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# TRANSLATIONS ON USSR RESOURCES

(FOUO 5/79)

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FUELS AND RELATED EQUIPMENT

## ELECTRIC POWER AND POWER EQUIPMENT

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## USING HIGH-TEMPERATURE GAS-COOLED REACTORS

Moscow ATOMNAYA ENERGIYA in Russian Vol 45 No 6, Dec 78 pp 411-418

[Article by V. A. Legasov, N. N. Ponomarev-Stepnoy, A. N. Protsenko, Yu. F. Chernilin, V. N. Grebennik, and A. Ya. Stolyarevskiy: "Prospects of Utilization and Basic Problems of Adoption of High-Temperature Gas-Cooled Reactors in Technological Processes and Electric Power Engineering"]

[Text] The widespread and comprehensive discussion of various problems of the prospective development of power engineering has come about due to increasing difficulties of supplying the country with cheap energy and power resources, the level of consumption of which has reached a massive scale.

Difficulties involved in developing power engineering are due chiefly to the fact that organic resources are becoming increasingly more expensive, especially petroleum and gas, the most convenient and widely used sources of energy, reserves of which are limited; also the necessity of taking account of ecological factors, which make energy production more costly and impose additional restrictions on the scale and location of energy-producing installations; and, finally, the considerable "inertia" of power engineering --the most labor-intensive and capital-intensive sector of the economy, as a result of which it is essential to develop prototype installations long before the widespread adoption of plants of new energy profile in the TEB [Fuel-Energy Balance].

All of this requires expending the domains of application of nuclear power in the country's fuel-energy structure, and the maximum effectiveness of its utilization [1, 2]. Of great importance in power development in the near future is the gradual replacement of liquid and gas organic fuel [1, 3, 4].

At present, nuclear power is being used in practice to generate electricity, thus replacing organic fuel necessary to generate it. The developmental nuclear power in the European part of the Soviet Union will make it possible to substantially reduce the deficiency of energy resources in that region. However, the functions of AES's in reducing the deficiency of hydrocarbon fuel are relatively limited. Since assimilated power reactors are designed primarily for use in the base portion of power system loads, their adoption is driving coal-fired condensation power plants out of the energy balance.

Table 1 shows that the greatest consumption of fuel-energy resources, including oil and gas, is necessary in the generation of medium and low-potential heat and steam and high-potential heat for technological processes (metallurgy, chemistry, and so on) and also to supply the national economy with motor fuel. In addition, gas and oil fuel is utilized to generate peak and semi-peak energy.

The consumption of gas and liquid fuels in some of these domains can be reduced in part through the use of AST's [Nuclear Heating Plants] to generate low-potential heat, and assimilated AES's in certain technological processes for the integrated supplying of low-potential heat and electricity. Possibilities of utilizing nuclear power on the basis of assimilated reactors to supplant gas and liquid energy resources are limited. Broader perspectives are opened up by the development and adoption of VTGR's [High-Temperature Gas-Cooled Reactors].

The characteristic features of VTGR's is the generation of heat at temperatures of around 1,000 degrees C or more. Such a temperature will make it possible to adopt these reactors in various central-heating, power-technological, and other processes to replace scarce hydrocarbon fuels. Tables 2 to 4 indicate the domains of potential application of VTGR's. The potential scope of development of VTGR's is examined on the example of utilizing high-temperature heat for the steam conversion of methane, and is presented in Table 2.

About 20 percent of all organic fuel that will be produced in 1980 will have to be consumed to generate high-temperature heat. Moreover, 60 to 70 percent of the fuel consumed for these purposes will consist of scarce hydrocarbons, and this share will not change substantially over the next 15 to 20 years. The high-temperature potential is essential in the production of ammonia and ammonia fertilizers, synthetic alcohol, hydrogen, and so on, also in metallurgy for the direct reduction of iron, blast-furnace processes, and so on.

The key problem in most high-temperature processes is the production of various reducing agents, especially hydrogen, which can be obtained by means of VTGR's. From organic fuel, hydrogen as a raw material is obtained by steam conversion of methane or coal gasification (see Table 2). In the long-run, thermochemical or thermoelectrochemical decomposition of water may provide an unlimited source of hydrogen (Table 3). The production of reducing agents, especially hydrogen, by means of VTGR's makes it possible to replace all the organic fuel consumed in this sphere of energy production.

Table 1. Structural Consumption of Fuel-Energy Resources, Percent of Fuel-Energy Balance

Структура потребления топливно-энергетических ресурсов, % ТЭБ — Таблица 1

| (1) Область потребления | (2) Период 1970—1980 гг. | | (5) На перспективу *** | | (8) Потенциальная доля ядерной энергетики | |
|---|---|---|---|---|---|---|
| | (3) Всего * | (4) Доля нефти и газа (на конец периода) ** | (6) Всего | (7) Доля нефти и газа | (9) ЛВР **** | (10) ВТГР |
| (11) Выработка электроэнергии | 25 | 13 | 30—35 | ~ 10 | (16) До 20—25 | (18) До 25—28 |
| (12) Выработка тепла и пара среднего и низкого потенциала | 32 | 22 | 25—30 | ~ 20 | (17) До 8—10 | До 25 (19) |
| (13) Выработка высокопотенциального тепла | 19 | 14 | 14—16 | 10 | — | До 12—14 (20) |
| (14) Мобильные и стационарные силовые установки | 18 | 14 | 16 | 15 | — | Производство синтетического топлива (21) |
| (15) В химической, нефтехимической промышленности в качестве сырья | 6 | 5 | 10 | ~ 8 | — | — |
| Всего (22) | 100 | 68 | 100 | 60 | | |

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(23) * По данным [5], в среднем за период.

(24) ** По оценкам авторов, выполненным с учетом структуры потребления нефти и газа по данным [5] и масштабов потребления нефти и газа на 1960 г. по данным [6].

(25) *** По оценкам авторов с учетом основных тенденций изменения ТЭБ и прогнозов, например [3].

(26) **** Легководные реакторы (ВВЭР, РБМК).

Key:

1. Domain of consumption
2. 1970-1980
3. Total*
4. Share of oil and gas (as of end of period)**
5. Prospective***
6. Total
7. Share of oil and gas
8. Potential share of nuclear power
9. LVR****
10. VTGR
11. Generation of electricity
12. Generation of heat and steam of medium and low potential
13. Generation of high-potential heat
14. Mobile and stationary power plants
15. As raw material in the chemical and petrochemical industry
16. Up to 20-25
17. Up to 8-10
18. Up to 25-28
19. Up to 25
20. Up to 12-14
21. Production of synthetic fuel
22. Total
23. *According to [5], average for period.
24. **According to authors' estimates made on the basis of the structure of consumption of petroleum and gas in accordance with [5] and scale of consumption of petroleum and gas for 1980 according to [6].
25. ***Authors' estimates on the basis of main tendencies of utilization of TEB and forecasts, for example [3].
26. ****Light-water reactors (water-cooled reactors, high-power boiling-water reactors).

Table 2. Nuclear Power-Technological Processes with VTGR's on the Basis of Methane Conversion

Атомные энерготехнологические процессы с ВТГР на основе конверсии метана

Таблица 2

| (1) Область применения | (2) Тип технологического производства | (3) Продукт производства | (4) Вытесняемый газ (мазут) на АЭТУ мощностью 300 МВт (тепл.) | | (7) Экономическая эффективность | (8) Потенциальные объемы вытесняемого топлива при внедрении АЭТС с ВТГР, млн. т усл. т./год |
|---|---|---|---|---|---|---|
| | | | (5) млрд. м³/год | (6) млн. т усл. т./год | | |
| (9) Сокращение потребления природного газа | (10) Паровая конверсия метана для получения водорода | (11) Аммиак, аммиачные удобрения, синтетический спирт, водород | 1,7 | 2,1 | (12) Снижение себестоимости на 10—15% | (13) 30—50 (при АЭТС, на 15—20 млн. т аммиачных удобрений) |
| | (14) Прямое восстановление руды | (15) Губчатое железо | 1,5 | 1,8 | (16) Не оценивалась | (17) 2—3 (20 млн. т губчатого железа) |
| | (18) Восстановление руды в домнах | Чугун (19) | 1,4—1,6 | 1,7—2,0 | Не оценивалась (20) | 5—6 (30—40 млн. т чугуна) (21) |
| (22) Производство синтетического топлива | (23) Газификация угля | (24) Синтетический газ | 3—3,2 | 3,6—3,8 | (25) 40—50 руб./т усл. т. | (26) 60—70 (при газификации 50 млн. т угля) |
| Замена газожидкостного топлива (27) | Хемотермическая передача энергии (28) | Децентрализованное бытовое и промышленное тепловое снабжение (29) | 1,3—1,6 | 1,6—1,8 | Более экономичны, чем АСТ на расстоянии > 20—30 км (30) | 80—120 (50% децентрализованного теплоснабжения европейской части СССР на перспективу) (31) |
| | Хемотермическое аккумулирование энергии (32) | Пиковая электроэнергия (33) | 1,9—2,1 | 2,4—2,6 | Не оценивалась (34) | 32—35 (установленная мощность маневренных АЭС ~ 20 ГВт) (35) |

---

(36) АЭТС — атомная энерготехнологическая станция.

Key:

1. Domain of application
2. Type of technological production
3. Product
4. Gas (fuel oil) replaced in AETU of 300 megawatts capacity (heat)
5. Billions of cubic meters per year
6. Millions of tons of standard fuel per year
7. Economic effectiveness
8. Potential volumes of fuel replaced through the adoption of AETS with VTGR's , millions of tons of standard fuel per year
9. Reduction in consumption of natural gas

[Key continued on following page]

[Key to Table 2 Continued]

10. Steam conversion of methane to produce hydrogen
11. Ammonia, ammonia fertilizers, synthentic alcohol, hydrogen
12. 10 to 15 percent reduction in prime cost
13. 30 to 50 (in the case of AETS's, 15 to 20 million tons of ammonia fertilizers)
14. Direct reduction of ore
15. Slaggy iron
16. Not estimated
17. Two to three (20 million tons of slaggy iron)
18. Reduction of ore in blast furnaces
19. Pig iron
20. Not evaluated
21. Five to six (30 to 40 million tons of pig iron)
22. Production of synthetic fuel
23. Coal gasification
24. Synthetic gas
25. 40 to 50 rubles per ton of standard fuel
26. 60 to 70 (in the case of gasification of 50 million tons of coal)
27. Replacement of gas and liquid fuel
28. Chemothermal transmission of energy
29. Decentralized domestic and industrial heat supply
30. More economical than AST's at distances of more than 20 to 30 kilometers
31. 80 to 120 (50 percent of decentralized heat supply of the European part of the USSR over the long-term)
32. Chemothermal energy storage
33. Peak electricity
34. Not evaluated
35. 32 to 35 (installed capacity of maneuverable AES's roughly 20 gigawatts)
36. AETS--nuclear power-technology plant.

Table 3. Nuclear Power-Technological Processes With VTGR's on the Basis of Various Methods of Decomposition of Water

**Атомные энерготехнологические процессы с ВТГР на основе различных методов разложения воды** Таблица 3

| (1) Технологический процесс | КПД, % (2) | (3) Производство водорода на АЭТС мощностью 3000 МВт (тепл.) | | $T_{макс}$, °C (6) |
|---|---|---|---|---|
| | | (4) млрд. м³/год | (5) млн. т усл. т./год | |
| Термохимический цикл (7) | 65—70<br>55—60<br>35—40 | 4—4,5<br>3,5—3,8<br>2,2—2,5 | 1,6—1,8<br>1,4—1,5<br>0,9—1,0 | 1225<br>925<br>800 |
| Термоэлектрохимический цикл (8) | 45—50 | 2,9—3,2 | 1,2—1,3 | 800 |
| (9) Высокотемпературный электролиз | 40—45 | 2,5—2,9 | 1,0—1,2 | 800—900 |

Key:

1. Technological process
2. Efficiency, percent
3. Production of hydrogen in AETS of 3,000 megawatts capacity (heat)
4. Billions of cubic meters per year
5. Millions of tons of standard fuel per year
6. $T_{max}$, degrees C
7. Thermochemical cycle
8. Thermoelectrochemical cycle
9. High-temperature electrolysis

Thus, the use of VTGR's in energy-intensive technological operations opens up broad prospects for the development and use of nuclear power; this can have a positive effect on resolving the problem of environment.

As mentioned earlier, most of the organic energy resources being produced, including hydrocarbons, are consumed to produce medium and low-potential heat and steam. Some of the concentrated consumers of low-potential heat could be supplied by AST's based on assimilated reactors. A high proportion of gas and fuel oil is essential for decentralized domestic and industrial heat supply characterized by low concentration of energy consumption, the conversion of which to coal is made difficult by technical-economic and ecological factors. One possible way to resolve this problem is provided by ASDT's [long-distance nuclear heating plants]. In this case, the VTGR is used for the steam conversion of methane, with transmission of the cooled conversion products (CO and $H_2$) (Figure 1) through gas utility lines to the places of heat consumption, where the reverse reaction of methanization takes place to release heat. The temperature of methanization is roughly 450 to 650 degrees C. In the process, the CO and $H_2$ are converted almost wholly into methane, which can be returned to the reactor through the pipelines.

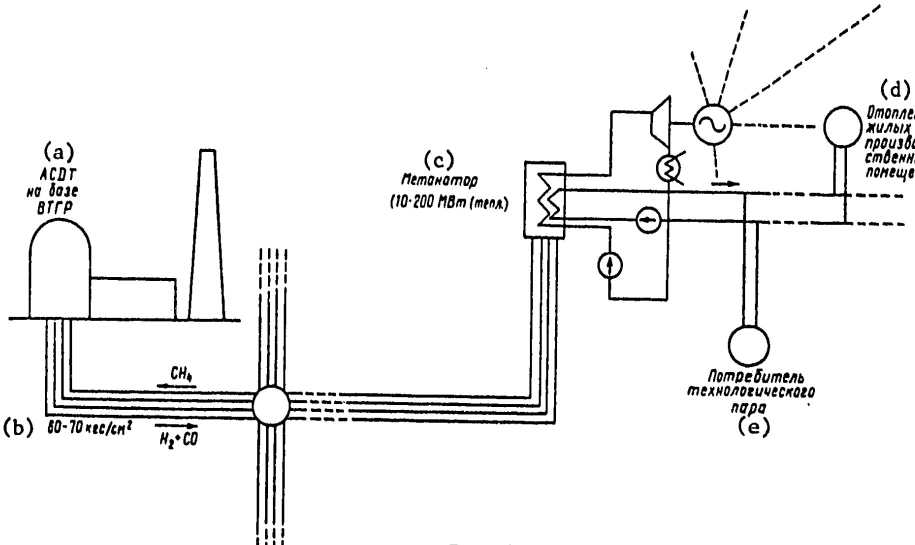

Рис. 1. Схема дальнего хемотермического теплоснабжения

Figure 1. Schematic of Long-Distance Chemothermal Heat Supply

Key:

a. ASDT based on VTGR
b. 60 to 70 kgf/cm$^2$
c. Methanator (10 to 200 megawatts (heat)
d. Heating of housing and industrial facilities
e. Technological steam consumer

All of these schematics for the use of VTGR's in power-technological processes call for using some of the heat generated by the reactor to produce electricity. Thanks to the high temperatures of the heat-carrier in this case it is possible use steam turbines with contemporary high steam parameters (550 degrees C and 170/240 bar) and an effective net efficiency of about 40 percent.

The ability of VTGR's to generate heat of higher parameters makes them highly promising in the development of AES power engineering with direct gas-turbine cycles. Gas turbines are becoming economical at temperatures of 800 degrees C or more. In this case, the direct gas-turbine cycle will be superior to the steam cycle both in terms of high efficiency and by virtue of reduced metal-consumption of the equipment and reduced capital outlays. Other advantages of the direct-cycle AES are the considerably lower consumption of cooling water and the probability of conversion to air cooling, higher maneuverability of the AES, and the possibility of using it in regulating conditions. Various alternative uses of VTGR's in electricity generation are presented in Table 4.

Table 4. AES's With VTGR's

**Атомные станции с ВТГР**

Таблица 4

| (1) Энергетический цикл | (2) КПД, % | (3) Особенности |
|---|---|---|
| Паротурбинный (4) | 38—40 | (5) Использование серийных паротурбинных блоков, например на 170 бар и на 545 °C. Снижение тепловых сбросов на 30—35 % |
| Замкнутый газотурбинный (6) | 41—44 | (7) Возможность достижения высоких КПД, в том числе при использовании бинарных циклов. Снижение капитальных затрат, повышение маневренности АЭС, возможность применения «сухих» градирен и использования сбросного тепла (до 250+ +300 °C) для теплофикации |
| (8) Замкнутый газотурбинный с термосорбционным компримированием | (9) 50—55 (с учетом низкопотенциального теплоподвода)<br>80—90 (без учета низкопотенциального теплоподвода) | (10) Высокий КПД, возможность использования «сухих» градирен.<br>Необходим подвод низкопотенциального (100—150 °C) тепла |

Key:

1. Energy cycle
2. Efficiency, percent
3. Characteristics
4. Steam-turbine
5. Use of series-produced steam-turbine blocks, for example of 170 bar and 545 degrees C. 30-35 percent reduction in heat emissions
6. Closed gas-turbine
7. Possibility of achieving high efficiency, including through the use of binary cycles. Reduction in capital outlays, higher maneuverability of AES, possibility of using "dry" cooling towers and the use of waste heat (up to 250 + 300 degrees C) for central heating.
8. Enclosed gas-turbine with thermosorption compression
9. 50 to 55 (counting low-potential heat supply); 80 to 90 (not counting low-potential heat supply)
10. High efficiency, possibility of using "dry" cooling towers. Necessity of supplying low-potential (100 to 150 degrees C) heat.

The development of nuclear power should be based on a reliable solution to the problem of fuel supply. The development of a helium technology for thermal VTGR's will speed up the resolution of the problem of gas-cooled breeder-reactors [1].

As Academician A. P. Aleksandrov has noted, " . . . evidently, the development of high-temperature reactors on par with breeder reactors will become a characteristic tendency of change in the structure of nuclear power by the 1990's.

"It may turn out that the development of breeder reactors cooled by sodium will prove to be complicated and unfeasible in the case of a four to six-year doubling time, because the appreciable degradation of the neutron spectrum by sodium reduces the breeding ratio. In this case it may be feasible to have a gas-cooled reactor, although the necessity of a very high calorific intensity of the fuel will lead to high pressures and complicated emergency shut-down cooling systems. It appears, nevertheless, that this trend should be followed up, especially considering that reducing the doubling time in metal-cooled reactors will require conversion from oxide fuel compounds to denser carbides, nitrides, or metal compounds, the stability of which is easier to ensure in chemically inert helium than in sodium" [1].

One of the outstanding and substantial advantages of the whole VTGR concept is the commonality and uniformity of the basic technical, technological, and design solutions for all of the above-listed thrusts of development. This applies to the design of the fuel elements, the basic equipment, the design of the reactor housing, structural and heat-insulating materials, the regulating system, and so on. This kind of commonality and uniformity of basic solutions makes it possible to reduce the volume of scientific-research and experimental-design work and to shorten implementation times. This advantage of the VTGR's will also undoubtedly have a positive effect on the development of the production base.

Among the most important scientific-technical problems in developing VTGR's are: Development of the design and technology for the making of fuel, high-temperature radiation- and corrosion-resistant graphite, high-temperature materials for the equipment, fittings, conduits, and so on, and heat-insulating materials and structures; designing of the basic technological equipment (heat-exchangers, gas blowers, fittings, steam generators, and so on) and high-pressure multi-chamber housings made of prestressed ferroconcrete; and also assimilation of helium technology (control, cleaning, mass-transfer, and so on).

Research is under way on practically all of these problems in order to realize characteristics meeting VTGR requirements for the production of high-potential heat. High requirements are imposed on reactors of this type, and meeting these requirements simultaneously resolves problems for other reactors of the VTGR type as well.

At present, research and development is underway on numerous uses of VTGR's. On the one hand, this characterizes the extensive interest in VTGR's as a new source of energy and, consequently, promotes the development of this thrust. On the other hand, the use of VTGR's creates the problem of seeking the development and optimal schematic of a reactor installation designed for various sectors of the national economy. Most of the current research in AETS's with VTGR's demonstrates the close link between the domain of application and the design, layout, and parameters of AETS's. It follows that in principle a particular optimal design and installation layout could be developed for each domain of application (see Tables 2-4). So far it is impossible to unequivocally single out from all this great variety of applications the basic directions that are most promising both in terms of the national economy's needs and in terms of technical feasibility and economy. This can be done only in the process of further research, study, accumulation of operating experience, and so on.

It should be cautioned that some components and parameters of VTGR's for different thrusts (active zone, gas blowers, control and safety rod drives, helium input and output parameters, and so on) can and must be standardized. Depending on the domain of application and the technical and schematic solutions adopted, however, there may be substantial differences in such vital elements and parameters of the installation as the heat-exchangers, steam generators, ratios between the capacities of these heat-exchangers and, consequently, the hydraulics of the first circuit, the design of the housing of prestressed ferroconcrete and so on. The parameters of VTGR's of various types are shown in Table 5.

Table 5. Basic Thermotechnical Parameters of VTGR

| Parameters | AES with steam-power cycle | AES with gas-turbine installation | AETS | AES with fast helium reactor |
|---|---|---|---|---|
| $t_{max}^{He}$, °C | 650-750 | 800-1000 | 900-1000 | 600-650<br>up to 800 |
| $t_{min}^{He}$, °C | 300-350 | 300- 350 | 300- 350 | 250-300 |
| p, bar | 50 | 50- 80 | 50 | 120-160 |

Another problem is that of providing high reliability, redundancy, and maximum utilization of the reactor's capacity. For VTGR's with ball fuel elements running on the OPAZ [single passage of active zone] principle there are hopes of achieving a high KIM [coefficient of capacity utilization]. For example, in the case of experimental AVR high-temperature reactor, which operates for a long time at a helium output temperature of 950 degrees C, this coefficient has been 0.85 to 0.90 in recent years. We cannot anticipate, however, that the VTGR's KIM will be substantially higher than in the case of installations with other reactors. Evidently we should aim at a KIM of 0.80 to 0.95.

At the same time, in the metallurgy and chemical industry operating load coefficients approach 0.95 to 0.98. Many specialists in these sectors believe that this load level should also be achieved in nuclear power being utilized in technology. Although it is not obvious that the most economical solution for AETS's is the provision of energy in which the load coefficient of the technological operation would be 0.95 to 0.98 (for example, by increasing the reliability of individual elements of the reactor, supplementary redundancy, and so on), nevertheless there is the problem of the discrepancy between load coefficients for nuclear reactors and certain technological operations.

Rather closely linked to this problem is the question of reliability. Some technological processes are carried out continuously. Emergency stoppage can lead to disruptions which require subsequent repair and restoration work (for example, blast furnace operations) for after which it is necessary to have a lengthy tune-up period to reach steady-state conditions. In this case, the nuclear energy source must meet the condition of providing highly reliable energy supply--that is, the coefficient of operational readiness of the reactor should approximate 1.

In a number of domains of application, the "scale discrepancy" problem may arise. For example, in utilizing an AETS for the direct reduction of iron ore, with a productivity of five million tons per year, the required thermal capacity of the reactor for technological heat amounts to roughly 1,000 megawatts [7]. Thus, even for a plant of that productivity the necessary thermal capacity of the AEU [nuclear power installation] does not fall within the domain of the economic capacities of the reactors. But a reactor of the same thermal capacity could turn out roughly two million tons of ammonia per year.

At present we have no unequivocal recipes for resolving problems of VTGR development. The developmental process, from the experimental test-stand installations and reactors to the prototype industrial models, will provide answers to all problems. It is possible here to indicate only the possible thrusts of research and the solutions which must be verified, including: Development of maximally standardized reactor installations suitable for use in various technological processes; facilities for the centralized production of hydrogen for distribution to various consumers; accumulators of intermediate AETS products (gases of various composition for metallurgy and chemistry); AES's with several nuclear reactors of medium capacity; formulation of specifications for maintaining technological installations in operating condition by means of emergency power sources.

At present, several types of AETS's are being developed. The most acceptable, however, is the VG-400 schematic shown in Figure 2 [8, 9], the main characteristics of which are the combined generation of heat and electricity and the use of the intermediate circuit to draw off high-potential heat. What are the advantages of this layout?

In the USSR, as has been mentioned, in the selection of the development of VTGR's for technological processes as a thrust of high priority, the development of prototype installations to generate electricity is ruled out as an independent stage of development. Nevertheless, it is essential to assimilate temperatures sequentially in time: 660-750 degrees C and then 900 to 950 degrees C [9]. The VG-400 layout provides this possibility: In the first stage, the unit can operate to generate electricity with the maximum temperature up to 750 degrees C in the first circuit. By means of special devices installed in place of the heat-exchanger of the intermediate circuit it is possible to conduct tests at high temperatures without having to bring the intermediate and technological circuits in.

If necessary, technological operations based on such an installation can be postponed to subsequent stages in order to ensure operation of the reactor devices themselves at high temperatures. Another possible variant utilizes both the intermediate circuit and a special steam generator in the technological part to feed steam into the steam-turbine unit.

The use of the intermediate circuit in the prototype installation introduces several useful properties. The nuclear portion, ruling out explosion hazard, is separated from the technological chain, can be operated practically without any consideration of radiation hazard. Constant or accidental penetration of the first circuit by products of the technological circuit, primarily hydrogen, is practically ruled out [10]. The replacement and repairing of the experimental technological equipment does not entail any measures to deactivate it. It is possible to install technological heat-exchangers after the reactor itself is work-tested; this simplifies their replacement during operation.

The use of several loops of the first circuit in the VG-400 makes it possible to investigate various technological processes in them. The capacities of prototype industrial installations of this type range between 3,000 and 5,000 megawatts (heat), while the capacity of a prototype 1,000-megawatt unit will be 20 to 30 percent; this can be considered the optimum level. The VG-400, one of the first prototype AETS's, will make it possible to study and resolve the above-listed problems of both a technical nature and problems relating to the adoption of the concept of high-temperature nuclear power engineering.

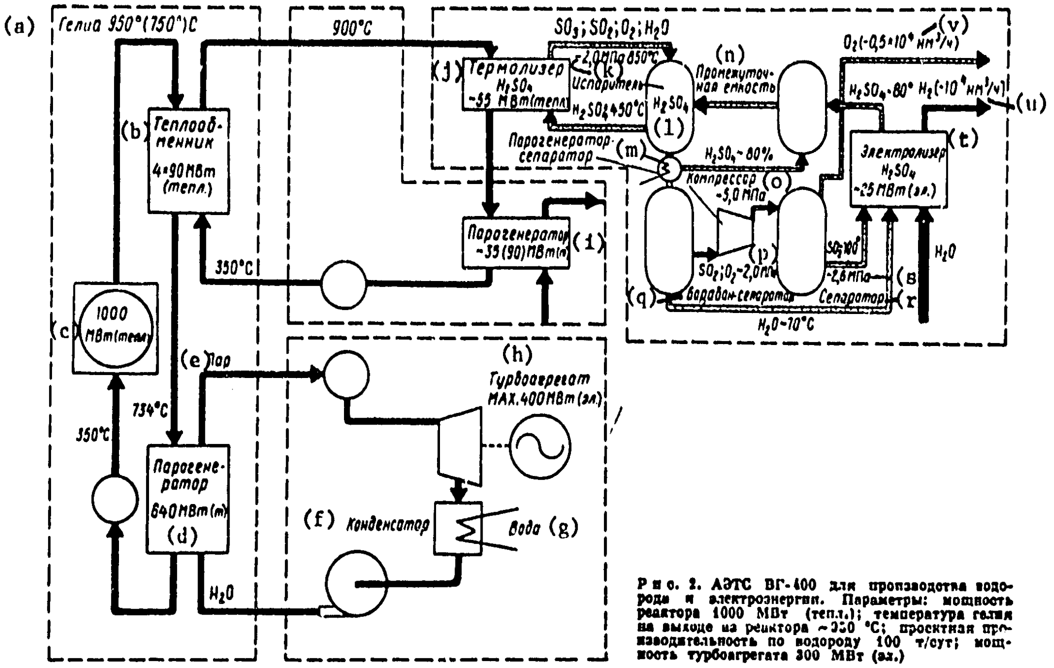

Рис. 2. АЭТС ВГ-400 для производства водорода и электроэнергии. Параметры: мощность реактора 1000 МВт (тепл.); температура гелия на выходе из реактора ~950 °С; проектная производительность по водороду 100 т/сут; мощность турбоагрегата 300 МВт (эл.)

Figure 2. VG-400 AETS for the production of hydrogen and electricity. Parameters: Reactor capacity 1,000 megawatts (heat); temperature of helium at reactor outlet roughly 950 degrees C; projected hydrogen productivity 100 tons per day; turbogenerator unit capacity 300 megawatts (electricity).

Key:

a. Helium
b. Heat-exchanger 4x90 megawatts (heat)
c. 1,000 megawatts (heat)
d. Steam generator 640 megawatts (heat)
e. Steam
f. Condensor
g. Water
h. Turbogenerator unit Max. 400 megawatts (electricity)
i. Steam generator roughly 35 (90) megawatts (heat)
j. Thermolyzer $H_2SO_4$ roughly 55 megawatts (heat)
k. Roughly 2.0 MPa 850 degrees C

[Key continued on the following page]

[Key for Figure 2 continued]

l. Evaporator
m. Steam generator-separator
n. Intermediate container
o. Compressor roughly 5.0 MPa
p. $SO_2$; $O_2$ roughly 2.0 MPa
q. Drum-separator
r. Separator
s. Roughly 2.6 MPa
t. Electrolyzer $H_2SO_4$ roughly 25 megawatts (electricity)
u. $nm^3/hr$
v. $nm^3/hr$

Conclusion. More than 20 years of development of nuclear power in the USSR has led to the widespread adoption of AES's in electric power engineering, and their role will continue to grow. VVER and RBMK reactors have served as the basis for the development of large power blocks with high technical-economic indicators which will make it possible to substantially reduce the deficiency of energy resources in the European part of the USSR. The present structure of the country's energy balance and long-range prospects of this development indicate that AES's in existence and under construction are primarily displacing in the energy balance KES's [condensation power plants] intended for use in the base portion of power system loads. The main KES fuel is coal. At the same time, because of the higher costs of hydrocarbon types of fuel it is essential to seek ways to replace oil and gas with nuclear energy in such domains as the generation of medium- and low-potential heat and steam, the production of synthetic types of fuel, the provision of energy for large-scale technological operations, and the generation of peak and semi-peak electricity.

In part, this problem can be successfully resolved by building AST's on the basis of already-assimilated reactors, also through the optimal utilization of such reactors for the provision of heat and electricity for technological operations. Even broader possibilities for the displacement of oil and gas in the energy balance will come from the development and extensive adoption of VTGR's capable of making more effective use of the capabilities of nuclear energy. At present, the optimal domains of adoption of VTGR have been mapped out and the possible scale evaluated; technical solutions making it possible to ensure their adoption have been worked through. We may anticipate that about two-thirds of the potential domain of application of high-temperature nuclear sources of heat can be handled by VTGR's, and with substantial national-economic effect. In connection with this, it is essential to step up the pace along these lines in order to accelerate the development of the first industrial AETS's.

The main task at the first stage is to develop an experimental-industrial AETS with a VTGR of 1,000 megawatts capacity (heat) and a helium temperature of roughly 950 degrees C at the outlet from the active zone. In an experimental-industrial--and in some cases in industrial AETS's--it is advisable to make integrated use of VTGR energy for the combined generation of high-potential heat and electricity. This solution will make it possible to carry out the staged work-testing of the plant under purely power-producing and power-technological conditions. Moreover, in the experimental-industrial installation it will be possible, by stages or simultaneously, to investigate power-technological processes based on high-temperature processes of thermochemical or thermoelectrochemical decomposition of water, high-temperature electrolysis of water, high-temperature steam catalytic conversion of methane, and also promising power cycles, for example enclosed gas-turbine.

The experiment gained in the operation of such systems in the provision of energy from VTGR's will serve as the basis for the development of atomic-industrial complexes serving various purposes on the basis of VTGR's.

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## ELECTRIC POWER AND POWER EQUIPMENT

### FUEL UTILIZATION IN POWER PRODUCTION

Moscow ATOMNAYA ENERGIYA in Russian Vol 45 No 6, Dec 78 pp 469-470

[Article by B. Ye. Novikov: "Problems of Fuel Utilization in Power Engineering"]

[Text] The dominating role played by large AES's operating in the base mode to supply energy to the European part of the USSR is leading to a situation in which substantial fluctuations in the daily loads on the power systems must be covered by remodelling existing highly-maneuverable power blocks running on organic fuel and building new ones.

The larger role played by coal in supplying energy is giving rise to certain vital problems. The main reserves of hard and brown coal are located in the eastern regions of the country. In order to reduce the cost of long-distance transportation of fuel and energy from the East to the West a program of construction of large-scale fuel-energy complexes will be implemented in the eastern regions.

The resolution of these problems must be directed toward the development of new methods of burning and processing solid fuel in order to reduce the metal-consumption of boiler units, increase fuel economy, and reduce harmful emissions into the atmosphere.

These problems were the focus of an all-union conference "New Methods of Fuel Utilization in Power Engineering," held in Moscow 29-30 May 1978; it was organized by the scientific council of the USSR Ministry of Power and Electrification's Glavniiproyekt [Main Administration of Scientific-Research and Project-Planning Organizations] and ENIN [Power Engineering Institute imeni G. M. Krzhizhanovskiy]. It was attended by more than 120 specialists from 47 organizations. Some 33 reports were presented and discussed.

Survey reports at the conference dealt with prospective methods of burning solid fuel, the mechanism of the formation of harmful emissions in the burning of organic fuel, and problems of environmental protection.

The remaining reports can be provisionally divided into three groups.

Turbulence-chamber furnaces. Reports in this section of the conference dealt with the experience of firing turbulence-chamber furnaces with peat, pulverized brown coal, and shale at relatively low temperatures (the temperature in the combustion nucleus drops by 100 to 200 degrees C). This makes it possible to substantially reduce slag buildup in the furnace and on the convective heating surfaces, also to reduce the formation of nitrogen and sulfur oxides. At present, furnaces of this type are used for boilers of up to 500 tons per hour productivity. Some of the reports dealt with the use of the high-temperature furnace process in a special turbulence chamber. It was noted that for furnaces of this type it is possible to build powerful steam generators of half the height.

Combustion of fuel in "fluidized bed." Recently, extensive work has been under way on the development of steam generators burning pulverized coal in a fluidized bed. Thus, a steam boiler with a fluidized bed and a productivity of 10 tons of steam per hour has been started up. Project studies of powerful steam generators of this type are under way.

The burning of fuel in a fluidized bed intensifies heat-exchange substantially, reduces the formation of nitrogen oxides considerably, and makes it possible to reduce sulfur compound emissions by 90 percent compared with chamber combustion. Such steam generators are considerably smaller in size and correspondingly cheaper.

Processing and gasification of fuel, burner devices. At present, substantial importance attaches to efforts to make integrated use of thermally-enriched fuel. The ENIN report presented the results of operating experimental-industrial installations for the integrated processing of Kansk-Achinsk coal, also shale. Also of interest is a method developed in the Institute of Mineral Fuels for the thermal processing of moist Siberian coal to make thermal coal with a combustion heat of 7,000 kilocalories per kilogram.

Substantial efforts are under way on the development of various methods of coal gasification. Mention should be made of highly-promising studies of processes with plasma coal gasification (an ENIN report) and coal gasification in a reactor with fluidized bed, with heat energy fed into the reaction zone from a high-temperature external source of heat--a furnace chamber, and eventually a nuclear reactor.

Also worth noting is a report concerning the development of gas burners operating by the method of double-front ignition of gases of maximally low combustion heat. These burner devices ensure steady combustion of large quantities of low-calorie gases that were formerly not utilized as fuel and polluted the air. In evaluating the work of the conference, it should be mentioned that many important and interesting findings were presented; they will make it possible to develop and expand research into new methods of fuel utilization and will help to promote their adoption in power engineering.

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## ELECTRIC POWER AND POWER EQUIPMENT

### BIOGRAPHIC SKETCH OF A.M. PETROKOVSKIY

Moscow ELEKTRICHESTVO in Russian No 10, Oct 78 p 93

[Article by a "group of comrades" commemorating the 70th birthday of Aleksandr Mikhaylovich Petrokovskiy]

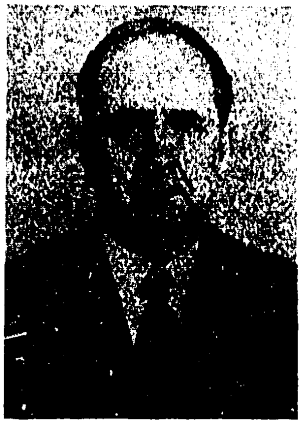
[Text] A. M. Petrokovskiy, deputy chief of the Power and Electrical Technology Department of the USSR State Committee for Science and Technology, has celebrated his 70th birthday.

Petrokovskiy began his career as an electrician at the Moscow electrical plant, where he worked for several years. In 1930, he was sent to study at the Moscow Power Engineering Institute and remained there after graduation (he was a graduate student and a lecturer in the Electrical Equipment Department, and then he became a leader in Komsomol affairs.)

From 1939 to 1957, Petrokovskiy worked on the staff of the CPSU Central Committee and the USSR Council of Ministers, where he was concerned with the problems of the electrical equipment industry for many years; during World War II, he helped to evacuate electrical plants to the Eastern part of the country and to organize production in the Urals and Siberia. For the exemplary manner in which he fulfilled the assignments of the State Defense Committee during World War II, Petrokovskiy was awarded the Order of the Red Star, the Order of the Red Banner, and the Order of the Great Patriotic War, First Class.

From 1957 to 1965, Petrokovskiy worked as the chief specialist, deputy chief, and chief of the Power and Electrical Technology Department of the State Committee for the Coordination of Scientific Research of the RSFSR Council of Ministers. During this period the committee accomplished a great deal of work in organizing, planning, and introducing new electrical power and equipment technology in the krays, oblasts and autonomous republics of the RSFSR.

In 1965, Petrokovskiy was transferred to the State Committee for Science and Technology of the USSR Council of Ministers (now the USSR State Committee for Science and Technology), and for 13 years he held the post of deputy chief of the Power and Electrical Technology Department; he was concerned with making scientific and technological advances in electrical engineering. He did a great deal to improve the scientific and technical level of the electrical equipment industry. He took a direct part in the development of proposals to accelerate scientific and technical progress in the national economy, and they were reflected in the resolution of the CPSU Central Committee and the USSR Council of Ministers entitled "Measures to improve the efficiency of scientific organizations and to accelerate the introduction of scientific and technological advances into the economy" and in the resolution of the USSR Council of Ministers entitled "Measures to improve the efficiency of scientific research, design and planning, and technological organizations of the Ministry of the Electrical Equipment Industry and to accelerate the introduction of their advances into production."



The practical implementation of a number of major organizational and production arrangements to improve the management of scientific and technological development in the electrical equipment industry in which Petrokovskiy took an active part allowed the innovations of this segment of industry to be extended to many other segments of the national economy of the USSR.

For many years Petrokovskiy played an active and fruitful role in the scientific councils of the Committee on the problems of "Semiconductor Power Engineering and Electrical Power," being the deputy chairman of these councils.

On 9 September 1971, by the order of the USSR Supreme Soviet Presidium, Petrokovskiy was awarded the Badge of Honor for his services in the development of science.

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## FUELS AND RELATED EQUIPMENT

### REGULATION OF GAS CONSUMPTION NONUNIFORMITY

Moscow GAZOVAYA PROMYSHLENNOST'. SERIYA: EKONOMIKA GAZOVOY PROMYSHLENNOSTI in Russian No 1, Jan 79 pp 13-20

[Article by F. T. Agayev, R. I. Konyushev, and R. Ye. Glikina, VNIPIgaz Institute]

[Text] On the basis of an International Agreement between the USSR and Iran a contract was concluded by which Iran gas in the amount of 10 billion cubic meters per year began to flow into the Soviet Union through the Transiranian Pipeline from the Persian Gulf to the Soviet-Iranian border (Astara) in October 1970.

The mutually advantageous agreement between six countries (Iran, the USSR, Czechoslovakia, the Federal Republic of Germany, France and Austria) signed in Teheran on 30 November 1975 guarantees the delivery of Iranian gas in the amount of 13.6 billion cubic meters per year to Czechoslovakia, the Federal Republic of Germany, France and Austria for 23 years beginning in 1 January 1981. In addition, a contract was concluded between Iran and Czechoslovakia according to which 3.6 billion cubic meters of gas per year must be delivered to Czechoslovakia through the territory of the USSR [1].

All of the gas delivered by Iran in the amount of 27.2 billion cubic meters per year will be consumed by the republics of the Transcaucasus, the developed economic areas of the Northern Caucasus and the Eastern Ukraine. In place of Iranian gas, the Federal Republic of Germany, Austria and France will receive gas from the Orenburg Deposit and the deposits in the northern rayons of the Tyumen' Oblast across the territory of Czechoslovakia [2].

In order to transport the indicated volumes of gas from the Transcaucasus to the Northern Caucasus a plan has been made to expand the existing gas line from Astara to Kazi-Magomed and lay a new gas line from Kazi-Magomed along the west coast of the Caspian Sea to the north through the towns of Sumgait, Siazan', Khachmas, Derbent, Makhachkala, Groznyy, and Mozdok, cutting into the existing system of gas lines of the Kavkaztransgaz Association. The gas supply to the indicated areas will in the future provide a basis for all-around development of industry. In order to increase the amount of gas received from the Transcaucasus and the capacity of the Ordzhonikidze Mozdok Gas Line to 3 billion $m^3$ per year across complex, rugged terrain, the construction of a pumping station has been started in Ordzhonikidze. A distribution line is being constructed, as a result of which it will become possible to supply gas to users in the Nakhichevanskaya ASSR and the Nagorno-Karabakhskaya autonomous oblast. A result of expanding the existing gas line system and laying new ones will be increased capacity of the gas flows in the territory of the Caucasus-Transcaucasus region, cross feeding of the Transcaucasus and Northern Caucasus Gas Line systems permitting additional gas to be supplied in emergencies for users not having reserve fuel and connecting the basic gas users of the Dagestanskaya ASSR to other regions.

At this time the demand for gas in the republics of the Transcaucasus and the regions of the Northern Caucasus is being met by gas extraction in Azerbaijan, the Checheno-Ingushskaya ASSR, the Stavropolskiy and Krasnodarskiy Krays and importing gas from Iran.

The gas extracting regions of the Northern Caucasus are characterized by decreasing extraction as a result of which by 1980 these regions will convert from being suppliers of gas to consumers. Reformation of the flows from the Transcaucasus to the Northern Caucasus is required for this.

In the future of the power of the gas flows in the most stressed parts of the Transcaucasus economic region will increase significantly. Under such conditions the organization of flexible and reliable operation of the investigated system of gas lines represents an important problem which can be solved by several methods. The underground gas storage which can be created on the basis of the exhausted beds in the investigated region will be capable of solving the problem with the greatest cost benefit.

In the Caucasus and Transcaucasus economic region at the present time there are two operating (Kalmasskoye and Yerevan) storages and one storage in the construction stage (Northern Stavropol'). The first two perform the functions of a regulator for "smoothing" the nonuniformity in the gas consumption of the Transcaucasus republics. The Yerevan PKhG [underground gas storage] has been designed to eliminate the gas shortage for stressed periods only in Yerevan.

The Northern Stavropol' PKhG will assume the functions of a regulator for the Strapolskiy (without users in the southeastern part) and partially the Krasnodarskiy Krays.

The nonuniformity of the gas consumption of the other parts of the Northern Caucasus--the Chechens-Ingushskaya, Severo-Osetinskaya, Kabardino-Balkarskaya and the Dagestanskaya ASSRs autonomous republics and the southeastern part of the Stavropolskiy Kray--will remain unregulated in the future. In order to discover the possibility of regulating the nonuniformity of the gas consumption of these regions a calculation was made of the nonuniformity of the gas consumption of the indicated regions and the republic of the Transcaucasus planned for the future.

In the investigated version of the calculation for the southeastern part of the Strapolskiy Kray in the future a consumption volume will be adopted in the amount of 25 percent of the total gas consumption of the Stavropolskiy Kray beginning with the actual data on gas consumption in the preceding years.

The initial base for calculating the nonuniformity of the gas consumption for the future was the data of the VNIIEgazprom Institute with respect to volume and structure of the gas consumption for the future and the actual coefficients of nonuniformity of the gas consumption by each category of users in the regions of Northern Caucasus and the Transcaucasus. The actual nonuniformity coefficients of the gas consumption were discovered in the process of analyzing the gas consumption data with respect to the indicated regions in 1971-1975.

The study of the structure of the gas consumption of the analyzed regions demonstrated that in the overall gas consumption significant weight goes to the buffer users operating as regulators. To a defined degree they "smooth" the actual nonuniformity in the gas consumption.

Therefore when determining the volumes of the nonuniformity in order to obtain reliable data on the fluctuations of the gas consumption, the effect of the forced gas consumption graph for the buffer users on the total indexes of the intensity of fluctuations of gas consumption for which redistribution of their gas consumption by month in accordance with the fuel consumption regimen of the buffer users, was excluded.

As a result of the calculation, the gas consumption nonuniformity coefficients were discovered (see Table 1).

When going from the nonuniformity volume to the planned volume of underground gas storage the factors of the temperature deviation in the coldest winters and the occurrence of emergency situations on the gas line were taken into account which give rise to the necessity for creating a reserve. For the first case, this reserve is taken in the amount of 20 percent, and the latter case, 10 percent of the discovered volume of the nonuniformity (Table 2).

From Table 2 it is obvious that in the future the seasonal gas shortage will be 4,700 million $m^3$.

Under the conditions of continuous intensive growth of the gas consumption one Kalmass PKhG will not be able to eliminate the seasonal gas shortage in the future, in connection with which the problem of creating a large base PKhG in the investigated region will become highly urgent.

Table 1. Nonuniformity Coefficients of Gas Consumption for the Future by Months

| Regions | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Azerbaijan SSR | I,19 | I,22 | I,2I | 0,99 | 0,86 | 0,82 | 0,8I | 0,80 | 0,85 | 0,93 | I,09 | I,24 |
| Georgian SSR | I,I0 | I,25 | I,19 | 0,90 | 0,85 | 0,82 | 0,85 | 0,78 | 0,8I | 0,95 | I,2I | I,29 |
| Armenian SSR | I,2I | I,29 | I,I7 | 0,85 | 0,8I | 0,77 | 0,73 | 0,77 | 0,8I | 0,92 | I,22 | I,45 |
| Dagestanskaya ASSR | I,33 | I,35 | I,20 | 0,95 | 0,77 | 0,74 | 0,75 | 0,68 | 0,7I | 0,9I | I,25 | I,38 |
| Checheno-Ingushskaya ASSR | I,32 | I,3I | I,I4 | 0,97 | 0,8I | 0,8I | 0,70 | 0,77 | 0,85 | 0,89 | I,I6 | I,27 |
| Severo-Osetinskaya ASSR | I,3I | I,38 | I,28 | 0,85 | 0,73 | 0,72 | 0,69 | 0,59 | 0,74 | I,05 | I,26 | I,40 |
| Kabardino-Balkarskaya ASSR | I,4I | I,44 | I,35 | 0,89 | 0,6I | 0,62 | 0,6I | 0,6I | 0,67 | I,02 | I,28 | I,49 |
| Southern part of Stavropolskiy Kray | I,I6 | I,23 | I,I5 | 0,99 | 0,78 | 0,80 | 0,83 | 0,85 | 0,88 | 0,88 | I,I4 | I,3I |
| Total | I,2I | I,29 | I,20 | 0,94 | 0,8I | 0,79 | 0,77 | 0,77 | 0,82 | 0,92 | I,I6 | I,32 |

Table 2. Indexes of Consumption Volume, Nonuniformity and Gas Storage with Respect to the Caucasus-Transcaucasus Region, Millions of $m^3$

| Region | Consumption | | Seasonal non-uniformity | | Reserve | | Storage volume | |
|---|---|---|---|---|---|---|---|---|
| | Current | In the future | Current | In the future | Current | In the future | Current | In the future |
| Azerbaijan SSR | 9900 | 14400 | 830 | 1100 | 250 | 330 | 1080 | 1430 |
| Georgian SSR | 3400 | 6500 | 350 | 570 | 105 | 170 | 455 | 740 |
| Armenian SSR | 3100 | 6600 | 400 | 740 | 120 | 220 | 520 | 960 |
| Dagestanskaya ASSR | 250 | 700 | 50 | 90 | 15 | 30 | 65 | 120 |
| Checheno-Ingushskaya ASSR | 2300 | 3900 | 240 | 390 | 70 | 120 | 310 | 510 |
| Severo-Osetinskaya ASSR | 650 | 1300 | 100 | 180 | 30 | 55 | 130 | 235 |
| Kabardino-Balkarskaya ASSR | 450 | 1500 | 80 | 250 | 25 | 75 | 105 | 325 |
| Southern Part of Stavropolskiy Kray | 1100 | 3600 | 100 | 300 | 30 | 90 | 130 | 390 |
| Total | 21150 | 38500 | 2150 | 3620 | 645 | 1090 | 2795 | 4710 |

In the Transcaucasus and in the Northern Caucasus projects have been ongoing for a number of years to find sites for the creation of underground gas storage in the depleted beds and aquifers. In Krasnodarskiy Kray, 210 sites have been investigated, and the Lower Cretaceous deposits of the Kushchevkkiy Field have been recommended for underground gas storage; in the Stavropol' Kray, 170 sites have been investigated, and the deposits of the Green Suite of the Northern Stavropol' Field have been recommended; in Checheno-Ingushetia, 100 beds of the Karaganchokrakskiy Complex were investigated, and none were recommended.

In the territory of the Georgian SSR, the Soyuzburgas Trust has worked on finding local water-bearing structures and collector beds for underground gas storage.

In order to create underground gas storage in water-bearing structures, there are geological prerequisites, and a final solution of this problem will require a number of exploratory operations.

The selection of the sites for underground gas storage in the water-bearing structures of the Armenian SSR has low prospects.

In spite of a large number of investigated depleted beds (about 400) in the Azerbaijan SSR no favorable site was found except the beds of the VII horizons of the Karadagskiy Field.

The site for underground gas storage is the depleted beds of the VII horizons coordinated with the lower limb of a brachyanticlinal 15 km long and 6 to 8 km wide. The structure is divided into two blocks I (large) and II (small) by two dislocations.

The VII horizons differ from the other horizons by significantly more effective thickness of the sand and aleurite beds.

Above the VII horizon suite is an argillaceous section VI-VII 250-300 meters thick, which is a reliable confining bed.

In addition to the favorable geological characteristic, the additional prerequisites for creating underground gas storage in the VII horizons are the possibility of extracting the condensate deposited in the bed, the effect on the oil margin underdevelopment, the use of the existing wells, field structures and lines for underground gas storage.

The II (small) block is recommended as the primary block [3].

| | |
|---|---|
| Number of operating wells | 14 |
| Capital investments, millions of rubles | 15.2 |
| Operating expenses, millions of rubles | 1.45 |
| Reduced expenses, millions of rubles | 3.27 |
| Specific capital investments, rubles/thousand of $m^3$ | 15.2 |

The cost benefit from creating the first phase of the Karadagskiy underground gas storage will be 6.7 million rubles per year.

The next phase of the underground gas storage is to be created in block I (the large one) with subsequent buildup of it.

The joint use of the two underground gas storages (Kalmasskiy and Karadagskiy) requires investigation of the problem of the distribution of the pumping laws and the selection of gas between them. In this case it appears expedient to use the Karadagskiy underground gas storage as the base, and Kalmasskiy, as the peak.

Thus, the creation of a large base underground gas storage in the depleted bed of the VII horizons of the Karadag Field will make it possible to regulate the nonuniformity of the gas consumption in the Transcaucasus and individual areas of the Northern Caucasus, to create a reserve and improve the operating reliability of the cross-connected main gas line systems.

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## FUELS AND RELATED EQUIPMENT

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## DISTRIBUTION OF PETROLEUM RESERVES AND OIL RECOVERY FROM THE UZEN' FIELD

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[Text] More than 1800 wells have been drilled in the Uzen' formation. The geophysical data for more than half of them have been interpreted by the known procedure of [2].

More than 50 separate productive beds have been isolated in the XIII-XVIII horizon section. A large amount of initial data including tens of thousands of individual determinations and characteristics have been accumulated for these beds. They offer the possibility of studying the structure of the formations chosen for development with a high degree of detail and accuracy. An information retrieval system (the Uzen' IPS) has been developed and set up for complete use of this broad material. It permits operative, multiple sorting and processing of the data pertaining to the index or object under study.

The Uzen' information retrieval system is a set of programs for automatic recording, classification, storage and processing of geological and geophysical data on productive beds executed on the BESM-6 computer [4]. In addition to the data on the effective thickness and permeability of the bed, the information retrieval system catalogue contains data on the coordinates of drilled wells, the position of the initial oil-bearing contours for each productive member, tectonic disturbances, and so on. The system permits graphical constructions and calculations to be made connected with the spatial propagation of the oil-bearing traps in the body of the formation.

A special program was used to determine the oil-bearing volumes within the limits of a given bed, band or horizon, a block or the entire formation. An important characteristic of the system is the possibility of limiting the selection of information to an arbitrary range of values of the permeability, in particular, selectively calculating the productive volumes only for those beds, the permeability characteristic of which corresponds to the previously given range of values.

By using the information retrieval system it has become possible to carry out detailed differentiation and evaluation of the initial balance reserves of the oil in the XIII-XVIII horizons of the Uzen' formation for 961 wells. The primary goal of this evaluation was not a review of the total oil reserves but only a study of their structure that is, the nature of the distribution with respect to area, section, and beds with different percolation properties. For separate calculation of the reserves with respect to beds with different percolation characteristic, various oil saturation coefficients were used for the rock. The presence of a stable correlation between the permeability and the oil saturation [3] made it possible to use different values of the latter coefficient for low, medium and highly permeable traps. The first category included the beds with a permeability of less than 50, the second category, beds with a permeability of 50 to 150, and the third, 150 mD or more. The category of low-permeable traps was divided into two subcategories. The first includes the beds with a permeability from 10 (the extreme value of the parameter adopted when calculating the reserves, approved by the State Commission on Mineral Resources of the USSR) to 20-30 mD (the lower limit under the cold water pumping conditions [1]); the second includes the productive deposits with a permeability from 25-30 to 50 mD. In accordance with the classification of the Uzen' traps [3] the third category is divided into subcategories corresponding to the beds with permeability from 150 to 400 mD or more.

Table 1

| Permeability range for oil-saturated traps, mD | Horizons | | | | | | Total with respect to XIII-XVIII horizons |
|---|---|---|---|---|---|---|---|
| | XIII | XIV | XV | XVI | XVII | XVIII | |
| 10—20 | $\frac{14,0}{32,4}$ | $\frac{6,9}{34,8}$ | $\frac{6,2}{9,2}$ | $\frac{4,5}{5,2}$ | $\frac{12,9}{15,2}$ | $\frac{10,0}{3,2}$ | $\frac{8,7}{100,0}$ |
| 20—50 | $\frac{15,6}{24,5}$ | $\frac{10,1}{34,6}$ | $\frac{17,2}{17,5}$ | $\frac{11,2}{8,8}$ | $\frac{10,9}{8,8}$ | $\frac{26,8}{5,9}$ | $\frac{12,8}{100,0}$ |
| 50—150 | $\frac{24,7}{16,0}$ | $\frac{28,7}{40,8}$ | $\frac{42,5}{17,9}$ | $\frac{36,8}{11,9}$ | $\frac{29,7}{9,9}$ | $\frac{37,8}{3,5}$ | $\frac{30,8}{100,0}$ |
| 150—400 | $\frac{22,5}{16,8}$ | $\frac{30,2}{49,1}$ | $\frac{21,7}{10,5}$ | $\frac{33,9}{12,5}$ | $\frac{25,9}{9,8}$ | $\frac{10,7}{1,2}$ | $\frac{27,0}{100,0}$ |
| >400 | $\frac{23,2}{22,8}$ | $\frac{24,0}{50,8}$ | $\frac{12,3}{7,7}$ | $\frac{13,6}{6,6}$ | $\frac{20,4}{10,1}$ | $\frac{14,7}{2,0}$ | $\frac{20,7}{100,0}$ |
| Всего Total | $\frac{100,0}{20,1}$ | $\frac{100,0}{43,8}$ | $\frac{100,0}{13,0}$ | $\frac{100,0}{10,0}$ | $\frac{100,0}{10,2}$ | $\frac{100,0}{2,9}$ | $\frac{100,0}{100,0}$ |

Note. Proportion of reserves, percent: proportion from total horizon in the numerator; from the total range in the denominator.

The reserves were evaluated by the following scheme. The address for each analyzed section of the formation was calculated, by which the volumes of the productive beds, bands and horizons as a whole were calculated on the computer. Then these volumes were multiplied by the mean values for the given horizon of the porosity coefficient, the oil density and the conversion factor and also by the oil saturation factor corresponding to the given permeability range.

As a result, a detailed estimate was made of the initial balance reserves of the oil with respect to the horizons, beds, bands, and sections of the blocks in each of the five given permeability ranges. The balance reserves with respect to the formation have turned out in practice to be equal to those approved. The distribution of the initial balance reserves with respect to permeability ranges and generalized results from estimating are presented in Table 1.

Most of the reserves turn out to be associated with traps with permeabilities from 50 to 150 mD--more than 30 percent of all of the balance reserves of the XIII-XVIII horizons. The traps with permeability with less than 50 mD contain on the whole more than 20 percent of the reserves of the XIII-XVIII horizons, and some of them, even more (in XIII 29.6, XVIII 36.8 percent). A noticeable proportion (8.7 percent) is associated with the beds with the permeability of less than 20 mD.

The oil reserves associated with the highly permeable traps (150 mD or more) amount to a total of 47.7 percent of the overall initial balance reserves of the formation. Half of them are concentrated in the XIV horizon. Among the highly permeable traps, as has been noted, a category has been established with permeability of more than 400 mD containing more than 1/5 of the total reserves.

The presented values of the volumes of the reserves in a formation with different permeability indicate how wide the range of variability of the bed properties is, how nonuniform the collectors are with respect to their percolation characteristics and how large the proportion of the reserves in the low-permeable beds.

This can be presented more clearly by depicting (see Figure 1) the oil reserve distribution with respect to permeability in the form of the f(K) and F(K) curves.

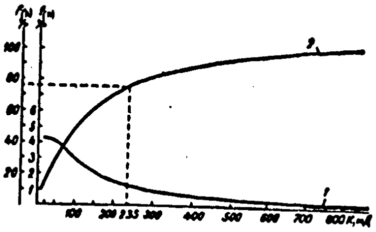

Figure 1. Distribution of the balance oil reserves of the Uzen' formation with respect to permeability. Distribution curves for the balance reserves: 1--Differential--f(K), 2--Integral--F(K).

The weighted mean value of the permeability as a whole with respect to the formation is 235 mD. , More than 70 percent of the oil reserves are associated with the beds and interstitial beds with permeability below this figure, and the minimum permeability of the beds, the reserves of which are considered industrial, is 23 times less than the weighted means.

The reserves connected with beds having permeability above 235 mD amount to less than 30 percent of the formation, and the ratio of the maximum permeability to the mean in this group reaches 7-10. The dispersion of the mean value of the permeability is 1.16, which is appreciably more than for the Ural-Povolzh'ye fields.

The investigation of the structure of the initial balance reserves, their distribution with respect to traps with different percolation characteristics are of great interest when analyzing the flooding conditions of the productive formations.

In recent years, a relatively fast rise in flooding of the production formations has been observed in the Uzen' field. It is known that the effectiveness of the flooding process is determined by many factors, among which the pumping system, the viscosity of the oil, the discontinuity of the oil-bearing strata, the condition of the bottom-hole pumping and operating wells, and so on play an important role. The nonuniformity of the flooded formations with respect to permeability also has very great significance.

In order to estimate the role of the natural nonuniformity of the beds of the XIII-XVIII horizons with respect to permeability and ratio of the viscosity of oil and water in the flooding characteristic, a study was made of the following approximate calculation (idealized) scheme. All of the operating sites in the formation are represented as a single multilayer nonuniform bed, the reserves in which are distributed in scattered layers with different average permeability corresponding to the above defined permeability ranges. The thickness of the layers is proportional to the fraction of the balance reserves characterized by one permeability rating or another (see Figure 2). This schematized bed is drained by using the working and pumping galleries under constant conditions. Under the flooded and oil-bearing zones, the percolation resistances remain equal, that is, the reductions in phase permeability and viscosity of the liquid in the flooded zone are the same. The layers will be worked in this case proportionally to the mean values of their permeability, and the water will break through into the working gallery from the more permeable layers through the less permeable ones.

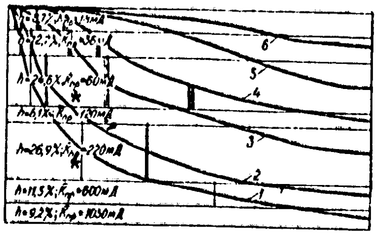

Figure 2. Idealized schematic of flooding process. Curves 1-6--Position of the pumping front at the time of flooding the corresponding layer.
Key: *--Permeability

When a layer (see Figure 2) with the highest permeability (in the range of 800 to 1,200 mD, $\bar{K}_{perm}$ = 1059 mD) is completely flooded, the position of the water front in the other layers (indicated by a single vertical line) turns out to be proportional to their mean permeabilities; the pumping front line will be described in curve 1. At the next point in time--complete flooding of the layer with an average permeability of 600 mD (the range 400-800 mD) --the position of the water front is shifted (indicated by the double vertical line) and the pumping front line will be described by curve 2, and so on.

Considering the simplifications of the percolation process discussed above, the flooding of the production formation at each investigated time is defined by the formula

$$n = \frac{\Sigma \bar{K}_B h_B}{\Sigma \bar{K}_B h_B + \Sigma \bar{K}_H h_H} \cdot 100\%$$

where $\bar{K}_B$ and $h_B$ are the main values of the permeability and the effective thickness of the flooded layers, $\bar{K}_H$ and $h_H$ are the mean values of the permeability and the effective thickness of the layers not yet flooded.

The coefficient of displacement of oil by water in the flooded formation is assumed to be equal for all beds (0.62). Here, however, it is considered that the collectors with different mean permeability are encompassed to a different degree by the drainage, which is caused by their discontinuity. The factor indicating the degree to which the beds are encompassed by the drainage is assumed to be equal to the following values for the given permeabilities: for 10-20 mD, 0.5; 20-50 mD, 0.6; 50-150 mD, 0.7 and above 150 mD, 0.9. This corresponds to the actual state of nonuniformity of the horizons in the formation and encompassing of them by the drainage. The low-permeability beds are characterized by greater discontinuity and are less encompassed with respect to thickness in the wells not exceeding 0.5.

Beginning with these conditions, the following relations were obtained between the flooding and the current relative oil extraction calculated in percentages of the final planned extraction (see Table 2).

The ratio between the indexes of the different stages of development indicates that in the Uzen' field very high nonuniformity with respect to permeability of the initial balance oil reserves in the working sites of the XIII-XVIII horizons predetermines the relatively high flooding rate of the production formation. The characteristics obtained under the conditions of the idealized model are close to the actual characteristics.

Table 2

| Relative oil extraction, % | Production flooding, % |
|---|---|
| 26,8 | 38,3 |
| 39,1 | 65,6 |
| 66,1 | 88,9 |
| 76,8 | 91,8 |
| 98,4 | 97,6 |
| 100 | 99,4 |

In addition, the actual conditions of the working of the formation are characterized by the presence of a number of factors having a negative influence on the flooding effectiveness, increasing the nonuniformity of the section and leading to an increased rate of flooding of the extracted production.

One such factor obviously is the precipitation of paraffin (at least in the bottom-hole zones of the beds) when the thermodynamic conditions change. This has a negative effect on the percolation first of all in the low-permeable sections of the beds and, as a consequence, partial or complete exclusion of them from the drainage process.

If we assume that the layers representing the productive beds with a permeability to 50 mD are completely isolated from the drainage, then the dynamics of the calculated indexes of flooding of the extracted production and relative oil extraction will be characterized as follows (see Table 3).

A comparison of these indexes of the flooding process with analogous ones under ideal conditions without considering the precipitation of paraffin indicates that the latter leads to plugging of the pores in the low-permeable traps and, as a result, to reduced oil extraction with greater flooding of the production.

Table 3

| Relative oil extraction, % | Flooding of the production, % |
|---|---|
| 26,3 | 39,3 |
| 38,2 | 67,2 |
| 64,1 | 91,1 |
| 73,4 | 94,0 |
| 85,7 | 100 |

In the first stages of development, this difference has little effect, for the low-permeable beds are worked at a slow rate, and the proportion of their exploitation in the extracted production is insignificant. Later, the divergence becomes significant and leads to a much lower final oil extraction.

If all of the traps with a permeability of less than 50 mD are exluded from the drained part of the formations as a result of complications of the development conditions (which is entirely possible), it is difficult to achieve the planned final oil extraction from the beds with ordinary flooding.

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