipelines of 56 kgf/cm^2.

Key:

1. Versions of pipeline system
2. Growth rates of gas volume, billion m^3/year
3. Gas pipeline diameter, mm
4. Carrying capacity, billion m^3/year
5. Reduced expenditures, percent
6. Metal expenditures, percent
7. One-pipe pipeline
8. Two-pipe pipeline with construction of second pipe every 15 years
9. Three-pipe pipeline with construction of each pipe every 10 years
10. Four-pipe pipeline with construction of each pipe every 7-8 years

It is obvious from the data of Table 4.10 that the reduced expenditures for development of the entire system over a 30-year period are more favorable with a gradual increase of carrying capacity by laying additional pipes every 7-10 years, although the total metal consumption increases in this case.

4.4. Increasing the Efficiency of Gas Pipelines

a) Quality of Pipe Metal

An increase in the strength of steel and consequently a reduction of the wall thickness and mass of pipes can be achieved by heat treatment.

Engineering and economic comparison of pipes 1,020 mm in diameter of the Novomoskovsk Metallurgical Plant is presented in Table 4.11: data for unstrengthened pipes are presented in the numerator and data for thermally strengthened pipes are presented in the denominator [4, 34, 46].

If thermally strengthened pipes are used, the metal expenditures are reduced by 17-20 percent while the reduced expenditures are reduced by 14-17 percent. The effectiveness of this method will increase as the technique and technology of thermal strengthening are developed and improved.

Table 4.11.

Толщина стенки, мм (1)	Масса труб на 1 км, т (2)	(3) Затраты на производство 1 км труб, тыс. руб.		
		(4) капиталовложения	(5) эксплуатационные затраты	(6) приведенные затраты
$\frac{11,0}{9,0}$	$\frac{273,7}{224,4}$	$\frac{85,0}{70,0}$	$\frac{36,4}{31,6}$	$\frac{49,1}{42,3}$
$\frac{12,5}{10,0}$	$\frac{310,5}{243,1}$	$\frac{92,7}{75,6}$	$\frac{40,8}{35,0}$	$\frac{54,7}{46,3}$
$\frac{14,0}{11,0}$	$\frac{347,3}{273,7}$	$\frac{100,7}{81,0}$	$\frac{45,2}{38,2}$	$\frac{60,3}{50,4}$

Key:

1. Wall thickness, mm
2. Pipe mass per km, tons
3. Expenditures for production of 1 km of pipe, thousand rubles
4. Capital investments
5. Operating expenses
6. Reduced expenditures

Approximate variations in the cost of one ton of steel pipe of different strength and the effect of alloying additives on production expenditures of 1 km of pipe are presented in Table 4.12 [34].

An increase of metal quality by using alloying additives and other methods leads to a significant increase of expenditures for pipe manufacture, but expenditures per kilometer of pipeline increase insignificantly due to a reduction of wall thickness. However, the need for metal is reduced sharply in this case, which is a decisive factor for accelerating the development of pipeline transportation.

Especially high requirements are placed on pipe metal during construction of pipelines in Arctic regions. According to SNiP II-45-75 [46], pipes designed for

Table 4.12.

(1) Показатели	Временное сопротивление, кгс/мм² (2)						
	48	52	56	58	60	65	70
(3) *Трубопровод диаметром 1220 мм, давление 75 кгс/см²*							
Толщина стенки, мм (4)	17,2	15,9	14,8	14,3	13,8	12,8	11,9
Масса труб на 1 км, т (5)	507	469	437	422	408	379	353
Цена 1 т трубы, руб. (6)	180	210	236	240	245	255	269
Стоимость труб на 1 км, тыс. руб. (7)	91	98	103	101	100	97	95
То же, % к стоимости при временном сопротивлении 52 кгс/мм² (8)	92,8	100	105,1	103,1	102,0	99,0	96,9
(9) *Трубопровод диаметром 1420 мм, давление 75 кгс/см²*							
Толщина стенки, мм	20	18,5	17,2	16,6	16,1	14,9	13,8
Масса труб на 1 км, т	686	635	591	571	554	513	476
Цена 1 т труб, руб.	190	220	249	252	256	268	282
Стоимость труб на 1 км, тыс. руб.	129	133	139	137	136	131	128
То же, % к стоимости труб при временном сопротивлении 52 кгс/мм²	92,5	100	104,5	103	102,2	98,5	96,2

Key:

1. Indicators
2. Ultimate resistance, kgf/mm^2
3. Pipeline 1,220 mm in diameter, pressure of 75 kgf/cm^2
4. Wall thickness, mm
5. Pipe mass per km, tons
6. Price of one ton of pipe, rubles
7. Cost of pipe per kilometer, thousand rubles
8. Cost of pipe, percent of cost at ultimate resistance of 52 kgf/mm^2
9. Pipeline 1,420 mm in diameter, pressure of 75 kgf/cm^2

pressure of 75 kgf/cm^2 should meet impact strength of 8-8.5 kgf/cm^2 (instead of 3-4 kgf/cm^2 for pipes laid in non-Arctic regions). Alloying additives must be employed to fulfill these requirements, which leads to an increase in the cost of pipe: thus, according to preliminary estimates, pipes 1,420 mm in diameter meeting the indicated requirements in impact strength will cost 75-80 rubles less per ton [34]. Since the increased requirements on impact strength of steel lead to a significant increase in the cost of pipe, the use of them for gas pipelines should be substantiated by engineering and economic indicators.

One of the very promising trends of improving pipe design is the use of thin-walled multilayer pipes for high-pressure pipelines based on the use of low-alloy hot-rolled steel in rolls [11], production of which has been widely assimilated by Soviet metallurgy (proposal of the Institute of Welding imeni Paton, Ukrainian SSR Academy of Sciences). The characteristic feature of thin sheet steel is an increase of strength and homogeneity with a decrease of sheet thickness.

Despite the laboriousness of manufacturing multilayer pipes, it is expected that they will be less expensive than pipes with a solid wall due to the use of inexpensive metal, especially with the wall thickness required for pressure of 100-120 kgf/cm^2. It is obvious that the use of multilayer pipes will make it possible not only to use considerably less expensive metal without loss of pipe strength and operating reliability of the pipeline, but also to significantly increase the productivity of pipelines by conversion to pressure of 120 kgf/cm^2 and thus to improve the engineering and economic indicators of major gas pipelines.

b) The Surface Roughness of Pipes

Pipes now produced by Soviet industry and purchased by import usually have an inner surface roughness of approximately 30 microns since they are manufactured without additional machining.

Calculations show that reducing surface roughness by one-half, to 15-17 microns, yields an increase of gas pipeline productivity by 4-6 percent. A reduction of surface to 3-5 microns leads to an increase of productivity by 8-10 percent without any increase of capital investments and operating expenses except those related to reduction of the inner surface roughness of pipes and prevention of contamination of them. The saving from reducing surface roughness by one-half and of increasing the productivity of a pipeline 1,420 mm in diameter, for example, 3,000 km long, is expressed in an increase of gas delivery by 1.5 billion m^3/year and by a saving of reduced expenditures by 18-20 million rubles/year. Provision of this quantity of gas delivery through a pipeline of the considered diameter would require approximately 100,000 tons of metal.

A reduction of surface roughness can be achieved by several methods and primarily by polishing the internal surface of pipes and of weld seams or coating them with epoxy resins, yielding a surface with very low roughness, approximately 5-8 microns. This method is economical and comparatively easy to accomplish under plant conditions during pipe manufacture. Obviously, it should be combined with polishing the seams at the plant prior to coating the pipe surface with epoxy resins and at the work production site to remove burrs and for coating sections of transverse seams made during construction with resins. A reduction of the tractive resistance of the gas can also be achieved by using full-flow fittings and high-quality manufacture of the booster binding of compressor stations that provide minimum pressure losses.

c) The Unit Output and Reliability of Compressor Station Units

Units with rating of 6,000, 10,000 and 25,000 kW are now installed at compressor stations [31].

The capital investments and operating expenses for a gas-turbine compressor station with piston pumps having different operating output are shown in Table 4.13. The data of the table reflect not only the saving from strengthening [31] of units but also from increasing their reliability and the stability of realizing the calculated outputs.

The more favorable economic indicators with unit output of 16,000 kW each are explained by the smaller fraction of reserve capacity--33 percent compared to 50 percent with units rated at 10,000 and 25,000 kW. The most rapid assimilation of

Table 4.13.

(1) Показатели	(2) Мощность агрегатов, тыс. кВт		
	10	16	25
Число агрегатов: (3)			
рабочих (4)	6	3	2
резервных (5)	3	1	1
Капиталовложения, млн. руб. (6)	15,8	10,5	11,5
Ежегодные эксплуатационные затраты, (7) млн. руб.	2,5	1,85	1,95
Приведенные затраты при $E_н$=0,12, % к затратам при агрегатной мощности 10 000 кВт (8)	4,44 100	2,99 66,4	3,23 72,8

Key:

1. Indicators
2. Output of units, thousand kW
3. Number of units
4. Operating
5. Standby
6. Capital investments, million rubles
7. Annual operating expenses, million rubles
8. Reduced expenditures at E_n = = 0.12, percent of expenditures with unit output of 10,000 kW

optimum-output units provides the possibility not only of reducing expenditures for construction and operation of compressor stations of 27-33 percent, but of increasing the optimum carrying capacity (productivity) of the pipeline since denser arrangement of them and accelerated use of the more expensive line part of the gas pipeline are effective with less compressor stations.

One of the important problems for development of long gas pipelines is the reliability of compressor stations.

Investigations showed that a breakdown of more than three units simultaneously on a gas pipeline having approximately 10 compressor stations is of low probability [6, 7]. The reliability of the gas pipeline can be increased by installing standby units at compressor stations. The number of standby units at each station is determined with regard to all the probability states with breakdown of units and the corresponding situations of reductions in gas pipeline productivity. Gas pipeline reliability $H_{k.sj}$ of any j-th compressor station is determined as the mean value of gas pipeline efficiency, i.e.,

$$H_{\text{к.с}j} = \sum_{(l)} \varphi_{lj} h_{lj},$$

where

$$\varphi_{lj} = \frac{Q_{lj}}{Q_{\text{пр}}};$$

$$h_{lj} = C^l_n p^{n-l} (1-p)^l;$$

Q_{ij} is the actual gas pipeline productivity during emergency situations, Q_{pr} is the planned gas pipeline productivity, n is the number of working units, i is the number of working units during the emergency, C_n^i is the number of combinations of n with respect to i and p is the reliability of a single unit.

Data on the reliability of a compressor station of three working units with readiness factor of 0.95 for each unit with regard to the operating modes of the gas pipeline are presented in Table 4.14 [6, 7].

Table 4.14.

(1) Количество отказавших рабочих агрегатов	(2) Значение $\varphi_{ij} h_{ij}$ при количестве резервных агрегатов			
	0	1	2	3
0	0,8560	0,8560	0,8560	0,8560
1	0,1300	0,1339	0,1339	0,1339
2	0,0091	0,0090	0,0100	0,0100
3	0,000078	0,000078	0,000078	0,0001
(3) Всего	0,995178	0,9980	0,9999	1,0000

Key:

1. Number of failed working units
2. Value of $\phi_{ij}h_{ij}$ with number of standby units

A safety factor of 0.998, that takes into account the operating conditions of the gas pipeline and a decrease of productivity with random failure of individual units, may be recognized as quite acceptable. Consequently, it is sufficient to have one standby unit for three working units. The characteristic feature of major gas pipelines is that failure of a compressor station does not lead to failure of the pipeline and the fraction of reduction of final productivity depends on the station's location along the route: failure of the main and two subsequent stations leads to 30-15 percent reduction of productivity and failure of the final stations reduce productivity by 2-5 percent.

The large number of calculations carried out for different combinations of compressor station units with regard to planned and preventive maintenance in the schedule for reducing the load of a gas pipeline during summer months made it possible to establish that one standby unit must be installed for each 2-5 working units to ensure reliable operation of compressor stations. This was adopted in the existing norms of the technological design of gas pipelines. Two-three standby units are installed in some cases due to possible failures of the unit.

This characteristic was taken into account in a number of pipelines in the United States laid in regions with well-developed highway system where installation of one working unit and the presence of a mobile standby unit for several compressor stations is provided to replace the main units while they are being repaired or during a serious emergency. Some concentrated arrangement of compressor stations is provided in this case, which makes it possible to better control the modes of the gas pipeline and to reduce the decrease of total gas pipeline productivity when one of the units fails due to regulation of compressor station operation.

d) Compression Ratio

As the experience of design and operation of major gas pipelines shows, the compression ratio is in the range of 1.2-1.5. Energy calculations show that the use of a compression ratio equal to 1.2 yields a saving of energy expenditures of approximately 40 percent compared to 1.45, but leads to the need to increase the number of compressor stations by 30 percent to provide given productivity. Thus, the energy saving comprises only about 10 percent. Consequently, final solution of the problem of compression ratio depends on the ratios of compressor station cost and the cost of energy or gas for the needs of the gas pipeline.

Table 4.15.

(1) Показатели	(2) Суммарная мощность компрессорных станций, тыс. кВт							
	30 (2+1)	40 (3+1)	50 (4+1)	60 (4+2)	70 (6+1)	80 (6+2)	90 (6+3)	100 (8+2)
(3) Удельные капиталовложения, руб/кВт	165	152	144	139	135	132	130	128
Годовые удельные эксплуатационные затраты, руб/кВт* (4)	32	32	33	29	33	32	28	31
Численность обслуживающего (5) персонала, чел/10 тыс. кВт работающих агрегатов . .	11,0	10,3	10,0	10,0	9,5	9,5	9,5	9,2

---

*With cost of fuel gas at 6 rubles per thousand m^3.

Key:
1. Indicators
2. Total output of compressor stations, thousand kW
3. Specific capital investments, rubles/kW
4. Specific annual operating expenses, rubles/kW
5. Number of maintenance personnel, men/10,000 kW of operating units

At the same time capital investments and operating expenses decrease significantly with an increase of the installed output of compressor stations.

It follows from the data of Table 4.15, in which the engineering and economic indicators are given for compressor stations of different output with units of 10,000 kW each that the specific capital investments and number of personnel decrease somewhat with an increase in the output of the compressor station even with fixed output of units. Operating expenses essentially remain at the same level and fluctuate as a function of the number of standby units. Moreover, with identicial standby capacity, there is a reduction of specific operating expenses. Thus, operating expenses comprise 32 rubles with two working units, 29 rubles with 4 units and 28 rubles with 6 units, respectively, at compressor stations with standby units equal to 50 percent of the number of working units.

These data indicate the feasibility of concentrating the outputs of compressor stations and of reducing their number. Detailed calculations with regard to the characteristics of units and variation of energy expenditures as a function of the compression ratio and other factors lead to the conclusion that a compression ratio in the range of 1.45-1.50 is feasible.

e) Gas Cooling

As is known, compression of gas is accompanied by an increase of its temperature, but the gas is cooled during its motion through the pipeline due to the throttling effect (expansion) and heat transfer to the soil through the pipe walls. Gas in pipes less than 1,020 mm in diameter can be cooled to the intake temperature to the compressor station during travel from one compressor station to another. In large-diameter pipes the heat losses through the soil and due to the throttling effect are insufficient for cooling the gas. This is related to the fact that the productivity of a gas pipeline increases in proportion to diameter at a ratio of 2.5, while the heat transfer surface is proportional to pipe diameter, i.e., the specific thermal loads (per unit of pipeline surface) increase significantly. With long length of gas pipelines, the gas temperature levels may reach the values at which insulating coatings melt (50-60°C). Thus, cooling gas to temperatures not above 10°C is a technologically compulsory measure at the current phase of development of the equipment and technology of transportation using large-diameter pipes and high pressures. Installation of air-cooling units is now obligatory according to existing standards for major gas pipelines 1,420 mm in diameter with working pressure of 75 kgf/cm^2.

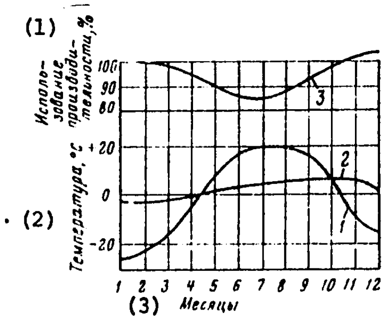


Figure 4.5. Variation of Carrying Capacity of Gas Pipeline as a Function of Annual Temperature Fluctuations: 1--mean monthly air temperatures; 2--soil temperature at gas pipeline level; 3--use of gas pipeline productivity (in percent of productivity in January)

Key:
1. Use of productivity, percent
2. Temperature, °C
3. Months

The changes of outside air temperatures, soil temperatures and gas pipeline productivity are shown in Figure 4.5. One must take into account that the soil temperature outside the effective zone of the gas pipeline is shown on the graph. Essentially, cooling the gas through the pipe walls and the soil temperature near the gas pipeline should be closely related to outside air temperature. It is obvious from the curve of possible carrying capacity that the average annual productivity of the gas pipeline even with constant total load of working compressor units and total operating continuity of the linear part may be at a level of approximately 0.9-0.93. Equalizing the gas pipeline load by seasons of the year is a significant reserve for increasing the efficiency of major gas transportation.

When using gas pipelines without heat insulation, the following cooling levels may be considered:

to temperature of gas pumped into a pipeline not higher than 50°C, which is already partially employed at gas pipelines under construction;

to gas temperature equal to soil temperature in the final part of the section (1-4°C); in this case the pipeline will have positive temperatures over the entire length of the section and its effect on the soil and surrounding medium will be minimal;

to gas temperature equal to soil temperature near the pumping station; the gas will be cooled somewhat due to the throttling effect as the distance from the compressor station increases, but the extent of this cooling, if the absence of heat losses through the pipeline walls is taken into account, will be insignificant.

Table 4.16.

Показатели (1)	(2) Температура перекачки, °C		
	50	27	—3
Температура, °C, в компрессорной станции: (3)			
на входе (4)	45	22	—5
на выходе (5)	55	32	+2
Мощность, МВт: (6)			
компримирования (7)	44	38	37
охлаждения (8)	4	4	5
Производительность, млрд. м³/МВт (9)	0,58	0,73	0,79

Key:

1. Indicators
2. Pumping temperature, °C
3. Temperature, °C, at compressor station
4. At input
5. At output
6. Rating, MW
7. Compression
8. Cooling
9. Productivity, billion m^3/MW

The results of cooling gas for a pipeline 1,420 mm in diameter and at working pressure of 75 kgf/cm^2 to the indicated levels are presented in Table 4.16.

It is assumed in the calculations that cooling to a temperature of not above 40-50°C is accomplished by air-cooling equipment and at lower cooling it is accomplished by combined units: by air-cooling equipment and propane-butane compressor cooling units.

As can be seen, the total output of energy units and energy expenditures for compression and cooling, although they increase somewhat, the increase is insignificant. At the same time the annual productivity of the gas pipeline increases due to the more complete utilization of productivity during the summer months. An increase of gas pipeline productivity makes gas cooling an economically effective measure and means of metal conservation when pipes without heat insulation are used.

A complication during operation of gas pipelines with gas cooling to negative temperatures at the end of sections may be freezing up of them, which may cause some difficulties in conducting emergency repairs on the route.

The problem of providing a stable position of pipelines laid under complex hydrogeological conditions of the country's Arctic regions through swamps and sections with flooded soils with low drying capacity is of special interest when studying this question. Operation of these pipelines without gas cooling leads to disturbance of the established ecological balance, flooding of the pipeline route, formation of a type of flooded trenches and disturbance of stable operation of pipelines.

Cooling the gas to bring the pipeline temperature closer to soil temperatures obviously makes it possible to reduce to a minimum the disturbance of the ecological equilibrium and to ensure the operating stability of pipelines and the possibility of their maintenance and repair.

It must be noted that equipping existing pipelines with cooling units leads to improvement of their economic indicators and may be regarded as a measure to increase the efficiency of existing systems.

f) Electric Drive of Pumps

Gas pumps with electric drive are used primarily at relatively low output of the units: their specific weight comprised 19.3 percent of 1975 and 20.4 percent by established rating.

Electric drives have mainly become widespread in Western European countries, which is explained primarily by the relatively high cost of gas fuel.

Selection of the type of compressor drive for gas pipelines is usually made in the United States by comparison of expenditures.

The results of calculation, in millions of dollars, on selecting the type of drive for the gas pipeline from South Carolina approximately 1,600 km long (a station with rating of 15,000 hp) are reduced in Table 4.17. The compressor drive was selected with regard to expenditures for construction, maintenance and local costs for fuel and electric power. An electric drive is recommended for zone A and a gas-turbine drive is recommended for zone B.

A significant reduction of energy expenditures compared to other types of drives dictates the use of piston compressors with electric drive, but this type of installation requires considerably higher capital investments and is less profitable than centrifugal pumps.

Table 4.17.

(1) Показатели	(2) Один центробежный нагнетатель		(5) Шесть поршневых компрессоров мощностью по 2500 л. с.
	(3) с электроприводом	(4) с газовой турбиной	
(6) Капиталовложения	2,100	3,000	4,200
Ежегодные затраты (13%)(7)	0,273	0,390	0,546
Эксплуатационные расходы без затрат на топливо и электроэнергию (8)	0,158	0,194	0,227
То же с учетом затрат:(9)			
Зона А: (10)			
на электроэнергию (11)	0,438	—	—
на топливо (газ) (12)	—	0,351	0,311
Итого по зоне А: (13)	0,869	0,935	1,084
Зона Б: (14)			
на электроэнергию	0,940	—	—
на топливо (газ)	—	0,419	0,372
Итого по зоне Б: (15)	1,371	1,003	1,145

Key:

1. Indicators
2. One centrifugal pump
3. With electric drive
4. With gas turbine drive
5. Six piston compressors with rating of 2,500 hp each
6. Capital investments
7. Annual expenditures (13 percent)
8. Operating expenses without expenditures for fuel and electric power
9. Operating expenses with regard to expenditures:
10. Zone A
11. For electric power
12. For fuel (gas)
13. Total for zone A
14. Zone B
15. Total for zone B

The results of calculating the comparative efficiency of electric and gas turbine drives for an abstract model of a gas pipeline of two pipes 762 mm, made for United States conditions, are presented in Table 4.18 (in million dollars). It was taken into account in the calculations that approximately 10 percent of gas must be consumed for one's own needs with a gas-turbine drive, while obtaining an identical amount of commercial gas requires the construction of four additional compressor stations.

Thus, the reduced expenditures with a gas-turbine drive are approximately 47 percent higher than with an electric drive.

Table 4.18.

(1) Показатели	(2) Электрический привод	(3) Газотурбинный привод
(4) Капиталовложения	64,5	129,3
Ежегодные затраты (15%)(5)	9,7	19,3
Эксплуатационные расходы с учетом затрат на топливо и электроэнергию (6)	37,5	49,3
Итого ежегодные расходы: (7)	47,2	68,6

Key:
1. Indicators
2. Electric drive
3. Gas-turbine drive
4. Capital investments
5. Annual expenses (15 percent)
6. Operating expenses with regard to expenditures for fuel and electric power
7. Total annual expenses

The given examples confirm the feasibility of using an electric drive, especially with the high cost of gas, but zones for which it is efficient to use electric or gas turbine drive are determined carefully during design.

The use of an electric drive for pumps in gas pipelines of the USSR makes it possible:

to simplify the operating conditions of gas pipelines, to reduce the staff of compressor stations, to simplify all conditions for automation of control of the production processes of compressor stations and to reduce the number of workers by approximately 25-27 percent;

to increase the operating reliability of compressor stations. The number of forced shutdowns per electric drive unit is less by a factor of 2.2 than of a unit with gas turbine drive. Moreover, the cost of major overhaul of an electric drive unit is 1/10th that of a gas turbine unit [62];

to reduce fuel consumption during transportation since the total beneficial utilization factor of fuel resources with electric drive of pumps is approximately 30 percent higher than with a gas turbine drive. In the first case, the electric power consumption for one's own needs comprises 36-37 percent with regard to losses in the electric power transmission line and transformer substations; the actual efficiency of the gas turbine usually comprises no more than 26-27 percent under operating conditions;

to improve the working conditions of maintenance personnel since complete automation of compressor stations and a reduction of noise level are possible;

to reduce significantly the need for drive units by reducing the number of standby units and of increasing their service life: 15 years for electric units and 10 years for gas turbine units. Two electric drive or 3 gas drive units are required to provide a gas pipeline service life of 30 years. Moreover, reducing the self-needs for gas by almost 30 percent makes it possible during a design of a gas pipeline for electric drives and fixed commercial gas delivery to reduce somewhat the number of compressor stations and additionally to reduce the number of units;

more high-quality fuel, which can be used as raw material for the chemical industry or as a fuel for high-temperature production processes where its use yields an increased saving compared to its use as a fuel for electric power plants or gas turbines, can be conserved with electric drive with compressor stations powered from electric power plants operating on coal, hydroelectric power plants or nuclear power plants.

The national economic estimate of expenditures for gas fuel is decisive when making calculations to determine the effectiveness of electric and gas turbine drives.

Based on prospects for development of gas pipeline transportation as part of the country's fuel-energy complex when selecting the drive of compressor stations, one must take into account:

the actual expenditures for gas delivery with regard to production and transportation from newly involved fields of Arctic regions;

the consumer's saving when replacing the gas released at compressor stations and the capability of using it by highly qualified consumers.

Calculations made for these conditions show that a gas drive can be more feasibly used near high-yield fields and an electric drive can be used in regions where electric power can be produced from inexpensive local fuel, for example, Ekibastuz coal, and also in regions where there are large hydroelectric and nuclear power plants and high-voltage systems capable of providing the electric drive with power.

An obstacle to extensive distribution of an electric drive is the high capital investments for construction of an electric power plant and other energy supply facilities. When selecting the type of drive, one must obviously compare them with regard to the specific conditions of the construction region. One must take into account in this case that wider use of a drive that provides high efficiency and that operates on electric power generated from the least scarce and qualified fuel is desirable to improve the country's energy balance and moreover a significantly greater saving can be achieved by increasing the unit output of the units of electric power plants and pumping stations.

4.5. Optimum Parameters of Major Gas Pipelines

When selecting the optimum parameters of gas pipelines, the numerous factors and primarily the capabilities of related sectors of industry that supply pipes and equipment must be taken into account. This factor is decisive in most cases. However, the main problem when selecting the parameters of gas pipelines is achieving the required gas supply with minimum reduced expenditures upon realization of all capabilities of related sectors of industry and import.

The graphs of variation of specific reduced expenditures for gas pipelines from 720 to 1,620 mm in diameter are given in Figure 4.6 as a function of the realizable productivity (carrying capacity).

The specific expenditures were calculated on the basis of a 30-year service life of the gas pipeline, uniform gas supply at mean load factor of 0.90, at working pressure of 56 and 75 kgf/cm^2 and coefficients of the effectiveness of capital investments of 0.10 and 0.15; the expenditures for fuel are calculated from prices of "closing fuel" for the country's central regions.

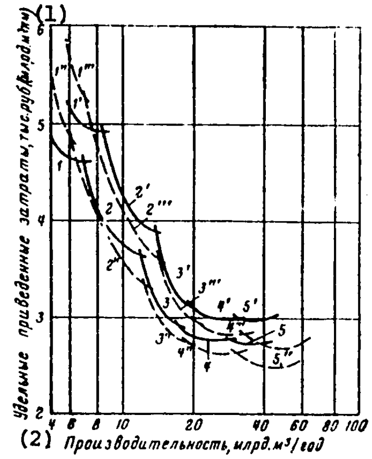


Figure 4.6. Zones of Application of Gas Pipelines 820, 1,020, 1,220 and 1,420 mm in Diameter: 1, 2, 3, 4 and 5--for the indicated diameters at E_n = 0.12 and for average conditions; 1', 2', 3', 4' and 5'--for indicated diameters for Arctic conditions; 1", 2", 3", 4" and 5"--for the indicated diameters at E_n = = 0.15 and for average conditions; 1"', 2"', 3"', 4"' and 5"' --for the indicated diameters for Arctic conditions

Analysis of the results permits one to primarily advance a number of concepts on the parameters of long-distance major gas pipelines.

1. Specific transportation expenses are reduced with an increase of pipeline diameter. The reduction is very significant for pipes up to 1,020 mm in diameter, there is a reduction for large-diameter pipes of smaller dimensions, but it also occurs for pipes greater than 1,420 mm in diameter; if the gas pipeline diameter increases from 1,020 to 1,220 mm, the reduced expenditures decrease by 12-15 percent, if diameter increases from 1,220 to 1,420 mm, the expenditures decrease by 10-12 percent and if the diameter increases from 1,420 to 1,620 mm, expenditures decrease by 5-8 percent.

The indicators for pipes 1,620 mm in diameter are conditional to a significant degree. They were obtained while maintaining the organization of work of welding and laying them in the trench, now adopted for pipe up to 1,420 mm in diameter without regard to expenditures for re-equipping of the construction base. Pipes are welded on the edge of the trench and the welded lengths are lowered into the trench with an increased layer of pipe layers used in construction of pipelines 1,420 mm in diameter. This organization of work provides for flexing of the already welded and insulated pipe when it is lowered into the trench. This operation is sharply complicated with an increase of pipe diameter since the flexibility of pipe is proportional to diameter to the fourth power. Consequently, laying pipe 1,620 mm in diameter into the trench requires an approximately 65 percent increase of bending forces. An increase of pipe diameter may require total re-equipping of the construction equipment and a change of the construction technology with laying individual pipe sections into the trench and welding and insulation of the seams in the trench. The use of pipes 1,620 mm in diameter requires careful engineering and economic analysis with regard to specific conditions of delivery of more powerful construction equipment. Moreover, the buoyant force is increased considerably with pipes 1,620 mm in diameter and additional expenditures on weighting compared to smaller diameter pipes are required to ensure the stability of their positions in swamps in flooded soil.

The basic direction for increasing unit productivity in the near future is the use of pipes 1,420 mm in diameter with cooling of the gas being transported and with an increase of pressure.

2. An increase of working pressure from 56 to 75 kgf/cm^2 leads to an increase of the optimum pipeline productivity with similar fixed parameters approximately in proportion to the variation of pressure. An increase of pressure above the indicated value, for example, to 120 kgf/cm^2, leads to a further increase of productivity and improvement of engineering and economic indicators.

Organization of multilayer pipe production is required to develop high-pressure gas pipelines (up to 120 kgf/cm^2).

3. Optimum productivity depends on the coefficient of the effectiveness of capital investments, working pressure and construction conditions (coefficients of an increase of construction costs and operation of the line part and of compressor stations). Thus, the productivity of a gas pipeline 1,020 mm in diameter at pressure of 56 kgf/cm^2 in the median zone of the European USSR can be brought up to 12 billion m^3/year or more, while the minimum reduced expenditures are reflected at 7.5-8 billion m^3/year with coefficient of the effectiveness of capital investments of 0.1 and 8-9 billion m^3 with coefficient of 0.15. The figures are 16-18 and 18-20 billion m^3/year, respectively, for a pipeline 1,220 mm in diameter.

The minimum reduced expenditures for a pipeline 1,420 mm in diameter is at the level of 27-28 and 29-31 billion m^3/year, respectively, in the central regions of the European USSR at pressure of 75 kgf/cm^2 with 130-140 km between compressor stations and compression ratio of 1.45-1.50. These calculations were obtained from conditions of minimum expenditures throughout the sector of the gas industry. Accelerated utilization of gas pipeline hardware is desirable in order to produce a large quantity of gas and to thus provide an increased saving from efficient use of gas in sectors where it yields a high national economic saving, i.e., with the gas pipeline productivity achieved at higher coefficient of the effectiveness of capital investments.

4. The optimum productivity of major gas pipelines depends to a significant degree on the time utilization factor. Gas pipelines are usually designed with a load factor of 0.9. However, despite the presence of regulator consumers, in practice major gas pipelines rarely achieve a productivity utilization factor of more than 0.80-0.82. An increase of the utilization factor of carrying capacity of long gas pipelines is a very effective measure since only energy expenditures decrease with a decrease of load.

Development of gas depots in consumer regions, the use of gas during the summer season by consumers supplied with another type of fuel for the winter season and implementation of other measures to improve the structure of the fuel and energy balance toward full loading of long major gas pipelines permit one to count on an increase of the productivity utilization factor of major gas pipelines, for example, to 0.5, i.e., to the level essentially possible according to repair and maintenace conditions.

Achieving this indicator will make it possible to bring the carrying capacity of a pipeline 1,420 mm in diameter at working pressure of 75 kgf/cm^2 up to 32-34 billion m^3/year and to decrease the reduced expenditures for gas transportation by 15-16 percent without increasing the need for metal and equipment to construct gas pipelines.

5. The indicators given in the graph in Figure 4.6 were obtained for construction of gas pipelines in the central regions of the European USSR.

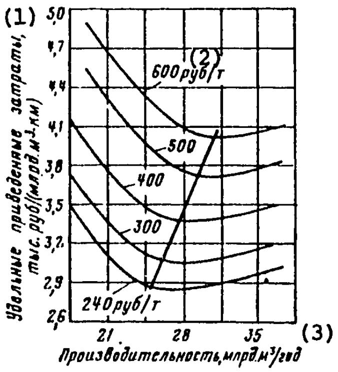


Figure 4.7. Dependence of Optimum Productivity of Gas Pipeline 1,420 mm in Diameter on Prices for Pipe

Key:
1. Specific reduced expenditures, thousand rubles/(billion m^3·km)
2. Rubles/ton
3. Productivity, billion m^3/year

the increase of pipeline construction and operating costs under the less favorable conditions of the Western Siberian lowland or in Arctic regions of the European USSR is 2-2.5-fold.

On the other hand, expenditures for fuel gas in these regions are minimum since gas is a local fuel. These relations lead to the fact that it is economically feasible to permit accelerated operation of expensive gas pipeline structures with increased fuel consumption. As a result of calculations for Arctic regions, the minimum reduced expenditures occur with gas pipeline load at the level of 32.0-34.0 billion m^3/year for a pipeline 1,420 mm in diameter at working pressure of 75 kgf/cm^2 and at capacity utilization factor of 0.9 in time.

6. The prices for pipe and consequently expenditures for construction of the line part of the gas pipeline, expenditures for compressor stations and primarily expenditures for fuel gas or electric power and the level of mechanization and consequently expenditures for wages have an important effect on the optimum productivity of a gas pipeline and the disposition of compressor stations. The dependence of reduced expenditures on prices for pipe and consequently the cost of the line part of the gas pipeline are presented in Figure 4.7.

As can be seen, the optimum productivity is increased from approximately 26.0-27.0 to 31.0-32.0 billion m^3/year, i.e., by almost 20 percent, with an increase in the cost of pipe from 240 rubles per ton to 600 rubles per ton. The optimum distance between compressor stations is thus reduced from aprpoximately 150 to 95-100 km, while the compression ratio can be reduced from 1.48 to 1.35.

Analysis of the main factors affecting the engineering and economic indicators of major pipelines (pipe diameter, working pressure, utilization factor, construction conditions, prices for pipe and other factors) showed that accelerated use of gas pipelines and bringing their productivity up to 32-34 billion m^3/year, for example, for pipes 1,420 mm in diameter at working pressure of 75 kgf/cm^2 are feasible for further development of gas transportation.

The engineering and economic indicators of major gas pipelines for the current five-year plan, including bringing the average annual load factor up to 0.95 and cooling the gas to soil temperature, are presented in Table 4.19.

4.6. Further Improvement of Major Gas Pipeline Parameters

Assimilation of increasing volumes from the northern regions of Tyumenskaya Oblast to the European USSR with existing transportation equipment and technology can be achieved by laying a greater number of pipelines with high metal expenditures and capital investments.

The main purpose of scientific and technical progress in pipeline transport is to increase the unit capacity of gas pipelines and to reduce metal expenditures, energy expenditures and reduced expenditures for gas transportation.

In this case the effectiveness of the traditional method--an increase of gas pipeline carrying capacity by using larger diameter pipes--is reduced as the diameter

Table 4.19.

(1) Показатели	(2) Центральные районы страны		(3) Северные районы страны	
	1220 мм	1420 мм	1220 мм	1420 мм
Пропускная способность, млрд. $м^3$/год (4)	19—20	31—32	21—23	32—34
Металлозатраты (предел прочности (5) 65 кгс/$мм^2$), т/(млрд. $м^3$·км)	19,5	18,1	17,8	16,5
Энергозатраты, тыс. кВт·ч/(млрд. $м^3$·км) (6)	180	152	158	142
Капиталовложения, тыс. руб/(млрд. $м^3$·км) (7)	16,8	14,7	29,5	28,4
Эксплуатационные затраты, (8) тыс. руб/(млрд. $м^3$·км)	1,45	1,23	2,5	2,0
Приведенные затраты, тыс. руб/(млрд. $м^3$·км) (9)	3,47	3,00	6,04	5,52

Key:

1. Indicators
2. Central regions of country
3. Northern regions of country
4. Carrying capacity, billion m^3/year
5. Metal expenditures (ultimate strength of 65 kgf/mm^2), tons/(billion m^3·km)
6. Energy expenditures, thousand kW•hr/(billion m^3·km)
7. Capital investments, thousand rubles/(billion m^3·km)
8. Operating expenses, thousand rubles/(billion m^3·km)
9. Reduced expenditures, thousand rubles/(billion m^3·km)

increases, i.e., the generatrix of the optimum parameter is always an exponent whose gradient decreases as diameter increases and is dependent on the engineering and economic indicators of the means of transportation, construction conditions and so on.

Conversion to pipes 1,620 mm in diameter requires replacement of equipment for manufacture of large-diameter pipes and supplying construction organizations with the necessary equipment.

Some machine tools installed in the pipe shops of Soviet plants have already been designed to produce pipes 1,620 mm in diameter, by which prerequisites have been created for conversion to these diameter pipes with minimum expenditures for reequipping.

The feasibility of replacing construction equipment for laying pipes 1,620 mm in diameter should be determined as a result of extensive investigations.

The problem of producing multilayer pipes 1,420 mm in diameter merits special attention, which would provide the possibility of producing pipes designed for high pressure, for example, 120 kgf/cm^2, with relatively moderate requirements on steel quality.

As is known, the productivity of gas pipelines of any diameter can be increased by increasing the pressure and by reducing the temperature, i.e., by increasing the density of the gas being pumped. The main thing in this case is selection of those temperatures and pressures at which each variation of the indicated parameters would most effectively increase the carrying capacity of gas pipelines. Investigations showed that this zone can be determined by studying the physical principles of gas motion in pipelines.

Table 4.20.

(1) Температура перекачки, °C	(2) Увеличение пропускной способности, %, при увеличении давления, кгс/см²					Температура перекачки, °C	Увеличение пропускной способности, %, при увеличении давления, кгс/см²				
	75	100	120	160	200		75	100	120	160	200
+50	100	128	161	214	260	—20	100	131	169	235	275
+30	100	134	166	218	265	—30	100	139	172	214	268
0	100	131	158	240	268	—70	100	130	148	175	195
—15	200	130	168	228	268						

Key:

1. Pumping temperature, °C
2. Increase of carrying capacity, percent, with increase of pressure, kgf/cm^2

An increase of pressure is not reflected identically in an increase of gas pipeline carrying capacity (Table 4.20). Thus, conversion to a pressure of 100 kgf/cm^2 is most effective at a temperature of -30°C, an increase to pressure of 120 kgf/cm^2 is most effective at -15 to -30°C, an increase to pressure of 160 kgf/cm^2 is most effective at 0°C and so on. In this case conversion from pressure of 75 to 100 kgf/cm^2 is characterized by an increase of productivity for corresponding temperatures of 28, 34, 31, 30, 31, 39 and 30 percent.

Conversion from pressure of 100 to 120 kgf/cm^2 yields an increase of productivity by 33, 32, 29, 38, 38 and 18 percent. This is explained by the fact that the state of the gas varies with variation of temperature and pressure. One of the characteristics of the state of gas is the compressability factor. Its variation due to pressure at different temperatures for gas of the Urengoy field is presented in Figure 4.8. Zone 1 of parameters at which gas pipelines now operate is also presented in this figure and zone 2 of the greatest increase of gas pipeline carrying capacity with variation of pressure and temperature parameters is also determined.

Final determination of parameters depends on energy expenditures, the cost of hardware, especially of insulation, construction conditions and so on.

Multivariant optimization calculations for different pressures and degrees of cooling of gas were made to estimate different parameters:

plus 30°C--cooling by air-cooling equipment;

0°C--pipelines of carbon steel of all marks (they can operate without insulation);

minus 20-30°C--heat insulated pipelines of carbon and low alloy steels with regard to requirements on impact strength;

minus 60-70°C--heat insulated pipelines of alloyed steels operating on the boundary of the gaseous state.

Selection of the indicated cooling levels is explained mainly by the phases of possible development of related sectors of industry producing the pipes and insulation pipes and also by the capabilities of construction and operation.

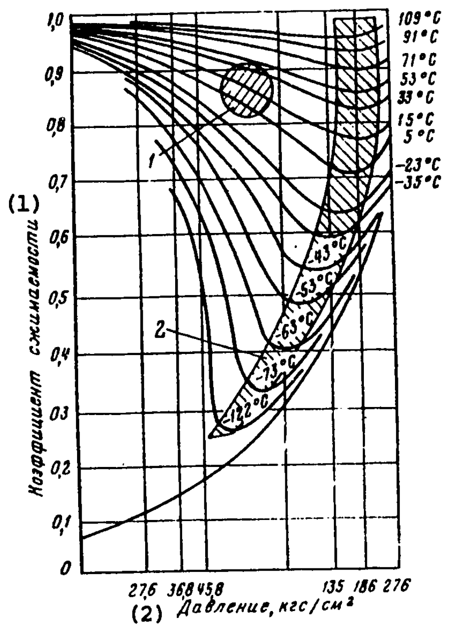


Figure 4.8. Dependence of Gas Compressibility Factor on Pressure and Temperature: 1--parameters of existing and planned gas pipelines; 2--zone of most effective increase of gas pipeline productivity with increase of pressure

Key:
1. Compressibility factor
2. Pressure, kgf/cm^2

Cooling the gas to 30°C and lower to 0°C is the main problem for improving gas pipeline parameters. Investigation of problems of deeper cooling to 20-30 or 60-70°C is of important significance for the future.

Optimization problems were resolved for each of the versions of gas transportation and in this case productivity, working pressure, the compression ratio and pipeline diameters varied. As a result the optimum productivity and optimum pressures for pipelines of different diameters were determined. The already selected optimum versions were then compared at different temperatures. As a result values of optimum productivity of pipelines of different diameters and optimum values of working pressure and temperature were found.

Consideration of the dependence of the main engineering and economic indicators on cooling temperature and pressure leads to the following conclusions.

The least metal consumption occurs at temperature of -70°C. An increase of pressure at this temperature above 100 kgf/cm^2 leads to an increase of metal. The minimum need for metal occurs at pressure of 120 kgf/cm^2 for temperatures of 0°C and -30°C.

The industrial output of pipe which can operate at temperature to -20-30°C can be considered realistically at established prices and requirements on pipe quality. Thus, by reducing gas pumping temperature to 20-30°C, one can increase the carrying capacity of a gas pipeline by 40-50 percent with moderate cooling without a significant increase of prices for pipe. Accordingly, one should anticipate a significant saving of the specific cost of pipe with a simultaneous decrease of pumping temperature and an increase of pressure.

The specific expenditures for compression of natural gas at different temperatures are presented in Figure 4.9. As can be seen, they decrease with a reduction of gas temperature. Under specific conditions, energy expenditures are lower with cooling than expenditures for pumping uncooled gas.

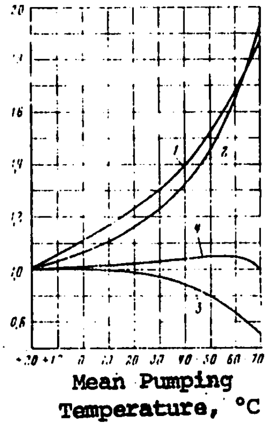


Figure 4.9. Relative Specific Energy Expenditures for Compression and Cooling of Gas During Transportation Through a Pipeline 1,420 mm in Diameter (with respect to expenditures at 20°C): 1--productivity at pressure of 100 kgf/cm^2; 2--productivity at 75 kgf/cm^2; 3--energy consumption at 100 kgf/cm^2; 4--energy consumption at 75 kgf/cm^2

Table 4.21.

(1) Показатели	+30°C	0	0	0	—30°C	—30°C	—30°C	—70°C	—70°C
Давление, кгс/см² (2)	75	75	100	120	75	100	120	75	100
Пропускная способность, млрд. м³/год (3)	32	35	47	57	40	56	68	60	81
Временное сопротивление (4) металла труб, кгс/мм²	57	57	65	65	57	65	65	65	70
Металлозатраты, (5) т/(млрд. м³·км)	18,1	16,5	14,5	14,2	14,5	12,1	11,9	13,6	11,9
Энергозатраты, тыс. кВт·ч/(млрд. м³×км) (6)	120	132	130	129	120	110	110	100	100
					Северные районы (7)				
Капиталовложения, (8) тыс. руб/(млрд. м³×км)	24,86	22,92	18,78	15,56	17,90	17,76	18,22	23,74	24,4
Эксплуатационные затраты, тыс. руб/(млрд. м³·км) (9)	3,26	3,30	2,99	2,92	2,90	2,64	2,64	2,88	2,8
Приведенные затраты, (10) тыс. руб/(млрд. м³×км)	6,24	6,05	5,24	5,14	5,05	4,77	4,83	5,73	5,80
					Центральные районы (11)				
Капиталовложения, тыс. руб/(млрд. м³×км)	12,43	11,46	9,39	9,28	8,95	8,88	9,11	11,87	12,2
Эксплуатационные затраты, тыс. руб/(млрд. м³·км)	2,25	2,37	2,20	2,21	2,11	1,90	1,90	1,94	1,9
Приведенные затраты, тыс. руб/(млрд. м³·км)	3,74	3,72	3,33	3,31	3,18	2,97	2,99	3,36	3,4

Key:
1. Indicators
2. Pressure, kgf/cm^2
3. Carrying capacity, billion m^3/year
4. Ultimate resistance of pipe metal, kgf/mm^2
5. Metal expenditures, tons/(billion m^3·km)
6. Energy expenditures, thousand kW·hr/(billion m^3·km)
7. Northern regions
8. Capital investments, thousand rubles/(billion m^3·km)
9. Operating expenses, thousand rubles/(billion m^3·km)
10. Reduced expenditures, thousand rubles/(billion m^3·km)
11. Central regions

The main engineering and economic indicators of gas transportation through pipes 1,420 mm in diameter are presented as an example in Table 4.21.

It follows from the data of Table 4.21 that the most favorable economic and other results, according to the authors' calculations, are provided by cooling to -20-30°C and the indicators (reduced expenditures) compared to systems operating without cooling even at increased pressure (120 kgf/cm^2) are reduced by 14-16 percent, and are reduced to 15-20 percent compared to indicators with cooling to -70°C [89].

The decisive factor here is an increase of steel costs [34,46], complication of insulation and of all equipment of compressor-cooling stations; therefore, detailed development of equipment for the indicated parameters and comparison of them for all indicators, including expenditures for supplying with construction equipment, maintenance of the ecological balance and other factors, are required. The resulting integrators of a system at 0°C are also inferior to indicators with moderate cooling. However, it can be achieved considerably more rapidly. This is explained mainly by the fact that system with cooling to 20-30°C completely utilizes the capabilities of already developed marks of steels and conversion to this level of cooling causes no fundamental change of requirements on the quality of pipe metal and equipment, but it requires additional expenditures to insulate the pipelines.

Pipelines, gas-pumping units, cooling units, insulation and other equipment must be developed to achieve the optimum gas transportation parameters. The possibility of using heat-strengthened pipes to pressure of 75 kgf/cm^2 and temperature to -20°C causes no problems and these pipes can be delivered even during the 10th Five-Year Plan. Conversion to production of multilayer pipes for pressure up to 120 kgf/cm^2 has laready been resolved.

Steam-compression cooling units based on propane pipe-cooling units can be used for cooling to 20-30°C at main and intermediate compressor stations. The designs of these units for relatively lower productivity have been developed and are used extensively. Recovery cooling systems may also be installed at intermediate stations. Both versions of cooling are similar to each other in energy expenditures.

A temperature of -70°C requires development of special pipes and new cooling units and in this case the steam-compression units are low-power, while cryogenic units are high-power. New pumping units must also be developed to transport gas at -70°C.

Thus, gas transportation systems with gas being cooled to temperatures of -20-30°C can be developed.

The development of experimental-industrial units for the considered gas parameters to work out an insulation design, to develop a method of work organization for laying heat-insulated pipelines and also development of moderate and deep cooling of gas are required as the next phase in improving the major gas transport system with improved engineering and economic parameters.

4.7. Regulation and Reservation of Gas-Supply Systems

Outside air temperature is related to the most significant factors affecting irregular gas consumption. The degree of the effect of climatic conditions on variation of gas needs is determined to a significant degree by the fraction of consumption for heating and domestic purposes. A reduction of use at production enterprises during weekends and holidays has an important effect on the irregularity of gas consumption.

The annual fluctuations of fuel consumption and deviations of consumption from the mean perennial fuel (gas) consumption, which is usually taken as a basis by planning and design organizations, must be taken into account when developing the country's energy balance or that of individual economic regions. A fuel and capacity reserve should be provided for the onset of a cold year for uninterrupted fuel supply to consumers.

The increasing requirements on the quality and reliability of the fuel supply have posed the problem of optimum regulation and reservation of a unified gas-supply system and other fuel-energy systems to the national economy, i.e., the need to create fuel reserves optimum in quantity, structure, quality and territorial disposition and capacity reserves in the country's fuel-energy system as a whole and also the need to select optimum methods of regulating them.

Problems of long-term, short-term and operational regulation and reservation of the development and operation of fuel and energy sectors with optimum relationship of them to each other are an important independent national economic problem that requires extensive investigations and improvement of both the structure of individual systems and management of the country's fuel and energy complex as a whole. Only general problems of regulation and reservation that concern the gas-supplying country, related to gas transportation and storage, are considered below.

The reserves in gas-supply systems must be divided into national economic and operational reserves.

National economic reserves are used to cover the possible above-plan load formed due to fulfillment of the plan by industry and construction ahead of schedule and also to compensate for the uncertainty of input data used in planning. The scope of the national economic reserve should be substantiated in plans on the basis of designation. If there are no adequate input data with regard to the enormous scales of production of fuel and energy resources, the scope of the national economic reserve is taken in the range of 4-6 percent of the maximum gas needs of a region. The reserve given above is based on the following approximate estimates. The error of input data with medium-term planning of development and design of components of a unified gas-supply system does not exceed 3-4 percent as a whole. Possible overfulfillment of the plan by industrial enterprises and construction is 1-2 percent. No stricter quantitative method of estimating national economic reserves is now known.

The operational reserves in different elements of the system must be divided into emergency, repair and load. The different types of reserves are not independent; therefore, detailed analysis of their interaction is required when substantiating operational reserves in different elements. Thus, a free repair reserve can be used as an emergency reserve. In turn, an emergency reserve can be used as a load reserve and so on. The operating period of a gas-supply system with incomplete load can be used to carry out planned-preventive maintenance of individual components. The following method can be used to substantiate the load reserve. Based on analysis of operational data over a number of years (for periods of maximum winter loads), graphs of the deviation of the actual load of the gas-supply system from the planned system must be produced. Statistical processing of these graphs yields the frequency of appearance of a given deviation of actual load from planned load. The data can be used to plot the graph of the dependence of random excess of load compared to planned load on the probability that this excess will appear. Areas of probable excesses of actual load compared to planned load will be found on the plotted graph and the maximum excess load above calculated load will be determined from them. The load reserve should be selected so that the maximum probable random excess of load compared to planned load is covered. The load reserve may be determined at the rate of 1-2 percent of maximum daily load in the absence of adequate input information. The storage capacity of the last line section of a major gas pipeline system can be used as one of the sources of providing a load reserve. If the storage capacity of a section is inadequate, acceleration of the operating modes of gas-pumping units and an increase in the number of reserve units above the needs dictated by conditions of providing an emergency and repair reserve may be utilized.

When considering problems of reservation and covering of irregularity in loads, the authors feel that one must proceed from the prerequisite of providing a maximum load of major long-distance pipelines in which the greater part of the basic funds and metal will be concentrated, and their operating indicators will determine the operating efficiency of the country's entire gas transportation system. The load of these major pipelines should be brought up to the maximum possible, while irregular gas consumption by consumers is made up by measures on regulation of gas consumption and storage implemented in the European regions, i.e., in the regions of consumption. With this postulation of the problem, the calculated load of long-range gas pipelines can be determined only by the operating reliability of these components and of the system as a whole.

The problem of utilizing the calculated carrying capacity up to 95 percent can be posed for multipipe systems equipped with connectors at compressor stations and for line connectors every 25-50 km. The most feasible load factor of gas pipelines, as indicated by calculations, is 0.94-0.96 at length of more than 2,000 km, 0.92-0.94 at 1,000-2,000 km, 0.85-0.87 at 500-1,000 km and 0.75-0.80 at less than 500 km. In the latter case the gas pipeline can be used as a booster regulator of irregular gas consumption.

The results of calculating the reduced expenditures for pipelines 1,020, 1,220 and 1,420 mm in diameter for conditions of northern and central regions of the country with calculated load factor of $K_1 = 0.82$ and $K_2 = 0.95$ are presented in Figure 4.10.

An increase of the load factor considerably improves the main engineering and economic indicators and optimum carrying capacities of pipelines. Thus, the primary problems for further development of the country's unified gas-supply system are creation of a storage system and implementation of other measures that provide coverage of irregular gas consumption at a high average annual level of use of major long-distance gas transportation pipelines.

Soviet and foreign experiments of developing gas depots and regulation of consumption confirms the feasibility of implementing the following measures:

a) a dual fuel economy;

b) development of underground gas depots located in different areas along the route of major gas pipelines;

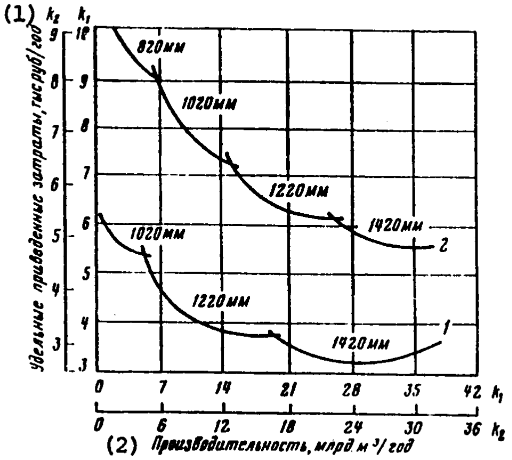


Figure 4.10. Zones of Application of Gas Pipelines 820, 1,020, 1,220 and 1,420 mm in Diameter with Output Utilization Factors of K_1 = = 0.85 and K_2 = 0.9: 1--for the central zone; 2--for northern conditions

Key:
1. Specific reduced expenditures, thousand rubles/year
2. Productivity, billion m³/year

c) development of isothermal liquefied methane and propane-butane depots;

d) use of regulator fields;

e) use of the storage capacity of line sections of major gas pipelines and acceleration of the operating modes of compressor stations (provided that the complex of production restrictions for long-range transportation of gas is observed).

A dual fuel economy as a source of reservation in the components of gas-supply systems should be understood as creation of solid or liquid fuel reserves for consumers operating on gas and use of them during increased gas consumption where production technology permits this.

The scope of expenditures to create reserve mazut, gas and coal depots is shown in Figure 4.11, from which it follows that coal storage is feasible as a reserve fuel. Since mazut consumption for the needs of power engineering is reduced with regard to a reduction of oil refining and an increase of the fraction of petroleum products as a raw material for the chemical industry, if there are surpluses of gas reserves, they can be used at coal-fired electric power plants, for which storage warehouses of coal reserves accumulated during operation of electric power plants on gas must be developed. This scheme requires the least expenditures for fuel storage and has the greatest maneuverability under conditions of increased consumption of coal fuel at electric power plants. Creation of coal-gas electric power

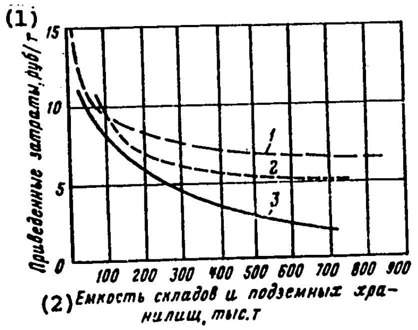


Figure 4.11. Expenditures for Development and Operation of Fuel Depots (in conditional calculation): 1--mazut; 2--gas; 3--coal

Key:
1. Reduced expenditures, rubles/ton
2. Capacity of warehouses and underground depots, thousand tons

plants with developed coal storage depots is feasible from the viewpoint of fuel transportation by rail and of equalizing the work of the coal-mining industry. Coal can be transported to the depots of electric power plants during decreased shipments of other freight.

Underground gas depots in water-bearing strata are the most promising types of gas depots for equalizing the production and consumption schedule. Development of depots and their disposition are limited by the presence of natural geological structures for this purpose which are not universally found. Underground gas depots are created along the gas pipeline route and in regions of gas consumption. Depleted oil and gas pools and also water-bearing strata can be used for underground depots. Underground storage usually includes wells and their casings, gas purification, drying and other pocessing plants, compressor stations and cushion and active gas.

Depots created on the basis of depleted gas fields are characterized by the best engineering and economic indicators since the well, the casing and the gas scrubbing and drying device are used and the expenditures for cushion gas are sometimes no longer required.

The specific reduced expenditures in underground gas depots in water-bearing strata are presented in Figure 4.12. As can be seen, they decrease with an increase of storage volume and increase with an increase of the maximum daily productivity. Thus, if the storage volume increases threefold, the engineering and economic indicators improve by 30 percent. The specific capital investments vary considerably with the depth of deposition of the bed and to a lesser degree on well yield. The distance from consumers has a significant effect on the engineering and economic indicators of depots.

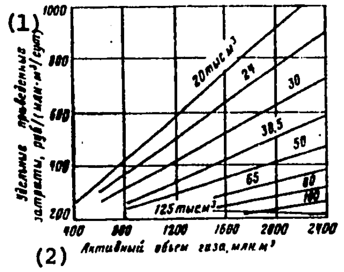


Figure 4.12. Specific Reduced Expenditures in Underground Gas Depots in Water-Bearing Strata as a Function of the Active Volume of Gas and the Maximum Daily Production

Key:
1. Specific reduced expenditures, rubles/(million·m^3/day)
2. Active volume of gas, million m^3

The use of a number of gas fields of the European USSR, located in mass consumption regions or having developed and now unutilized pipeline outlets, as regulators to compensate for a gas shortage during increased consumption is possible. No additional capital investments are required to equip these fields and a production schedule only during periods of increased gas consumption should be established for them. The unextracted gas remaining in the beds will be consumed during peak loads and its reserve will be sufficient for a considerably longer period than with uniform production over an entire year.

It is natural that major gas pipelines from remote fields should fully provide these regions with gas during a decrease of loads and cessation of gas production at regulator fields. The proposal to use the fields of the European USSR deserves the most serious intention under conditions of the rapid development of further gas transportation and the need for universal improvement of the recovery of basic stocks of long-distance gas pipelines.

Gas storage in salt domes is becoming widespread abroad. Gas storage in salt domes is achieved by dissolution of the salt by water pumped into the stratum and by pumping out the saline solution. Two pipes are usually lowered into the well for this; water is delivered to the stratum through the space around the pipe and the saline solution is pumped out throught the inner pipe.

The characteristics of a number of these gas depots are presented in Table 4.22 [61].

Liquefied gas depots have recently been constructed in the United States and Canada to compensate for irregular consumption. Depending on designation, two types of installations are being developed:

for propane-butane fractions which are used to provide short-term peak loads at relatively low gas consumption, primarily at points where domestic consumers are supplied with gas;

Table 4.22.

(1) Хранилище	(2) Глубина, м	(3) Толщина соляного пласта, м	(4) Размер каверны, тыс. м^3	(5) Предельное рабочее давление, кгс/см^2	(6) Полезный объем газа, $3\cdot10^6$ м^3
Мерисвилл (США) (7)	650	167	117	76—10	7,7
Мельвилл (Канада) (8)	1124	161	45	155—48	4,8
Реджина (Канада) (9)	1670	97	99×2×128	240	н. д.
Терсан (Франция) (10)	1400	130	95×125	255—80	13,8+18,1
Килс (ФРГ) (11)	1305	Соляной (13) купол	32	760—80	2,8
Ковингтон Коунти (США) (12)	1740	(13) То же	175×175	270—88	31,8—31,8

Key:

1. Depot
2. Depth, meters
3. Thickness of salt dome, meters
4. Dimensions of cavern, thousand m3
5. Maximum working pressure, kgf/cm^2
6. Useful gas volume, $3\cdot10^6$ m^3
7. Merisville (United States
8. Melville (Canada
9. Regina (Canada)
10. Tersan (France)
11. Kiels (West Germany)
12. Covington County (United States)
13. Salt dome

for liquefied natural gas--methane--with the gas being cooled to -163°C and stored in double-walled tanks similar to those used during transportation of gas in the liquefied state (see Section 4.8).

Pipelines, mainly delivery mainlines constructed with a high reserve of carrying capacity and used as reserve tanks to cover short-term peak loads in gas consumption, are frequently used as gas depots abroad. This method of supply regulation is economical when previously constructed pipelines are used.

Table 4.23.

(1) Хранилища	(2) Капиталовложения	(3) Амортизационные отчисления	(4) Текущие эксплуатационные издержки	(5) Суммарные ежегодные расходы
Каверны в соляных пластах (6)	100	100	100	100
Заглубленные трубы (7)	160	160	100	150
Магистраль резервного накопления (8)	180	180	—	150
Хранилище в виде скважин (9)	200	200	100	190

Key:

1. Depots
2. Capital investments
3. Depreciation deductions
4. Current operating expenses
5. Total annual expenses
6. Caverns in salt domes
7. Submerged pipes
8. Major reserve storage
9. Storage in wells

This method is used rather extensively in the gas transportation system of the USSR where part of previously constructed mainlines is not fully loaded and is essentially used as gas depot regulators.

Comparable indicators of gas depots of different types are presented in percent in Table 4.23.

4.8. Gas Transportation and Storage in the Liquefied State

Transportation and storage of natural gas (methane) in the liquefied state have become widespread in worldwide practice during the past few years. It is known that methane is converted to liquid at atmospheric pressure and at temperature of -162°C. It remains in liquid form to -82°C if the pressure is not lower than 47 kgf/cm^2. The density of liquefied gas is 425.5 kg/m^3. One cubic meter of liquefied gas is equivalent to 632 m^3 of gas at atmospheric pressure.

Aluminum or steel with nickel content of approximately 9 percent is used to manufacture tanks, pipelines and equipment for storage and transportation of liquefied gas. The cost of this steel, according to United States data, is 5.5-6.0 times higher than ordinary carbon steel. A vacuum is used in most cases as heat insulation. The tanks and pipelines are constructed with double walls between which a vacuum is created. The space between the walls is filled with insulating materials. Only the inner walls of the tanks are constructed from aluminum or steel with nickel content on the order of 9 percent with this design; the outer walls are constructed from ordinary carbon steel. There are cases of pipelines being constructed with insulation of different insulating materials without double walls and without creation of a vacuum between them. However, experience shows that preference is given to insulation with formation of a vacuum between the double walls of tanks.

Liquefied gas was first shipped from the United States to England in 1959 on the special ship "Methane Pioneer" and since 1964 a permanent system for shipment of liquefied gas from Algeria to England and France has begun to operate.

Operation of this system showed its reliability and the relatively favorable engineering and economic results that permit competition of the imported gas with other types of fuel. Moreover, the possibility of storing gas reserves in the liquefied state for a long time to cover the peak loads and also the possibility of developing pipelines for liquefied gas transportation were determined.

The use of liquefied gas is now being developed in worldwide practice in the following directions:

intercontinental shipments by special methane tankers;

intracontinental transportation of gas by motor and rail transportation;

development of liquefied gas depots to cover peak loads and to equalize the load of pipelines in the form of special installations or in combination with intercontinental or intracontinental gas transportation and also in combination with installations to extract the valuable components (helium, butane, ethane, propane and so on) from the natural gas.

The problem of intracontinental transportation of gas through pipelines is being studied in some countries.

The main industrially developed countries have been developing transportation of gas in the liquefied state during the past few years from developing countries at very rapid rates with regard to the high effectiveness of using natural gas for domestic purposes and also with regard to the sharp increase of oil prices.

Data on transcontinental liquid methane transport systems being operated, constructed and planned are presented in Table 4.24, but despite the development of these systems, a large shortage of gas is felt in the industrially developed countries. The gas shortage was estimated at 750 billion m^3 in 1980, of which 400 billion were in the United States, 190 billion were in Western European countries and 60 billion were in Japan; the shortage will reach 800 billion m^3 in 1985, of which 430 billion m^3 will occur in the United States.

Intensive development of a special tanker fleet, liquefaction plants, liquefied gas loading and unloading ports and storage and regasification bases was begun with regard to the indicated needs. The capacities of methane tankers have been increased continuously: the first methane tankers (1965) trasnported approximately 25,000 m^3 of gas in the liquefied state, tankers with capacity of 71,500 m^3 of gas were introduced in 1972, the capacity was 120,000 m^3 in 1975 and tankers with capacity up to 160,000 m^3 are now being designed. A total of 34 methane tankers were being operated in 1975 and it is expected that the number will reach 78-80 in 1980.

The capacity of liquefaction plants and the capacity of tank depots and individual tanks are increasing continuously. It is expected that the unit capacity of plants will reach 30-40 billion m^3 of gas annually. The unit capacity of tanks increased from 1,200 m^3 in 1965 to 35,000 m^3 in 1972. Tanks with capacity of 80,000 and 120,000 m^3 are being constructed. Gas receiving, storage and regasification bases are usually designed to cover peak loads, i.e., they are simultaneously warehouses that provide regulating functions for gas consumption of the country's adjacent regions.

It is difficult to talk about specific expenditures and other engineering and economic indicators of liquefied gas transportation with regard to inflation and the increase of gas prices.

The cost of liquefied natural gas in the United States, Japan and Western European countries showed its competitiveness compared to other types of fuel, which indicates the prospects of intercontinental gas transportation.

Shipments of liquefied methane by motor and rail transportation in the United States never became widespread and are essentially still in the stage of experimental industrial verification since methane shipments are considerably more complex than propane and butane shipments. Propane and butane are shipped by rail at any outside air temperatures at pressure of 16 and 7 kgf/cm^2, respectively.

The simplicity of the production process of transportation, storage, transfer to tanks and delivery of tanks to consumers led to the mass use of propane and butane as a domestic fuel both in the USSR and in other countries.

Table 4.24.

(1) Экспортер — импортер	(2) Начало поставок	(3) Количество газа, млн. м³/сут				(4) Срок контракта, лет
		1975	1976—1980	1981—1985	1986—1990	
Эксплуатируемые системы (5)						
(6) Алжир — Англия	1964	2,8	2,8	2,8	2,8	15
Алжир — Франция (7)	1965	1,4	1,4	1,4	1,4	15
Аляска — Япония (8)	1969	4,0	4,0	4,0	—	15
Ливия — Италия (9)	1971	6,7	6,7	6,7	6,7	20
Ливия — Испания (10)	1971	3,1	3,1	3,1	3,1	15
Алжир — США (11)	1971	1,1	3,4	3,4	3,4	20
Алжир — Франция (12)	1972	10	10	10	10	15
Бруней — Япония (13)	1972	15	21,5	21,5	21,5	20
Всего (14)		41,1	52,9	52,9	48,9	
Сооружаемые системы (15)						
Алжир — США	1977	—	28	28	28	25
Абу-Даби — Япония (16)	1976	—	9	9	9	20
Индонезия — Япония (17)	1979	—	28	28	28	20
Всего			65	65	65	
(18) *Планируемые системы*						
Аляска — Зап. побережье США (19)	1976	—	1,1	1,1	1,1	10
Алжир — США (11)	1981	—	—	17,4	17,4	22
Саравак — Япония (20)	1981	—	—	21,4	21,4	20
Алжир — США (11)	1981	—	—	28,3	28,3	25
Индонезия — США (21)	1979	—	15,6	15,6	15,6	20
Алжир — США (11)	1981	—	—	12,7	12,7	20
Алжир — Испания (22)	1981	—	—	17,0	17,0	—
Всего			16,7	126,2	126,2	—

Key:

1. Exporter-importer
2. Beginning of deliveries
3. Amount of gas, million m³/day
4. Life of contract, years
5. Operating systems
6. Algeria-England
7. Algeria-France
8. Alaska-Japan
9. Libya-Italy
10. Libya-Spain
11. Algeria-United States
12. Algeria-France
13. Brunei-Japan
14. Total
15. Systems under construction
16. Abu-Dabi— Japan
17. Indonesia-Japan
18. Planned systems
19. Alaska-West coast of United States
20. Sarawak-Japan
21. Indonesia-United States
22. Algeria-Spain

Tank trucks with capacity of 5, 10 and 36 m^3 are used to ship liquefied gas in West Germany.

Tank trucks with capacity of 13.5 and 22.5 m^3 with two-wall tanks and perlite insulation under vacuum between walls are used in the United States for experimental shipments of liquefied methane between New Jersey and Birmingham.

Experimental shipments of liquefied methane for a distance of 2,400 km showed that motor transport may be economically effective for supplying small consumers remote from gas transport mainlines if there are liquefied gas depots.

A tank truck with capacity of 121 m^3 and load capacity of approximately 51.6 tons (which is equivalent to 75,000 m^3 of gas) has been developed in the United States to ship liquefied methane by rail. The tank is double walled, the inner tank is made of stainless steel and the outer tank is made of ordinary carbon steel. The space between them is filled with perlite insulation under vacuum.

The expenses for shipping 28.3 m^3 (1,100 gallons) of liquefied methane by rail over a distance of 800 km are approximately 30 dollars, the cost is 46-47 dollars for 1,600 km, 15 dollars for 160 km by motor transport, 27 dollars for 200 km and 48 dollars for 480 km. However, expenditures for rail and motor shipment are in the range of 240-320 km.

Liquefied natural gas shipments in rail tank cars may be compared to gas pipeline transport for the Soviet Union. If the same engineering solutions as adopted in American practice are taken, we find that a gas pipeline can be constructed for a distance of 500-600 km with gas needs of 1-1.5 billion m^3/year and it is more economical to trasnport gas in rail tank cars over a greater distance. Rail shipment over a distance of more than 300-500 km is feasible with gas needs of 0.5 billion m^3/year.

Supplying gas by rail transport in the USSR may be promising only for small consumers remote from gas mainlines where construction of a gas pipeline is inefficient due to the great distances and low needs for gas.

The feasibility of organizing rail shipment of liquefied gas should be considered with regard to the balance of byproduct gas (propone, butane). Propane and butane are transported by rail simpler and with lower expenses than liquefied methane.

Taking into account the heat-producing capacity of liquefied gas, it is more effective to ship it in tank cars than any other fuel: the heat-producing capacity of liquefied gas is 12,000 kcal/kg (that of oil is 10,000-10,200 and that of coal is 4,000-7,000 kcal/kg). Comparison of the engineering and economic indicators of gas pipeline trasnport and transportation of liquefied gas by large-capacity aircraft showed the high effectiveness of gas pipeline trasnport (thus, the capital investments are one-third as much and operating expenses are one-twelfth as much). Air transportation is also less efficient compared to intercontinental shipment by maritime transport.

Pipelines for liquefied methane operate at short distances, mainly only within liquefaction plants, ports and regasification plants. Development of pipelines for pumping natural gas in the liquefied state over great distances encounters significant difficulties: the need for reliable heat insulation of the pipes, compensation for the very significant temperature deformations due to the high temperature drop, the need for intermediate cooling of the gas during trasnportation and so on. One should bear in mind the high cost of steel or aluminum for pipes operating at low temperatures.

A plan for pipeline transport of liquefied gas over pipes 914 mm in diameter has been developed in the United States. Comparison of the engineering and economic indicators of methane transportation by pipeline in the gaseous and liquefied state yielded results unfavorable for liquefied gas. The effectiveness of gas trasnport in the gaseous state compared to pumping in the liquefied state will be even higher, especially upon conversion to gas pipeline parameters with increased pressure up to 120 kgf/cm^2 and moderate cooling.

However, development of liquefaction technology, development of new synthetic materials and less expensive steels suitable for working at low temperatures may change the results of comparing the transportation of methane in the gaseous and liquefied state. With further development of this problem, one cannot help but take into account that the influx of liquefied gas to the consuming region creates conditions for reservation and covering peak loads and that intermediate parameters can be selected, i.e., the gas can be pumped at temperatures considerably higher than -162°C, but at pressure that provides pumping of it in the liquid phase.

So-called satellite liquefied gas stations, which are regasification plants to which gas is delivered by rail or motor transport, are beginning to become widespread in the United States. These stations are designed to supply consumers in regions having no systems or to cover peak loads where the systems do not have adequate carrying capacity.

Finally, systems are being developed and operated which consist of transportation equipment that includes not only tanks for shipment of liquefied gas but also regasification equipment. These plants are used for temporary supply of consumers with gas, for example, during emergencies of gas pipelines, a delay in startup of gas pipelines and in other similar cases.

Chapter 5. Pipeline Transport of Oil

5.1. Development of Pipeline Transport of Oil in the USSR and Abroad

Discovery of oil fields in the Volga-Urals region, on the Mangyshlak Peninsula and in the Central Ob' region and the rapid growth of oil production and changes in the disposition of the petroleum refining industry in the USSR had a decisive influence on the rates of oil pipeline construction in the Soviet Union and on their parameters [2, 12, 35].

Oil production (including gas condensate production) increased from 70.1 to 490.1 million tons from 1955 to 1975 and will reach 620-640 million tons in 1980, whereas the center of gravity of production has shifted from the southern regions (the Caucasus and Transcaucasus) to the Volga-Urals region and then to the Central Ob' region of Tyumenskaya Oblast. There has also been a shift of petroleum refining plants from oil producing regions to consuming regions and whereas oil refining was previously concentrated in oil producing regions and petroleum products were transported to consumers, oil refining plants were constructed during the later period in consuming regions with delivery of oil to them primarily by pipelines. New plants were constructed in Western and Eastern Siberia, in the central regions of the country, in the Ukraine and in Belorussia. The capacity of plants located in producing regions was usually not increased.

The development of pipeline transport is based on the principles of converting them to mainlines: concentration of oil volumes, an increase of pipeline diameter and productivity and laying parallel pipes. These principles predetermined the high engineering and economic indicators of pipeline transport of oil.

The parameters of oil pipelines under construction increased according to the increase in the volume of transported oil and the pumping distance and the scales of pipeline construction increased: thus, whereas 3,200 km of oil and petroleum product pipelines were constructed during the period 1966-1970, 15,900 km were constructed during the period 1971-1975 [30]. At the same time the oil pipeline parameters increased: whereas the maximum pipeline diameter was 1,020 mm in 1971-1975 with carrying capacity two times higher than pipelines 820 mm in diameter, pipelines 1,220 mm in diameter with carrying capacity two times higher than pipelines 1,020 mm in diameter were mainly constructed during the period 1975-1980.

The main indicators of pipeline transport of oil and petroleum products are presented in Table 5.1. It must be noted that the length of the petroleum product pipeline system comprises approximately 20 percent of the total length of oil and petroleum product pipelines, while the freight turnover performed by them comprises only about 5.0 percent, while the remaining part falls to oil transport.

Table 5.1.

(1) Показатели	1965	1970	1975
Объем перекачки, млн. т/год (2)	225,7	339,9	497,6
Протяженность, тыс. км (3).	28,2	37,4	56,9
Грузооборот, млрд. т·км (4)	146,7	281,7	665,8
Грузонапряженность, млн. т·км/км (5). . .	5,20	7,53	11,50
Средняя дальность транспортировки, км (6).	650	828	1338

Key:

1. Indicators
2. Pumping volume, million tons/year
3. Length, thousand km
4. Freight turnover, billion tons·km
5. Freight intensity, million tons·km/km
6. Average transportation distance, km

The rapid development of oil pipeline transport is explained primarily by better engineering and economic indicators compared to rail transport. Thus, the cost of pipeline transport of oil comprised about 0.95 kopeck per 10 tons·km compared to 2.48 kopecks on the average for all freight in rail transport during the past few years. Less than 10 percent of oil is transported by rail and partially by river transport, primarily in those cases when there are small oil volumes and construction of pipelines is inefficient.

Several large pipeline systems of great length having no equal in the world have been developed in the Soviet Union. The first large pipeline system for oil transport is the Druzhba oil pipeline, constructed in 1960-1964 through the joint efforts of CEMA member countries: the Soviet Union, Poland, East Germany, Czechoslovakia and Hungary. The oil pipeline was constructed to provide East European countries and a number of oil refining plants of the western Soviet Union with oil from the Volga-Urals fields at minimum transportation costs.

The total length of the Druzhba oil pipeline is 5,116 km, including 3,455 km in the USSR. It begins in the region of Kuybyshev, crosses the Volga river and passes through the central part of the RSFSR near Bryansk and through Belorussia to Mozyr'. The pipeline then branches off. The southern branch is laid in the Ukraine to the border of the Soviet Union and Czechoslovakia and proceeds to Bratislava with a branch to Hungary. The northern part proceeds to the border with Poland and passes through Poland to ghe German Democratic Republic, supplying the oil refining plants of Poland with raw material en route. At the same time the oil pipeline supplies oil to the Polotsk plant in Belorussia and to the Baltic seaports. This is one of the world's largest oil pipelines [12, 13, 38].

An oil pipeline has been constructed from fields of the Volga-Urals region to Novorossiysk to supply oil for export and an oil pipeline has also been constructed from fields on the Mangyshalk peninsula to the Kuybyshev region. Further development of pipeline transport in the Soviet Union has been predetermined mainly by development of oil production in the regions of the Western Siberian lowland. An oil pipeline on the Ust'-Balyk--Omsk section approximately 1,000 km long is already under operation and the Omsk-Pavlodar pipeline has been laid to supply oil to the Pavlodar plant. The total length of this pipeline system will reach 1,820 km after the pipeline has been laid to the Chimkent and Chardzhou plants. An increase of the carrying capacity of this oil pipeline is planned on the section to Omsk [12, 13, 44].

The Nizhnevartovsk--Andero-Sudzhansk oil pipeline has been constructed to supply Eastern Siberia and the Far East with oil, for which part of the previously constructed Tuymazy-Irkutsk pipeline was used. This pipeline is also used to deliver oil liquid terminals for further transportation to the east over the trans-Siberian mainline railroad and subsequently over the Baykal-Amur mainline railroad under construction.

A large oil pipeline system is being developed from fields in the Central Ob' region to Al'met'yevsk and Kuybyshev to deliver oil to the Druzhba system and other pipelines proceeding from this region. A multipipe pipeline is being constructed from Al'met'yevsk to the oil refining plants in the central regions. A continuation of the Nizhnevartovsk-Kuybyshev oil pipeline is the long pipeline to the Ukraine and to Odessa port for delivery of oil for export [12, 13].

Table 5.2.

(1) Показатели	1965	1970	1976	1977
(2) Добыча	384	534	466	463
Импорт (3)	121	167	301	419
В том числе: (4)				
нефть (5)	62	66	204	331
нефтепродукты (6)	59	101	97	88
Экспорт (7)	5,8	5,8	10,7	10,7
В том числе:				
нефть	—	—	0,3	0,3
нефтепродукты	5,8	5,8	10,4	10,4
Мощность нефтеперерабатывающих заводов (8)	537,5	630,0	710,8	838,0

Key:
1. Indicators
2. Production
3. Import
4. Including
5. Oil
6. Petroleum products
7. Export
8. Capacity of oil refining plants

It is planned to construct oil pipelines 15,000 km long and not less than 3,500 km of petroleum product pipelines by the end of 1980 [2].

Pipeline transportation of oil has become most widespread abroad in the United States. Pipeline transportation is used to transport oil produced not only in the United States but also delivered from other countries and also to transport oil refining products. The main oil-producing region in the United States is the coast of the Gulf of Mexico, where the main part of oil reserves is concentrated: 32 percent in Texas, 13 percent in Louisiana, 10 percent in California, 3.5 percent in Oklahoma and so on. Offshore fields in the Gulf of Mexico have been developed intensively during the past few years. Thirty percent of the country's oil reserves are concentrated in Alaska. Data on production and export-import of oil in millions of tons/annually in the United States are presented in Table 5.2 [94, 95].

Oil is delivered by pipeline from the southern producing regions to local refining plants and a number of plants in the central and northern states of the country. A large volume of oil and petroleum products is transported by sea to the industrially developed and densely populated northwest (New York and Philadelphia) [SIC]. A significant volume of oil is delivered from southern states to the Chicago region and to the east coast. Petroleum products are transported by pipelines from the oil refining plants located mainly on the coast (the region of the Gulf of Mexico, New York, Philadelphia, Los Angeles and San Francisco) to the interior of the country, since the capacity of plants in the central states is unable to meet the needs of the attractive regions for petroleum products. The concentration of oil refining is explained in some cases by the high local needs for fuel oil used to make up the deficit of boiler-furnace fuel.

The main oil suppliers of the United States were Canada (15.0 percent), Nigeria (16.8 percent), Iran (7.5 percent), Venezuela (10.8 percent), Saudi Arabia (14.5 percent), Indonesia (8.9 percent), Algeria (6.5 percent) and the United Arab Emirates (3.7 percent). Moreover, the main fraction (75 percent) of imported petroleum products is fuel oil. This is explained by the extent of oil refining. The output of light petroleum products upon refining comprised 43.7 percent of gasoline, 7.4 percent kerosene and jet fuel, 21.4 percent of motor and diesel fuel and 72.5 percent of all light products in 1975. The output of fuel oil is relatively low and the need for it is made up to a significant degree by imports [94, 95].

Table 5.3

(1) Нефтетрубопровод	(2) Диаметр, мм	(3) Протяженность, км	(4) Стоимость, млн. долл.
(5) Прадхо-Бей — Валдиз	1220	1277	10 000
(6) Нефтебаза (залив Делавэр) — нефтеперерабатывающий завод (Филадельфия)	900	144	—
Порт Луизиана — Батон-Руш (7)	1220	104	—
Фрипорт (Техас) — Кашинг (Оклахома) (8)	760; 900	848	130
Бьюмонт (Техас) — Кашинг (Оклахома) (9)	760	755	96,5
Сиэттл (Вашингтон) — Каспер (Вайоминг) (10)	1000; 1060	1760	—

[Key on following page]

[Key continued from preceding page]:

1. Oil pipeline
2. Diameter, mm
3. Length, km
4. Cost, million dollars
5. Prudhoe Bay-Valdez
6. Petroleum base (Gulf of Delaware)-oil refining plant-(Philadelphia)
7. Port Louisiana-Baton Rouge
8. Freeport (Texas)-Cushing (Oklahoma)
9. Beaumont (Texas)-Cushing (Oklahoma)
10. Seattle (Washington)-Casper (Wyoming)

The structure of oil producing sources predetermines the complexity of the oil and petroleum product transportation and economic ties of the United States and the involvement of various types of transport in oil transportation. Thus, 75 percent of oil is transported by pipeline, 0.2 percent by rail, 18 percent by water and 6.8 percent by motor transport and the figures are 27, 2.0, 22 and 39 percent, respectively, for petroleum products.

The most widespread type of oil and petroleum product transport is pipeline. Development of pipeline transport proceeded through increasing the pipe diameter and pipe productivity and increasing capacities by laying parallel pipes. However, smaller diameter pipes are used mainly in the United States than in the USSR. The characteristics of large pipelines constructed and planned for construction and presented in Table 5.3.

The Prudhoe Bay-Valdez oil pipeline with pipe diameter of 1,220 mm and carrying capacity of 90 million tons/annually, which has become widely known as the Trans-Alaskan pipeline [76, 98], intersects Alaska from north to south and is designed to deliver oil from the Prudhoe Bay field in northern Alaska with proven reserves of approximately 1.6 billion tons to the nonfreezing port on the southern coast of Alaska--Valdez. It was laid under extremely complicated permafrost conditions with a considerable length over collapsing soils. The following methods of laying the pipeline were employed during construction: on pilings with spans of 15-21 meters between supports on sections 615 km long, in trenches in the absence of collapsing soils on sections 658 km long and in trenches with laying two pipes parallel to cool the soil and to maintain permafrost in sections 11 km long. The sections of pipeline laid aboveground were insulated with polyurethane and reinforced with fiberglass and epoxy resins. Steel pipe 9-15 meters long and 450 mm in diameter with wall thickness of 9-12 mm were used for pilings. Each support consists of two pilings and a crosspiece on which the pipeline rests. Installations of pipe cooling systems 50-65 mm in diameter and 9-18 meters long were constructed near the pilings to maintain the permafrost.

The trans-Alaskan oil pipeline was developed from pipes with wall thickness of 11.7-14.3 mm. The pipes were manufactured from steel which contains 1.39 percent manganese and 0.08 percent niobium. The impact strength of the steel at -10°C is 7 kgf/cm^2. Special spherical gate valves 1,220 mm in diameter, designed to operate at temperatures to -65°C, have been installed on the pipeline.

Twenty-four gas turbines with capacity of 10,000 kW each have been installed at eight pumping stations of the first unit. The fuel for the first four pumping stations is gas delivered through a special gas pipeline and the remaining stations are equipped with devices that extract light gas fractions from oil which are also the fuel for the gas turbines. Control of all stations is remote from the main pumpinb station.

Tanks designed for 35,200 m^3 of oil have been constructed at the main station. Construction of the main oil pipeline facilities required extensive work to dry up the lake and fill it with gravel. Coils for cooling the soil and to prevent it from thawing have been laid under the foundation of the tanks and pumps. A petroleum product storage and distribution center consisting of 18 tanks with capacity of 80,000 m^3 of oil each and with volume of a 10-day reserve of oil pipeline productivity has been developed at the final station at Valdez. The tanks are installed at a height of 120-150 meters above sea level, which provides filling of tankers by gravity flow and permits loading of 2-3 tankers daily. The ballast water is also purified of oil, for which three additional tanks with capacity of 68,000 m^3 each have been constructed. A specialized highway was constructed along the route of the oil pipeline from the Yukon River to Prudhoe Bay, a distance of 580 km, to deliver freight. Nineteen worker settlements were erected for construction and later for operation of the oil pipeline. The United States Department of Defense mainly managed the construction of the oil pipeline.

The total cost of constructing the oil pipeline, according to approximate calculations for the end of 1977, was estimated at 9.0-11.0 billion dollars, and with regard to the port equipment, tanker acquisition and development of the fields, it was estimated at 14-15 billion dollars or 155-170 dollars per ton of oil.

An oil pipeline is now being planned from Valdez to regions of the mid-west over a distance of 1,770 km.

The experience of construction and operation of the trans-Alaskan oil pipeline confirmed the complexity and low reliability of "hot" pipelines under permafrost conditions. More modern methods of pipeline transportation of oil under these complex conditions must be found.

Comparison of the main indicators of pipeline transport in the USSR and United States is presented in Figure 5.1. As can be seen, pipeline transport in the USSR is almost equal to oil and petroleum product transport in the United States in freight turnover. At the same time the length of the system in the USSR is considerably less, while the average freight intensity is higher (approximately 2.7 million tons·km in the United States and 11.7 million tons·km/km in the USSR). This indicates the incomparably higher concentration of capacities.

Until quite recently, the oil pipelines of Western European countries usually delivered oil from the seaports, where it was delivered by tankers from the Near East and Africa to the oil refining plants located in the petroleum product consuming regions. Major oil pipelines that service the oil refining plants of several countries: France, Italy, Switzerland, Austria and West Germany have now been constructed. The following should be named among the more significant oil pipelines [91]:

The Northwestern pipeline from Wilhelmshafen to Wesseling with a branch to the plant in the Ruhr with total length of 384 km with branches, 720 mm in diameter and productivity of 25 million tons/year;

The Rotterdam-Koln pipeline 454 km long, 620 mm in diameter and with productivity of 17.5 million tons/year;

The Southern European pipeline from Marseilles port to the oil refining plants in eastern France and southern West Germany 780 km long, approximately 900 mm in diameter and with calculated productivity in the main part of 30-34 million tons/year;

The Central European pipeline from Genoa (Italy) to Echallens (Switzerland) and further to Ingoldstadt (West Germany) 650 km long and with productivity of about 8 million tons/annually;

The trans-Alpine pipeline from Trieste port (Italy) across the Alps to Austria to Ingoldstadt (West Germany) with a branch to the oil refining plants in Bavaria and in the region of Vienna, 1,000-1,050 mm in diameter, and with calculated productivity of 54 million tons/annually. Since the pipeline in the central part is laid under severe mountain conditions and passes through three tunnels with a total length of about 7 km, the cost was high. A total of 11 pumping stations was planned for a pipeline 480 km long.

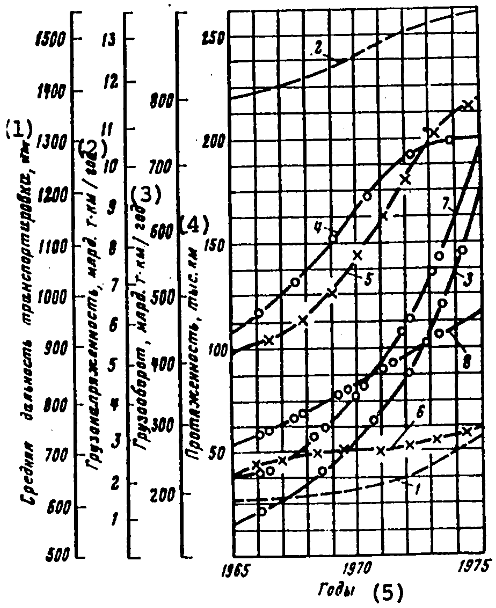


Figure 5.1. Indicators for Development of Pipeline Transport of Oil and Petroleum Products in the USSR and the United States: 1--length of pipelines in the USSR; 2--length of pipelines in the United States; 3--freight turnover of oil pipeline transport in the USSR; 4--freight turnover of oil pipeline transport in the United States; 5-- freight intensity in the USSR; 6--freight intensity in the United States; 7--average distance of transportation in the USSR; 8--average distance of transportation in the United States

[Key on following page]

Key [Continued from preceding page]:

1. Average distance of transportation, km	4. Length, thousand km
2. Freight intensity, billion tons•km/year	5. Years
3. Freight turnover, billion tons•km/year	

Data on transport [85] of oil and petroleum products of Western European countries are presented in Table 5.4.

Mass construction of pipelines from prospected fields to coastal production and storage centers with underwater laying of pipelines was organized in 1975 after discovery of oil fields in the North Sea, the reserves of which are estimated at 3.5 billion m^3 of oil. It is planned to construct a number of pipelines from 400 to 900 mm in diameter with a total length of about 2,000 km and pipelines 900 mm in diameter will be most widely distributed.

Oil production in Western European countries increased rapidly after discovery of fields in the North Sea and had already reached 23.8 million tons in 1975 (compared to 15.5 million tons in 1973).

Table 5.4.

(1) Страны Западной Европы	1970			1975		
	(2) Протяженность, тыс. км	(3) Объем перекачки, млн. т/год	(4) Грузооборот, млрд. т·км	Протяженность, тыс. км	Объем перекачки, млн. т/год	Грузооборот, млрд. т·км
Австрия(5)	0,16	18,5	2,93	0,60	31,5	5,5
Бельгия (6)	0,05	5,4	0,28	0,32	30,5	1,5
Франция(7)	3,53	78,8	28,2	5,23	103,0	31,1
Нидерланды (8)	0,41	24,5	4,1	0,61	36,9	4,4
Швейцария (9)	0,22	2,8	1,2	0,24	13,2	1,2
Великобритания(10)	1,78	23,6	2,67	2,62	28,8	5,3
ФРГ (11)	2,06	88,0	16,8	2,08	91,0	14,4

Key:

1. Western European countries	7. France
2. Length, thousand km	8. Netherlands
3. Pumping volume, million tons/year	9. Switzerland
4. Freight turnover, billion tons•km	10. Great Britain
5. Austria	11. West Germany
6. Belgium	

Since oil pipelines from the North Sea fields are laid under water, the costs of constructing them are 10 times greater than the cost for construction of the same pipelines laid on land. However, the high prices for oil and the short length of the pipelines make construction of them and exploitation of the fields on the North Sea shelf areas profitable. According to an optimistic estimate, it is planned to bring the total production in these fields up to 300 million tons.

The Socialist countries of Europe receive oil mainly through the Druzhba pipeline from the USSR (except Rumania and Yugoslavia). The oil pipeline system of these countries is comparatively short sections of pipelines that deliver oil to oil refining plants. A number of countries have ports for receiving oil from the sea and pipelines from them to the plants. The total length of the pipelines of the European Socialist countries is approximately 7,000 km [85].

The pipeline transport of oil exporting countries is usually relatively short pipelines from the fields to the ports. The plan of a pipeline from the southern fields of Iran to Iskander port on the southern coast of Turkey 1,688 km long and 1,060 mm in diameter is of interest among the oil pipelines of these countries. This pipeline will transport Iranian oil to Western European countries by a short route.

Problems of constructing a pipeline from southern Iran to the Mediterranean coast of Syria 1,243 km long and 1,220 mm in diameter and also that of constructing a pipeline from the fields of southern Iraq to the Mediterranean coast of Turkey 1,008 km long and 1,000 mm in diameter are under consideration [78, 83, 85]. Construction of these pipelines is induced by the rapid increase of oil production, which reached, for example, 276-302 million tons in Iran during 1974-1977 and 91-111 million tons in Iraq, and by the high costs of transporting oil by sea around the Cape of Good Hope.

A mixed shipping scheme has been organized to reduce expenses for transporting oil from the Near East to Western European countries. Since the size of the Suez Canal permits passage of tankers with capacity only up to 80,000 tons, a two-pipe oil pipeline 340 km long and 1,060 mm in diameter has been laid along the Suez Canal. The oil is pumped from supertankers with capacity from 120,000 to 170,000 m^3 prior to entry into the canal at Port Suez and the oil is loaded into the supertanker in the Mediterranean Sea at Alexandria port. Petroleum storage and distribution centers with tanks having capacity of 120,000 m^3 have been constructed in the ports.

5.2. The Engineering and Economic Indicators of Oil Transportation by Pipeline in the USSR

During the past few years the major oil pipelines of the USSR have been constructed from large-diameter pipes (Table 5.5). Thus, whereas only 5.9 percent of oil pipelines consisted of pipes 1,020 mm in diameter, pipes 1,020 and 1,220 mm in diameter comprised 24.8 percent in 1976 in the total length of pipelines. Optimum productivity was assumed when designing pipelines 1,220 mm in diameter.

Table 5.5.

(1) Годы	Количество нефтепроводов, % общей протяженности, в зависимости от диаметра труб мм (2)				
	1220	1020	800	700—500	500—150
1965	—	5,9	9,9	51,3	32,9
1970	—	12,7	7,9	52,6	26,8
1975	10,3	13,6	13,1	46,6	16,4
1976	10,9	13,9	12,8	46,2	16,2

Key:
1. Years
2. Number of oil pipelines, percent of total length, as a function of pipe diameter, mm

The main pumping equipment of oil pipelines is centrifugal pumps of type NM (Table 5.6). The most widely used scheme is series connection of three pumps.

Table 5.6.

Насосы (1)	(2) Подача, $м^3/ч$	Напор, м (3)	(4) К. п. д., % (на воде)	Мощность насоса, кВт (5)
(6) НМ-10000-210	10 000	210	89	5540
НМ-7000-210	7000	210	89	3870
НМ-5000-210	5000	210	88	2800

Key:
1. Pumps
2. Delivery, m^3/hr
3. Pressure head, meters
4. Efficiency, percent (in water)
5. Pump output, kW
6. Nm

The engineering and economic indicators of pipeline transport of oil achieved over a period of 10 years are presented in Figure 5.2. The specific capital investments, despite construction under complicated conditions, are being decreased by converting to pipelines 1,220 mm in diameter. There is some reduction of oil pumping cost: it decreased from 1.0 kopeck/(10 tons·km) to 0.94 kopecks/(10 tons·km) over 10 years. At the same time the expenditures for one ton of oil increased by 68 percent with regard to the increased distance of transportation from 650 to 1,338 km, i.e., more than twofold. Labor productivity is also increasing systematically: it reached 15,600 tons·km/man in 1975 compared to 7,500 tons·km/man in 1965. This made it possible to maintain expenditures of live labor to deliver one ton of oil at approximately the same level with an increase in the distance of transportation [13].

Since the number of pipeline maintenance workers is hardly dependent on pipe diameter and carrying capacity, an increase of the diameter and concentration of oil volumes are the most effective methods of increasing labor productivity.

One can expect an increase of labor productivity on USSR oil pipelines in the near future due to the proposed increase of the average diameter of pipelines, automation of control of pumping stations, an increase of equipment reliability, joining of occupations of repair personnel and also construction of parallel pipelines on some routes.

The main stocks of oil pipeline transport in the USSR and the United States increased 4.67- and 1.86-fold, respectively, during the period under consideration, whereas the main production stocks of the countries increased 2.25- and 1.43-fold, respectively, i.e., the development of oil pipeline transport in the countries is proceeding at accelerated rates and these rates are 1.8 times higher in the USSR. Fund recovery in the USSR increased 1.28-fold during the decade under consideration, whereas it remained unchanged in the United States. The cost of pumping oil through pipelines in the USSR decreased by 16 percent during the past few years, while the cost in the United States remained unchanged [15, 96, 97].

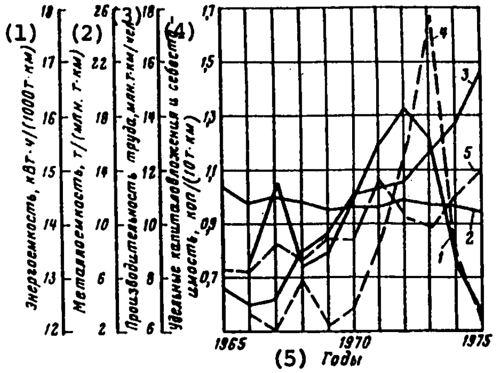


Figure 5.2. Dynamics of Engineering and Economic Indicators of USSR Pipelines: 1--specific capital investments; 2--cost of pumping; 3--labor productivity; 4--metal consumption; 5--energy consumption

Key:
1. Energy consumption, kW·hr/(1,000 tons·km)
2. Metal consumption, tons/(million tons·km)
3. Labor productivity, million tons·km/man
4. Specific capital investments and cost, kopecks/(10 tons·km)
5. Years

All this indicates that oil pipeline transport in the USSR is not inferior to that of the United States in rates of development. Further improvement should proceed toward an increase of the specific weight of large-diameter pipelines, improvement of transportation equipment and mainly of extensive introduction of remote control and automation.

5.3. Selecting the Optimum Parameters of Oil Pipelines

a) Classification of Pipelines

Pipelines can conditionally be divided into three groups by the nature of operation and the rates of increase of carrying capacity.

1. Major pipelines for pumping large volumes of oil from oil-bearing regions to numerous branches operating and being constructed by oil refining plants and for export. This group may include mainly the oil pipeline system from the fields of the Urals-Volga region and the Central Ob' region to the west and also the pipeline systems from the Central Ob' area to the east and south. These routes have a continuous growth in the volume of oil due to connection of newly discovered and developed oilfields to the major pipelines and due to an increase of needs for oil in the regions being serviced. The final capacity of the system is unknown. The carrying capacity of some sections of these pipelines is calculated according to plans for development of individual oil fields and according to development of oil consumption with compilation of five-year plans and planned developments for the longer term.

2. Branches from the major pipelines to individual oil refining plants and ports. Frequently one branch services several consumers. There is also a tendency on these mainlines to increase the carrying capacity with regard to introduction of capacities at the plants serviced by them. Development of these pipelines is being planned on the basis of the general scheme of the disposition and development of the oil refining industry and long-term contracts for delivery of oil for export.

3. Delivery pipelines from the fields to the mainline or directly to plants. The size and growth rates of oil volumes in these pipelines are determined by geological reserves, the conditions of their exploitation and other factors. The main ones among them are production indicators that predetermine the rates of exploitation of the fields. Selection of the optimum parameters for these pipelines encounters considerable difficulties and is usually made with a lack of information.

Despite the conditional nature of this classification, it makes it possible to work out general approaches in selection of parameters for each of the enumerated groups of pipelines.

It is usually difficult to call the final carrying capacity for pipelines of the first group or of their individual sections and sometimes for the second group as well. But the principle of conversion to mainlining, which predetermines the feasibility of volume concentration, operates for them. It is not excluded that parallel or straightening routes of these mainlines may occur in the future, but the general principles of their formation are stable. The engineering and economic indicators of mainlines are much better than pipelines of medium and low productivity with regard to the use of large-diameter pipes in these systems, heavy-duty pumping equipment and combining of a number of facilities. The significant reduction of specific capital investments and operating expenses justifies some lengthening of branches to plants and other oil consumers.

Pipelines of the third group have a constant load and sometimes, which is typical for them, a decrease of load as the fields are depleted.

b) Optimum Pipeline Productivity

The most important measures for increasing the efficiency of oil pipelines both during the design stage and during reconstruction is selection of the optimum distances between pumping stations, the working pressure and pipe diameter. Moreover, a number of still inadequately studied factors must be taken into account with further development of pipeline transport, namely: selection of the optimum carrying capacity of the pipeline, distribution of the oil shipments among different types of transport and establishing the optimum phases of increasing the carrying capacity of pipelines.

The carrying capacity of a pipeline is established for the calculating period in the plan and the problem of its optimization is of great practical interest. Carrying capacity depends on a number of factors: construction conditions, the periods of bringing the pipeline up to design productivity, the normative coefficient of efficiency and so on.

Pipelines have usually been constructed during the past few years from pipes not less than 720 mm in diameter and major pipelines have been constructed from pipes 1,020 and 1,220 mm in diameter with regard to the high growth rates of oil production and construction of oil refining plants with installations of high unit capacity (6-8 million tons/year) with 2-3 or more installations at each plant.

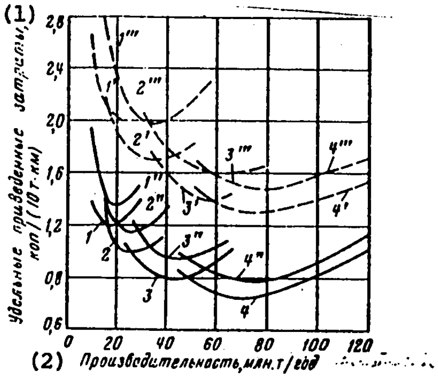


Figure 5.3. Zones of Application of Pipelines 720, 820, 1,020 and 1,220 mm in Diameter: 1, 2, 3 and 4--at E_n = 0.12 and under mean conditions; 1', 2', 3' and 4'--at E_n = 0.12 and under northern conditions; 1", 2", 3" and 4"--at E_n = 0.15 and under mean conditions; 1"', 2"', 3"' and 4"'--at E_n = 0.15 and under northern conditions

Key:

1. Specific reduced expenditures, kopecks/(10 tons·km)
2. Productivity, million tons/year

The reduced expenditures for average conditions of the European USSR and the unfavorable conditions of the swampy regions of Tyumenskaya Oblast with efficiency coefficient of 0.12 and 0.15 are presented in the graph (Figure 5.3). All the data were calculated for conditions of rapid assimilation of carrying capacity (2-3 years) and a constant load throughout the entire lifetime of the pipeline (30 years)

If a calculation accuracy of ± 5 percent is assumed, which is very high for planning and especially preplanning calculations, we find the given reduced expenditures for pipelines 1,020 mm in diameter with productivity from 38 to 52 million tons/year and for pipelines 1,220 mm in diameter with productivity from 65 to 80 million tons/year.

As can be seen in the graphs, the optimum productivity with an increase of the coefficient of the effectiveness of capital investments shifts to the right and increases from 43 to 55 million tons/year for pipes 1,020 mm in diameter and increases from 70 to 85 million tons/year, respectively, for pipes 1,220 mm in diameter.

An increase of specific capital investments with regard to the complicated conditions of construction leads not only to an increase of reduced expenditures but also to some variation of optimum productivity. Pipelines constructed under unfavorable conditions (swamp or mountainous regions and so on) can be operated in a more accelerated mode.

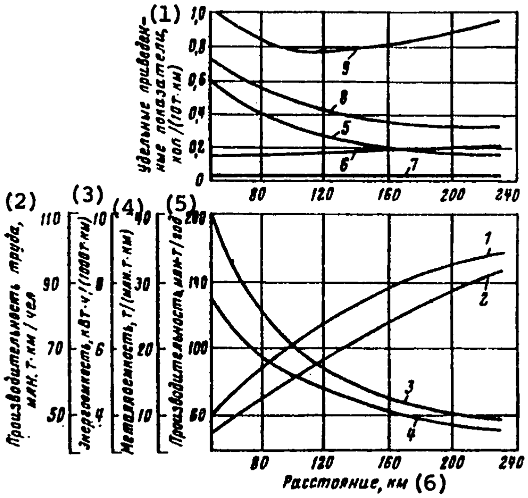


Figure 5.4. Variation of Engineering and Economic Indicators of Pipeline 1,220 mm in Diameter as a Function of Distance Between Pumping Stations: 1--productivity; 2--metal consumption; 3--energy consumption; 4--labor productivity; 5--depreciation deductions; 6--expenditures for electric power; 7--wages and miscellaneous expenses; 8--cost; 9--reduced expenditures

Key:

1. Specific reduced indicators, kopecks/(10 tons·km)
2. Labor productivity, million tons·km/man
3. Energy consumption, kW·hr/(1,000 tons·km)
4. Metal consumption, tons/(million tons·km)
5. Productivity, million tons/year
6. Distance, km

Optimum pipeline productivity is 5-8 percent higher than under average conditions of the European USSR with a twofold increase in the cost of construction and installation work compared to average conditions and with a 1.5-1.6-fold increase of operational indicators.

In practice oil pipelines are operated at productivity considerably variable over the perennial profile as a function of the variation of oil production level and oil consumption by oil refining plants.

Variations of engineering and economic indicators of an oil pipeline 1,220 mm in diameter are presented in Figure 5.4 and Table 5.7 as a function of the distances

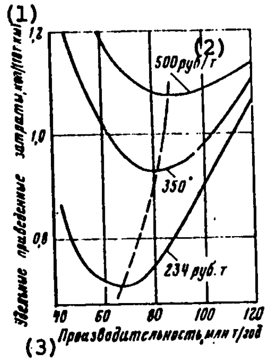


Figure 5.5. Dependence of Optimum Productivity of Pipeline 1,220 mm in Diameter on Pipe Prices

Key:

1. Specific reduced expenditures, kopecks/(10 tons·km)
2. Rubles/ton
3. Productivity, million tons/year

between pumping stations. As can be seen, the minimum reduced expenditures correspond to productivity of 65-85 million tons/year.

Analysis of the effect of different factors of development of pipeline transport and the national economy as a whole requires that a number of concepts usually omitted from calculations to substantiate pipeline productivity and selection of its parameters must be taken into account when selecting the calculated productivity of oil pipelines.

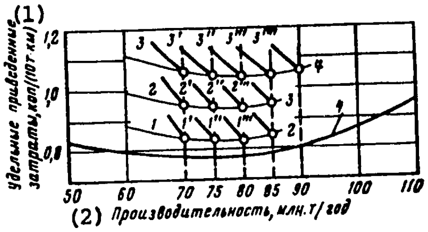


Figure 5.6. Variation of Reduced Expenditures With Different Periods of Assimilation of Capacities of Pipeline 1,220 mm in Diameter; 1, 2 and 3--with periods of assimilation of capacity of 5, 10 and 15 years and planned productivity of 70 million tons/year; 1', 2' and 3'--with assimilation of capacity of 5, 10 and 15 years at productivity of 75 million tons/year; 1",2" and 3"--at capacity of 5, 10 and 15 years with productivity of 80 million tons/year; 1"',2"' and 3"'--at productivity of 5, 10 and 15 years with productivity of 85 million tons/year; 3""--at capacity of 15 years and 90 million tons;year; 4--without regard to periods of assimilation of capacity

[Key on following page]

Key [Continued from preceding page]:

1. Specific reduced expenditures, kopecks/(10 tons·km)
2. Productivity, million tons/year

Part of the pipes for construction of oil and gas pipelines is imported to the USSR at prices that exceed domestic prices used in calculations. The variations of the engineering and economic indicators of an oil pipeline with an increase of pipe prices to 500 rubles/ton are presented in Figure 5.5. The optimum productivity of a pipeline 1,220 mm in diameter at these prices is at the level of 85-90 million tons/year. An increase of pipeline productivity leads to a saving of metal.

The calculations whose results are presented in Figure 5.3 were made without regard to development of pipeline transport. In practice, relief of pipelines under conditions of constant rates of development of the national economy usually increase gradually. Construction of pipelines with greater productivity than optimum leads to some increase of energy expenditures during the operating period under full load. However, this permits transfer of the deadlines of measures to increase pipeline productivity, i.e., construction of a parallel pipe of a pipeline or a relief pipeline over another route, with an increase of volume. This factor is rarely taken into account during planning and moreover its value is very significant in many cases.

The variations of reduced expenditures during the entire period of reaching the design capacity of pipelines, calculated for different maximum productivity, are of interest. The results of these calculations are shown in Figure 5.6 for pipelines 1,220 mm in diameter. The specific expenditures at calculated carrying capacities near the optimum, for example, with productivity from 60 to 90 million tons/year for pipes 1,220 mm in diameter, are essentially equal during comparatively long periods of assimilation of final capacity, for example, 10-15 years. Some increase of expenditures during pipeline operation under full load is compensated for my more favorable indicators during preceding years.

One of the measures to increase the efficiency of pipelines constructed under unfavorable conditions is to increase working pressure. Thus, an increase of working pressure from 55 to 75 kgf/cm^2 for a pipeline 1,220 mm in diameter with spacing of 100 km between pumping stations leads to an increase of carrying capacity from 83 to 96 million tons/year, i.e., by 16 percent. Despite the increase in the cost of one ton of pipe from 180 to 270 rubles due to an increase of metal strength from 52 to 65 kgf/mm^2, the reduced expenditures under severe construction conditions decrease by 8-10 percent. The results of calculations to select the optimum pipeline parameters upon conversion to pressure of 75 kgf/cm^2 with an increase in the strength characteristics of pipe metal are shown in Figure 5.7. Construction of pipelines under northern conditions is economical at pressure of 75 kgf/cm^2 with a moderate increase of pipe prices and with an increase of the strength characteristics. In this case an increase of pressure is more effective for large-diameter pipelines. Conversion to a pressure of 75 kgf/cm^2 is not effective in central regions and the expenditures are essentially equalized only for a pipeline 1,220 mm in diameter. Conversion to pressure of 75 kgf/cm^2 essentially yields no improvement of engineering and economic indicators with a significant increase of pipe prices with improvement of metal quality.

Table 5.7.

(1) Показатели	(2) Расстояние между насосными станциями, км															
	160				100				80				50			
	(3) Диаметр, мм															
	1220	1020	820	720	1220	1020	820	720	1220	1020	820	720	1220	1020	820	720
Производительность, млн. т/год (4)	64	39	22	15	83	51	27	20	94	58	33	23	123	76	43	30
Металлозатраты, т/(млн. т·км) (5)	6,6	7,7	8,5	9,8	5,1	5,2	6,9	7,3	4,5	5,0	5,7	6,4	3,4	3,9	4,3	4,9
Энергоемкость, кВт·ч/(100 т·км) (6)	12,5	12,5	12,5	12,5	20,0	20,0	20,0	20,0	25,0	25,0	25,0	25,0	40	40	40	40
Капиталовложения, коп/(10 т·км) (7)	3,0	3,9	4,6	5,8	2,6	3,2	4,1	4,9	2,5	3,0	3,7	4,4	2,5	2,6	3,3	4,0
Эксплуатационные затраты, коп/(10 т·км) (8)	0,35	0,41	0,46	0,53	0,46	0,50	0,56	0,62	0,56	0,58	0,64	0,69	0,77	0,78	0,85	0,91
Приведенные затраты, коп/(10 т·км) (9)	0,71	0,88	1,02	1,22	0,78	0,89	1,06	1,20	0,86	0,94	1,08	1,22	1,07	1,10	1,25	1,39
Производительность труда, млн. т·км/чел. (10)	88	61	32	26	70	40	23	17	64	40	22	16	60	37	21	15

Key:

1. Indicators
2. Distance between pumping stations, km
3. Diameter, mm
4. Productivity, million tons/year
5. Metal expenditures, tons/(million tons·km
6. Energy consumption, kW hr/(100 tons·km)
7. Capital investments, kopecks/(10 tons·km)
8. Operating expenses, kopecks/(10 tons·km)
9. Reduced expenditures, kopecks/(10 tons·km)
10. Labor productivity, million tons·km/man

Operating expenses have a significant effect on the optimum productivity of pipelines constructed under severe conditions. The structure of operating expenses for pipelines 1,020 mm in diameter operated in the mid-zone of the USSR is presented in Table 5.8.

Depreciation deductions usually comprise 40-50 percent of total operating expenses with distance of 100-160 km between pumping stations. An increase of construction costs, for example, a twofold increase, leads to a 40-50 percent of operating expenses. Laying the pipeline in an aggressive medium may also significantly increase operating expenses by 40-50 percent due to depreciation deductions. Specific depreciation expenditures also increase with incomplete loading of the pipelines.

Table 5.8.

(1) Расстояние между насосными станциями, км	(2) Эксплуатационные затраты, коп/(10 т·км)	(3) В том числе, %		
		зарплата (4) с начислением и пр.	(5) электроэнергия	(6) амортизационные отчисления и ремонт
50	0,784	3,3	76,5	20,2
80	0,582	3,8	67,0	29,2
100	0,501	4,0	59,9	36,1
160	0,414	3,9	45,6	50,5
320	0,385	3,1	24,2	72,7

Key:

1. Distance between pumping stations, km
2. Operating expenses, kopecks/(10 tons·km)
3. Including, percent
4. Wages with bonuses and so on
5. Electric power
6. Depreciation deductions and repair

The cost of pumping oil through pipelines and their optimum productivity are considerably dependent on the cost of electric power. The optimum productivity of pipelines at average rates for electric power is achieved in most cases with distance of 80-100 km between pumping stations. Expenditures for electric power comprise 40-50 percent, while they comprise 60-70 percent in regions with higher rates. In regions with inexpensive electric power, the optimum productivity is 5-8 percent higher than that presented in Table 5.8. Thus, in regions with inexpensive electric power, for example, in Eastern Siberia where electric power plants operate on coal from the Ekibastuz and Kuznetsk basins, more accelerated use of pipelines is feasible. The operating expenses to pump oil may vary as a function of local conditions over a rather wide range, but one should not expect an increase of them by more than 1.0 kopeck per 10 tons·km, except pipeline sections laid under the most unfavorable conditions.

The data given above indicate that the degree of pipeline intensification should be resolved as a function of local conditions and primarily as a function of construction cost, expenditures for electric power to drive pumping units and common trends of development of the system if there is a need to increase the effectiveness of capital investments and for accelerated development of the country's economy.

Taking all the factors considered above into account that indicate the feasibility of accelerated use of pipelines of the first and second groups under full load with design of new pipelines, the disposition of pumping stations should be taken so that the productivity for pipelines 820 mm in diameter be 25-27 million tons/year, that for pipelines 1,020 in diameter be 48-55 million tons/year and that for pipelines 1,220 mm in diameter be 85-90 million tons/year.

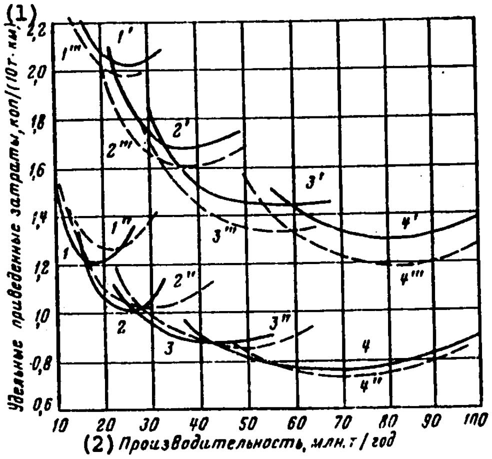


Figure 5.7. Zones of Application of Pipelines 720, 820, 1,020 and 1,220 mm in Diameter: 1, 2, 3 and 4--for all diameters at pressure of 56 kgf/cm^2, steel strength of 56 kgf/mm^2 and under average conditions; 1', 2', 3' and 4'--the same under northern conditions; 1", 2", 3" and 4"--the same at pressure of 75 kgf/cm^2, steel strength of 65 kgf/mm^2 and under average conditions; 1"', 2"', 3"' and 4"'--the same under northern conditions

Key:

1. Specific reduced expenditures, kopecks/(10 tons·km)
2. Productivity, million tons/year

c) Optimum Phase of Increasing the Carrying Capacity of Pipelines

Those measures which would provide a reserve of carrying capacity for a specific period can be designated to increase the carrying capacity of single-pipe pipelines or systems of several pipes having constant growth of oil volume. At $E_n = 0.12$, this period is usually equal to 8-10 years and at $E_n = 0.15$ it is usually equal to 5-7 years.

Table 5.9.

Число ниток трубопровода, диаметр, мм (1)	Капиталовложения на первый год, млн. руб. (2)	(3) Приведенные затраты, млн. руб., при $E_н$		
		0,08	0,12	0,15
1×1220	343	1764	1353	1142
1×820; 1×1020	176	2032	1501	1225
1×1020; 1×820	260	1847	1395	1160
3×820	176	1872	1391	1142

Key:

1. Number of pipes of pipeline, diameter, mm
2. Capital investments for first year, million rubles
3. Reduced expenditures, million rubles, at E_n

The results of calculating expenditures to increase the carrying capacity of a pipeline to 90 million tons/year over a period of 15 years by implementation of various measures: laying a single-run pipeline 1,220 mm in diameter and development of a two-run system of pipelines 820 and 1,020 mm in diameter and a three-run system of pipelines 820 mm each in diameter at $E_n = 0.08$, 0.12 and 0.15, are presented in Table 5.9.

It is obvious from the data of Table 5.9 that construction of large-diameter pipelines requires large initial capital investments. However, the reduced expenditures at $E_n = 0.12$ or 0.15 are essentially equal for all versions except that which provides for construction of pipelines 820 mm in diameter and a second run 1,020 mm in diameter.

Construction of a single-run pipeline with reserve carrying capacity of 15 years is more advantageous at coefficient $E_n = 0.08$.

It should be noted that, although formation of pipeline systems from several runs requires greater capital investments and more metal, they can be dispersed over time, which is one of the methods of increasing the effectiveness of development of the national economy.

Pipelines whose calculated capacity is utilized after being put into operation, within approximately 5-7 years at $E_n = 0.15$, 7-11 years at $E_n = 0.12$ and 12-15 years at $E_n = 0.08$, have minimum reduced expenditures.

Obviously, it is desirable to lay large-diameter pipes for convenience of construction and operation since this reduces the number of pumping stations and advances the periods of redeployment of construction organizations. At the same time rapid introduction of a second and subsequently a third run of pipeline sharply increases the operating reliability, increases the flexibility of the system and permits parallel pumping of oil or petroleum products of different marks at relatively low capacities of tank depots.

The normative coefficient E_n is now taken at not less than 0.12. The effectiveness of capital investments in development of pipeline transport is very high--considerably higher than in a number of other sectors of the national economy. This determines the accelerated development of pipeline transport and contributes to improvement in the structure of the energy balance.

Based on the foregoing, one can orient oneself to a reserve pipeline capacity calculated at 7-11 years of operation. However, in some cases, even with a high value of E_n, it is feasible to increase the reserve carrying capacity of pipelines. This is primarily true of pipelines laid under especially unfavorable conditions where the specific weight of construction and installation work in total capital investments is high.

This is also confirmed by the worldwide experience of construction and operation of pipelines. The parameters and periods of assimilation of calculated capacity vary as a function of the conditions of available credit and the complexity of construction operations. Thus, the Southern European pipeline introduced in 1962 had a load of only 80 percent of the calculated load by the 50th operation. The use of the calculated capacity at some other pipelines in Western Europe and the United States proceeded at approximately the same rates. The trans-Alpine pipeline laid under severe topographic conditions, partially in special tunnels, has a reserve carrying capacity for a very long period--it is planned to reach its full productivity only by the 14th-15th year of operation.

The volume of oil being pumped increases intermittently in most pipelines of the second group as primarily oil refining plants become operational. This determines the selection of pipeline productivity and the phases of development. For example, if oil consumption by an oil refining plant should increase every 7 years, a pipeline with productivity can be developed with regard to an increase every 7 years. In this case pumping stations are put into operation as the oil volume increases. A further increase of volume with expansion of the plant can be achieved by construction of loopings or the next continuous run. Construction of a pipeline to total calculated capacity to support a group of plants is also feasible if it is planned to reach this capacity during the 7th-11th year after the beginning of operation. Expenditures to redeploy construction organizations and miscellaneous expenses should be considered when selecting the optimum phases of pipeline development.

One can cite as an example the phases of development of a pipeline 530 mm in diameter and 700 km long with a single pumping station and with carrying capacity of 2.0 million tons with an increase of oil volume every two years of 5, 7, 10, 14 and 17 million tons each, i.e., at growth rates of approximately 1.5 million tons/year. The diameter of the laid second run or looping is 630 mm (Table 5.10).

Table 5.10.

(1) Этапы развития пропускной способности	(2) Техническое состояние трубопроводов при потоке, млн. т/год														(6) Суммарные приведенные затраты на расчетный период, млн. руб.
	2		5		7		10			14			17		
	(3) Число ниток	(4) НС	Число ниток	НС	Число ниток	НС	Число ниток	НС	(5) Длина лупингов, км	Число ниток	НС	Длина лупингов, км	Число ниток	НС	
(7) 1. Ввод насосных станций (НС), строительство лупингов (Л)	1	1	1	3	1	6	1	6	290	1	6	540	} 1 1	6 —	37,61
(8) 2. Ввод насосных станций, строительство лупингов и второй нитки	1	1	1	3	1	6	1	6	290	} 1 1	6 2	— —	} 1 1	6 4	40,19
(9) 3. Ввод насосных станций, строительство второй нитки	1	1	1	3	1	6	} 1 1	6 1	— —	} 1 1	6 2	— —	} 1 1	6 4	41,25

Key:

1. Phases of development of carrying capacity
2. Technical state of pipelines with volume, million tons/year
3. Number of runs
4. Pumping stations
5. Length of loopings, km
6. Total reduced expenditures for calculated periods, million rubles
7. Introduction of pumping stations (NS) and construction of loopings (L)
8. Introduction of pumping stations, construction of loopings and second run
9. Introduction of pumping stations and construction of second run

The least total expenditures are calculated for the first version--construction of loopings. Construction of loopings in two phases 290 and 540 km long is more feasible than laying a second run or short loopings and then bringing them up to a continuous second run. The difference in expenditures in construction of loopings in two phases and a continuous parallel pipeline is very significant--10 percent of reduced expenditures (over a calculated period of 20 years). However, to select measures for increasing the carrying capacity during the last phase (when the length of the loopings is close to that of the pipelines), it may be that a continuous second run of pipeline should be constructed instead of extending the loopings with regard to the actual expenditures to redeploy the construction organizations, due to losses from shutting down the pipeline to cut in loopings and other losses. The carrying capacity in this case will provide an increase of volume for another 5-6 years.

Loopings 630 mm rather than 530 mm in diameter (the diameter of the first run) can be laid at the volume growth rates under consideration. The carrying capacity of a second run of this diameter creates a reserve capacity during phased construction for optimum periods. If a pipe of smaller diameter is laid (equal to the diameter of the first pipeline or less than its diameter), an optimum period of reserve capacity can be achieved only with construction of a long looping or of a continuous pipeline immediately, which is less economical.

This remark refers to routes with fully stable volume growth rates adopted in the calculations. If the increase in volume is slower, phased lengthening of loopings may still be more effective and on the contrary accelerated conversion to a continuous second run of pipeline and an increase of its diameter is more feasible at higher volume growth rates. Laying loopings makes it possible to use a larger value of diameter for the construction, having thus provided an improvement of the engineering and economic indicators of the system by performing work on continuous laying of pipe in two or three phases and consequently increasing the effectiveness of capital investments.

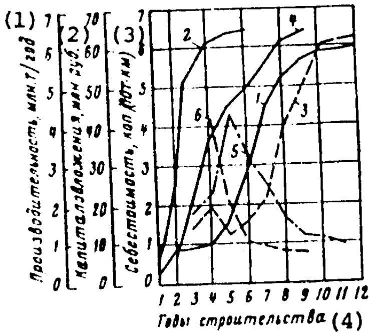


Figure 5.8. Engineering and Economic Indicators of Pipelines During Construction Period: 1--capital investments of pipeline No 1 (increasing total); 2--capital investments of pipeline No 2; 3--productivity of pipeline No 1; 4--productivity of pipeline No 2; 5--cost of pipeline No 1; 6--cost of pipeline No 2

[Key on following page]

Key [Continued from preceding page]:

1. Productivity, million tons/year	3. Cost, kopecks/(10 tons·km)
2. Capital investments, million rubles	4. Years of construction

The characteristic feature of pipelines of the third group is the dependence of their load on the scheme for exploitation of fields, coming up to a stable production level and the operating period at the level achieved and in the declining production mode. The problem of the parameters of the pipeline being laid and the scheme for intensifying it can be solved in the presence of relatively reliable data on reserves as a function of the planned rates of exploitation of fields. If an increase to a stable production level over a period of 6-7 years is planned, then a pipeline can obviously be constructed immediately for the calculated capacity with an increase of productivity within this period by construction of pumping stations. If the period of development of the field is longer, a version of laying a pipeline with smaller diameter than is required for maximum volume must be considered, with subsequent construction of a second run or loopings.

If fields with insignificant reserves or unfavorable conditions of exploitation are being developed, the oil volumes are frequently insignificant and increase slowly. These volumes, especially during the first phase of exploitation of the fields, can sometimes be assimilated by rail transport. Pipelines are laid during the first phase of assimilation only up to the nearest railroad.

An increase in the efficiency of pipeline transport and a reduction of expenses over the country's transportation system as a whole can be achieved by correct establishment of the periods of introducing pipelines constructed in regions with a developed railway system. This is primarily related to cases of developing fields with initial transportation of oil by rail.

The engineering and economic indicators of construction (capital investments) and operation (volume of pumping and operating expenses) for two pipeslines with calculated carrying capacity of approximately 7 million tons are presented in Figure 5.8.

Pipeline No 1 was constructed over a period of 10 years; approximately 25 percent of capital was invested during the first 5 years--the first section was constructed and pumping of 1.5 million tons of oil was begun. During the next two years the pipeline was constructed over the entire length but without intermediate pumping stations, and these were constructed over a period of 3 more years. The design capacity and calculated cost indicators were achieved only by the 10th year of operation. The pipeline was laid along a railroad, for which the actual expenses for shipping petroleum products comprised 1.8-2.0 kopecks/(10 tons·km). Thus, a saving of total expenditures on the transportation system not only was not achieved but on the contrary capital investments increased until the eighth year after the beginning of construction and the fifth year from the beginning of operation of the pipeline.

The inefficiency of this construction is also aggravated by the fact that the railroad had the required reserve carrying capacity and the volume of pumping during all the years of construction comprised no more than 4-5 million tons/year, which is acceptable for rail shipments.

A second example: pipeline No 2 and part of the pumping stations were constructed over a period of 3 years, the remaining pumping stations were completed by the fifth year of operation, pipeline productivity of 5.0 million tons was achieved and the cost of pumping the oil comprised 1 kopeck/(10 tons·km), which is considerably lower than the cost of transporting the oil by the parallel railroad. However, even in this case it was possible to improve somewhat the engineering and economic indicators by introduction of pumping stations parallel to introduction of the line part, which would make it possible to begin operation of the facility with specific expenditures less than on rail transport.

Thus, pipelines with relatively low productivity, laid along railroads, must be constructed during the shortest possible periods and with their being put into operation at a load which provides operation at reduced expenses less than during shipments over the parallel railroad.

d) Further Improvement of Pipeline Efficiency

A further increase in the efficiency of pipeline transportation of oil is possible by reducing the viscosity of oil and consequently by increasing the carrying capacity of pipelines with their characteristics remaining fixed.

Heating of paraffin oils to 50-60°C, i.e., to a temperature at which their viscosity is reduced, is now widely employed. However, the pipelines must be coated with especially strong anticorrosion insulation at such high temperatures to avoid rapid corrosion [75].

Proposals are now being advanced to heat non-paraffin oils to reduce their viscosity and to increase the productivity of pipelines.

Heating oil being pumped to 30-40°C requires no special insulation of pipelines. The viscosity of the oil in most fields is approximately one-half that at 30-40°C than at 5-10°C. However, if the oil temperature reaches 30°C while being pumped into a pipeline, it drops to 10°C within 500-600 km. Therefore, the temperature of the oil being pumped must be maintained over the entire length of pipelines at a level approximately equal to the temperature when it is pumped into the pipeline and heating along the pumping route is possible for the oil of some fields.

A decrease in the viscosity of oil being pumped permits an increase of the carrying capacity of pipelines. Thus, reducing viscosity by 50 percent leads to a 15-20 percent increase of productivity, all things being equal.

Study of the conditions of laying oil pipelines in permafrost soils is now of important significance with regard to discovery of oilfields in the northern regions of the USSR. If the characteristics of oil permit it to be cooled to negative temperatures close to 0-2°C without a sharp increase of viscosity, the problem can be solved rather easily without great difficulty by cooling and pumping the oil at temperatures equal to soil temperature.

Technological solutions of pipeline transport under permafrost conditions and swamped depressions for oil containing a considerable quantity of paraffins and other substances that lead to an increase of viscosity with a reduction of temperatures close to 0°C require the most serious study.

The experience of constructing the trans-Alaskan heat-insulated pipeline, located on cooled pilings, if it can be considered successful, then only for a large-diameter pipeline (1,220 mm) with high carrying capacity of 90 million tons/year, since the use of these engineering decisions for small- and medium-diameter pipelines and productivity leads to high expenditures. One of the promising directions for pumping oil under permafrost conditions may be pumping gas-saturated oil.

The experience of pumping gas-saturated oil (saturated with methane, propane or butane) through a pipeline shows that its viscosity decreases up to one tenth. The experience of pumping oil with paraffin content up to 9 percent showed the possibility of operating a pipeline at low temperatures without heating the oil. However, it became necessary to develop special equipment and fittings due to formation of gas plugs.

Moreover, a pipeline system must be developed that operates at pressure which provides gas saturation of the oil in a volume sufficient to prevent formation of a structural lattice, an increase of viscosity and shear resistance.

A reduction of oil viscosity to a level that provides pumping at temperatures close to 0°C can be achieved by using additives. However, the use of additives requires expenditures that exceed those when oil is heated; therefore, a search must be made for inexpensive additives that provide the required effect at insignificant expenditures.

5.4. Storage of Oil and Reservation of Oil Pipelines

The presence of oil reserves in fields near consumers and at ports for transferring oil to tankers and removing oil from tankers at some pipeline pumping stations is a compulsory condition for normal functioning of the entire oil production, transportation and refining system. If pipelines are designed according to existing standards, capacities are provided for storage of oil at the main pumping station and at intermediate pumping stations (every two or three). Additional capacity, which is established by the schedule for pumping different grades of oil, is required for sequential pumping of oil of different grades.

Special attention is given to the problem of creating oil depots in oil-importing countries.

Construction of depots that provide oil reserves for 90 days is provided in many industrially developed countries.

Underground oil depots which are constructed in rocky soils have become widespread in Finland, Norway and Sweden. The volume of underground depots in these countries reached approximately 50 percent of the total volume of oil depots in 1970 and it is planned to bring the volume of underground depots to approximately 70 percent with regard to the increased prices for steel by 1980 with a more than 2.5-fold increase in the volume of depots.

The economic effectiveness of using underground depots instead of surface depots with metal tanks depends on their capacity. With a capacity of 32,000 m^3, the costs for surface and underground storage are approximately equal and comprise approximately 20 dollars per cubic meter, with capacity of 64,000 m^3, the costs for underground storage decrease to 15.70 to 16.40 dollars and with surface storage they increase to 20-20.70 dollars and with capacity of 96,000 m^3 and above, the costs are 13.80 to 15.10 and 19.70 to 20 dollars per cubic meter, respectively.

Depots are being constructed in the United States in granites, shales and limestones, in France they are constructed in chalk deposits and limestone and in West Germany they are being constructed in gypsum, limestone, sandstone, dolomite, basaltic lava and in shales. Rock in which underground depots can be developed should be strung without installation of intermediate supports.

Construction of oil depots in salt beds and in caverns formed by dissolving salts with water and pumping the saline solution through pipes has become widespread. Oil is extracted from these depots by filling them with brine. Ponds having capacity approximately equal to that of the depots are being constructed for the brine pool.

The design of 14 underground oil depots in salt beds with total capacity of approximately 9.0 million m^3 has been developed in the United States and oil will be pumped into them from tankers unloaded near floating docks. It is planned to develop the depots at a depth of 500 meters. Each depot is 70 meters in diameter and 225 meters high. A special tank with capacity of 2.4 million m^3 is being developed to store the saline solution. Expenditures for underground storage in salt beds comprise 18 dollars per cubic meter, which is lower than expenditures for ordinary surface tanks, which comprise 40 dollars per cubic meter [38, 50].

Construction of reserve depots with total capacity of 35 million m^3 was begun in West Germany after a law was adopted to create a 90-day reserve of oil and petroleum products. A total of 700 tanks covering 14 km^2 of area and expenditures of 1.2 billion dollars would be required to construct surface tanks having capacity of 50,000 m^3 each for the required volume of oil.

Development of depots of the required volume in salt beds requires only one-third the costs required to construct surface tanks, i.e., approximately 7 dollars per cubic meter.

Development of depots in worked-out mines is effective. Thus, the cost to develop a depot on Bell Island near Newfoundland with capacity of 14 million m^3 of oil comprised 1.13 to 1.7 pounds sterling per cubic meter (compared to 31.4-44.0 pounds sterling per cubic meter for surface depots). The largest depot with capacity of 5.0 million m^3 was created in 1972 in France in a worked-out iron-ore mine.

Formation of caverns by nuclear explosions in the soil under the sea bed at a distance of approximately 70 km from shore was investigated in France to create a depot with capacity of 11.13 million m^3. This location of the depots was caused by the high population density of the coastal area and by the presence of architectural monuments.

Detonation of 12 charges of 250 kg each would be required to create this storage area. The rock would evaporate and caverns would be formed at these high temperatures. The caverns could be opened approximately 6 months after the explosion and cleaning could begin.

Engineering and economic comparison of storage areas under the sea bed, produced by nuclear explosions, with depots of other types is carried out below:

Storage area formed by nuclear explosions	9.5 dollars/m^3
Storage area in salt beds	15.7 dollars/m^3
Storage area with the need to build a tank for storing the brine solution	22.0 dollars/m^3
Metal surface tanks	31.4 dollars/m^3

Surface oil and petroleum product depots of metal tanks with capacity up to 50,000 m^3 and oil storage areas of submerged reinforced concrete tanks with capacity up to 50,000 m^3 have become widespread in the USSR. The engineering and economic indicators of metal tanks and storage bases with total capacity up to 500,000 tons are presented in Chapter 6. The engineering and economic indicators of submerged tanks of precast concrete are presented in Table 5.11.

Table 5.11.

(1) Показатели	(2) Номинальный объем, м^3			
	5000	10 000	20 000	30 000
Полезный объем, м^3 (3)	5057	10 020	19 985	29 300
Высота, м (4)	7,4	8,2	9,0	9,6
Диаметр, м (5)	29,6	42,0	54,0	66,0
Удельный расход железобетона на 1 м^3 полезного объема, м^3 (6)	0,07	0,06	0,05	0,04
Удельный расход металла, кг/м^3 полезного объема (7)	6,08	6,38	4,32	4,25
Удельная стоимость 1 м^3 полезного объема, руб. (8)	5,56	5,5	4,23	4,44

Key:

1. Indicators
2. Nominal capacity, m^3
3. Useful capacity, m^3
4. Height, meters
5. Diameter, meters
6. Specific consumption of reinforced concrete per cubic meter of useful capacity, m^3
7. Specific consumption of metal, kg/m^3 of useful capacity
8. Specific cost of one cubic meter of useful capacity, rubles

According to the data obtained, the metal consumption of submerged reinforced concrete tanks is one-fourth to one-fifth that of vertical metal tanks, but the former require 60-70 percent greater capital investments. Moreover, the cost to construct large-capacity oil storage areas in salt beds by dissolving the salts and pumping out the saline solution, according to foreign data, are lower by a factor of 1.5-3.0 than metal tanks, and the indicators are especially favorable when worked-out mines are used for storage. Even construction of underground storage areas in rock yields more favorable results than the use of surface metal tanks. It should also be taken into account that underground oil storage areas do not require excavation of large sections of earth and are incomparably more favorable in the fire-hazard sense.

Detailed geological study of the region of location and determination of the possibility of using worked-out mines or caverns in salt beds for oil storage or creation of storage area in rock by excavating them by modern tunnelling methods that have been well developed by domestic construction organizations are required when solving the problem of constructing oil storage depots.

Chapter 6. Transport of Petroleum Products

[Text] 6.1. Development of Petroleum Product Transportation

Supply of numerous consumers dispersed throughout the USSR with petroleum products is a complex problem in which all types of transportation participate and interact closely. Petroleum products are now delivered from oil refining plants to consumers usually by two or three types of transportation with transshipment from one type to another at oil storage and distribution centers.

The total volume of shipment of petroleum products with regard to shipment of petroleum carried out by general-purpose transportation is presented in Table 6.1 [12, 52].

Table 6.1.

(1) Транспорт	Грузопоток, млн. т (2)			(3) Грузооборот, млн. т·км		
	1965	1970	1975	1965	1970	1975
(4) Железнодорожный	222,2	302,8	389,0	280,4	353,9	481,4
Речной (5)	25,0	33,5	39,0	27,8	33,0	39,1
Трубопроводный (6)	20,4	25,3	39,4	17,5	21,9	27,0

Key:
1. Transport
2. Freight traffic volume, million tons
3. Freight turnover, million tons·km
4. Rail
5. River
6. Pipeline

As can be seen, petroleum products are transported mainly by railroads. The fraction of shipments of petroleum products in the total freight turnover of railroads comprised approximately 15 percent in 1975. Shipment of petroleum products by rail is a complex problem with regard to the concentrated nature of loading petroleum products at terminals of oil refining plants and the significant freight traffic volume of petroleum products over the more loaded routes.

Engineering and economic analysis of the efficiency of using various types of transport to deliver petroleum products to consumers shows that the established structure of transportation of this type of freight is not optimum. There are reserves both in the area of changing the distribution of shipments by types of transport and in the technical parameters of transportation equipment used to ship petroleum products.

The use of various types of transportation and shipping schemes is determined to a significant degree by the physical properties of individual petroleum products.

Fuel oil and viscous petroleum products are usually transported by rail and river transport. Pumping through pipelines in the heated state due to high viscosity at temperatures below 40-70°C is employed only between plant shops. Problems of heat insulation of the pipeline and heating by laying a special heater pipeline alongside or inside the main pipeline or using another petroleum product to force the fuel oil from the pipeline that does not congeal when temperature is reduced in the case of a planned or unforeseen shutdown of the pipeline and the danger of congealing of the fuel oil in it must be solved to pump fuel oil over long distances.

Naval fuel oil is produced in relatively small quantities and delivery of it to consuming points--ports--by rail is usually economically justified. When the plants are located near the ports, the use of water transport is possible.

Asphalt, coke and other hard or especially viscous final oil-refining products can essentially be transported by rail with subsequent hauling by trucks and over short distances by motor transport directly from the oil refining plants to consumers. Especially rigid requirements are placed on preventing its contamination by other types of petroleum products or foreign impurities during transportation of aviation kerosene. Because of this, the problem of transportation through pipelines with subsequent pumping together with other petroleum products has not yet been resolved. Under these conditions the main type of transport of aviation kerosene is rail transport with delivery of it in tank cars directly to the unloading platforms of the oil storage and distribution centers of airports or with participation of motor transport when small airports having no railroad access tracks are being supplied with fuel. In some cases pipeline transport that connects the airport to the oil refining plants or to rail depots is employed to supply especially large airports with aviation kerosene.

Oils and individual fractions used as raw materials for the chemical industry and produced in relatively limited quantities are usually transported by rail and partially by river transport. The volumes of these products usually do not justify the use of pipeline transport for them.

Diesel fuel and various marks of gasoline permit sequential pumping through a single product pipeline and the problem of developing a system of product pipelines for transportation of them and switching shipments from rail to other types of transport is one of the timely problems for further improvement of the country's transportation system.

Serious difficulties are encountered when analyzing the effectiveness of developing the transport of petroleum products due to the instability of transportation and economic ties and variation of the range of consumers serviced by individual oil refining plants.

During the first phase of development of the oil refining industry in the USSR, the plants were usually located directly in the oil-producing regions. Plants were constructed during this period in the trans-Caucasus, the Northern Caucasus, the Volga area and Bashkiriya. Stable volumes of petroleum products from these plants to the west and east of the country were established. Product pipelines of comparatively high productivity were constructed for part of them and operation was profitable. These pipelines include the Tuymazy-Omsk, Kuybyshev-Bryansk-Mozyr', the Groznyy-Trudovaya and a number of other pipelines. However, a large part of the products of these plants were still hauled by rail and water transport over considerable distances.

The oil refining plants subsequently began to be located directly in the consuming regions as the specific weight of liquid fuel in the country's fuel balance increased and as conditions were created for development of pipeline transport of oil.

Plants have already been constructed at Irkutsk, Omsk, Polotsk, Lisichansk, Kremenchug and a group of plants in the central regions of the country (Gor'kiy, Ryazan', Yaroslavl' and Moscow) and also at Achinsk, Pavlodar, Chimkent, in the Baltic area and other western regions of the country. All this changed the previously established transportation and economic relationships of petroleum products and led to a decrease of the load of a number of oil pipelines, primarily those intended to supply the country's eastern regions with petroleum products where plants began to be constructed at accelerated rates to refine the oil from Western Siberia. Construction or development of oil refining plants in the consuming regions leads to a further dispersion of production and reduces the transportation distance of the main petroleum products and changes the transportation and economic relationships for these types of goods.

Along with the general trend of construction of new plants in consuming regions due to different factors, there are still cases of consolidation of existing plants located in the Volga-Urals region [8] with an increase of the shipping distance of petroleum products.

A tendency to intensify oil refining by using secondary methods of recovery that ensure production of fuel oil from light petroleum products has been planned during the past few years with regard to the large increase of oil prices on the worldwide market [8, 12] and the need to conserve oil for use as a raw material for the chemical industry. Development of these trends naturally leads to pre-equipping of existing plants to intensify refining of oil and to increase the output of light petroleum products and may postpone the periods for introducing new plants in consuming regions.

At the same time the variety of petroleum products (the number of brands of gasoline and diesel fuel and so on) is increasing continuously. Capacities are being introduced to produce some types of petroleum products at different plants on a continuing basis, which leads to shipments of newly developed products over long distances to the zones serviced by other plants. This process is also dynamic. The variety of products produced by a plant increases as each plant is developed and the average shipping distance is reduced.

Moreover, the density of consumption of petroleum products throughout all regions of a country developed in the industrial or agricultural sense increases.

These contradictory trends make it extremely difficult to plan the development of petroleum product pipelines. However, despite the difficulties, the main condition in all cases when substantiating the routes and selecting the productivity or growth rates of the load of one or another product pipeline is sufficiently full use of its capacity during the operating period close to the depreciation period.

Otherwise, consideration of a shorter depreciation period or increased expenditures when operating a pipeline with reduced load are required when determining the efficiency and upon comparison with other types of transport [8].

It should be noted that the characteristic features of the location of oil refining plants had a significant effect on development of the product pipeline system in the United States [94, 95]. Refining of a considerable part of the oil (approximately 60 percent) produced in the country is concentrated in several regions, from which the petroleum products are delivered by pipeline and inexpensive waterways to consuming regions. This explains the wide development of the petroleum product system in the United States: approximately 113,000 km in 1977. Petroleum products are hauled by motor transport over short distances and the latter is used extensively to transport petroleum products that have already come into the consuming region and handled in the large plant system of relatively low productivity (up to 6 million tons of refined oil annually), which have been partially operating during the past few years on imported oil.

The specific weight of different types of transportation in the total volume of shipments of petroleum products in the United States were as follows during the past few years: 36.0 percent by pipeline, 22.6 percent by water, 39.4 percent by motor transport and 2.0 percent by rail. Waterways operating in most transportation and economic ties year-round or with comparatively short interruptions between navigation systems and motor transport with delivery of petroleum products in most cases directly from the oil refining plants to consumers play the decisive role in shipment of petroleum products.

The diameter and carrying capacity of product pipelines in the United States is usually low: the average productivity of product pipelines is approximately 1.5 million tons/year. This is explained to a significant degree by the competition of companies by which parallel product pipelines have been constructed on a number of routes.

6.2. The Effectiveness of Using Different Types of Transportation of Petroleum Products

The basic direction for developing the petroleum industry with disposition of plants in consuming regions and expansion of the nomenclature of petroleum products produced at each plant leads to gradual contraction of the region serviced by one or another plant and a reduction of the distance of transportation of petroleum products.

When considering the problem of transportation of petroleum products, one must take into account the significant changes expected in the structure of the country's truck fleet. Startup of the Kama Motor Vehicle Plant will make it possible to outfit the motor fleet with tank trucks having capacity of 15-16 tons with semitrailer and 23-24 tons with semitrailer and trailer. Since the characteristic feature of these trucks is a load restriction of 6 tons on the axle, this permits operation of them over highways of lower categories and provides shipment of petroleum products into interior regions directly to consumers without intermediate handling, forcing out short-run rail shipments of petroleum products and expanding the sphere of motor shipments of them throughout the country as a whole.

The rates of development of the highway system contribute to development of motor shipments of petroleum products. Among the highways accounted for by TsSU [Central Statistical Administration] [30] with total length of 1.4 million km in 1975, 660,000 were paved, including almost 300,000 km of cement-asphalt and oil tar highways. The length of paved highways increased by 149,000 km during the period 1970-1975. A diagram of the developed highway system mainly reflects administrative and economic ties. Oblast centers are linked to rayon centers, rayon centers are linked to central farmsteads of kolkhozes and sovkhozes and the latter are linked to the farmsteads of individual brigades. Some rayon centers and central farmsteads of kolkhozes and sovkhozes are linked by highways to nearby railroad stations.

The layout of consumer supply with petroleum products under current conditions is as follows.

Diesel fuel consumers (mainly sovkhozes and kolkhozes) are located on the entire territory of the region. Fuel is transported from the transshipping centers of Goskomneftesnab [Expansion unknown] usually located at railroad stations. In this case the maximum shipping distance (most remote individual consumers from the railroads) rarely exceeds 70-80 km in regions with developed agricultural production and comprises an average of 25-30 km. In some cases there are distribution or remote centers of Goskomneftesnab in remote agricultural regions to which petroleum products are shipped by motor transport from the main centers. The consumption of diesel fuel will increase at urban construction sites as the truck and bus fleets and construction machinery are converted to diesel fuel.

The consumption of gasoline is concentrated mainly in the cities and suburbs where the greater part of motor shipments are made. Motor shipments related to servicing of agriculture and intercity shipments comprise a smaller part of the total shipments carried out in the national economy. Automobile filling stations are also supplied with fuel by motor transport from centers of Goskomneftesnab located primarily at railroad stations.

The transshipping basis of Goskomneftesnab are also located on the banks of navigable ports. Fuel is delivered to these centers by water transport. Fuel is delivered by short pipelines (loops) to centers located near oil refining plants or near the routes of truck product pipelines. However, light petroleum products are mainly shipped to centers of Goskomneftesnab by rail.

Thus, the following scheme of supply of mass consumers with light petroleum products has been traditionally established: plant-railroad-petroleum storage and distribution center of Goskomneftesnab-motor transport-filling station (sovkhoz and kolkhoz warehouse)-consumer (Figure 6.1, a). Pipeline transport can effectively replace rail shipments of petroleum products from oil refining plants to transshipping and distribution centers in this scheme and motor transport can effectively replace rail shipments with delivery of fuel from centers near railroads to centers located in remote agricultural regions.

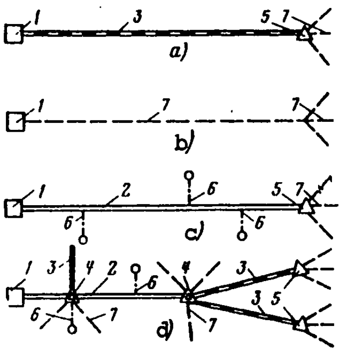


Figure 6.1. Typical Schemes of Petroleum Product Transportation: 1--oil refining plants; 2--oil product pipeline; 3--railroad; 4--transshipping center of Goskomneftesnab from pipeline to railroad and to motor transport; 5--center of Goskomneftesnab; 6--branches to interior centers of Goskomneftesnab; 7--motor transport of petroleum products from plants to consumers

The following scheme (Figure 6.1, b) may subsequently become widespread with an increase in the number of oil refining plants and mainly saturation of the country's truck fleet with large-capacity trucks: center of Goskomneftesnab at oil refining plant-motor transport-filling station (kolkhoz or sovkhoz warehouse)-consumer, replacing expensive short-run rail shipments.

Consequently, if the final or intermediate centers of Goskomneftesnab are located at railroad stations in the consuming regions, the spheres of economically substantiated use of various types of transport can be established:

by comparing the indicators of a pipeline planned for construction and the rail transport replaced by it in delivery of petroleum products from plants to rail centers of Goskomneftesnab;

by comparison of the indicators of a pipeline planned for construction and motor transport when hauling fuel to intermediate centers in remote agricultural regions from intermediate centers of Goskomneftesnab at railroads, at rivers or in pipelines and also directly from the centers at plants;

by comparison of the indicators of direct delivery of petroleum products from centers directly at plants to filling stations (warehouses, kolkhozes, sovkhozes and other organizations) with indicators of petroleum product delivery to intermediate centers of Goskomneftesnab by rail or pipeline and subsequent hauling by truck to consumers.

The types of motor vehicles used plays the decisive role in the latter two cases. Indicators of motor shipments are presented in Table 6.2.

Table 6.2.

(1) Тип автомобилей	Грузоподъемность, т (2)	(3) Эксплуатационные расходы		(4) Капиталовложения		Дорожная составляющая, коп/(10 т·км), при категории дорог (7)	
		коп/(10 т·км) (5)	коп/10 т (6)	коп/(10 т·км)	коп/10 т	капитальный, II (8)	переходный, IV (9)
ЗИЛ-130 (10)	4	58,0	291,2	39,5	770	0,44	1,3
ЗИЛ-130 с прицепом (11)	4+4	32,2	230,0	28,4	708	0,44	1,3
(12) МАЗ с полуприцепом	16	23,4	217,6	26,4	638	2,67	2,08
КАМАЗ, полуприцеп с прицепом (13)	16+8	20,3	176,6	23,4	605	0,44	1,3

Key:

1. Type of trucks
2. Load capacity, tons
3. Operating expenses
4. Capital investments
5. Kopecks/(10 tons·km)
6. Kopecks/10 tons
7. Highway component/(10 tons·km), with highway category
8. Capital, II
9. Intermediate, IV
10. ZIL-130
11. ZIL-130 with trailer
12. MAZ with semitrailer
13. KAMAZ, semitrailer with trailer

It follows from the data given in Table 6.2 that the use of a KAMAZ type truck with semitrailer and trailer having total load capacity up to 24 tons reduces expenditures on the main component of expenses dependent on the shipping distance from 58-32.2 to 20.3 kopecks/(10 tons·km) compared to a ZIL-130, by which the sphere of motor shipments is sharply expanded. The expenditures for shipment by this vehicle are lower than by a MAZ truck, which, moreover, can navigate only over highways with capital pavement and is essentially unsuitable to supply remote regions with fuel.

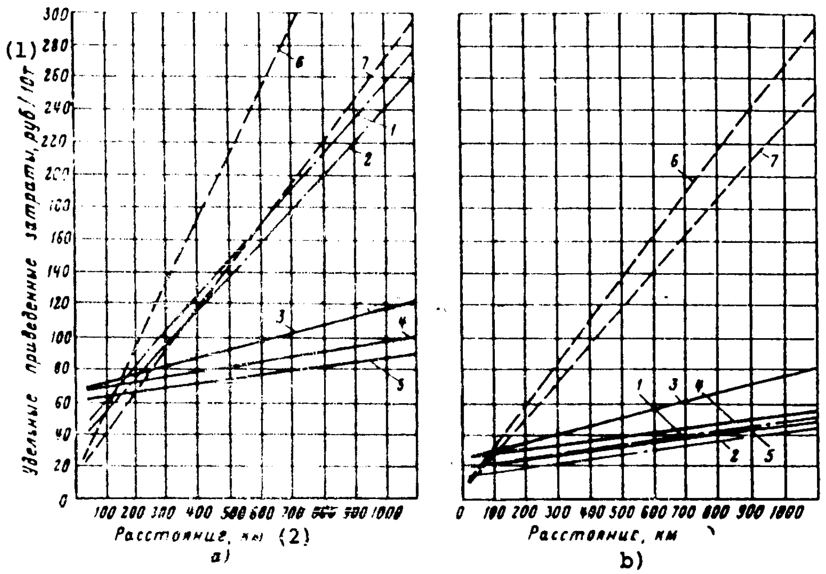
Comparison of expenditures to transport petroleum products by various types of transport is given for the case of direct delivery by truck from oil storage and distribution centers at plants and with delivery by pipeline and rail transport with hauling from the centers of Goskomneftesnab to consumers over an average distance of 25 km. Average conditions of shipments and average newly arising expenditures for shipment are taken for rail transport. The actual expenditures may fluctuate, as was considered in Chapter 3.

The results of calculations for a volume of petroleum products of 200,000 tons/year are presented in Figure 6.2, a, the results for a volume of 3.0 million tons/year are presented in Figure 6.2, b and in this case truck trains with load capacity of 16 + 8 tons were used in direct motor shipments and trucks with capacity of 6 and 16 tons were used for truck hauling depending on the distance. From the given calculations, one can conclude that there are spheres of application of various types of transport and spheres for further improvement of petroleum product transportation. When transporting small volumes of petroleum products by rail, the increase of shipping distance, especially under favorable conditions of train traffic, hardly affects transportation expenses due to the high expenditures for the initial-final operations related to preparation of tank cars for filling and unloading at intermediate stations by assembled trains and also for hauling by motor transport to consumers. Thus, an increase in the shipping distance from 50 to 1,000 km leads to an increase of expenditures from 65-70 to 85-95 rubles. Expenditures increase to approximately 115 rubles per 10 tons, i.e., twofold, only under unfavorable shipping conditions (overloaded railroad mainline, single-track railroad with small train mass and so on) if the shipping distance increases to 1,000 km.

Initial-final operations during transportation of small volumes of petroleum products over special pipelines are also significant due to the need to have available capacities for sequential pumping and expenditures for hauling of the fuel by truck at the beginning and end of the pipeline. However, even the line part requires considerable expenditures with small-diameter pipes due to the high drag and the need to operate low-capacity pumping stations. Expenditures per 10 tons increase from 46-50 rubles at 50 km to 240-250 rubles at 1,000 km with regard to expenditures for truck hauling for an average distance of 25 km. In sum, product pipelines are more economical with distance up to approximately 150-200 km (Figure 6.1, c) and rail transport yields better results at longer distances.

The indicators of pipeline transport with low volumes of petroleum products with delivery over branches (loops) from the truck product pipeline, when structures and operation of special pumping stations are not required, are more favorable than shown in Figure 6.2.

The reduced expenditures indicate the feasibility of the sometimes suggested mixed pipeline-rail method of shipping petroleum products over relatively short distances, for example, 200-300 km, by pipeline and then by railroad (Figure 6.1, d). Maintenance of low-capacity line devices and terminals for preparation of tank cars for loading requires large expenditures, which is not compensated for by the saving due to reduction of shipping distance by rail. Mixed pipeline-rail shipments are effective at long distances (500-1,000 km) and with a significant volume and also on loaded routes where transfer of petroleum products to pipeline transport makes it possible to postpone the deadline for implementing expensive measures on fundamental



a) b)

Figure 6.2. Effectiveness of Using Various Types of Transport: a--with assimilation of petroleum product volume of 200,000 tons/year; b--with assimilation of volume of 3 million tons/year; 1--pipeline transport with truck hauling of 6 tons; 2--pipeline transport with truck hauling of 16 tons; 3--rail transport with truck hauling of 6 tons; 4--rail transport with truck hauling of 16 tons; 5--rail transport under less favorable shipping conditions; 6 and 7--motor transport as a function of highway conditions and type of trucks

Key:
1. Specific reduced expenditures, rubles/10 tons
2. Distance, km

reconstruction of a railroad, for example, on construction of second tracking under complex topographic conditions.

Mixed pipeline-rail shipments are sometimes feasible with high concentration of capacities of oil refining plants when the volumes of loading at one railroad terminal exceed the capabilities of developing it and normal operation and loading must be transferred to an adjacent railroad terminal to a distance of 100-200 km with delivery of fuel by pipeline to the loading point.

Truck shipments have minimum expenditures for initial-final operations and can provide delivery of petroleum products directly to consumer warehouses or to general-purpose service stations. However, reduced expenditures by 30-40 rubles per 10 tons at 50 km increase to 270-400 rubles at 1,000 km depending on the type and condition of roads. These indicators of motor shipments naturally exclude the possibility of using them for long-range shipments of petroleum products, except special cases of supplying the country's remote regions with fuel during the winter season where the use of other types of transport is impossible. Comparison of the considered types of transport shows that motor transport using Kama trucks with capacity of 23-24 tons with trailer, which permit delivery of petroleum products directly to consumers even under unfavorable conditions, is most efficient with relatively small volumes of petroleum products and with their being shipped over comparatively short distances. The use of motor transport is feasible compared to small-diameter pipelines, even under unfavorable highway conditions at distances up to 150-350 km, depending on the hauling conditions from the oil storage and distribution centers with pipelines to consumers and with volumes of less than 100,000-150,000 annually and over long distances.

When motor and rail transport are compared, the use of trucks yields more favorable indicators at distances of 150-200 km.

Supply within the region of an oil refining plant can usually be accomplished without the participation of rail and pipeline transport by motor transport alone from the central oil storage and distribution center located near the plant to consumers, by changing the intermediate centers and also the numerous overloads and related losses. This same scheme of supply of numerous consumers of a region can be adopted upon approach to the center of the region where highways converge from regions of a truck pipeline. In the latter case it is natural to construct branches to the regional centers located near the route of the truck pipeline to reduce the distance of motor shipments.

Consequently, one will be oriented in the future toward significant expansion of the sphere of use of motor transport in shipments of petroleum products to numerous small consumers with the transport being shipped to short-run rail shipments with primary hauling of fuel-lubricating materials to consumers, by changing the intermediate centers.

Different relations occur with transport of petroleum products in significant volumes. In this case the high load of the line part and especially of pumping stations leads to a significant reduction of specific indicators and rates of their reduction with an increase of transportation distance. As a result pipeline transport under identical conditions of hauling petroleum products to consumers is more economical in the entire range of distances up to 1,000 km or more than rail shipment, even if there is a reserve carrying capacity of rail shipment and even if it has modern hardware.

Optimum pipeline parameters by diameter and loading have been adopted in calculations of reduced expenditures with pipeline transport, the results of which are shown upon comparison with other types of transport. Moreover, the engine ring and economic indicators of pipelines vary sharply as a function of utilizing their capacity.

The results of calculating expenditures with pipelines of different diameters and their different load are presented in Figure 6.3. The upper part of the zone corresponds to a load of 0.9 and the lower part corresponds to 0.5-0.6.

The use of pipes smaller than 114 mm in diameter does not lead to significant improvement of indicators for volumes less than 100,000 tons/year. Expenditures on

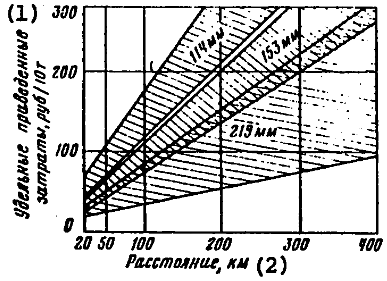


Figure 6.3. Variation of Reduced Expenditures as a Function of Pipeline Diameter

Key:
1. Specific reduced expenditures, rubles/10 tons
2. Distance, km

pipe acquisition and depreciation deductions with a reduction of pipeline diameter decrease insignificantly in the total expenditures on pipeline construction and operation. Therefore, the use of separating pipelines less than 114 km in diameter can hardly become widespread in the case when one can expect a further growth in the volume of pumping of petroleum products.

An exception are branches (loops) that operate without pumping stations or with pumps located at oil storage and distribution centers when expenditures for construction and operation of them are insignificant due to combining with the corresponding facilities of the oil storage and distribution centers. It is economically feasible in these cases to use pipes less than 100 mm in diameter.

Thus, a branch 80 km long with pressure of 20 kgf/cm^2 at the connection point and 60 km long provides delivery of 30,000-35,000 tons of diesel fuel or about 70,000 tons of gasoline during 5,000 hours of operation annually with indicators more favorable than motor shipments.

One should make the following conclusions from the given data:

the average distance of transporting petroleum products more than 1,000 km is temporary--it will decrease as oil refining plants are constructed in the consuming regions;

if oil refining is expanded, the distance of transporting petroleum products may remain basically unchanged, but an increase of volumes creates prerequisites for expansion of the spheres of use of product pipelines;

construction of pipelines is primarily feasible between oil refining plants and nearby oblast centers or large cities, where transportation and economic ties are stable and do not vary with construction of new plants. Connection of all adjacent centers to the product pipeline is feasible;

the reduced expenditures during shipment of petroleum products by rail and by separate product pipelines differ only in specific spheres. Therefore, construction of a pipeline should be substantiated with regard to local shipping conditions over specific sections of railroads from which switching of the volume of petroleum products to a pipeline is planned;

the deadline for putting branching pipelines into operation, like truck pipelines, is determined by the load level at which the reduced expenditures will be lower than on railroads. Under conditions of development of a product pipeline system, construction and operation with less than full load and expenditures higher than rail shipments cannot be regarded as economically justified.

Accounting for losses may play a significant role in selecting the version of transportation of petroleum products to consumers.

It is obvious that reducing the number of shipments and intermediate storage centers will contribute to a reduction of petroleum product losses. There will be more favorable conditions with extensive development of product pipelines with branches that provide delivery of petroleum products directly to large consumers with one-time motor transport with single transloading. There will also be favorable conditions with motor shipment directly from the center at the plant to the consumer. One should expect that consideration of this factor leads to expansion of the spheres of use of product pipelines with branches and motor shipment of petroleum products directly from the centers at plants.

6.3. Engineering and Economic Indicators of Product Pipelines and Storage Centers

The most favorable engineering and economic indicators during pumping petroleum products through pipes--diesel fuel with kinematic viscosity coefficient of approximately 0.1 cm^2/s and gasoline with coefficient of approximately 0.01 cm^2/s--occur in approximately equal proportions with distances of 100-150 km between pumping stations.

The nature of variation of reduced expenditures is similar to the principle established above for trunk pipelines. Variation of expenditures with location of pumping stations in this range is insignificant and frequently does not go outside the accuracy of calculations. Pipeline productivity for these conditions is presented in Table 6.3.

Table 6.3.

(1) Диаметр трубы, мм	(2) Производительность, тыс. т	Диаметр трубы, мм	Производительность, тыс. т
114	150—250	325	2000—3000
159	300—500	377	2700—4000
219	700—1000	426	3500—5000
273	1300—2000	530	6000—9000

Key:
1. Pipe diameter, mm
2. Productivity, thousand tons

Table 6.4.

Движенческая операция, коп/(10 т·км) (1)				(2) Начально-конечная операция, коп/10 т		Движенческая операция, коп/(10 т·км)				Начально-конечная операции, коп/10 т	
(3) Диаметр трубопровода, мм	(4) Производительность, млн. т/год	(5) Эксплуатационные расходы	(6) Капиталовложения	Эксплуатационные расходы	Капиталовложения	Диаметр трубопровода, мм	Производительность, млн. т/год	Эксплуатационные расходы	Капиталовложения	Эксплуатационные расходы	Капиталовложения
219	0,8	2,56	30,74	30,0	480	377	3,2	0,91	10,93	14,0	225
	1,0	2,12	24,60	30,0	480		4,0	0,78	8,74	14,0	225
273	1,6	1,45	16,4	25,0	380	426	4,0	0,79	9,77	15,0	235
	2,0	1,23	13,11	25,0	380		5,0	0,67	7,80	15,0	235
325	2,4	1,08	12,23	17,0	280	530	7,2	0,66	8,70	16,0	245
	3,0	0,92	9,78	17,0	280		9,0	0,56	6,96	16,0	245

Key:

1. Traffic operation, kopecks/(10 tons·km)
2. Initial-final operation, kopecks/10 tons
3. Pipeline diameter, mm
4. Productivity, million tons/year
5. Operating expenses
6. Capital investments

Table 6.5.

(1) Поток нефтепродуктов, млн. т/год	(2) Диаметр трубопровода, мм	(3) Приведенные затраты, руб/10 т, при дальности транспортировки, км				
		10	30	100	300	1000
0,2	114	17,8	20,7	30,7	72,5	233,9
0,4	153	10,3	11,3	18,9	44,5	143,2
0,8	219	5,6	6,7	10,7	24,7	79,1
1,4	273	3,5	4,3	6,7	15,4	49,4
2,0	325	2,7	3,2	5,0	11,8	37,5
3,0	377	1,9	2,5	4,1	9,6	30,1

Key:

1. Volume of petroleum products, million tons/year
2. Pipeline diameter, mm
3. Reduced expenditures, rubles/10 tons, at transportation distance, km

The operating expenditures and capital investments for traffic and initial-final operations for product pipelines with spacing of 150 km between pumping stations are shown in Table 6.4 for the middle regions of the European USSR.

The coefficients that take into account local conditions will be significant and may reach 50 percent or more for regions having significant deviations in the level of wages or rates for electric power or that require construction of product pipelines in mountainous terrain. The averaged indicators for these conditions can be used only as approximate indicators.

Variation of reduced expenditures for pumping petroleum products through small-diameter pipelines is presented in Table 6.5 as a function of transportation distance.

Thus, the indicators of pipeline transport vary as a function of the pumping volume, pipeline diameter and distance over a very wide range. Thus, if the volume of petroleum products increases 15-fold from 0.2 to 3.0 million tons, expenditures increase 8-9-fold and expenditures increase 13-15-fold with an increase of transportation distance from 10 to 1,000 km, i.e., 100-fold. Expenditures for initial-final operations are very high at short distances.

An organic part of the country's petroleum product supply system is centers and tank depots designed to accept petroleum products from rail, water or pipeline transport, storage and issue of petroleum products to different   of transport and primarily loading into tank cars or trucks for further hauling.

Cylindrical metal tanks have become most widely used for storage of petroleum products. However, underground reinforced concrete tanks and trench type tanks are used and caverns in salt beds, worked-out mines and other capacities are used abroad for storage of petroleum products.

Table 6.6.

(1) Показатели	(2) Номинальный объем резервуаров, м³				
	100	1000	5000	10 000	20 000
(3) *Стальные цилиндрические резервуары с рулонированным корпусом и днищем*					
Полезный объем, м³ (4)	87	1013	4161	9590	17 050
Диаметр резервуара, м (5)	4,7	12,3	22,8	34,2	45,6
Высота резервуара, м (6)	5,96	8,94	11,92	11,92	11,92
Металлоемкость, т/м³ (7)	73,0	31,0	27,4	26,5	22,9
Удельная стоимость, м³/руб (8)	72,4	15,5	10,1	10,0	9,73
(9) *Стальные цилиндрические резервуары с рулонированным корпусом и днищем, щитовой кровлей и металлическим понтоном*					
Полезный объем, м³	101	1013	4622	10 950	19 450
Диаметр резервуара, м	4,7	12,3	22,8	39,9	45,6
Высота резервуара, м	5,96	8,84	11,84	11,92	11,92
Металлоемкость, т/м³	55,8	25,3	21,7	18,9	19,7
Удельная стоимость, м³/руб	54,5	12,4	7,4	7,3	7,2

Key:

1. Indicators
2. Nominal volume of tanks, m3
3. Cylindrical steel tanks with rolled body and bottom
4. Effective volume, m3
5. Tank diameter, meters
6. Height of tank, meters
7. Metal consumption, tons/m3
8. Specific cost, m3/rubles
9. Cylindrical steel tanks with rolled body and bottom, panel roofing and metal pontoon

The characteristic trend of modern tank construction in the USSR is enlarging the capacity of individual tanks and depots as a whole. Tanks of the most diverse capacities from 3 to 75 m^3 at delivery centers and from 100 to 20,000 m^3 at distributing centers have been established as a function of the designation of the center. Tanks with capacity of 50,000 m^3 have recently begun to be used. Tanks with capacity up to 100,000 m^3 or more are used abroad in countries that mainly utilize imported oil.

The engineering and economic indicators of steel tanks for storage of petroleum products are presented in Table 6.6 [43, 44].

The specific indicators of metal consumption and construction cost will improve significantly with a furtehr increase of the unit capacity of tanks. Thus, specific metal consumption is reduced to 17.0-20.0 kg/m^3 of effective capacity and the specific estimated cost is reduced to 5.7-5.8 rubles/m^3 of effective capacity for tanks having capacity of 50,000 m^3 with permanent covers and pontoons that prevent evaporation of the petroleum products.

Indicators of the specific cost of tank depots are presented in Table 6.7 with regard to expenditures for fire-safety measures and expenditures for tying in to local conditions.

Table 6.7.

(1) Емкость парка, тыс. м³	(2) Емкость одного резервуара, тыс. м³	(3) Число резервуаров в парке, шт.	Удельная сметная стоимость на 1 м³ емкости, руб. (4)	
			резервуарных парков (5)	(6) резервуаров
		(7) *Загрубленные железобетонные*		
480	10	48	20,2	14,6
	20	24	17,9	12,7
	30	16	17,0	11,4
500	50	10	16,7	9,8
		(8) *Вертикальные стальные*		
480	20	24	10,9	6,7
	30	16	9,8	5,6
500	50	10	10,1	5,8

Key:
1. Depot capacity, thousand m^3
2. Capacity of single tank, thousand m^3
3. Number of tanks in depot, units
4. Specific estimated cost per cubic meter of capacity, rubles
5. Tank depots
6. Tanks
7. Hardened reinforced concrete
8. Vertical steel

The specific construction costs of specific tank depots are 10-25 percent higher in some cases that those indicated in Table 6.6 and 6.7.

Thus, further development of the transportation-storage system to supply numerous consumers with petroleum products can be achieved with primary use of pipeline transport to ensure delivery of fuel from plants to large consuemrs (cities) with construction of branches to adjacent oil storage and distributing centers. Delivery of petroleum products from delivery centers near oil refining plants directly to consumers by primarily large-capacity trucks, replacing the intermediate centers of Goskomneftesnab, should be widely developed. The specific weight of shipments of light petroleum products by rail is effectively reduced in the future, especially in mixed pipeline-rail communications with pipelines of relatively short length.

Wider use of river transport, primarily in regions with a sparse rail and highway system, to transport petroleum products is possible.

Development of storage capacities can be oriented toward construction of steel tanks with rolled bodies and bottoms equipped with pontoons and other devices to reduce losses of petroleum products.

Chapter 7. Pipeline Transport of Coal

7.1. Experience of Construction and Operation of Slurry Pipelines for Coal Transport

The favorable engineering and economic indicators of pipeline transport of oil and petroleum products, the positive experience of coal transportation through pipes in mines with hydraulic mining, the extensive use of hydraulic transport at electric power plants to remove slag and also distribution of this type of transport for ore, limestone and other materials over short distances induced extensive investigations on the use of pipelines to move coal over long distances at an electric power plant instead of shipment by rail, water or transmission of electric power over wires.

Hydraulic transport of coal is closely related to mining and burning of the fuel. It cannot be considered in isolation from the entire production chain: mining, storage, preparation for transport, transport, storage, preparation for burning and burning of the fuel.

The engineering solutions and engineering and economic indicators of the Cadiz-Eastlake and Black Mesa coal pipelines constructed in the United States are presented below, which may serve as the initial base for preliminary analysis in solving the problem of the feasibility of using this type of transport.

The Cadiz-Eastlake coal pipeline 174 km long and with productivity of approximately 1.1 million tons/year has been in operation for approximately 6 years and showed high reliability of the entire coal delivery system [70]. Operation of the coal pipeline was economically unprofitable as a result of reducing the rates on the parallel railroad and it was disassembled. The coal pipeline was entered in the production chain of coal delivery without changing the system of mining and burning. The coal pipeline was constructed 254 mm in diameter with average wall thickness of 12 mm (the wall thickness was increased to 18 mm after the pumping stations and was reduced to 8-10 mm before the pumping stations). The working pressure of the pumping units was approximately 80 kgf/cm^2. Pipes of ordinary carbon steel with ultimate strength of about 30 kgf/mm^2 were laid at a depth of 1.2-14. meters (freeze line) with ordinary insulation to protect the pipelines against corrosion. Three pumping stations were constructed on the route--the main station near Cadiz and two intermediate stations 48 and 83 km from the main station. The final section about 81 km long had a slope in the direction of motion of the water-coal slurry.

Water-coal slurry with ratio of 1:1 with coal size up to 1.2 mm was transported when the pipeline was started up. It was found during operation that slurry with composition of one part coal to 0.72 part water by mass with coal size up to 2.4 mm was more economical transport.

A time-equivalent composition of the mixture of 0.7 percent with fraction content of 2.4-1.4 mm, 16.2 percent with fraction content of 1.4-0.6 mm, 21.3 percent with fraction content of 0.15-0.07 mm and 21.3 percent with fraction content up to 0.07 mm was maintained during the operating period. The coal content in the slurry was 594-600 kg/m^3, the density of the hydraulic mixture was 1,200 kg/m^3, coal density was 1,400 kg/m^3, the ash content in it was 7.5-9 percent and sulphur content was 2.5-3.5 percent.

Two reciprocating pumps each with delivery of 150 m^3/hr operated at the pumping stations. They were set in motion by an electric motor with rating of 335 kW through a hydraulic speed-control clutch. The slurry was delivered by pumps to special tanks--covered tanks (dampers) filled with nitrogen, from which it was uniformly ejected into the pipeline. The wet coal concentration wastes were pumped through the pipeline. The water-coal slurry was delivered by two pipelines to the station for preparing the coal for transportation. A flotation concentrate with coal fractions up to 0.15 mm and low content of solid component was delivered through one of them and a flotation concentrate with fractions of 0.15-9.5 mm and high coal content (coal to water ratio in the slurry was 1:2.4) was delivered through the other pipeline.

The hydraulic pulp is crushed into lumps of coal at the hydraulic slurry preparation station, the coal delivered from the concentration plant is dehydrated to optimum slurry composition and inhibitors that protect the inner walls of the pipes against corrosion are added. This part of the installation was a continuation of the wet concentration installation with addition of units to crush thecoal to fractions of 2.4-9.5 mm. Moreover, the installation included a standby warehouse of coal with fractions of 3-9.5 mm which made it possible to provide continuous operation of the pipeline during one-shift operation of the concentration plant.

The experience of operation showed that stable operation of the pipeline depends to a significant degree on a fraction content of 0.045 mm or less, which forms a suspension with increased density that maintains larger fractions in a suspended state.

The coal was dried to total moisture content of 8.5 percent at the receiving end of the pipeline and was delivered in this form by belt conveyor to the electric power plant warehouse. The installation for dehydration and drying of the coal was a complex structure. The water-coal slurry, after pressure was reduced (a vertical pipe with conical plate), was delivered to settling tanks with total capacity of about 5,000 m^3 where the coal was left for 13 hours. The concentrated mixture was delivered by centrifugal pumps from the settling tanks to three vacuum-filters, after which the coal was delivered to four tubular driers. In this case the quartz dust that had already been dried was added to it before the drier. Approximately 3 percent of the transported coal was burned for drying. A scheme for trapping fine dust was provided in the drier. Water with solid particle content of 0.0001 percent was discharged into the waste water system of the electric power plant. The sediment having significant coal content was delivered to the drier where the water was evaporated. The installation was automated and a total of 15 men were involved in maintenance of it.

A total of 7.5 million dollars was expended to construct the pipeline and 5.5 million dollars was expended on the initial and final installations. Moreover, 2.5 million dollars was expended on scientific research work related to development of the pipeline.

The structure of the operating expenses (without deductions for payment of credits) was 43.7 percent electric power, 4.9 percent inhibitors, 22 percent work force, 18.3 percent tools and materials, 9.6 percent miscellaneous expenses and 1.5 percent deductions for special needs. The total expenses in startup of the installation was approximately 25-30 percent below the hauling fee by rail [100]. When the depreciation deductions and other payments were calculated, the calculated service life of the pipeline was taken as 20 years. No appreciable wear of the pipe walls was detected after 6 years of operating the pipeline. It is interesting that microscopic analysis of the coal particles at the beginning and end of the pipeline did not reveal significant differences in the sharpness of edges and pelletization, which indicates the absence of strong friction against the walls and of the particles between each other.

The pipeline was operated with average productivity of 1.2-1.4 million tons/year, but experiments were conducted to operate it under conditions that provide delivery of approximately 220 tons/hr or 1.8-1.9 million tons/year.

The experience of operating the Cadiz-Eastlake pipeline permits the following conclusions:

abrasive wear of pipes by coal at flow rates used in the pipeline and with the adopted granulometric composition is insignificant and the operating periods of trunk coal pipelines with optimum granulometric composition of the coal and coal content in the slurry can be sufficiently long;

the practical possibility of operating a pipeline with approximately 580 kg of coal and 420 liters of water per cubic meter of slurry (the ratio of solid fuel to liquid was 1:0.72) was proven. Slurry with higher coal content up to 600 kg/m^3, i.e., with solid matter to liquid ratio of 1:0.67, was pumped during individual periods;

normal operation of the pipeline is possible at slurry flow rate of approximately 1.4 m/s;

stable operation of the pipeline, the possibility of starting it up after premature and random shutdown and operation with minimum wear of the pipe walls required a quite specific granulometric composition and flow rate and it was determined that these parameters are predetermined to a significant degree by the physicochemical properties of the coal being transported;

the adopted scheme of coal dehydration was extremely complicated and developments were begun during operation to dehydrate the coal by the mechanical method using centrifuges, which simplified the entire system of receiving devices;

the decisive factors of efficient operation of coal pipelines are the engineering and economic indicators not only of the pipeline itself but also of the parallel railroads changed with regard to technical progress and the possibility of changing the rate policy in this regard. Failure to consider this factor led to shutdown of the installation as unprofitable.

Investigations of the spheres of economically feasible use of pipeline transport of coal compared to shipment by rail were carried out with regard to the experience of the Cadiz-Eastlake coal pipeline in the United States. The investigations showed that pipeline transport of coal is effective with volume of 5 million tons/annually or more under conditions of a weakly loaded railway system when assimilation of new volumes of coal does not require development of permanent devices. At the same time the efficiency of coal pipelines begins only with high volumes of coal under conditions favorable to railroads (low development factor, presence of free capacities and so on).

The second trunk pipeline 437 km long was a system introduced in 1970 to deliver coal from the Black Mesa mines in Arizona to the Machova Electric Power Plant in southern Nevada. The system includes a slurry preparation plant, pipeline, pumping station, information monitoring and transmission systems on the operating modes of the pipeline and its individual units and a slurry dehydration installation. The latter is not included in the control of the overall system and is a part of the electric power plant. A system of pipes 450 mm in diameter passes through terrain which has a total slope from the mine to the electric power plant from 1,900 to 150 meters and the drop in height is 900 millimeters during the last 20 km and the pipeline diameter on this section is 300 mm. There are a number of rises on the pipeline route which it intersects without any difficulties. The productivity of the pipeline with regard to irregular operation is 4.4-4.5 million tons at 48-50 percent concentration of solid fraction and flow rate of 1.7-1.75 m/s. The slurry flow rate reaches 4.0 m/s on the final section where a pipeline 300 mm in diameter has been laid to prevent formation of flow interruptions or partial clogging of the pipeline and consequently intensified corrosion of the walls. Transportation time is three days and the filled pipeline contains 45,000 tons of coal.

Four pumping stations were constructed for pumping. Three stations have two each operating and one standby unit and four have three operating and one standby unit of lower productivity, but higher pressure. The pumping stations in the pipeline are controlled from a terminal at the beginning of the system.

The overall operating scheme of the pipeline is as follows. After being crushed to coarseness of not more than 50.8 mm, the coal is delivered from the mines in

Arizona over belt conveyors through scales to the slurry preparation plant. Pit coal with density of 1.45 and moisture content up to 11 percent has an average heat of combustion of approximately 6,800 kcal/kg, ash content fluctuates from 6.5 to 17 percent, with an average of 9.8 percent, and sulphur content fluctuates from 0.38 to 0.43 percent with an average of 0.4 percent.

The coal is delivered by belt conveyors to three hoppers. Each hopper feeds a separate preparation line consisting of an impact (inertial) crusher, rod mill, classifier and centrifugal pump. The inertial crushers pulverize the coal to coarseness of 6.35 mm or less and the rod mills reduce it to coarseness of 2.36 mm or less by wet pulverization. The crushed coal (slurry) is delivered from the rod mill to the classifier. The discharge of the classifier passes through a filter and enters two tanks with capacity of approximately 24,000 m^3 which are supplied with mechanical mixers to maintain the coal particles in a suspended state. The thickened classifier product (coal coarser than 2.4 mm) is returned to the rod mill for prepulverization.

After analysis of the composition, the slurry is pumped from these tanks to a third tank in which the granulometric composition is regulated by addition of water or a solution of high content of small particles and is reduced to strictly given conditions and is pumped in this form by the pumps into the pipeline.

The characteristic feature of slurry preparation is a content of a specific quantity of coal (19.5-21 percent or 20-25 percent according to different data) of coal with coarseness of 0.043 mm or less in it, which does not settle out of the water, holds large fractions in the suspended state for a specific time and ensures stable start-up of the system when it is shut down. Continuous monitoring of the granulometric composition of the slurry is carried out during operation and the established content of fractions less than 0.043 mm is a compulsory condition for delivery of it to the pumping units.

The experience of operating the pipeline led to the fact that the fourth tank at the slurry preparation station should always store a reserve slurry containing only coal with coarseness of not more than 0.043 mm, which is used to flush out the pipeline if large fractions of coal fall into it during a planned or accidental shutdown of the pumps.

The pipeline is operated in a rigid automated mode. Variation of productivity is permitted in the range of ±5-6 percent of the calculated variation, which is achieved by regulating the number of strokes of the pumps by special clutches installed on the drives. All the units are controlled from the central main station combined with the slurry preparation station. Only two persons each work at each station on the "home standby" principle, the task of whom includes overall observation of the units and manual control of them upon variation of operating modes upon instructions from the central control station. The entire system, except the dehydration station, is maintained by 56 persons, of which 12 are workers of the control equipment and 10 are laboratory workers to monitor the slurry composition.

There are slurry storage tanks at the electric power plant designed for 4 days of operation of the electric power plant under full load. The slurry is pumped from the tanks by centrifugal pumps to a bank of 40 centrifuges (20 each for each boiler unit), where 75 percent of the water is removed from it. The coal is heated in the centrifuges, which contributes to better moisture removal.

The wet coal concentrate is transported to 20 fine-crushing mills (10 each for each unit) and further dehydration. Air is delivered to the mill for drying the coal at temperature of 400°C, which also dries the coal during its crushing and transports it to the boiler furnaces. The drainage from the centrigues (centrifuge effluent) containing 6.5-8.5 percent fines is pumped to clarifiers and is subjected to chemical treatment to separate the coal and ash from the water.

The thickened product is usually pumped from the clarifiers having approximately 20 percent of coal by mass directly to the furnaces, while the clean water is directed to the circulating water-cooling system of the electric power plant. Moreover, there are two evaporating ponds at the electric power plant for evaporation of the water from the centrifuge effluent passing through the clarifier. The dried product is used as needed by introducing the slurry formed from the dried coal into the common coal-delivery system of the electric power plant.

The coal delivered from the clarifying tank has increased ash content (40 percent) and is delivered to the boiler furnaces and is burned mainly to prevent environmental pollution by the coal and primarily of the Colorado River on which the electric power plant is located. Evaporation of the water delivered from the settling tanks with the coal reduces the efficiency of the boiler by approximately one-half, but even so an overall improvement in the use of fuel is achieved since the sediment contains 4-5 percent general fuel received by the electric power plant through the pipeline (per fuel mass).

A reserve coal warehouse with capacity for more than 30-day consumption was created at the electric power plant during adjustment of operation of the entire coal pipeline transportation system. However, the pipeline has been operating very reliably during the past year and the reserve warehouse is essentially not used. A pipeline utilization factor equal to 99.2 percent in time has been achieved, which indicates the very high operating reliability of the entire coal pipeline system [100].

The main thing in the coal dehydration system is a continuous coil type horizontal centrifuge with rotor diameter of 1 meter, 2 meters long and with productivity of 19.8 tons/hr.

The use of centrifuges instead of filters to dehydrate the coal after hydraulic transport and adapting the boiler furnaces to burn coal of increased moisture content and also burning the sediment of the centrifuge effluent with evaporation of water contaminated with coal fines are the main differences of the described coal pipeline in preparation of coal for burning from the Cadiz-Eastlake coal pipeline.

Numerous investigations were carried out during adjusting operations to improve the design of the coal preparation installations, coal dehydration and transfer for burning. The pipeline, preparation station and dehydration station now supply coal to an electric power plant with output of 3.58 MW. However, the electric power plant operates in a system with the hydroelectric power plants on the Colorado River and usually has sufficiently uniform load and fuel consumption. An irregular load of the electric power plant leads to irregular operation of the pipeline and causes a number of difficulties in operation since possible fluctuations in coal delivery are limited.

The economic effectiveness of the Black Mesa pipeline is very high. It is constructed in a region where there are no competing railroads and required one-fourth the capital investments that would be required to construct a railroad. The total expenditures for coal transportation comprised about 65 cents/(ton·km) without regard to dehydration expenses, i.e., at the level of rates of existing railroads constructed under favorable relief conditions and having a higher load.

Table 7.1.

Трубопроводные системы (1)	(2) Длина, км	(3) Диаметр, мм	(4) Производительность, млн. т/год
Штат Юта-штат Невада (5)	1760	588	10
Норт Вест (6)	1782	490—588	10
Энеджи Транспортейшн (7)	1678	965	25
Витекс (8)	2000	920—1200	21—38
Хьюстон Нейчрл (9)	1760	200—720	15
Солт ривер (10)	292	392	4
Итого: (11)	9272		85—102

Key:

1. Pipeline systems
2. Length, km
3. Diameter, mm
4. Productivity, million tons/year
5. Utah-Nevada
6. North West
7. Energy transportation
8. Vitex
9. Houston Natural
10. Salt River
11. Total

The least developed link of the system was the dehydration system. The total expenditures per ton of coal and preparation for burning were as follows for 1975: 3.6 dollars for coal, 2.76 dollars for transportation and 1.63 dollars for dehydration and preparation for burning. As can be seen, the fraction of expenditures for dehydration and preparation for burning is high and reaches 25.4 percent of the prepaid cost of the coal of the electric power plant. Moreover, a rapid increase in the cost of reagents for coagulation and the high expenses for a work force to maintain the centrifuges led to the need to develop other less expensive and efficient methods of slurry dehydration and preparation of it for burning. Investigations are being conducted in this direction. It must be noted that the entire system of the pipeline and the dehydration installation was constructed using equipment already being produced by industry with minimum modification. This led to installation of a large number of centrifuges and mills and complication of the entire system for dehydration and preparation of the coal for burning. Enlarging the units and improving them in a direction corresponding more to operating conditions with a slurry of granulometric composition selected by pipeline transportation conditions would undoubtedly improve the economic indicators of this link of the coal delivery system.

The problem of constructing six new systems (Table 7.1) is now being considered in the United States [84, 101].

Designs of a coal pipeline in the Vancouver region to transport coal to Japan and of a coal pipeline from Alberta to the industrial regions of the eastern part of the country have been worked out in Canada. However, despite the great attention devoted to the problem of pipeline transport of coal and bulk products, construction of pipeline systems is proceeding slowly.

The slow rates of development of this type of transport are apparently explained by the following concepts:

inadequate study of the physicochemical processes of pumping coal and preparation of it for pumping and dehydration during burning;

the economic effectiveness of hydraulic transport of coal in coal pipelines of relatively low productivity is similar to an in some cases is even higher than additional expenditures during shipment by parallel railroads. To increase profitability, the railroads frequently establish incentive rates for coal shipment, covering only part of the expenses to maintain permanent facilities, thus increasing the total profitability of shipment of other freight. With reserve carrying capacity of the railroads, this factor is significant and in some cases is of decisive significance. It is for this reason that the possibility of constructing systems with productivity of 25 and 25-38 million tons/year, i.e., with volumes of coal which the railroads are unable to significantly assimilate, is being studied intensively in the United States;

the absence of flexibility in pipeline transport in selection of suppliers of coal or other types of fuel;

the absence of developed types of equipment on the market for pumping stations and slurry preparation installations and high-capacity coal dehydration units.

7.2. The Engineering and Economic Indicators of Slurry Pipeline Transport of Coal

The main parameters that determine the efficiency and engineering and economic indicators of pipeline transport of coal are its concentration in the slurry, the flow rate of the slurry, the wear of the pipeline walls, the tractive resistance of the slurry and consequently energy expenditures, the wear of the pipe and the economic indicators of initial and final operations, i.e., preparation of the slurry and dehydration prior to burning. The difficulties of analyzing the engineering and economic indicators of pipeline transport of coal also include the fact that they differ significantly for different grades of coal and different granulometric composition of the slurry.

The coal concentration in the slurry is usually recommended at 1:1. The tractive resistance is increased and mainly the operating stability is reduced with an increase of coal concentration in the slurry. It is obvious that the pipeline should be capable of startup after premature or accidental shutdown. Otherwise expensive operations are required to flush out the coal that has settled in the pipes and interruptions of the operating mode are inevitable.

Processes of of transporting hydrogenous coal, semibituminous and coking coal in the form of a water-coal slurry have been investigated in Canada. Hydrogenous coal permitted a concentration of not more than 30 percent. A gel formed rapidly in the pipeline with higher concentration which behaves like a clay suspension. Oxidation of the coal and formation of acids are observed in this case. Semibituminous coal with concentration of 28.6-33.7 percent in pumping the slurry through a pipeline 52.2 mm in diameter showed a sharp increase of pressure losses with an increase of coal concentration in the slurry and with an increase of the flow rates. Thus, the pressure losses comprised 0.6 kgf/cm^2 per 100 meters of pipeline at coke concentration of 30.9 percent and approximately 13.0 kgf/cm^2 with concentration of 33.7 percent at a flow rate of 1.5 m/s. An increase of flow rate to 2.5 m/s increased these indicators to 10 and 26, respectively.

Pressure losses when pumping coking coal with reduction of concentration, on the contrary, increased somewhat [45] and decreased with an increase of pipeline diameter. The losses were a total of 0.35 and 0.75 kgf/cm^2 per 100 meters, respectively, for pipeline diameter of 100 mm at flow rates of 1.5-1.6 m/s.

The dependence of the pressure losses of a water-coal slurry with coal content of 60 percent and different granulometric composition with maximum coal particle size of 2 mm on flow rate is presented in Figure 7.1. As can be seen, an increase in the content of particles measuring 0.07 mm or less sharply increases the tractive resistance and this increase is greater, the higher the flow rate [45]. The data were found for a pipe 50.8 mm in diameter. The indicators of pressure losses also varied sharply with variation of pipe diameter, but the overall nature of the function remains constant--the tractive resistance increases with an increase of fine fractions. Wear of the pipes is also dependent on flow rate. Wear of the pipes increases rapidly with an increase of flow rate. Abrasive wear of pipes was insignificant at flow rate of the water-coal slurry of 1.5 m/s in the Cadiz-Eastlake pipeline.

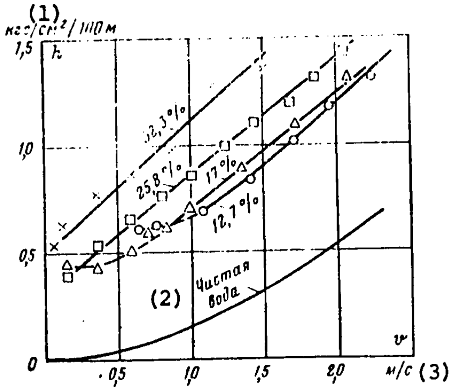


Figure 7.1. Dependence of Flow Pressure Losses of Water-Coal Slurry With Different Content of Fine Fractions of 0.07 mm on Flow Rate

Key:
1. kgf/cm^2/100 meters
2. Clean water
3. Meters per second

Laboratory investigations showed that the wear of pipe walls increases sharply with an increase of flow rate, especially above 2.0-2.5 m/s. This can be explained by the very careful approach to selection of slurry flow rates with an increase of pipeline diameter. Thus, in proposals to construct pipelines with productivity of 25-38 million tons, the slurry flow rates were increased to 1.85-1.90 m/s and the productivity of a pipeline 1,000 mm in diameter was approximately 23-25 million tons, while that of a pipeline 1,200 mm in diameter was 35-38 million tons depending on the slurry concentration.

It is obvious that, except for pipe diameter, the slurry flow rate limited by wear of the pipe walls is also dependent on the strength of the coal and mainly on the abrasiveness of the inclusions. Thus, one can assume that coal of the Ekibastuz basin, having a considerable number of quartz inclusions in its composition, will have high abrasiveness and transport of it through pipelines will apparently encounter serious difficulties; on the other hand, coal of many seams of the Kuznetsk basin do not have these inclusions and may apparently be transported at somewhat higher flow rate than coal with increased abrasiveness.

On the other hand, the slurry flow rate cannot be lower than the critical flow rate since the coarser coal particles begin to settle to the bottom part of the generatrix of the pipe. At the same time the critical flow rate depends to a significant degree on the granulometric composition and primarily on the content of fractions of particles 0.043 mm or less, which slowly settle out from the slurry and prevent coarser particles from settling out. An increase in the content of these fractions leads to an increase of the tractive resistance of the slurry and to an increase of energy expenditures.

It is obvious that investigations must be conducted for each grade of coal subject to transportation and for each pipe diameter to select the optimum granulometric composition of the slurry, to determine the critical flow rates that determine startup of the pipeline after shutdown and the maximum flow rates that provide permissible wear of the pipe walls and acceptable energy expenditures and also to protect the pipe walls against corrosion due to the effect of oxygen dissolved in the water, for example, by the use of inhibitors.

Development of pipeline transport of coal, especially over long distances, requires solution of the problem of a phased increase of pipeline productivity. A desire to increase the economic effectiveness of long pipelines dictates the use of large-diameter pipes with high productivity: for example, laying pipes 1,220 or 1,420 mm in diameter and with productivity of 35-40 and 50-60 million tons/year, respectively, is required to deliver Kuznetsk or Kansk-Achinsk coal to the European USSR. This amount of coal will support the operation of three to five of the largest electric power plants with output of 5-6 million kW each, depending on the calorific value of the fuel being transported. Putting these systems into operation requires solution of the following problems in pipeline design:

the fuel consumers will be dispersed over a significant distance from each other and construction of a branched system and distribution of the slurry through the branches will be required to deliver fuel to them;

the units will be introduced at these stations over several years rather than at the same time as a function of the needs for electric power and heat. Consequently, the productivity of the coal pipeline system should be increased gradually.

One of the ways of regulating fuel delivery may obviously be variation of the slurry concentration with output to the optimum mode by the time all the electric power plants supplied by the pipeline are brought up to full capacity. However, this leads to an increase of expenses during the partial loading period with regard to pumping a large quantity of water.

This scheme for increasing the carrying capacity requires that all pumping stations be put into operation simultaneously and it cannot be optimum. More effective methods of a phased increase of pipeline productivity must be found, which requires special investigations.

There may be startup of the first units of electric power plants with delivery of coal to them by rail as one of the versions for putting a coal pipeline of high productivity into operation with high load level. In this case the pipeline can be introduced at a moment when its load will immediately support operation in a mode close to optimum. Some complication of the coal management of the power plant adopted to receive coal from the railroad is required, which will subsequently remain as a reserve. There is no experience in these solutions.

Long and short pipeline systems were previously constructed to supply an electric power plant of specific output without extensive changes in coal delivery during operation. There were cases at short installations of laying additional runs of pipeline with an increase of electric power plant output, for example, at plants in the Kuznetsk coal basin.

The process of bringing high-productivity slurry pipelines, designed to deliver coal to several consumers, for example, large electric power plants with sequential introduction of individual units at them, up to design capacity is a complex scientific and engineering problem that requires the most careful attention. Solution of it will predetermine to a significant degree the effectiveness of using hydraulic transport of large-diameter pipes to move considerable quantities of Kuznetsk and Kansk-Achinsk coal to the Urals and to the western regions of the country.

Comparative data on the engineering and economic indicators of pipeline transport of coal, rail transport and electric power transmission lines are of interest. The results of calculating the expenditures to transport coal with different particle size, made for United States conditions when using pipes from 300 to 610 mm in diameter are presented in Figure 7.2. As can be seen, the expenditures to transport coal with an increase of productivity of the unit from 5 to 15 million tons decrease from 10 to 8.0-8.5 centers per 10 tons·km in 1975 prices. If these indicators are compared to the rates for rail shipments effective in the United States (approximately 8 cents for mass freight), then we see that the expenditures in pipelines of even relatively large diameter (610 mm) are at the level of rail tariffs and the use of pipelines to transport coal is economically justified if they significantly reduce the length of the route or operating conditions of the railroads and they require significant expenditures to develop carrying capacity. This indicates the need for an individual approach to analysis of the economic effectiveness of

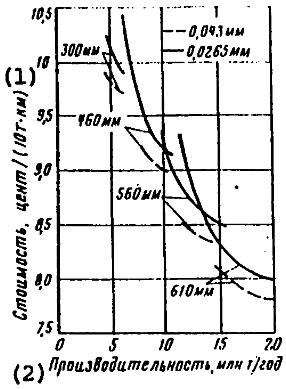


Figure 7.2. Cost of Coal Transportation by Coal Pipelines of Different Productivity

Key:
1. Cost, cents/(10 tons·km)
2. Productivity, million tons/year

using coal pipelines. The results of these comparisons, made for the Wyoming-Arkansas pipeline [101] with productivity of 25 million tons and with pipe diameter of 965 mm, are presented in Table 7.2.

an increase of metal expenditures by 30 percent in rail transport (with lifetime of rolling stock used in the USSR) is explained to a significant degree by lengthening the route. If the output of the power plants is compared, one must take into account that the utilization factor of locomotive output is lower by several factors in time than pumping equipment usually operated under a load close to full. A significant saving is achieved in pipeline transport in work force: the number of personnel in pipelines is reduced by a factor of 7.5 and even by a factor of 5.5 with identical length of the route due to the more extensive automation of production processes.

Data on variation of expenditures on moving fuel by different types of transport are presented in Figure 7.3 as a function of productivity determined by the Bechtel Company (United States) which designed the Black Mesa pipeline. As can be seen, the indicators of electric power transmission lines are less favorable in all cases than pipeline transport and rail shipments.

The indicators of pipeline transport of coal with productivity of 25 million tons/year and route length of 1,600 km is lower by a factor of 1.4-1.6 than in rail shipments and approximately 30 percent of this saving is related to shortening of the route and the remaining part is due to the characteristics of pipeline transport. It must be noted that the expenditures for rail shipments were assumed to be stable and do not vary with an increase of volume in the given functions. This does not correspond to reality since specific transportation expenses on railroads decrease with an increase of their load within optimum limits.

Table 7.2.

(1) Показатели	(2) Трубопровод диаметром 965 мм	(3) Железная дорога и 4600 вагонов с опрокидывающимися кузовами
Расстояние, км (4)	1660	2140
Расход стали, тыс. т (5)	387	750[1]
Силовые установки мощностью, тыс. л. с. (6)	(7) 10 насосных станций 273	(8) 210 локомотивов 630
Энергоноситель (9)	(10) Каменный уголь, электроэнергия	(11) Дизельное топливо
Численность обслуживающего персонала, чел. (12)	335	2575

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[1] With regard to replacement of all rolling stock after 15 years of service. Steel consumption is about 500,000 tons with service life of rolling stock of 30 years.

Key:
1. Indicators
2. Pipeline 965 mm in diameter
3. Railroad and 4,600 rail cars with tipper bodies
4. Distance, km
5. Steel consumption, thousand tons
6. Power plants with output, thousand horsepower
7. Tin pumping stations of 273 hp
8. 210 locomotives of 630 hp
9. Energy carrier
10. Pit coal and electric power
11. Diesel fuel
12. Number of maintenance personnel, persons

Inflation processes observed in the capitalist world are reflected in current expenditures. Different authors have estimated inflation for pipeline transport at 1-3 percent and for rail transport, which has a considerably higher specific weight of current expenses, at 5.0-7.5 percent annually. In the total annual increase of expenditures, even with equal indicators in 1975 prices, the expenditures with pipeline transport are one-half as much or less within 20-25 years than in rail transport.

It must be noted that the cost of coal shipments by rail have been reduced by one-half during the past 25 years in the USSR (see Chapter 3), while they have remained unchanged in pipeline transport (gas or oil pipeline) (see Chapters 4 and 5), despite construction and operation of these pipelines during the past few years under all less favorable conditions. Technical progress compensated for the increased expenditures for construction and operation of pipelines under northern or desert conditions.

Energy expenditures with coal pipelines are somewhat higher than in rail shipments. The consumption of electric power on the Cadiz-Eastlake pipeline was 35-40 kW·hr per 1,000 tons·km of natural fuel or it was 49-55 kW·hr per 1,000 tons·km of

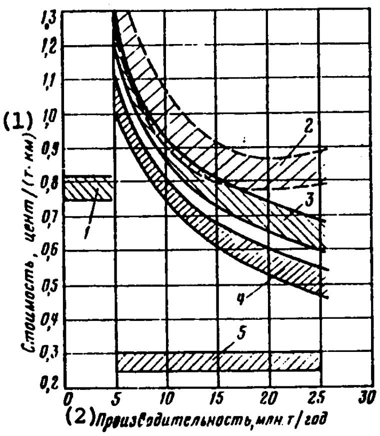

Figure 7.3. Comparison of Engineering and Economic Indicators of Coal (Electric Power) Transport by Various Types of Transportation: 1--rail shipments over a distance of 800-1,600 km; 2--electric power transmission lines for a distance of 1,600 km; 3--coal pipeline for a distance of 800 km; 4--coal pipeline for a distance of 1,600 km; 5--shipments over rivers in barges for a distance of 800 km

Key:
1. Cost, cents/(tons·km)
2. Productivity, million tons/year

comparison fuel with coal having heat-forming capacity of 51 kcal/kg. Electric power consumption of 20-30 kW·hr to pump 1,000 tons·km of slurry or 40-60 kW·hr in conversion to natural fuel can be expected for large-diameter pipes (600-700 mm). Expenditures to pump a water-coal slurry in the Black Mesa and Vitex pipelines, calculated for capacity of the installed operating equipment, are approximately 30-35 percent higher than with rail shipments. About 1.7-2 percent of the fuel to be transported will be expended on the average in transportation of coal with heat-forming capacity of 5,500-6,500 kcal/kg per thousand km. Fuel consumption for self-needs will comprise about 7 percent of the fuel to be delivered during transportation for 2,500 km with regard to expenditures of up to 3 percent of fuel for dehydration and drying.

With pipeline transport, one should expect a significant reduction of labor resources since pipeline control should be fully automated under all conditions for normal operation.

Investigation of the effectiveness of using coal pipelines under USSR conditions permits one to make the following conclusions:

construction of pipelines in regions where there are no railroads is feasible with any volumes, since a coal pipeline yields better engineering and economic indicators than construction and operation of a railroad just for shipping coal;

construction of a coal pipeline along a loaded single-track railroad is feasible with coal volume of more than 5-8 million tons;

construction of a coal pipeline along a loaded two-track railroad is feasible with coal volume of 15-20 million tons annually;

construction of a coal pipeline along a railroad mainline adapted to handle trains with mass of 10,000-12,000 tons, is feasible with coal volume of 30-35 million tons.

Since the expenditures for development of the carrying capacities of railroad mainlines, as was shown above, are very individual and since the indicators of pipeline transport should be confirmed by practice, the indicated recommendations should be assumed approximate. Rather reliable data for comparison of the effectiveness of coal pipelines, railroads and electric power transmission lines can be obtained only by detailed substantiations at the level of TEO [Engineering and economic substantiation], carried out with regard to specific conditions: a reduction in the length of the coal pipeline route compared to railroad routes, determination of the actual expenditures to develop rail transport with regard to retention of potential reserves to ship other freight, creation of reliable operating conditions of the coal pipeline under severe climatic conditions and so on. According to preliminary concepts, the use of coal pipelines is effective to transport mass quantities of coal from the country's eastern basins, primarily from the Kuznetsk basins, with it being used to power the electric power plants of the Urals and the European USSR.

With regard to the prospects of this type of transport, it is desirable to construct an experimental-industrial installation to check the operation of pipelines under severe climatic conditions, variable load and other features which may occur when transporting large masses of coal to a considerable number of consumers operating with irregular load.

Chapter 8. Water Transport of Fuels

8.1. River Transport

The role of river transport in fuel shipments varies significantly as the Soviet Union's energy balance develops. Formation of a system of deepwater routes in the European USSR created conditions for mass shipments of fuels. Construction of the Moscow Canal and Volga-Don Canal and development of the deepwater system of the Volga, Kama and Dnepr Rivers led to an increase of shipments by river transport, to an expansion of its sphere of influence and to an increase of efficiency.

The coincidence of river routes with transportation and economic ties in coal, oil and petroleum products from the Donetsk coal basin and the oil fields of Baku and the Northern Caucasus contributed to development of fuel shipments through the Volga-Kama basin. River transport played a significant role under these conditions in supplying the Donetsk basin and Volga and Ukrainian regions with coal. A mechanized port was constructed at Ust'-Donetsk to transload coal onto ships of the Volga-Kama basin and a fleet adapted for bulk cargo was created.

Improving the structure of the country's energy balance, increasing the specific weight of oil and gas, slowing the growth rates of coal production in the Donetsk basin and the vigorous development of industry in the country's southern regions led to a sharp increase of local coal consumption. All this caused stabilization and then some reduction of coal shipments in the Volga-Kama basin. The development of inexpensive coal mining in the Kuznetsk basin and the improvement of rail transport contributed to this. The reduced expenditures for mining and transport of Kuznetsk coal to the Volga area became lower than the corresponding expenditures for coal of the Donetsk basin with regard to the seasonal nature of river transport operation.

The overall direction of transportation and economic ties in coal changed: it became latitudinal instead of meridional.

River shipments of coal now coincide with the general route of transportation and economic ties only on the Dnepr River and in mixed rail-water traffic. Coal of the Kuznetsk basin is shipped along the Kama River and the upper reaches of the Volga River to the central and northwestern regions of the country with transloading from the railroad to water at Perm' or Kambarka.

Even more significant changes occurred in the transportation and economic ties for oil and petroleum products. Discovery of oil fields in Tatariya, Bashkiriya and the Volga area transformed these regions from oil importers to exporters of oil and petroleum products. Construction of a number of large oil refining plants in cities on the Volga River and delivery of oil to them through pipelines from local fields eliminated the mass shipments of petroleum products from the south. The system of river routes of the European USSR began to haul petroleum products mainly to regions adjacent to the Volga and Kama rivers and to navigable tributaries.

The rivers of the country's Asian part also participate in shipments of petroleum products. The country's northern regions are supplied along them, where there are no other transportation routes. Discovery of oil fields in the regions of the central course of the Ob' River and in the region of Mangyshlak led to temporary river shipments of oil from the fields not yet connected to truck pipelines, but these shipments fell off as pipelines were constructed.

The important role of river transport in development of the oil and gas fields of the Western Siberian lowland must be noted. The first and most complex phase in development of the oil fields of the Central Ob' region was fulfilled with shipment of all cargo by river and to a significant part by air transport. The gas fields of the northern regions of Tyumenskaya Oblast (Medvezh'ye, Urengoy and so on) are now being developed while still begin supplied by river transport. These shipments, although they are not shipments of fuels, made it possible to develop the oil and gas fields and to create the country's new fuel base.

There is a wide range of dimensions of self-propelled and nonself-propelled river vessels in the USSR that support shipments of coal, oil and mainly of petroleum products under different conditions of waterways. Self-propelled dry-cargo vessels and tankers with capacity from 2.7 to 5.0 million tons are used to ship fuels over the major river routes, specifically along the deepwater system of the European USSR and the Dnepr that have guaranteed depths, while dual vessels--a self-propelled ship and a nonself-propelled barge of approximately the same capacity are used extensively and the total tonnage reaches 9,000-10,000 tons.

Bulk and liquid cargo is shipped more and more in nonself-propelled vessels which are usually employed in combinations of 2-4 barges with a single pusher. The total tonnage of the barges is being increased continuously. During the past few years barge systems consisting of three nonself-propelled vessels with tonnage of 9,000 tons each and a pusher with rating of 4,000 horsepower have begun to be operated during the past few years. Experimental-operational voyages of systems consisting of four of these barges with total tonnage of 36,000 tons were carried out in 1976; extensive use of barge systems of this tonnage makes it possible to reduce expenditures for transportation of petroleum products from the oil refining plants to large consumers or transloading bases.

Mixed navigation vessels: river-sea, are becoming more and more widespread. These vessels, constructed for strength and equipped for conditions of limited operation at sea, are used to haul fuel and other cargo primarily to supply the needs of prospecting and exploitation drilling in the northern regions of Tyumenskaya Oblast. Tankers of reinforced design are used to operate under conditions of other Siberian rivers with exit to marine gulfs.

The use of pushed barges with greater tonnage than self-propelled vessels yields better engineering and economic indicators in the European USSR with relatively high volumes of petroleum products. The results of operating different types of vessels to transport fuel oil to coastal TETs in 1975, according to data of the Volgotanker Shipping Company, are presented in Table 8.1.

Table 8.1.

(1) Показатели	(2) Несамоходные суда		(3) Самоходные суда	
	(4) 2 баржи по 9000 т, толкач 4000 л. с.	2 баржи по 9000 т, толкач 4000 л. с.	1 баржа 9000 т, толкач 1340 л. с. (5)	Танкер, 5000 т (6)
(7) Грузооборот за рейс, млн. т·км	15,3	14,5	6,9	4,3
Производительность труда, (8) тыс. т·км/чел-сут	102,7	112,8	74,8	49,4
Себестоимость перевозок, (9) коп/(10 т·км)	0,62	0,36	0,66	0,83

Key:

1. Indicators
2. Nonself-propelled vessels
3. Self-propelled vessels
4. Two barges of 9,000 tons each and a pusher of 4,000 horsepower
5. One barge of 9,000 tons each and a pusher of 1,340 horsepower
6. Tanker, 5,000 tons
7. Freight turnover per voyage, million tons·km
8. Labor productivity, thousand tons·km/man-days
9. Cost of shipments, kopecks (10 tons·km)

A system consisting of two barges with tonnage of 9,000 tons each and a pusher with rating of 2,000 horsepower was the most efficient, but other less efficient combinations, according to all engineering and economic indicators, were fmre favorable than a self-propelled tanker of 5,000 tons. But since the navigation conditions through large reservoirs and in marine gulfs require extensive use of self-propelled vessels, one must proceed from the possibility of operating both pushed and self-propelled vessels when considering the engineering and economic indicators of river shipments of fuels.

A river fleet must be developed for the small rivers to supply the country's interior regions, especially the northern and northeastern regions, with petroleum products. Although the operational and economic indicators of these shipments are worse by a factor of 3-5 than similar indicators for major rivers, they usually are considerably more favorable than indicators in hauling of fuel by motor transport, especially through wintering-over areas.

Special barges of 1,000 tons with pushers of 300-450 horsepower, which can be operated with draft from 0.9 to 1.7 meters, and tankers of 200-250 tons are required for rivers 1.0-1.2 meters deep.

The engineering and economic indicators compiled for the main classes of ships are presented in Table 8.2 for preliminary analysis of the efficiency of river shipments of fuels [48].

The disruption of the overall situation in some cases on a reduction of expenses with an increase of the tonnage of vessels of the same class merits attention in the given indicators. This is explained by the difference in classes and the requirements on strength determined by navigation conditions for which they are designed, by the number of ships constructed and construction conditions and by the number of crews and other factors.

Table 8.2.

(1) Тип судна, грузоподъемность, т	(2) Осадка, м	Капиталовложения (3)		Эксплуатационные затраты (4)		Приведенные затраты при $E_{н} = 0,12$ (5)	
		(6) Движение, коп/(10 т·км)	(7) Начально-конечные операции, коп/(10 т·км)	Движение, коп/(10 т·км)	Начально-конечные операции, коп/(10 т·км)	Движение, коп/(10 т·км)	Начально-конечные операции, коп/(10 т·км)
Сухогрузные суда (8)							
(9) СО-5300	3,5	3,6	1937	0,34	168	0,77	400
СО-2700	3,5	8,2	1972	0,61	235	1,60	472
(10) СМ-2150	2,5	7,1	2000	0,76	221	1,62	461
СО-1800	2,25	3,9	946	0,54	158	1,01	283
СО-1500	2,2	4,5	984	0,64	173	1,18	291
СО-1000	1,4	5,7	1020	0,80	185	1,49	305
СО-340	1,25	9,8	1770	1,77	413	2,95	672
(11) СР-150	1,0	13,0	2320	3,35	686	4,92	918
Танкеры (12)							
(13) НО-4800	3,5	3,5	1835	0,38	177	0,80	397
(14) НМ-2152	2,5	7,1	1980	0,80	220	1,66	460
НО-1500	2,2	4,1	965	0,72	192	1,20	342
НО-600	1,55	4,8	1060	1,15	259	1,73	387
(15) НР-150	0,9	21,0	2864	4,51	754	6,99	1048
Сухогрузные составы (16)							
4×4500	3,5	1,67	645	0,2	68	0,4	146
4×3000	3,5—4,0	2,12	613	0,25	80	0,5	154
2×3000	2,8	2,76	702	0,31	87	0,59	172
2×1950	2,25	3,78	721	0,46	107	0,92	193
2×1000	1,6	3,90	764	0,52	150	0,99	241
4×6000	1,4	4,30	641	0,55	164	1,07	241
2×400	1,1	6,10	1088	1,04	287	1,77	417
2×200	1,0	4,60	1372	1,65	500	2,2	665
Наливные составы (17)							
2×9000	4,0	1,9	1140	0,22	90	0,45	226
2×3000	1,8	2,9	770	0,39	102	0,74	194
2×2000	2,2	3,2	677	0,44	105	0,82	185
2×400	1,1	5,1	9978	1,35	302	1,96	419
1×200	1,0	7,0	2736	3,4	690	4,20	1020

Key:

1. Class of vessel, tonnage, tons
2. Draft, meters
3. Capital investments
4. Operating expenses

[Key continued on following page]

Key (Continued from preceding page):

5. Reduced expenditures at E_H = 0.12
6. Traffic, kopecks/(10 tons·km)
7. Initial-final operations, kopecks/(10 tons·km)
8. Dry-cargo vessels
9. SO
10. SM
11. SR
12. Tankers
13. NO
14. NM
15. NR
16. Dry-cargo barge systems
17. Liquid barge systems

The considerably lower expenses for pushed barges, which are more promising for shipment of relatively inexpensive fuels, should also be noted.

Each river basin has a number of characteristics which can be taken into account with a knowledge not only of permanent characteristics but of shipping conditions during a given season (guaranteed depths, presence of a fleet, the possibility of return loading and so on). Therefore, the indicators of transportation expenses given in Table 8.2 are approximate. The length of the navigation system must primarily be taken into account for more accurate analyses. The data of Table 8.2 were compiled for a navigation season of 200 days along the Volga, Kama and other rivers of the central regions of the European USSR and expenditures for northern rivers are 10-15 percent higher, those for the rivers of Western Siberia are 40-60 percent higher, expenditures for rivers of the Amur basin are 72 percent higher, those for the Lena basin are 2.3 times higher, those for the rivers of the Kalymo-Indirgirko basin are 4 times higher and a coefficient of 0.85-0.9 can be introduced for rivers of the southern regions.

Chapter 9. Electric Power Transmission Lines

[Text] Construction of electric power plants of high unit capacity and development of the country's unified energy system and CEMA member countries led to rapid development of electric power transmission lines and the use of them not only to distribute electric power between consumers and formation of energy systems, but also for transportation purposes. Electric power transmission lines took on themselves in some cases the functions of replacing fuel transport by electric power transmission over wires, primarily transmission of electric power from hydroelectric power plants to regions where construction of thermoelectric power plants would be required as an alternative development of power engineering.

Electric power transmission lines with voltage up to 110 kV can be compared by scales of freight turnover to motor transport and those of higher parameters can be compared to rail shipments or pipelines.

The specific weight of the length of electric power transmission lines with voltage of 35 kV and higher and the corresponding specific weight of the freight turnover calculated by the number of hours of usage of the lines typical for each voltage are presented in Table 9.1.

Table 9.1.

(1) Напряжение, кВ	1965		1970		1975	
	(2) Удельный вес в общей протяженности линий, %	(3) Удельный вес в выполнении транспортной работы, %	Удельный вес в общей протяженности линий, %	Удельный вес в выполнении транспортной работы, %	Удельный вес в общей протяженности линий, %	Удельный вес в выполнении транспортной работы, %
35	42,6	2,2	39,7	2,1	41,3	2,2
110—154	40,0	10,6	41,5	10,1	43,0	10,2
220—330	14,8	29,6	14,6	26,7	12,0	25,2
500 и выше (4)	3,4	55,3	4,2	61,1	4,0	62,4

[Key on following page]

Key [Continued from preceding page]:

1. Voltage, kV
2. Specific weight in total length of lines, percent
3. Specific weight in performing transport work, percent
4. 500 and above

The total freight turnover performed by electric power transmission lines is relatively low and comprised 2.6 percent in 1965, 2.8 percent in 1970 and only about 3.0 percent in 1975 of the total freight turnover performed by the country's transportation system in freight shipments. In this case approximately 88 percent of the freight turnover is performed by electric power transmission lines with voltage of 220 kV and higher, although their specific weight in the total length of systems comprised only 16.0 percent in 1975. One must also take into account that part of electric power transmission lines performs distributing functions or intersystem communications, operating in a direction opposite to fuel delivery.

Electric power transmission lines with voltage of 500 kV and above are of interest for major transport of electric power in quantities comparable to the carrying capacities, for example, of rail transport.

The world's first alternating current electric power transmission line of this voltage with length of approximately 1,000 km was constructed in the USSR in 1957 from the Volzhskaya GES imeni V. I. Lenin to Moscow. The Volzhskaya GES imeni 22nd CPSU Congress to Moscow, a distance of 1,010 km, the Volzhskaya GES imeni V. I. Lenin to the Urals, a distance of 1,000 km, and so on were later constructed. These lines are mainly connecting lines for the power systems of the Center, the Volga area, the Urals and Siberia.

Taking the comparatively insignificant carrying capacities of electric power transmission lines with voltage of 500 kV into account, investigations are being conducted in many countries to create and develop alternating current electric power transmission lines with voltage up to 700-750 kV. An experimental-commercial electric power transmission line of this voltage, the Moscow-Konakovo-Leningrad line, with total length of approximately 600 km has been constructed in the USSR. The trans-Ukrainian line with voltage of 750 kV approximately 1,000 km long has been constructed in the southern power system.

Investigations are now being conducted in some countries to develop alternating current electric power transmission lines with voltage of 1,000-1,200 kV which will make it possible to transmit power of 5,000-6,000 mW over a distance of 1,000 km or more. The power delivery of two circuits of this line is equivalent to the carrying capacity of a single-track railroad specialized to transport coal (up to 30-35 million tons).

Developments of alternating current electric power transmission with voltage of 1,150 kV and power of 6,000 MW have been completed.

The dependence of the carrying capacity of alternating current electric power transmission lines on the length of transmission is shown in Figure 9.1. The

Table 9.2.

(1) Показатели	Напряжение, кВ (2)		
	500	750	1150
(3) Максимальная передаваемая мощность, МВт	900—1000	2000—2500	5000—6000
Капиталовложения, млн. руб(4)	54,0	156	320—480
в том числе: (5)			
линейная часть(6)	40,0	100	140
подстанции(7)	14,0	56	180—340*
Потребность в цветном металле, тыс. т (8)	7,7	12,4	20,7
Потребность в стали, тыс. т(9)	40,9	43,3	87,7
Эквивалентное количество минерального топлива, млн. т условного топлива(10)	2,0—2,5	4,8—5,2	10,0—11,0

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*The first figure is with a single transformer and the second figure is with two transformers.

Key:

1. Indicators
2. Voltage, kV
3. Maximum transmitted power, mW
4. Capital investments, million rubles
5. Including
6. Line part
7. Substation
8. Need for nonferrous metal, thousand tons
9. Need for steel, thousand tons
10. Equivalent amount of mineral oil, million tons of comparison fuel

graphs were calculated for economic current density based on generation of electric power from inexpensive strip-mined coal [68].

The engineering and economic indicators of these electric power transmission lines 1,000 km long are presented in Table 9.2.

It is obvious from these data that alternating current electric power transmission lines with voltage of 500 kV cannot serve as a means of transportation that replaces shipment of fuel in mass quantities. They have been developed extensively as distributing systems and to transmit electric power from large thermoelectric and hydroelectric power plants and also for intrasystem electrical communications. They transmit power opposite to the general flow of fuel in some cases. The use of these transmission lines makes it possible to strengthen the electric power plants, to improve reservation conditions and to have other advantages upon expansion of the unified power system, which makes their construction effective.

Electric power transmission lines with voltage of 1,150 kV yield an even more significant transportation saving. With a distance of 1,000 km they can replace shipment of 10-11 million tons of comparison fuel. These scales of carrying capacity create the possibility of extensive use of these lines to transmit electric power from large hydroelectric power plants or from large thermoelectric power plants operating on inexpensive hydrogenous coal with high expenditures for shipment of it by rail or another type of transport. Electric power transmission with these characteristics may, for example, be used extensively to supply Western and Eastern Siberia with electric power generated on coal from the Kansk-Achinsk basin.

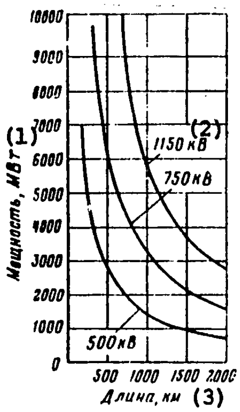

Figure 9.1. Carrying Capacity of Alternating Current Electric Power Transmission Lines as a Function of Voltage and Length of Line

Key:
1. Power, MW
2. Kilovolts
3. Length, km

The use of electric power transmission lines with voltage of 750 kV to replace shipment of coal by other types of transport is economically feasible only in some cases with unfavorable indicators of fuel transportation by rail.

Direct current electric power transmission lines are considerably more promising to transmit energy in mass quantities.

A direct current electric power transmission line with voltage of 800 (± 400) kV was constructed in 1962 to link the Volzhskaya GES imeni 22nd CPSU Congress (Volgograd system) to the power system of the Donbass, a distance of 473 km. The calculated output is 750 MW, while the maximum amount of transmitted electric power is estimated at 4 billion kW·hr/year. It can operate in the reserve mode, which is one of the advantages of direct current electric power transmission. Volgograd-Donbass electric power transmission made it possible to finish individual elements of the system and primarily to equip the converting substations for more powerful electric power transmission with voltage of 1,500 (± 750) kV, as, for example, Ekibastuz-Center [68].

Engineering Parameters of Electric Power Transmission Line

Length, km	2,414
Cross section of conductors, mm (per pole)	5ASO-1,200
Transmitted power at starting end of electric power transmission, MW	6,000
Power losses, percent	10.7
Power on receiving end of electric power transmission, MW	5,400
Amount of energy on starting end of electric power transmission, billion kw·hr/year	42

Power losses, percent	10
Amount of energy on receiving end of electric power transmission, billion kW·hr/year	38.5

Operation of this electric power transmission line with use of approximately 7,000 hours annually makes it possible to replace shipment of approximately 13.0 million tons of comparison fuel by rail (according to the amount of electric power on the receiving end of electric power transmission) or approximately 21.0 million tons of Ekibastuz coal. In this case approximately 2.5 million tons of coal will be consumed for power losses, i.e., approximately 2.5 times more than to ship this coal by rail with electric traction.

Comparison of the engineering and economic indicators of electric power transmission lines (without regard to the intersystems effect) to rail shipments of Ekibastuz coal with heat value of 4,000-4,100 kcal/kg showed that the capital investments in rail transport are 30-40 percent lower and metal consumption is lower with a two-track mainline, eight-axle rail cars of dimension 1-T with capacity of 125-130 tons, train mass up to 12,000-13,000 tons and with electric traction. The operating expenses for an electric power transmission line are considerably lower. The versions of constructing electric power transmission lines and development of a railroad are similar in the total reduced expenditures.

Electric power transmission lines will have more favorable specific indicators when the engineering and economic indicators of the electric power transmission line and a single-track railroad are compared to the parameters used. With these indicators, electric power transmission lines with voltage of 1,500 (± 750) kV permit accumulation of the experience required to develop more powerful lines with better engineering and economic indicators. Moreover, construction of an electric power transmission line of 1,500 (± 750) kV provides intersystems communication that permits a very significant intersystems saving equal to 1,400 MW, which will be achieved mainly by reducing the established output of electric power plants--reducing the emergency power reserve and as a result the relative time shift of maximum load connected by a given line of power systems. Construction of electric power transmission lines is quite economically justified with regard to the saving of expenditures for development of generated capacities.

However, the intersystems saving is achieved mainly with construction of the first latitudinal electric power transmission lines that connect the Siberian and Kazakhstan power systems to that of the European USSR in the Urals into the country's unified energy system and the intersystem saving will be decreasing in nature with introduction of new latitudinal lines. Subsequent lines constructed in the latitudinal direction will mainly play a transport role and the feasibility of constructing them can be established by comparing the engineering and economic indicators of possible versions of fuel and electric power transport.

Determination of the engineering and economic indicators of long distance direct current electric power transmission lines of superhigh voltages encounters serious difficulties due to the absence of experience in construction and operation and also similar analogs. The following characteristics of electrical transportation must be taken into account to achieve indicators of long-range electric power transmission lines comparable to the indicators of other types of transport.

Electric power losses for heating of conductors and the corona at conversion substations (in transformers, rectifiers, inverters and so on) are very high. The expenditures related to losses exceed several times the power expenditures in other types of transport. Achieving the indicators being compared requires consideration of corresponding expenditures for the types of transport being compared. In this case all losses in electric power transmission can be estimated from indicators for production of electric power taken from the buses of electric power plants and the expenditures (losses) of energy resources in other types of transport are distributed over the entire length of the transport mainline and covering these losses may require expenditures different from those to generate electric power for transmission over electric power transmission lines usually having favorable indicators.

These expenditures are customarily taken into account in the form of reduced expenses for construction and operation of generating capacity and for production of a corresponding amount of fuel.

Creation of reserve supplies of energy resources in the consuming region is impossible in electric transport. Therefore, the question of reliable operation of an open structure several thousand kilometers long acquires especially important significance due to the possible effect of meteorological and other conditions (discharge of atmospheric electricity, damage of poles, insulators and wires during icing and storms and so on). There should be reserve capacities with fuel reserves in the adopted energy system which could be put into operation if necessary and could make up for a possible undersupply of electric power during planned or accidental shutdown of the electric power transmission line.

In this regard the maximum output of an electric power transmission line is predetermined by the reserve generating capacities of the receiving power system which can be used to add a reserve to electric power transmission lines. The energy system of the European USSR will provide reserve electric power transmission lines with output on the order of six million kW for the near future according to conditions of operating reliability [70, 72]. Electric power transmission lines with voltage of 2,250 (± 1,120) and 2,500 (± 1,250) kV and power of 13 and 40 million kW, respectively, can be constructed in the more remote future with subsequent development of energy systems and with an increase of reserve capacities.

If the efficiency of electric power transmission lines is compared to other types of transport, the coefficient for development of length, dependent on the topographic conditions of terrain, is introduced. The route of electric power transmission lines can be laid over the shortest distance while the length of the route in river transport and to a lesser extent for rail and to an even lesser extent for pipeline transport, depends on many conditions.

The degree of time utilization of electric power transmission lines is insufficiently clear. The low cost of electric power in the region of generation and the high dependence of engineering and economic indicators on the number of operating hours of the transmission lines predetermines its operation in the basic part of the schedule with possibly higher time utilization factor and carrying capacity. Many authors feel that the number of hours of using electric power transmission lines should not be less than 7,000 annually.

Economically substantiated spheres of influence of electric power transmission lines require detailed study under conditions of extensive development of atomic power. The characteristic feature of atomic power plants is the constant and high level of loading, which also predetermines their operation in the basic part of the load schedule. Reducing the load of atomic power plants is clearly unprofitable on the basis of fuel expenditures. Not only the use indicators but also the rates of development of atomic power are dependent on the load level of atomic power plants. Consequently, it would be necessary to operate electric power transmission lines during the semi-peak part of the schedule with deteriorated engineering and economic indicators if atomic power is developed to a level which meets the needs of the basic part of the schedule.

Solution of the problem of development of long-distance electric power transmission lines and the scales of their development should take into account the rates of development of atomic power, the load level of atomic power plants and the possibility of producing not only electric power but heat as well on their basis.

The calculated lifetime of electric power transmission is very high--50 years. Calculations on the economic effectiveness of using electric power transmission lines should obviously consider in detail their loads in time and development of atomic power in the region under consideration since it may be that electric power transmission lines will operate during this period with lower utilization intensity. Therefore, the conditions of the energy supply of regions under consideration in the remote future must be analyzed upon engineering and economic comparison of transmission lines with other types of transport of energy resources. Development of the basic strategy for development of the country's fuel and energy balance for the remote future of 30-40 years, based on the anticipated results of scientific and technical progress in power engineering, is obviously required for this purpose.

The subsequent effectiveness of long-distance electric power transmission lines is being considered for operating conditions in the basic part of the schedule since their use during the semi-peak or peak part of the schedule with low number of operating hours is inadequately efficient.

The Energoset'proyekt [All-Union State Planning, Surveying and Scientific Research Institute of Power Systems and Electric Power Networks], ENIN [Power Engineering Institute imeni G. M. Krzhizhanovskiy] and NIIPT [Scientific Research Institute of Direct Current] are conducting research to develop direct current transmission lines that are more improved and economical than electric power transmission lines of 1,500 (± 750) kV.

Approximate Parameters of Systems:

	2,250 (± 1,120) kV	2,500 (± 1,250) kV
Length, km	3,300	3,950
Cross-section of conductors (per pole)	6AS-1,300	2(8AS-1,000)
Transmitted power on starting end of electric power transmission, MW	12,000	40,000
Power losses, percent	15.2	14.2

Power on receiving end of electric transmission, MW	10,430	35,100
Amount of energy on starting end of electric transmission, billion kW·hr/year	86.0	266.0
Power losses, percent	14.6	11.9
Amount of energy on receiving end of electric transmission, billion kW·hr/year	73.7	234.4
Equivalent amount of comparison fuel, million tons/year	23.5	75.0

The use of superhigh voltages in electric power transmissions naturally requires consideration of all the problems related to ecology and the possibility of using the corridors formed by electric power transmission lines for agriculture (cattle breeding and field crop cultivation) [68].

The possibility of developing crogenic electric power transmission, the basis of which will be the use of the superconductivity phenomenon, is being considered for the remote future. The working current density will increase to 100-10,000 A/mm^2 of conductor cross section for specific conditions and large amounts of electric power can be transmitted over conductors of relatively small cross section. It is assumed that these electric power transmissions will have very high carrying capacities and high efficienty. However, the most preliminary developments indicate that the reduced expenditures during cryogenic transmissions will be several times higher than for overhead power transmission lines. It should be expected that an increase of transmitted power will lead to a reduction of specific expenditures.

According to foreign data, the efficiency of overhead and cryogenic transmission may begin with transmitted power of 50,000-100,000 MW per circuit.

The boundaries of effective application of the considered direct and alternating current electric power transmission lines are presented in Figure 9.2.

When the engineering and economic indicators of electric power transmission lines are compared to other types of transport, one must take into account the variation of these indicators as a function of the distance of power transmission, the intensity of utilization and also the energy loss in converter substations and conductors for their heating and corona.

The large variation of engineering and economic indicators with an increase of the length of electric power transmission is explained by the significant specific weight of expenditures for initial-final operations. Main expenditures go to converter substations. Therefore, all indicators improve significantly with an increase of the distance of electric power transmission.

Variation of the economic indicators for direct current transmission lines is presented in Table 9.3.

Only the operating expenses related to losses of electric power in conductors and at substations vary with different load level of an electric power transmission line. Capital investments and remaining operating expenses do not depend on the

Table 9.3.

(1) Показатели	(2) Напряжение электропередачи, кВ					
	1500(±750)		2250(±1125)		2500(±1250)	
	(3) Протяженность линии электропередачи, км					
	2000	3000	3000	4000	3000	4000
Капиталовложения, млн. руб.: (4)						
в линии электропередачи (5)	200,0	300,0	530,0	710,0	1080,0	1440,0
в преобразовательные подстанции (6)	593,0	593,0	780,0	780,0	2400,0	2400,0
Итого: (7)	793,0	893,0	1310,0	1490,0	3480,0	3840,0
Эксплуатационные расходы, млн. руб.: (8)						
на линии электропередачи	5,0	7,5	13,2	17,8	27,0	36,0
на преобразовательные подстанции	36,0	36,0	47,0	47,0	144,0	144,0
Итого:	41,0	43,5	60,2	64,8	171,0	180,0
(9) Дополнительные затраты на покрытие потерь, млн. руб.:						
капиталовложения (10)	113,0	136,0	214,0	270,0	595,0	750,0
эксплуатационные расходы (11)	11,5	15,0	22,5	28,0	55,0	67,5
Удельные показатели с учетом потерь: (12)						
капиталовложения, руб/т (13)	74,8	89,5	60,0	72,0	54,5	61,0
эксплуатационные расходы, руб/т (14)	4,4	5,1	3,3	3,8	3,0	3,3
приведенные затраты, руб/т (15)						
(16) при $E_н=0{,}12$	13,4	15,8	10,5	12,4	9,6	10,6
(17) при $E_н=0{,}15$	15,6	18,6	12,3	14,6	11,2	12,4
(18) приведенные затраты, коп/(10 т·км):						
при $E_н=0{,}12$	6,7	5,3	3,5	3,1	3,2	2,6
при $E_н=0{,}15$	7,8	6,2	4,1	3,6	3,7	3,1

Key:
1. Indicators
2. Electric power transmission voltage, kV
3. Length of electric power transmission line, km
4. Capital investments, million rubles
5. In electric power transmission lines
6. In converter substations
7. Total
8. Operating expenses, million rubles
9. Additional expenditures to make up losses, million rubles
10. Capital investments
11. Operating expenses
12. Specific indicators with regard to losses
13. Capital investments, rubles/ton
14. Operating expenses, rubles/ton
15. Reduced expenditures, rubles/ton
16. At E_n = 0.12
17. At E_n = 0.15
18. Reduced expenditures, kopecks (10 tons·km)

load. As a result the fraction of expenses which can be related to the category of expenses dependent on the volume of shipments by analogy with other types of transport is extremely insignificant and a reduction of the load factor sharply reduces the engineering and economic indicators of electrical transmission use. Therefore, detailed analysis of the prospects for development of atomic power and a combination

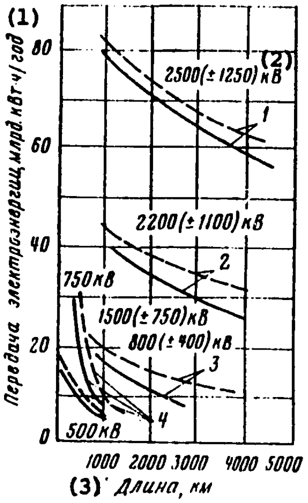

Figure 9.2. Areas of Application of Direct and Alternating Current Electric Power Transmission: —— --coal from underground mining; ---- --coal from strip mining; 1, 2 and 3--direct current; 4--alternating current

Key:
1. Electric power transmission, billion kW·hr/year
2. kV
3. Length, km

of the operation of electric power transmission lines with that of atomic power plants in the basic and other zones of the schedule is required when solving the problem of the effectiveness of using this type of transport.

The dependence of the engineering and economic indicators of electrical transmission on the utilization time of electric power transmission is shown in Table 9.4, where the results of calculations made for an electric power transmission line with voltage of 1,500 (± 750) kV and length of 2,000 km are presented.

Variation of losses in an electric power transmission line with voltage of 2,200 (± 1,100) kV is shown in Figure 9.3 as a function of the length of the transmission line and the number of hours of utilization. As can be seen, the electric power losses under all conditions are very significant and reach 13.0 percent of transmitted power or 16.0 percent of the amount of energy received at the point of consumption with a length of 4,000 km and power utilization of 7,500 hours annually. Approximately 2.5-3.0 percent is lost at converter substations and the remainder is lost in the electric power transmission line.

Summary indicators of reduced expenditures during transmission of electric power over direct current lines over long distances are presented in Figure 9.4. The nature of the curves shows the clear feasibility of using electric power transmission lines of higher parameters in voltage over greater distances. The reduced

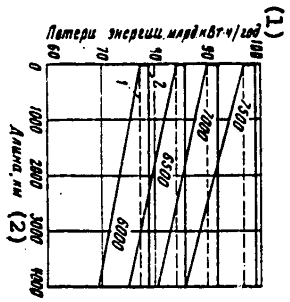

Figure 9.3. Energy Losses in Direct Current Electric Power Transmission With Voltage of 2,200 (± 1,100) kV: 1--in converter substations; 2--in conductors for heating and corona

Key:
1. Energy losses, billion kW·hr/year
2. Length, km

Table 9.4.

Показатели (1)	(2) Число часов использования электропередачи, ч				
	4000	5000	6000	7000	7500
Капиталовложения, млн. руб.: (3)					
в линии электропередачи (4)	200,0	200,0	200,0	200,0	200,0
в преобразовательные подстанции (5)	503,0	593,0	593,0	593,0	593,0
Итого: (6)	793,0	793,0	793,0	793,0	793,0
Эксплуатационные расходы, млн. руб.: (7)					
на линии электропередачи (8)	5,8	5,8	5,8	5,8	5,8
на преобразовательные подстанции (9)	40,0	40,0	40,0	40,0	40,0
Итого:	45,8	45,8	45,8	45,8	45,8
Дополнительные затраты на покрытие потерь энергии в электропередаче, млн. руб.: (10)					
капиталовложения (11)	60,0	73,5	88,0	113,0	118,0
эксплуатационные расходы (12)	6,1	7,3	8,5	10,2	11,2
Затраты по электропередаче с учетом потерь, млн. руб.: (13)					
капиталовложения	853,0	866,5	881,0	906,0	911,0
эксплуатационные расходы	51,9	53,1	54,3	56,0	57,0
Удельные показатели: (14)					
капиталовложения, руб/т (15)	117,0	94,0	83,0	76,0	71,8
эксплуатационные расходы, руб/т (16)	7,15	5,78	5,12	4,67	4,5
приведенные затраты, руб/т: (17)					
при $E_н$=0,12 (18)	21,15	17,08	15,07	13,77	13,1
при $E_н$=0,15 (19)	24,65	20,18	17,62	16,07	15,3
капиталовложения, коп/(10 т·км) (20)	58,5	47,0	41,5	38,0	35,9
(21) эксплуатационные расходы, коп/(10 т·км)	3,58	3,00	2,56	2,32	2,18
приведенные затраты, коп/(10 т·км): (22)					
при $E_н$=0,12	10,58	10,05	7,54	6,88	6,49
при $E_н$=0,15	12,38	12,0	8,78	8,02	7,57

Key:
1. Indicators
2. Number of hours of electric power transmission use, hours

[Key continued on following page]

Key [Continued from preceding page]:

3. Capital investments, million rubles
4. In electric power transmission lines
5. In converter substations
6. Total
7. Operating expenses, million rubles
8. For electric power transmission lines
9. For converter substations
10. Additional expenditures to make up power losses during electric power transmission, million rubles
11. Capital investments
12. Operating expenses
13. Expenditures for electric power transmission with consideration of losses, million rubles
14. Specific indicators
15. Capital investments, rubles/ton
16. Operating expenses, rubles/ton
17. Reduced expenditures, rubles/ton
18. At $E_n = 0.12$
19. At $E_n = 0.15$
20. Capital investments, kopecks/(10 tons·km)
21. Operating expenses, kopecks/(10 tons·km)
22. Reduced expenditures, kopecks/(10 tons·km)

expenditures for electric power transmission lines having voltage of 2,250 (± 1,125) kV of 3.1-3.5 kopecks per 10 tons·km and those at voltage of 2,500 (± 1,250) kV of 2.6-3.1 kopecks per 10 tons·km indicate the competitiveness of electric power transmission lines with rail shipments of even high-heat coal.

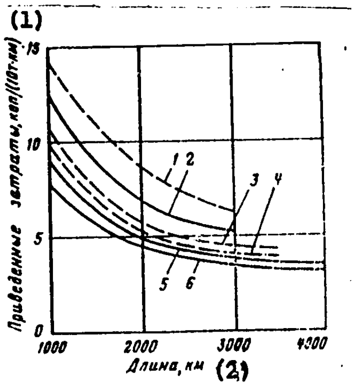

Figure 9.4. Reduced Expenditures for Direct Current Electric Power Transmission: 1--voltage of 1,500 (± 750) kV at $E_n = 0.15$; 2--the same voltage at $E_n = 0.12$; 3--voltage of 2,200 ± 1,100) kV at $E_n = 0.15$; 4--voltage of 2,500 (± 1,250) kV at $E_n = 0.15$; 5--voltage of 2,200 (± 1,100) kV at $E_n = 0.12$; 6--voltage of 2,500 (± 1,250) kV at $E_n = 0.12$

Key:
1. Reduced expenditures, kopecks/(10 tons·km)
2. Length, km

More detailed comparison of the reduced expenditures over electric power transmission lines with indicators of other types of transport and indicators of atomic power plants leads to the conclusion that parallel development of electric power transmission lines and atomic power using high-capacity reactors is feasible.

Chapter 10. Problems of Comprehensive Development of Transportation of Energy Resources

[Text] An increase of worldwide prices for oil and gas led to a significant gap between these prices and expenditures for the coal fuel of the country's eastern regions delivered to the European USSR. Expenditures for coal from the eastern basins transported to the Urals and to the European USSR are several times lower than worldwide prices for liquid and gaseous fuel. A further increase of prices for these types of fuel is expected in the future since oil and gas production on the offshore areas of the seas and in the difficultly accessible northern regions of the world requires an increase of expenditures. This trend indicates the feasibility of increasing the fraction of coal in the country's fuel balance and primarily for generation of electric power and extensive electrification of production and other processes with gas and petroleum products being forced out by electric power. This direction for development of the fuel and energy balance permits release of liquid fuel and gas resources for the national economy and export and thus permits an acceleration in development of the country's economy.

An increase in the fraction of coal in the country's fuel balance requires a search for methods of transporting this fuel and also investigations of the problem of replacing gas and liquid fuel with electric power in all sectors of the national economy, including fuel transportation as well.

The coal from the country's eastern basins can be transported to the west, as already considered above, by several methods:

directly by rail with creation of special mainlines with high carrying capacity if necessary;

in the form of a water-coal slurry through pipelines;

transmission of electric power over alternating or direct current electric power transmission lines;

in the form of refining products (methanol, light products, synthetic gasoline or diesel fuel and so on) through pipelines or by rail depending on the production volume.

The possibility and feasibility of using one or another method depends on the physicochemical properties of coal, its geographic location and the engineering and economic indicators of refining and transporting the fuel.

Let us consider these problems for the three largest coal basins: the Ekibastuz, Kuznetsk and Kansk-Achinsk.

The Ekibastuz basin has very favorable conditions of vein deposition and requires low expenditures for mining. However, Ekibastuz coal is comparatively low-heat (4,100-4,200 kcal/kg) and contains a large amount of ash having quartz inclusions in it. This coal essentially does not submit to concentration. The presence of quartz particles provides the basis to assume that the coal in pulverized form will have increased abrasiveness, which makes pipeline transport of it impossible without special measures to prevent rapid wear of pipes. There are as yet no engineering solutions to protect long welded pipelines against wear. The available experience of operating equipment for mining, loading and crushing of this coal at electric power plants confirms accelerated wear. Therefore, railraods and electric power transmission lines may be practically useful to transport coal from the Ekibastuz basin over a long distance.

Consideration of the problem of the distance of rail shipments of Ekibastuz coal showed that expenditures for rail transportation of this coal west of the Urals, for example, to the central regions, are higher than transportation of Kuznetsk coal, since coal from the Kuznetsk basin is high-heat and expenditures for transport of one ton of comparison fuel are lower by a factor of 1.55-1.60 than for Ekibastuz coal. This leads to the conclusion that the consumption zone of Ekibastuz coal with rail shipment is limited to the Urals, while it is more feasible to supply coal from the Kuznetsk basins to regions located west of the Urals.

The established fuel and energy balance of western Siberia and the Urals and adjacent regions of the northern Caucasus shows that the energy resources of the Ekibastuz basin can be used in the northern and southern Urals and in regions of northern and central Kazakhstan, i.e., at a distance up to approximately 1,000-1,200 km from the basin.

Under these conditions both rail shipments of coal located near the consuming regions to cover the semi-peak, peak and partially basic loads and to supply TETs and alternating current electric power transmission with voltage of 750 and 1,150 kW can be used in parallel to support the main part of the load schedule. Engineering and economic calculations show that both versions provide approximately identical results to support the regions of the southern and central Urals separated from the basin by approximately 1,000-1,200 km.

Consideration of both versions (transmission of electric power or shipment of fuel by rail) also yielded similar indicators for the northern regions of the Urals, which was caused by significant development of existing railroads compared to electric power transmission lines, which can be laid over the shortest distance.

The most favorable for the industrial regions of Northern Kazakhstan is electric power transmission; shipment of coal is feasible only to supply electric power plants that cover semi-peak and peak parts of the load schedule. The use of rail transport may be feasible for the southern regions of Kazakhstan, taking into account the considerable distance, the large fluctuations in the loads of the energy system and the favorable conditions for increasing the capacities of railroads.

Thus, the Ekibastuz coal basin is the energy base of a vast region that includes the northern part of Western Siberia, the Urals and the northern and partially the southern regions of Kazakhstan.

The use of coal from the Ekibastuz basin to cover the needs of the Volga area and the country's central regions is possible by using only direct current electric power transmission lines with voltage of not less than ± 750 kW. The engineering and economic indicators of this electric power transmission line with output of approximately 6 million kW using approximately 20-22 million tons of coal annually are similar to the indicators for rail shipments. Construction of this line also permits one to achieve an intersystem saving that significantly improves the use of the generating capacities in energy systems. Construction of an electric power transmission line with voltage of ± 750 kW is conversion to construction of larger and more economical transmission lines with voltage of ± 2,100 kW.

The Kuznetsk coal basin has very favorable conditions of coal deposition that permit strip mining. The energy coal of the Kuznetsk basin is usually high-heat, low-ash with heat-producing capacity of 6,200-6,500 kcal/kg and according to preliminary data can be transported through pipelines with insignificant abrasive wear of pipes.

Burning Kuznetsk coal to produce electric power and for transmission over electric power lines is unfeasible since the less transportable hydrogenous coal of the Kansk-Achinesk basin located somewhat more easterly can be used for this purpose.

Taking the technique for coke production and the variety of consumers into account, the coking coal of the Kuznetsk basin may be transported in the near future by rail since capacities for transporting it by pipeline has not yet been studied and in all probably requires fundamental restructuring of the coke-producing enterprises.

The distribution of Kuznetsk energy coal for shipment by rail and through slurry pipelines is predetermined by the engineering and economic indicators of these types of transport, which in turn depend to a significant degree on the concentration of coal consumption when pipelines are used. As already pointed out above, the engineering and economic indicators of pipeline transport of coal improve significantly with an increase of the volume of coal; therefore, development of a branched pipeline system of low productivity reduces the efficiency of this type of transport. Relatively small consumers can be supplied with coal by rail and large consumers, primarily large electric power plants located at relatively short distances from each other, for example, in the Ural-Volga and central regions, can be supplied with coal by pipeline.

Pipelines 1,200 mm in diameter with carrying capacity of approximately 40 million tons annually and those 1,400 mm in diameter with carrying capacity of approximately 60 million tons annually can be used to transport Kuznetsk coal. A pipeline 1,200 mm in diameter can service electric power plants with output of 17-18 MW operating during the basic part of the load schedule (the number of hours of utilization of established output annually is 7,000) or with an output of 30 MW operating during the basic and semi-peak parts of the schedule (the number of hours of utilizing the established capacity is 4,000-4,500 annually). One pipeline can supply fuel to three large electric power plants with established output of 6.0 MW operating during the basic part of the schedule or five electric power plants operating during the semi-peak part of the load schedule. Development of a slurry reserve required to supply electric power plants operating in this mode is a practically solvable problem.

Organization of Kuznetsk coal shipment by rail can be considered in several versions for development of the Kuzbass-Urals-Volga rail test area:

in relatively limited quantities (in addition to existing shipments of 40-60 million tons) by development of the existing railway system with already existing parameters, but with handling of coal trains of 8,000-9,000 tons of mass in it consisting partially of eight-axle rail cars;

in large quantities (an additional 120-150 million tons) by developing a specialized railroad on the basis of the Central Siberian Mainline with handling of trains 1,700-2,100 meters long on it, consisting of eight-axle rail cars;

additional development of the Kuzbass-Urals-Volga area rail test area is required if necessary to deliver an additional quantity of coal to the European USSR.

Comparison of the engineering and economic indicators of these types of transportation of Kuznetsk energy coal leads to the conclusion that the use of pipelines is more feasible than additional development of the Kuzbass-Urals-Volga area rail test area. However, the indicators for finishing the construction of the railway system being formed, including development of a specialized railroad based on the Central Siberian Mainline and pipelines 1,200 mm in diameter, are similar to each other with some advantage to pipelines. But even this conclusion cannot be regarded as final since the engineering and economic indicators may vary somewhat as a function of refining the expenditures for pipeline construction and railroad construction and as a function of the location of fuel consumers and other factors.

Thus, both rail shipments primarily to supply small consumers and pipeline transport to supply large fuel consumers and primarily high-capacity electric power plants located in the Volga area and the country's central regions can be developed in parallel to transport coal from the Kuznetsk basin. Putting the first pipeline of high-productivity into operation should be done during the period of exhausting the carrying capacity of already constructed railroads.

An experimental plant at which the production processes for pumping Kuznetsk coal under the severe climate of Siberia (preparation of slurry, dehydration of it and other processes) will be worked out is required with regard to the future of pipeline transport.

Pumping a water-coal slurry through pipelines with productivity of 40-60 million tons annually requires development of a pump with delivery of not less than five million tons annually.

The Kansk-Achinsk basin is a number of fields located along the Main Siberian Mainline for a distance of approximately 300 km. Most fields are represented by several coal veins up to 100 meters thick which permit mining of up to 50-60 million tons annually in a single mine with shallow depth of the overburden with low expenditures for mining. Hydrogenous coal with heat value of 3,300-3,500 kcal/kg, with low ash content, but containing up to 40 percent moisture, including approximately 50 percent in chemically bound form. The coal tends toward self combustion.

A method of concentrating Kansk-Achinsk coal and of producing semi-coke, resins and gas has been developed at experimental-industrial plants. Refining products in the form of briquettes from semi-coke or resinous powdery semi-coke are a high-quality fuel with heat-producing capacity of approximately 7,000 kcal/kg not subject to spontaneous combustion. The briquettes are transportable by rail and the powdery semi-coke is transportable by pipelines.

Investigations are being conducted to develop other, simpler methods of Kansk-Achinsk coal concentration that permit an increase of the heat value of the fuel to 5,500-6,000 kcal/kg.

Investigations are being conducted to pump the coal through pipelines in the form of a water-coal slurry: the optimum granulometric composition of the slurry, the coal concentration in the slurry and other parameters are being determined.

The problem of Kansk-Achinsk coal transport or products from refining it may be considered in two aspects: for an average distance (up to approximately 1,000 km) and over long distances to the European regions of the country (3,000-4,000 km).

This coal can be transported by rail for an average distance, which makes it possible to supply southern Krasnoyarskiy Kray and Irkutskaya, Kemerovskaya and Novosibirskaya Oblasts with inexpensive fuel and to release the transportable coal of the Kuznetsk basin in this region for shipment to the west and to limit their consumption to only existing electric power plants, conversion of which to the hydrogenous coal of the Kansk-Achinsk basin is economically unfeasible.

The extensive use of alternating current in electric power transmission lines from electric power plants located near the strip mines is feasible. The effectiveness of using electric power transmission lines in the given region is higher than for the Ekibastuz basin since coal from the Kansk-Achinsk basin has lower heat-producing capacity, while the terrain relief is primarily complicated and the cost of construction and operation of railroads is higher than in the valleys of the southern regions of Western Siberia and Northern Kazakhstan.

Thus, coal from the Kansk-Achinsk basin can primarily be used to supply inexpensive electric power to the indicated vast region of the country and to free high-quality coal from the Kuznetsk basin for transport to the country's western regions through pipelines and by rail.

The energy resources of the Kansk-Achinsk basin can be transported over long distances to the European regions of the country:

by burning it locally and by transmission of electric power over alternating current transmission lines with voltage of 2,200 and in thefuture of 2,500 kV;

by shipping the refining products by rail: resinated semi-coke or briquettes of it with increased heat-producing capacity not subject to spontaneous combustion;

shipment should be made over the same mainlines over which Kuznetsk coal is transported;

through pipelines in the form of a water-coal slurry of natural coal (if the results of investigations indicate the possibility of creating a slurry that provides stable operation with sufficiently favorable economic indicators) or of semi-coke;

through pipelines or by rail depending on the volume of production of the chemical products from refining this coal (synthetic gasoline, diesel fuel and methanol).

Preliminary calculations on shipment of Kansk-Achinsk coal over long distances yielded very similar indicators for various types of transportation (except refinement into synthetic liquid fuels).

The most favorable indicators are found when electric power is transmitted over direct current electric power lines with voltage of ± 2,500 kV and by pipeline transport in the form of a water-coal slurry.

Rail transportation of enriched coal in the form of dusty or briquetted semi-coke yields somewhat worse indicators with regard to the high expenditures for enrichment. Therefore, the problem of enrichment of Kansk-Achinsk coal to impart transportability over long distances to it and to increase the heat-producing capacity should be one of the main tasks of further investigations in working out this problem.

The coal from this basin should become the main fuel of the region indicated above for the near future in other to reduce to a minimum consumption of coal from the Kuznetsk basin in it for rail and pipeline transport to the country's western regions.

Conclusions

1. A high level of development of transportation systems has been achieved in the USSR for intracontinental movement of mass quantities of fuel and energy resources over long distances.

The existing gas- and oil-pipeline and rail transportation systems are the world's most productive and now already provide movement of approximately 1.0 billion tons of fuel annually over a distance up to 2,500-3,000 km.

The very high engineering and economic indicators of transportation achieved at low expenditures for fuel production in the country's eastern regions made it possible to supply consumers with relatively inexpensive fuel and energy resources and to achieve high efficiency of social production. Formation of the country's fuel and energy balance for the near future and especially for the more remote future places a number of problems for further improvement of transportation systems before scientific research, planning and design organizations with respect to productivity, improvement of engineering and economic indicators and interaction between them. The problems of development of transportation systems should be regarded in combination with development of the systems for producing fuel and energy resources by sectors of the national economy.

2. Analysis of the basic directions of scientific and technical progress and its effect on the engineering and economic, social, ecological and other indicators of individual types of transport indicate the possibility for significant improvement of each of the traditional types of transportation and also the possibility of developing new types of fuel and electric power transportation over long distances, primarily pipeline transport for coal in the form of a water-coal slurry and long-distance direct current transmission lines.

The possibility of a significant reduction of transportation expenses in the total expenditures to supply the country with fuel and energy is being determined. There is the possibility for a significant increase of the carrying capacity of all types of transportation to the level required to solve problems of supplying the country's European and Central Asian regions with fuel by delivering the energy resources of the country's eastern regions on scales that meet all the needs of individual sectors of the national economy, individual regions and of the country as a whole.

There are prerequisites for a twofold or more increase of the unit capacity of the system compared to those now achieved for all types of transportation, rail, gas pipeline and oil pipeline.

However, to solve the problem of increasing the unit carrying capacity of transportation mainlines, new means of transportation must be investigated, researched and developed for practically all types of transport: development of the design and assimilation of the entire complex of equipment for pumping gas under pressure of 100-120 kgf/cm^2 with moderate cooling and subsequently to develop a liquefied gas transportation system over long distances, conversion to large-diameter oil pipelines if necessary and development of a complex of permanent facilities and rolling stock related to an increase of the carrying capacity of railroads.

Moreover, scientific research, design and other work must be conducted to develop and introduce new types of highly productive transportation--pipelines to transport coal and long-distance electric power transmission lines that provide more favorable engineering and economic indicators under specific conditions than shipment of coal by rail.

3. The indicators for transportation of energy resources and optimization of them from the aspect of transportation are considered in the book. However, optimization of the structure of the energy balance and development of the fuel and energy

complex over the entire range from production to consumption of energy resources should also take into account problems of optimization of other components of the complex in addition to transport problems. Solution of these multifaceted problems is essentially possible by finding a coordinated optimum that ensures national economic efficiency of the entire system consisting of the fuel and energy balance of individual regions and of the country as a whole with regard to the numerous factors changing rapidly in time.

4. Selecting the spheres of application of various types of transportation under the conditions when they solve identical problems is of great practical interest in optimization of the fuel and energy complex. Experience shows that solution of this problem depends to a significant degree on the fuel production and consuming conditions and the operating mode of various types of transportation in the country's transportation system that supports functioning of the fuel and energy complex. Failure to consider the operating conditions of individual types of transportation may lead to incorrect conclusions. Variation of the engineering and economic indicators as a function of the loading conditions of transportation systems leads to significant distortion of the results of calculations and does not exclude erroneous decisions.

5. A timely problem for formation of the country's fuel and energy complex to supply European regions with electric power and with boiler-furnace fuel under conditions of rapid development of atomic power is determination of the optimum spheres of application of long-distance electric power transmission lines and partially of pipeline transport of coal. The engineering and economic indicators of these types of transportation deteriorate significantly when their load is reduced. A high saving from using them can be achieved when working during the basic part of the load schedule, i.e., in the spheres of operation of atomic power plants. At the same time the intersystem saving that in many cases sharply increases the efficiency of long-distance electric power transmission lines, must be taken into account when using long-distance transmission lines. The problem of selecting fuel transportation to cover the peak part of the loads requires solutions in formation of the fuel and energy complex of individual regions of the country with regard to all local conditions for covering the peak loads and the characteristic of varying the indicators of individual types of transportation depending on the schedule of electric power consumption.

6. Problems of the reliability of supplying consumers with fuel and energy resources and of supplying fuel during peak loads in extreme cases were only touched on in the book. This problem can be completely solved by optimizing the structure of the fuel and energy balance of individual regions and of the needs with regard to all local conditions and primarily of already existing energy consumers and adaptation of them to replace one type of fuel with another and also with regard to the engineering and economic indicators for creation of reserve depots of various types of fuel with regard to topographic, geographic and other local conditions. The problem goes beyond the framework of optimizing the development of transportation and requires solution of a complex of problems related to production, transportation and storage of fuel.

7. An independent problem that determines the operating indicators of pipeline transport, solution of which is possible only upon optimization of the fuel and

energy complex, is to establish the conditions for exploitation of gas and oil fields and consequently, as part of the problem of establishing the calculated carrying capacity of pipelines that deliver gas and oil from the fields to consumers. The carrying capacity of long-distance pipeline systems can be utilized over a longer time from the aspect of achieving high effectiveness of capital investments in pipeline systems, for which the value of sampling should be more moderate than is assumed in practice. More accelerated operation with reduction of the depreciation period, if this is required by the conditions for supplying fuel to consumers, is economically justified to supply pipelines of relatively short length. Some reduction in the efficiency of transportation may be justified from national economic aspects to accelerate the exploitation of fields.

8. Analysis of the development of transport of fuel and energy resources requires solution of a number of problems to improve them and to conduct a complex of investigations that ensure from the conditions for further development of the country's fuel and energy balance.

These problems include:

a) transportation of oil from permafrost regions in a cooled state and also of gas-saturated oil;

b) the need to conserve the higher quality gaseous fuel under conditions of extensive development of atomic power engineering and to supply a number of the country's regions with inexpensive coal advances as an urgent problem of extensive distribution of electric drives for gas-compressor units. This problem acquires special significance with regard to the large scales of development of long-distance gas transport and the high energy consumption of this type of transportation;

c) conducting a complex of investigations and development of a system of liquefied gas transportation with optimum parameters at which metal requiring comparatively few alloying additives can be used.

Development of the design and methods of construction and operation of heat-insulated pipelines and production of equipment for cooling, liquefaction, storage and regasification of liquefied methane;

d) developing the technology and hardware for transportation of pit and hydrogenous coal, primarily from the Kuznetsk and Kansk-Achinsk basin, through pipelines over long distances, including the problem of dehydration and combustion of this coal.

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