Development of a Solid Fuel
Ration Can Heating Unit
Final Report
15 Sept. 1954

Wyandotte Chem. Corp -
Contracts DA 44-109-qm-1278
and DA 44-109-qm-1518.

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DEVELOPMENT OF A SOLID FUEL RATION CAN HEATING UNIT

Final Report

15 September 1954

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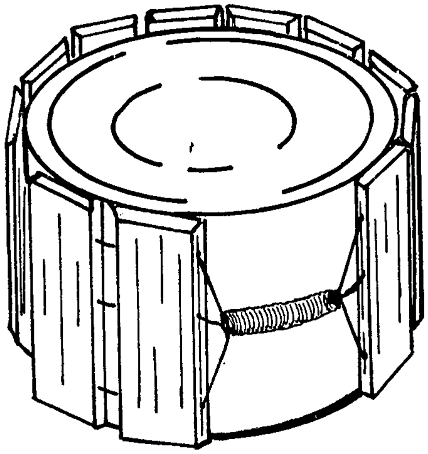

FOR

DEPARTMENT OF THE ARMY
QUARTERMASTER RESEARCH AND DEVELOPMENT CENTER
NATICK, MASS.

CONTRACTS DA44-109-qm-1278 AND DA44-109-qm-1518

DEPARTMENT OF CONTRACT RESEARCH
RESEARCH AND DEVELOPMENT DIVISION

WYANDOTTE CHEMICALS CORPORATION
WYANDOTTE, MICHIGAN

[redacted]

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DEPARTMENT OF THE ARMY
QUARTERMASTER RESEARCH AND DEVELOPMENT CENTER
NATICK, MASSACHUSETTS

CONTRACTS DA44-109-qm-1278 AND DA44-109-qm-1518

WYANDOTTE CHEMICALS CORPORATION PROJECTS 397A AND 397B

DEVELOPMENT OF A SOLID FUEL RATION CAN HEATING UNIT

FINAL REPORT

15 SEPTEMBER 1954

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DOC 1 REV DATE 25 JUN 1980 BY 064540
ORIG COMP 70 / OPI 56 TYPE 30
ORIG CLASS M PAGES 131 REV CLASS X
JUST — NEXT REV — AUTH: HR 70-2

WYANDOTTE CHEMICALS CORPORATION
Wyandotte, Michigan

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FOREWORD

This final report was prepared pursuant to the provisions of Army Contracts DA44-109-qm-1278 and DA44-109-qm-1518, and covers the period 22 October 1952 to 7 July 1954. The objectives of these contracts are set forth in Appendix I, p. 82. The work was performed by Mr. Arthur L. Austin and Dr. John J. Sebenick, assisted in the production of the 1000 units by David V. Burchfield and Richard C. Lyon, under the general direction of Mr. H. Earl Tremain and (subsequent to 1 April 1954) Mr. R. A. Graham. The report was written by Dr. Arthur B. Ash and Mr. Arthur L. Austin with final editorial assistance by Dr. Leslie R. Bacon. Technical guidance on behalf of the Quartermaster Corps was supplied by Mr. Theodore Kapala. The ready assistance of these and others who have contributed to this effort is gratefully acknowledged.

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ABSTRACT

Research and development efforts directed to the preparation of improved solid fuel units for heating assault and other ration cans in the field are described. One thousand units have been produced for field evaluation comprising a circumferential design of 11 briquets linked together with Fiberglas cord and secured to the can by means of a coil spring attached to looped ends of the Fiberglas cord. Ignition is by use of a match applied to an igniter spot on and between the fifth and sixth briquets, the ignition being propagated around the unit by means of an igniter strip applied to the inner surface and to a surface embedded asbestos cord linkage; an igniter formulation was developed for the purpose. Ignition by use of a book match at -40° F. has been demonstrated. The units burn without failure in gusts of wind.

The units display some visible activity, as evidenced by smoke and sparking, for approximately 15 seconds at 70° F. and 60 seconds at -40° F. and there is some odor during this ignition period. There is no visible activity following the ignition period. Carbon monoxide, present in the combustion gases to the extent of 0.3 to 1.7%, constitutes the only toxic hazard; caution in confined areas is recommended.

The units are hermetically heat-sealed in Kraft paper-backed aluminum foil. A storage life of at least five years is anticipated in the moisture-proof package, and the units should be capable of ordinary military handling and transportation without damage.

The raw materials used in the best formulation are Air-Float charcoal, iron powder, potassium and sodium nitrates, sodium acetate trihydrate, ammonium bicarbonate, potato starch and copper chromite (catalyst).

Six carbon fuels were evaluated as less expensive and less critical substitutes for charcoal; two products of the low temperature distillation of Pittsburgh coal, Disco and Char Feed, were found to be satisfactory. Six compounds were evaluated as less expensive and less critical substitutes for copper chromite combustion catalyst; manganese dioxide in its various grades was found to be satisfactory. Extensive formulation studies were performed to establish optimum compositions for Disco, Char Feed and manganese dioxide-containing formulations. The chromite formulation however still continues to give slightly the best performance. Various binding materials were studied; potato starch gave the best results. Wire and Fiberglas cord were evaluated as briquet linking materials; Fiberglas cord proved satisfactory. Design of the unit requires provision for admittance of air between individual fuel briquets and briquets and can for optimum results.

A very limited effort to utilize the fuel paste in extrusion molding was unsuccessful; the problem appears surmountable, however. Compression molding improved the breaking strength of the briquets but the loss in porosity resulted in a product which sparked and sputtered during combustion. Hand-loaded molds were adopted for forming the briquets of the 1000 delivered field test units. The eight-step manufacturing process employed for the 1000 field test units is described; only readily available and inexpensive equipment was employed. The pilot plant design is illustrated by means of a flow diagram and photographs showing the equipment and major operations.

Material costs are estimated at $0.0469 per unit which includes a cost of $0.022 for the spring fastener. Unit manufacturing costs for a plant design using a hypothetical mass production process, employing extruding and linking equipment, are estimated at $0.0532 with a spring fastener and $0.0312 without a spring fastener; these figures are based on an annual production of 11,520,000 units.

Recommendations are offered and discussed for work directed at further improvements in the combustion and physical characteristics of these units and reduction of their cost, as well as toward improved forming techniques for large scale production.

SUMMARY AND CONCLUSIONS

1. One thousand solid fuel ration can heating units of a circumferential linked belt design have been manufactured, packaged, and delivered to the Quartermaster Research and Development Center, Natick, Massachusetts.

2. The heating units consisted of 11 briquets, each 1-9/16 x 3/16 inches. The briquets were linked with two lengths of embedded Fiberglas cord and a third strand of asbestos treated with igniter formulation. The units may be attached to ration cans by means of a coil spring joining looped ends of the Fiberglas cords.

3. The once-folded units were packaged in Reynolds Metals Company heat-sealed barrier material RM 245 (Kraft paper-backed aluminum foil); the pouch units have a tested shelf life of one year and an anticipated shelf life of five years or more (hermetically sealed).

4. The units meet the following design objectives to the maximum practicable extent: (1) maximum security in use (minimum smoke, sparking, sputtering and odor), easily ignitable with book match from 125° F. to a -65° F. (tested at -40° F.), packaged unit not adversely affected by water or low atmospheric pressure, stable and usable until consumed, a storage life of not less than five years, non-toxic in use (0.3 to 1.7% carbon monoxide found in the combustion products), non-friable in military shipping and handling, and not easily extinguished by gusts of wind.

5. At -40° F. ambient temperature the units are capable of heating 150 g. of water from -40° F. to 130° F. in 16 to 18 minutes; visible activity occurs for approximately 60 seconds as evidenced by smoking and sparking.

6. At 70° F. ambient temperature the units are capable of heating 150 g. of water from 70° F. to boiling in 8 to 10 minutes; visible activity occurs for approximately 15 to 20 seconds as evidenced by smoke and sparking.

7. The composition of the fuel formulation employed for the 1000 manufactured units is as follows:

	Production Formula		Dry Basis	
	Parts By Wt.	%	Production Formula, %	Starch-Free Formula Basis, %
Charcoal	954	38.16	51.02	53.00
Iron powder	189	7.56	10.11	10.50
Potassium nitrate	261	10.44	13.96	14.50
Sodium nitrate	165.6	6.62	8.85	9.20
Sodium acetate trihydrate	93.6	3.74	5.00	5.20
Copper chromite	68.4	2.74	3.66	3.80
Ammonium bicarbonate	68.4	2.74	3.66	3.80
Starch) As 10% (	70	2.80	3.74	-
Water) dispersion (	630	25.20	-	-
	2500.0	100.00	100.00	100.00

8. A satisfactory fuel type igniter formulation of high oxidizer content was developed: charcoal, 23%; sodium nitrate, 27%; potassium nitrate, 41%; sodium acetate trihydrate, 4.5%; and ammonium bicarbonate, 4.5%. Water is added to make up a paste of a consistency suitable for application.

9. The quantity of igniter formulation applied to the briquets was found to be critical. Best results were secured with the application of a strip 3/8-inch in width around the interior circumference of the link belt unit, following the course of the asbestos igniter cord, and the application of an approximately 3/8-inch diameter igniter spot on the exterior surface between the fifth and sixth briquets.

10. The materials cost per unit is $0.0469, including a cost of $0.022 for the coil spring fastener, but not including costs for cartons and shipping cases.

11. Depending on the fuel formula chosen, the cost of the coil spring amounts to 47-57% of the total materials cost. The greatest opportunity for cost reduction lies in the search for or development of an alternate tensioning device.

12. The production of 48,000 units per day (11,520,000 annually) using a small extruder with attachments for linking is estimated to cost approximately $0.0532 per unit with coil spring fastener and $0.0312 per unit without any spring fastener.

13. In a search for less expensive and less critical fuels, six carbon-containing materials were screened as potential replacements for wood charcoal: Coke, lignosulfonate, anthracite coal, bituminous coal, Disco (from low-temperature distillation of a high-volatile content coal) and Char Feed (Disco-derived).

14. Disco and Char Feed fuels were considered satisfactory replacements for wood charcoal, although these materials produced slightly more smoke than charcoal.

15. In a search for less expensive and less critical combustion catalysts, six compounds were evaluated as potential replacements for copper chromite: ferric nitrate, barium dioxide, lead oxide (PbO), magnesium nitrate, nickel oxide and manganese dioxide. Manganese dioxide proved to be an effective substitute.

16. Formulations containing Disco and Char Feed fuels and manganese dioxide combustion catalyst were developed which performed satisfactorily in rate-of-heating studies; these formulations were then optimized in component variance studies.

17. Manganese dioxide catalyzed formulations required a greater air supply. The additional air was obtained by a minimum 1/8 inch clearance between the briquets of the circumferential link belt unit and the ration can. The copper chromite catalyzed formulations require only 1/16 inch clearance.

18. Two prepasted wheat starches and polyvinyl alcohol were found to be inferior to potato starch paste as a binding agent.

19. The quantity of starch paste required was found to vary inversely with the extent of grinding and milling of the fuel formulation components.

20. Compression molding increased the breaking strength of the fuel briquets moderately, but due to loss of porosity the combustion characteristics were unfavorable.

21. Wire proved unsatisfactory as a linking material for the fuel briquets; expansion during heating permitted the unit to slide down the sides of the can. Fiberglas cord proved to be a satisfactory linking material.

22. Time-temperature fuel briquet baking studies established the following schedule for the wood charcoal-copper chromite formulation employed for the manufactured units: one hour at 70-75° C. followed by four hours at 105° C.

23. A baking period of more than four hours at 110° C. was not deleterious, but the baking temperature of 110° C. should not be exceeded. A baking temperature above 110° C. for copper chromite-containing formulations resulted in increased sparking; a temperature of 115° C. was the upper limit for manganese dioxide catalyzed formulations. Smoke and odor were not affected by the baking temperature.

24. The details of the pilot plant employed for the production of the units are presented; eight manual operations were performed using readily available equipment: laboratory hammermill, six quart dough mixer, polyvinyl chloride Plastisol molds, air circulating oven and a belt type heat sealer for packaging.

25. Suggestions on equipment and operation of a plant in which five people should turn out about 48,000 fuel units per eight hour day (11,520,000 units per year) are offered. To accomplish this operations must be highly mechanized. Apparatus for automatically molding fuel briquets, including the operations of imbedding the three cords, cutting to length and joining the Fiberglas ends into loops, applying the igniter formulation, and attaching the tensioning device, remains to be designed; indications were obtained that the problems could be solved.

26. The cost estimates of (12) are predicated on the solution of the mechanical problems involved and an investment of $80,000 for standard and special machinery, tools and equipment, including installation.

INTRODUCTION

Wyandotte Chemicals Corporation, under small successive contracts with the Office of the Quartermaster Corps, undertook an extended investigation comprising research, development and manufacture of 1000 solid fuel units for the heating of rations in the field. Work under the initial contract DA44-109-qm-433 has been summarized in a final report dated 15 November 1951. Work completed under the two succeeding contracts DA44-109-qm-1278 and DA44-109-qm-1518 forms the subject matter of this single final report.

Under the initial contract a carbon-containing fuel was developed which burned without flame and with a moderate amount of smoke and odor. The composition contained Airfloat Grade wood charcoal as the heat source, iron powder to minimize disintegration of the ash, a low melting eutectic mixture of sodium and potassium nitrates as oxidizer, sodium acetate to reduce sparking (by providing a liquid phase during the initial combustion), ammonium bicarbonate to develop porosity, copper chromite as an oxidation catalyst to lower the ignition temperature and ensure complete combustion, and potato starch as binder to provide a mechanically sound briquet structure.

The fuel composition was successfully tested in the form of a linked belt which encircled the cylindrical surface of 12-ounce cans of C-rations. A single linked unit weighing 37 g. heated a 12-ounce can of beans with pork and tomato sauce from 33° F. to an average temperature of 133° F. in approximately 10 minutes. A 20-minute combustion time in still air was demonstrated and the heat content of the unit indicated that successful heating could be achieved from initial temperatures much lower than 33° F.

Under the two subsequent contracts the investigation was extended according to the defined scope of the contracts as reproduced in Appendix I of this report.

These contractual objectives included studies of certain components of the fuel formulation and a search for less expensive and less critical fuels and combustion catalysts. Binding materials were to be investigated to improve the moisture resistance and the strength of the fuel briquets and compression molding was to be studied as a possible means of improving the strength characteristics of the fuel briquets. Improved means of linking the individual briquets were sought and packaging materials were to be investigated. The production of 1000 units, meeting the specifications set forth in Article 1-(a)-(2) (See AppendixI), was required. Finally, a design of a pilot plant for the production, packaging and packing of small quantities of the heating units was to be supplied.

Work was initiated in October 1952 and the 1000 heating units were delivered in June 1954. The various laboratory experimental studies directed at a fuel formulation best meeting the requirements with respect to cost, criticality of materials and performance will be reported first. This phase includes studies of various carbon fuels, combustion catalysts, formulation screening studies, secondary air requirements, binding materials and baking procedures. The development of an igniter formulation is given. Three Memorandum Reports (Appendix III) covering evaluation studies of selected fuel formulations by representatives of Quartermaster Corps are then discussed.

Work relating to the production of the 1000 delivered units is presented in three major sections: Design of the Production Unit, Pre-Manufacturing Studies, and Manufacture. Extrusion methods, compression molding and hand-loaded molds were studied as means of forming the fuel briquets. Cost analyses are presented for several heating unit formulas using a hypothetical mass production process. Finally, the ability of the heating unit to meet the design objectives is discussed and a list of suggestions and recommendations directed toward further improvements is presented.

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FUEL FORMULATION STUDIES

Screening studies were performed to find potential replacements for wood charcoal fuel and copper chromite combustion catalyst. Alternate fuels and catalysts were then studied in various formulations, together with variations in other components, in order to arrive at the most efficient combinations. The necessity for providing additional air in the combustion through proper spacing of the fuel from the ration cans was demonstrated. Binding materials and baking methods were studied.

In many of these studies, the fuels and catalysts under test were substituted into the standard formulation developed under contract DA44-109-qm-433, as shown on page 42 in the Summary Report of 15 November 1951. The composition of this formulation is shown in Table 1. This is similar to but not exactly the same as adopted for making the 1000 heating units (compare formula on page 5).

EVALUATION OF CARBON-CONTAINING FUELS OTHER THAN WOOD CHARCOAL.

Airfloat Charcoal currently is priced at about $77 per ton, and in a period of national emergency the material could become a critical item. Accordingly, lower-priced and less critical acceptable substitutes for charcoal were sought. The following materials were selected for initial screening: coke, lignosulfonate, anthracite coal, bituminous coal, Disco and Char Feed (containing 10% volatile matter). The fuels were incorporated in the standard formulation of Table I and tested in the form of discs as reported in Table 2.

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TABLE 1

STANDARD FORMULATION DEVELOPED UNDER CONTRACT NO. DA44-109-qm-433 *

Component	Parts By Wt.	Anhydrous Basis With Starch, %	Starch-Free Formula Basis, %
Fuel (Wood charcoal, Airfloat grade)	40	49.68	52.63
Iron powder, 325 mesh	8	9.94	10.53
Potassium nitrate	11	13.66	14.47
Sodium nitrate	7	8.70	9.21
Sodium acetate trihydrate	4	4.97	5.26
Ammonium bicarbonate	3	3.73	3.95
Copper chromite	3	3.73	3.95
Starch) As 10% (	4.5	5.59	-
Water) Paste (	40.5		
	121.0	100.00	100.00

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* Also tested under designation CR-1036-I-4 - see page 36.

TABLE 2

SCREENING STUDY OF SIX CARBON FUELS

Fuel	Cost/Ton $	Smoke	Odor	Estimated Extent of Combustion,%
Coke	12.5	--	--	--
Lignosulfonate	--	Heavy-burns very rapidly	Objectionable; nauseating.	--
Anthracite coal	8.00	Satisfactory	Acrid for 3 min.	70%
Bituminous coal	8.00	Black, sooty	Acrid for entire combustion	60%
Disco	9.25	Medium	Acrid but less than anthracite	90%
Char Feed (10% VM)	--	Satisfactory	Faint	90%

Coke.

Coke is an unsatisfactory fuel for the present application. Its ignition temperature is too high for match use and the fuel did not continue to glow after an initial combustion period.

Lignosulfonate.

Lignosulfonate is a by-product of the sulfite paper process. It is a carbonaceous material consisting of 60% lignosulfonate and 20% carbon. Smoke evolution and sparking were excessive during test and a very obnoxious odor was noticed during the initial combustion period. It is doubtful if this material could be satisfactorily and economically purified to fulfill the design objectives.

Anthracite Coal.

The anthracite coal formulation failed to glow after the ignition combustion period until copper nitrate was added as a catalyst. This formulation then raised the temperature of 125 ml. of water initially at 43° F. to 158° F. in 15 minutes. The temperature of 158° F. was maintained for 10 minutes. However, the briquets became coated with a hard powder which acted as an insulator, limiting the air supply and preventing optimum heat transfer to the can. Work on this fuel was discontinued when it became apparent that a great deal of time and effort would be required in order to arrive at a satisfactory solid fuel formation.

Bituminous Coal (Pocahontas).

Formulations based upon bituminous coal (Pocahontas) evolved excessive smoke during the initial combustion period. This was expected in view of the high volatiles content of the coal. In an unsuccessful effort to decrease the rate of smoke evolution, fuels were formulated to lengthen the duration of the initial combustion period. Increasing the ratio of the nitrate to soft coal in the formulation reduced the amount of smoke, but the fuel then burned with a luminous flame, unsatisfactory for the present application.

Disco.

Disco, priced at $9.25/ton, is produced by low temperature distillation (850° F.) of a high volatile content, Pittsburgh seam coal. About 300,000 tons are manufactured annually by Pittsburgh Consolidation Coal Company. The heating value of the fuel is 12,810 B.T.U. per pound. Analysis of the fuel on a dry basis is as follows: volatiles, 18.7%; fixed carbon, 70.4%; ash, 10.9%*; sulfur, 2.1%.

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* Ash analysis is as follows: SiO_2, 47%; Al_2O_3, 27.3%; Fe_2O_3, 17.9%, CaO, 3.1%; MgO, 0.5%; other oxides, 3.0%; alkalies, 1.2%.

While, as noted in Table 2, smoke formation was excessive, the material appeared to be satisfactory in other respects. Accordingly, the material was evaluated further in studies reported later.

Char Feed.

Char Feed is an experimental product prepared at our request by the Pittsburgh Consolidation Coal Company in an effort to reduce the degree of smoking encountered with Disco. The product was produced by heating Disco for 15 minutes in the presence of an inert gas. The resulting product contains 77.2% fixed carbon and 10% volatile matter. The heating value is 12,380 B.T.U. per pound. As noted in Table 2, the product appeared quite promising, yielding less smoke during the initial combustion period than Disco and was selected, along with Disco, for further testing as reported later.

Subsequent to these screening studies, a Char Feed containing but 5% volatile matter was obtained. This material produced briquets of porous structure with good initial burning characteristics. After a high initial heat output, however, the fuel cooled very rapidly. Further work with this material was discontinued as it became apparent that considerable effort would be required to establish whether or not a satisfactory formulation could be obtained.

COMBUSTION CATALYSTS OTHER THAN COPPER CHROMITE.

Work performed under the Contract DA44-109-qm-433 confirmed the known effect of copper chromite as a combustion catalyst in charcoal formulations. Faster heating rates were obtained and combustion was more complete than when no catalyst was employed. The improved burning characteristics result in part from a reduction in the ignition temperature of the fuel.

The limited production and relatively high cost of copper chromite ($1.00-1.25 per pound) led to a search for less expensive catalysts. Manganese dioxide, nickel oxide, magnesium nitrate, lead oxide (PbO), barium dioxide, (BaO_2) and ferric nitrate were evaluated in the standard formulation shown in Table 1, replacing the copper chromite. The results appear in Table 3.

TABLE 3

EVALUATION OF COMBUSTION CATALYSTS

(In Standard Formulation of Table 1)

Catalyst	Wt. % Used	Observation
Ferric nitrate	4	Flashing and sputtering during initial combustion period.
Barium dioxide	6	Acted as a refractory; combustion about 70% complete.
Lead Oxide	6	Acted as a refractory; combustion about 70% complete.
Magnesium nitrate	4	Excessive flashing and sputtering during initial combustion period.
Nickel oxide	6	Acted as a refractory; combustion about 70% complete.
Manganese dioxide	6	Effective as a replacement for copper chromite; combustion about 90% complete.

Manganese dioxide was the only compound which warranted further consideration as a catalyst to replace copper chromite. The other materials either caused undue flashing and sputtering during the initial combustion period or acted as refractories, preventing complete combustion. Accordingly, three grades of manganese dioxide were tested: reagent, technical and African ore. Their performance is shown in Table 4 and their costs in Table 5. No significant difference in the catalytic activity of the three grades was apparent.

TABLE 4

COMPARISON OF VARIOUS GRADES OF MANGANESE DIOXIDE AS COMBUSTION CATALYSTS

(In Standard Formulation of Table 1)

MnO_2 Grade	Wt. % Used	Time to Raise 300 Ml. Water to 158°F., Min.	Extent of Combustion
Reagent	4	12.5	Combustion 90% complete
Technical (85%)	6	16.5	Combustion 90% complete
African Ore (84-87%)	6	11.5	Combustion 90% complete

TABLE 5

COSTS OF THREE GRADES OF MANGANESE DIOXIDE

Grade	Cost, $/lb.
Reagent	1.08
Technical	0.28
African ore	0.05

In addition to its low cost, African ore is readily available in tonnage lots. Accordingly this material was studied as a possible replacement for copper chromite catalyst as reported in the next section.

FORMULATION STUDIES INVOLVING CHARCOAL, DISCO AND CHAR FEED FUELS WITH MANGANESE DIOXIDE AS THE COMBUSTION CATALYST.

The fuel evaluation screening studies, reported above, indicated that Disco and Char Feed were potential replacements for charcoal as fuel and that manganese dioxide, in its various grades, was a promising alternate combustion catalyst for copper chromite. Accordingly, five formulations were prepared in the form of discs for heating studies.

Comparative water-heating tests are reported in Table 6 for three charcoal, Disco and Char Feed formulations using manganese dioxide as the combustion catalyst. In addition, two tests with very similar Disco formulations (small variation in nitrate contents and ratio) applied to heating 12-ounce ration cans are reported in Table 7. Although these five tests showed clearly that Disco and Char Feed formulations employing a manganese dioxide combustion catalyst could perform satisfactorily with respect to rate of heating, multiple tests showed poor reproducibility.*

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* Subsequent experience indicates that poor reproducibility may be attributed to variations due to hand mixing and inadequate clearance between the briquet and can for air supply for manganese dioxide catalyzed formulations.

TABLE 6

WATER RATE-OF-HEATING STUDIES WITH CHARCOAL, DISCO AND CHAR FEED FUEL FORMULATIONS

Test: 300 ml. of Water Initially at 40° F.
Ambient Temp.: 32° F.
Fuel Used: 60 grams

				Measured Temp., °F; After			
Formula	Ingredient	Wt., g.	Composition, Wt. %	10 Min.	15 Min.	20 Min.	30 Min.
A	Charcoal	53.0	50.0	110	195	180	160
	Iron Powder	10.0	9.4				
	KNO_3	14.5	13.7				
	$NaNO_3$	9.2	8.7				
	$NaC_2H_3O_2 \cdot 3H_2O$	3.8	3.6				
	NH_4HCO_3	3.8	3.6				
	MnO_2 (tech.)	6.0	5.6				
	Potato Starch*	5.7	5.4				
		106.0	100.0				
B	Disco	53.0	54.3	180	200	200	185
	KNO_3	13.0	13.3				
	$NaNO_3$	8.3	8.5				
	$NaC_2H_3O_2 \cdot 3H_2O$	6.0	6.2				
	MnO_2 (tech.)	10.0	10.3-				
	NH_4HCO_3	5.0	5.1-				
	Potato Starch*	2.3	2.4-				
		97.6	100.1-				
C	Char Feed	53.0	48.5	160	200	200	175
	Iron Powder	10.0	9.2				
	KNO_3	14.5	13.3				
	$NaNO_3$	9.2	8.4				
	$NaC_2H_3O_2 \cdot 3H_2O$	5.0	4.6				
	NH_4HCO_3	5.0	4.6				
	MnO_2 (tech.)	10.0	9.2				
	Potato Starch*	2.4	2.2				
		109.1	100.0				

---

* Dry basis; used as a 10% solution

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TABLE 7

HEATING OF 12-OUNCE RATION CANS OF BEANS WITH TWO DISCO FORMULATIONS

Initial Can Temp.: 100° F. below zero
Ambient Temp.: 30° F.
Fuel Used: 60 grams

Formula	Ingredient	Wt., g.	Composition, Wt. %	Observations During Heating
D	Disco	70.0	55.0	15 min.
	KNO_3	17.4	13.6	Small amount of frozen
	$NaNO_3$	11.0	8.6	beans in center of can.
	MnO_2 (tech.)	13.0	10.2	20 min.
	NH_4HCO_3	7.0	5.5	Temp. along wall, 160°F.
	$NaC_2H_3O_2 \cdot 3H_2O$	6.0	4.7	Temp. in center of can, 100°F.
	Potato starch*	3.0	2.4	Temp. upon mixing beans, 125°F.
		127.4	100.0	
E	Disco	70.0	54.4	15 min.
	KNO_3	18.1	14.1	Small amount of frozen
	$NaNO_3$	11.4	8.9	beans in center of can.
	MnO_2 (tech.)	13.0	10.1	20 min.
	NH_4HCO_3	7.0	5.4	Temp. along wall, 135°F.
	$NaC_2H_3O_2 \cdot 3H_2O$	6.0	4.7	Temp. in center of can, 80°F.
	Potato starch	3.1	2.4	Temp. upon mixing beans, 112°F.
		128.6	100.0	30 min.
				Temp. along wall, 145°F.
				Temp. in center of can, 90°F.
				Temp. upon mixing beans, 108°F.

* Dry basis; used as a 10% solution

Study of Minor Component Variations Involving Three Fuels and Two Grades of Manganese Dioxide.

At this point it seemed desirable to attempt to optimize the formulations with respect to each fuel and the technical and African Ore grades of manganese dioxide, using the standard test for rate-of-heating of 300 ml. water. A Latin Square experimental design was prepared involving the eutectic mixture of nitrates (approximately 61% potassium nitrate and 39% sodium nitrate), sodium acetate trihydrate and manganese dioxide (technical and African Ore

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grades independently) at four weight levels, the weight of fuel and ammonium bicarbonate being held constant. The drying time was held constant and the hand-mixing technique was performed as uniformly as possible. Iron powder was omitted from the design but was added as a separate component independently to test its effect on the rate of heating.

The experimental procedure and results of the studies are set forth in Appendix II, the design of the experiments being shown there in Table 20. The positive results of the studies, i.e., those formulations which achieved boiling of the water, are shown in Tables 21, 22, 23 and 24.

The following series of tests was conducted:

1. Sixteen duplicate tests with Disco fuel and technical grade manganese dioxide; iron powder omitted. (Table 21).

2. Sixteen tests with Disco fuel and African Ore grade manganese dioxide without added iron powder and 16 identical tests with 10 g. of added iron powder. (Table 22).

3. Sixteen tests with Char Feed and African Ore grade manganese dioxide without added iron powder and 16 identical tests with 10 g. of added iron powder. (Table 23).

4. Sixteen tests with charcoal and technical grade manganese dioxide without added iron powder (data not shown; none achieved boiling of the test water).

5. Two tests with charcoal and African Ore grade manganese dioxide with 10.5 g. of added iron powder. (Table 24).

In performing these tests, the formulations were cast as approximately one square centimeter pellets; these were held firmly against the can with ordinary fly screen. This procedure permitted easy preparation and rapid testing but as the work progressed it became evident that the surface presented to the air was inadequate, combustion being slow and incomplete. This factor, as well as possible difficult-to-assess variations occasioned by hand mixing, led to poor reproducibility which tended to cloud the test results. While it is felt that the effect of the small variations in composition were not conclusively evaluated, the general results and observations with respect to rates of heating listed below appear valid:

1. Disco fuel and Char Feed are satisfactory substitutes for wood charcoal.

2. Iron powder is not essential to the Disco or Char Feed formulations although charcoal formulations appear to perform somewhat better with added iron powder.

3. No substantial difference between technical grade and African Ore grade manganese dioxide was observed.

4. With manganese dioxide as a catalyst, charcoal formulations appear to require more air than do Disco and Char Feed formulations.

5. Formulas utilizing manganese dioxide as a catalyst appear to require more air than formulas using copper chromite as a catalyst.

Items 4 and 5, based on the present work, and taken in conjunction with previous experience, offer a reasonable explanation for the relatively poor performance of the charcoal-manganese dioxide formulations.

The formulations which performed best for each form of fuel according to the data presented in Appendix II were for Charcoal LS-1-I, for Disco LS-14, and for Char Feed LS-14. The compositions on a weight percent basis are shown in Table 8.

TABLE 8

"BEST" FUEL FORMULATIONS FROM LATIN SQUARE DESIGN STUDIES

	Fuel Component, Weight Percent		
Ingredients	Charcoal (LS-1-I)	Disco (LS-14)	Char Feed (LS-14)
Fuel	51.0	57.3	57.3
Iron powder	10.1	--	--
Potassium nitrate	13.3	14.0	14.0
Sodium nitrate	8.4	9.0	9.0
African Ore manganese dioxide	4.8	5.4	5.4
Sodium acetate	3.8	6.5	6.5
Ammonium bicarbonate	3.6	5.4	5.4
Potato starch *	5.0	2.4	2.4
	100.0	100.0	100.0

* Dry basis; added as 10% aqueous solution

The charcoal formulation is similar in composition to the recommended formulation of the final report of 15 November 1951 (See Table 1), with manganese dioxide replacing copper chromite as a combusion catalyst.

SUPPLY OF AIR FOR THE COMBUSTION PROCESS.

The desirability of utilizing air as efficiently as possible to carry on the combustion of the charcoal-copper chromite formulations after ignition and expenditure of the oxidizing agents in the formula had been recognized in work performed under the initial contract DA44-109-qm-433. The need for providing sufficient air had led to consideration of individual fuel briquets (greater surface exposure) in a wrap-around link belt unit, as opposed to methods involving heating only the ends of the ration can. However, time had not permitted studies involving clearance between the briquets and the ration can. In view of the poor reproducibility and poor heating efficiencies of certain formulations studied, it seemed likely that access of air from both sides of the briquet might be quite important, particularly with formulations involving manganese dioxide catalysts.

To establish the importance of clearance between the fuel briquets and the ration can, fuel briquets were prepared in which the necessary clearance was provided by protusions. Representative data are given in Table 9 for the charcoal-manganese dioxide formulation LS-1-I shown in Table 8.

TABLE 9

EFFECT OF CLEARANCE BETWEEN THE FUEL BRIQUETS AND THE RATION CAN ON THE RATE OF HEATING

Charcoal-Manganese Dioxide Formulation LS-1-I of Table 8

	Temperature, °C.			
	Approximate Clearance, In.			
Time, Min.	0	1/16	3/32	1/8
0	22	20	20	22
5	70	68	68	82
9	85	84	88	100*
12	88	90	96	
15	89	90	97	

* Reached boiling in 8 minutes

The data of Table 9 indicate that the rate of heating with the charcoal-manganese dioxide formulation increases markedly as the clearance between the fuel and the ration can is increased, very acceptable results being secured with 1/8 inch clearance. On the other hand, with copper chromite-catalyzed formulations, near peak performance was obtained with only a 1/16-inch clearance. Further testing confirmed these findings and indicate that a manganese dioxide combustion catalyst approaches closely the performance of copper chromite in test formulations provided an adequate air supply is available. This is generally borne out by the evaluation of copper chromite and manganese dioxide units in low temperature tests carried out by representatives of the Quartermaster. (See Appendix III, page 91-).

BINDING MATERIALS

Work under contract DA44-109-qm-433, had shown that a binding agent was essential to finish the fuel formulations as coherent solid masses of usable form. Potato starch had been employed for this purpose. While this material was generally satisfactory, a cooking period was required to convert it to a paste and the final briquets were not moisture-resistant without a protective wrapper.

To eliminate the cooking period, two prepasted wheat starches, Beatergel and Supergel, obtained from Stein Hall, Inc., were investigated. Several grades of duPont polyvinyl alcohol were also studied as a possible means of improving the moisture resistance of the briquet. These candidate binder materials, including potato starch, were dispersed in a wet slurry of the standard formulation (see Table 1) and briquets approximately 2-1/2 inch x 1 inch x 1/4 inch were then molded and dried. The briquets were evaluated with respect to mechanical strength and combustion characteristics.

The prepasted wheat starches produced fuel briquets which were inferior to those formed from potato starch both from the viewpoint of strength and burning characteristics.

Polyvinyl alcohols showed no improvement over the potato starch in increasing the moisture resistance or strength of the briquets. A slight aldehyde odor was detected during initial combustion.

With units using potato starch as a binder, the required strength characteristics are met and the units can be protected from ambient moisture by packaging. In view of the generally favorable characteristics of potato starch, more expensive substitutes were not studied further.

DRYING AND BAKING THE FUEL FORMULATION.

The drying of the molded fuel paste is an important step in obtaining briquets of the desired burning characteristics. After removing most of the water introduced with the starch paste binder, baking decomposes the ammonium bicarbonate incorporated in the formulation, producing a porous structure essential for spark reduction during the initial combustion period.

Earlier work under contract DA44-109-qm-433 employed a one-hour drying period at 70-75° C., followed by a four-hour bake at 105° C. Work performed under the present contracts confirms the advantage of low-temperature preliminary drying. A temperature of 105° C. for the initial drying period appears to cause the salts in the formulation to migrate to the surface of the fuel with subsequent increased sparking when the units are ignited.

A final four-hour bake at 105° C. has proved to be sufficient for complete drying and for the decomposition of ammonium bicarbonate. A vented air-circulating oven is considered necessary in order to remove the ammonia produced during the baking operation and to eliminate ammonia odor during ignition. Baking the units for periods up to 24 hours at 105° C. does not noticeably affect the burning characteristics of the fuel.

The possibility existed that baking the units above 105° C. (following the one hour drying period at 70-75°.) would decrease the baking time required and might be advantageous from the production viewpoint. Accordingly, experiments were carried out to determine the highest practical temperature at which the units could be baked and retain the desired burning characteristics. The following observations summarize these studies:

1. Baking at 125° C. increased the sparking of both the manganese dioxide- and the copper chromite-catalyzed units, even when the initial bake was carried out at 70° C. This effect is probably due to the dehydration of the sodium acetate trihydrate in the formulation at temperatures above 120° C. When dehydrated, the sodium acetate is no longer a low melting salt necessary for spark reduction.

2. Manganese dioxide units baked at 115° C. showed no increased tendency to spark.

3. Some of the copper chromite units dried at 115° C. burned with a visible flame for approximately thirty seconds after ignition.

4. The amount of smoke and odor produced immediately following ignition was not noticeably affected by baking at increased temperatures.

It was concluded that 115° C. for the manganese dioxide- and 110° C. for the copper chromite-catalyzed units are the maximum temperatures at which the fuel can be baked without impairing the burning characteristics of the units.

Possible Substitutes for Wire Baking Screens. Liners for Molds.

From the inception of the original program under contract DA44-109-qm-433, the paste formulations were oven-dried on wire screens. After completion of the bake, the fuel was then released from the screen by gentle flexing.

For manufacture of the heating units, it was considered likely that the briquets might be cast into molds and dried intact in the molds. Accordingly, various materials were investigated as possible mold materials or mold liners to permit ready release of the briquets from the mold after drying. The results obtained with a number of materials are shown in Table 10.

TABLE 10

MATERIALS TESTED TO DETERMINE EASE OF RELEASE OF FUEL AFTER BAKING

Material	Results
Aluminum (sheet)	Briquets broke on attempted release.
Holland Cloth	Ready release. Leaves residue. Surface of the fuel very irregular.
Wax paper (Cut-Rite)	Ready release. No distortion of surface of units. Smoke from wax pick-up.
Koroseal	Ready release.
Teflon	Ready release.
Silastic	Ready release
Polyvinyl Chloride Plastisol molds	Ready release

While several materials appeared satisfactory, the investigation was discontinued after observations showed that drying units with only one surface exposed increased sparking during the period of initial ignition of the fuel. The increased sparking was considered to be caused by the tendency of the salts of the formulation to migrate to the one surface exposed to air.

As will be discussed later, polyvinyl chloride Plastisol molds were ultimately adopted for casting the fuel, the link belt heating units being released at once from the molds in the wet form and placed on screens for drying and baking. The shape of the briquets was retained during the drying process.

DEVELOPMENT OF IGNITER FORMULATION

The development of a solid ration-heating fuel under contract DA44-109-qm-433 established the advantage of employing an igniter compound to insure the rapid propagation of ignition around the briquets composing the link-belt circumferential heating units. In this earlier work, a dilute starch solution containing potassium chlorate and sodium chromate was used: 20 g. of potassium chlorate and 12 g. of sodium chromate were added to 100 ml. of 10% starch solution. Satisfactory results were obtained when an asbestos cord was soaked in the igniter solution and dried, the asbestos cord being used as the middle strand in externally lacing the fuel briquets together. However, this igniter solution could not be adapted to the embedded Fiberglas units developed in the present work. Incorporating an asbestos cord, soaked with igniting solution, on the surface of the units prior to baking the fuel paste proved to be completely ineffective. Emplacing the asbestos fiber on the surface of the paste when the units were constructed and then coating the cord with igniting solution after the bake was completed also yielded erratic results.

A series of experiments was undertaken to determine the conditions controlling the effective employment of the potassium chlorate-sodium chromate igniting solution. These experiments indicated that the main factors involved were the freshness of the solution, its method of application, and the length of baking time. If the igniting solution was applied before baking, the solution was absorbed by the main body of the fuel and ignition was not propagated around the heating unit. In addition, the efficiency of the igniter stip was also seriously decreased by heating for more than an hour at 105° C.

Ageing also adversely affected the igniter solution. Upon standing for a comparatively short period of time, crystals begin to form which gradually increased in size. Application of a solution containing crystals to the fuel briquet frequently resulted in an igniter strip carrying separated crystals of the igniter compounds. Under these conditions, propagation of ignition was found to be erratic.

The adverse factors associated with the potassium chlorate-sodium chromate igniter system could not be eliminated and other formulations were studied. Tests indicated that a charcoal formulation of higher nitrate content than that of the fuel formulation had distinct possibilities. Further work developed an igniting compound which, when painted on as a thin paste to an asbestos cord embedded near the surface of the heating unit and across the surface above the embedded cord, smoothly propagated ignition around the entire heating unit within five to seven seconds under room conditions. Consistent results were obtained with the formulation shown in Table 11.

TABLE 11

FUEL TYPE IGNITER FORMULATION

Component	Weight, g.	Wt. %, Dry Basis
Charcoal, Airfloat	5	23
Sodium nitrate	6	27
Potassium nitrate	9	41
Sodium acetate trihydrate	1	4.5
Ammonium bicarbonate	1	4.5
Water*	8	--

* Water content may be adjusted to obtain a desired consistency.

The quantity of igniter solution applied to the card and briquets was found to be critical. Excess solution caused the units to crumble, and too little failed to provide the desired rapid propagation of ignition. Limiting the application of the igniter compound to a narrow strip on each briquet, following the course of the embedded asbestos cord, avoided the problem of excessive use and yet the quantity was adequate for propagation of the ignition to all fuel briquets. A strip, roughly 3/8 in. in width, as applied by hand with a small paint brush, proved satisfactory in practice.

The fuel type igniter formulation of Table 11 successfully passed low temperature tests conducted by Quartermaster representatives. Appendix III contains a full report of these tests with charcoal-manganese dioxide (CR-1036-H3) and charcoal-copper chromite (CR-1036-I-4) formulations. This igniter formulation accordingly was adopted for use in the final manufacture of the units. Additional details may be found in the manufacturing section of this report.

Also of interest is a composition, designated as Igniting Compound 1-36, obtained from the Diamond Match Company, Oswego, New York. A lighted match touched to an igniter spot of this compound ignited the fuel block readily at low temperatures.

EVALUATION OF FUEL FORMULATIONS BY REPRESENTATIVES OF THE QUARTERMASTER CORPS

Upon completion of the various fuel formulation studies reported in the preceding sections, samples of selected formulations were supplied to the project officer for evaluation and testing. Three separate studies were performed and the results obtained appear in Memorandum Reports dated 10 June 1953, 18 December 1953 and 28 May 1954. These reports are reproduced in Appendix III, pages 91 to 99. The essential features of the investigations are presented below:

MEMORANDUM REPORT OF 10 JUNE 1953.

The following three formulations were submitted for test:

A. Char Feed - African Ore Manganese Dioxide; Formula LS-14, Table 8.
B. Wood charcoal - African Ore Manganese Dioxide; Formula LS-1-I, Table 8.
C. Wood charcoal - Copper Chromite; Formula of Tabl 1.

These circumferential heater units were constructed in accordance with the interlaced Type 1 design shown in Figure 12 of the Summary Report for contract DA44-109-qm-433.

The purpose of the tests was to establish relative ease of ignition at 0° F. and 70° F. and the relative degree of sputtering, sparking, and smoke emission. The conclusions of the OQMC observers were as follows:

1. The wood charcoal-copper chromite formulation was "Superior to the other two since it ignited quicker, produced fewer and less violent sparks, and emitted the least amount of smoke".

2. The Char Feed-African Ore manganese dioxide formulation was rated second. It produced the most smoke and the largest sparks; it burned readily, however.

3. The third formulation, wood charcoal-African Ore manganese dioxide, was the least acceptable since it came apart during the combustion process.

At a later date, wood charcoal-African Ore manganese dioxide and wood charcoal-copper chromite link belt units were furnished OQMC for low temperature (-40° F.) evaluation. These tests are reported in the next section.

MEMORANDUM REPORT OF 18 DECEMBER 1953.

Two charcoal formulations, one with copper chromite combustion catalyst and one with African Ore manganese dioxide were submitted for thermal efficiency tests at -40° F. The copper chromite unit was designated CR-1036-A and two manganese dioxide units were designated CR-1036-B-1 and B-2. Formulation CR-1036-A-1 was the old charcoal-copper chromite formulation shown in Table 1. Formulations CR-1036-B-1 and B-2 were identical in composition and correspond to "best" formulation LS-1-I shown in Table 8. The B-1 formulation was baked 72 hours and B-2 was baked 15 hours, both at 105° C. The test specimens were in the form of link belt units and clearance between the briquets and ration can was provided by means of 1/8 inch protrusions. In addition, a trioxane fuel from Van Brode Milling Company of Clinton, Massachusetts, was included for comparison.

As set forth in Appendix III, page 94 , the fuels and the 150 ml of water (ice) in 6 ounce assault cans were conditioned at -40° F. and the tests were conducted at -40° F. The following test observations were recorded: time for complete ignition, maximum temperature (of water) attained and the time to reach this temperature, smoke, sputtering and odor.

The conclusions were as follows:

> "The thermal efficiencies of the fuels arranged in descending order are: Trioxane, CR-1036-A-1, CR-1036-B-1 and CR-1036-B-2.
>
> "The carbon wrap-around fuels sputtered and pieces broke off. Approximately 10-15% of the fuel broke away from the main body of the fuel due to sputtering. The smoking was not excessive. Odor will probably play an important part in acceptance of this fuel. These formulations seem to produce an acrid, unpleasant odor while in the process of ignition. Once ignited, however, the odor and smoke disappear."

Following this report, effort in the laboratory was directed toward reduction of sputtering and improving the low temperature performance of the fuel. Additional samples were submitted for a third series of tests.

MEMORANDUM REPORT OF 28 MAY 1954.

Tests similar to those in the previous tests were conducted in which certain changes were made to improve the low temperature properties. The number of briquets was increased from 10 to 12 and the new fuel type igniter formulation of Table 11 was applied. As before, link belt units were submitted in which clearance for secondary air was provided by means of 1/8 inch protuberances, and wires embedded in the briquets were used as the linking material. Two fuel formulations (CR-1036-H-3 and CR-1036-I-4) were submitted in which the eutectic nitrate content was increased in one of the samples (CR-1036-H-3) to provide better low temperature burning characteristics. A repeat test was also carried out with CR-1036-B-3, of the same composition as CR-1036-B-2 and B-3 of the previous test.

The three formulations tested were as follows:

1. Charcoal-Manganese Dioxide; CR-1036-B3, labeled ordinary fuel (formulation LS-1-I of Table 8).
2. Charcoal-Manganese Dioxide; CR-1036-H-3 (same as "best" formulation LS-1-I of Table 8, except that the eutectic nitrate content was increased by 10%).
3. Charcoal-Copper Chromite; CR-1036-I-4 (identical to original formulation developed under contract DA44-109-qm-433 as shown in Table 1).

Tests were conducted at -40° F. and +70° F., using frozen rations in both cases, and the following observations were recorded: ignition time, time to thaw, temperature at thaw, maximum temperature attained, time to attain the maximum temperature, odor, and smoke. The full report is presented in Appendix III, page 95.

The following conclusions were reached:

A. Fuel CR-1036-I-4 appears to have the best characteristics. The fuse ignited rapidly and smoothly. It burned with the least objectionable odor and smoking.

B. The time necessary to heat the water to 130° F. was 16-18 minutes.

C. Some objectionable points were the amount of smoking of all circumferential fuels during the ignition; the fuse was not secured well enough; the wire binding was not satisfactory because upon heating it expanded and the fuel slipped down the sides of the ration can.

D. This type fuel appears to be more adequate for heating food cans at very low ambient temperature where the food in the can is frozen throughout. Other types of fuel which heat only the bottom of the can will burn the food before it can be loosened enough to mix with some type of utensil.

In general the results were considered reasonably satisfactory. The heat output of the three units was substantially equal (page 99). Certain objectionable features were noted under Item C. The fuse problem was surmounted by additional studies as shown on page 42 in the Design Section under the heading of "Igniter Strip". The wire binding was replaced by Fiberglas cord as discussed on page 39 in the Design Section under the heading "Studies of Briquet Linking Materials". The question of smoke may require further attention. Smoke is evolved for 15 to 60 seconds, depending on the ambient temperature. Total elimination of smoke and odor would require more extended research. This is discussed more fully later.

FINAL DESIGN OF HEATING UNIT

The extended fuel formulation studies reported in previous sections had established a number of important factors relating to the fuel. At this point effort was directed toward finalizing details on the 1000 heating units to be produced. A fuel formulation was selected and a basic design was established. Further necessary design studies were performed and studies of techniques and equipment to be used in the final manufacture of the units were conducted.

Studies more directly concerned with the manufacturing problems are discussed subsequently under "Pre-Manufacturing Studies".

SELECTION OF THE BASIC DESIGN OF THE UNIT.

Because of their superior heating performance, only ration-heating units of a circumferential type were considered for the design of the final units.

Four circumferential designs were investigated to determine the type of unit most practical for field use:

1. Single screen - briquets molded on a wire mesh.
2. Double screen - folded screen filled with pellets.
3. Screen cell - double screen with pellets contained in individual pockets to allow more flexibility than the folded screen design.
4. Link belt.

The best unit (Type I) developed under contract DA44-109-qm-433 had utilized an externally-linked belt design. Ten briquets were externally laced together with asbestos cord; the fracture of one briquet prevented propagation of the ignition around the units. Accordingly the various screen designs listed above were considered. The use of screens offered greater strength and support, reducing the likelihood of breakage. However, screen units have greater weight, higher cost, are more difficult to package and they were found less efficient heaters under the earlier contract studies.

Consideration of these factors led to a decision to adopt the link belt design for the production units. The asbestos cord would be replaced by a more satisfactory (and less critical) linking material, if possible. The fabrication problem would be evaluated in pre-production studies, reported later. The search for replacements for asbestos cord is reported below.

Studies of Briquet Linking Materials.

Initial effort to find a material to replace asbestos cord for linking the briquets was concentrated on wire. A number of types of flexible wire, including Anaconda Magnet Wire No. 30, were found to offer promise for linking as well as attaching the link-belt unit to the container. Certain disadvantages were also observed. On repeated bending, wires of the required small diameter had a tendency to break. Finally, the evaluation of the wire-linked units in low-temperature (-40° F.) studies (see Appendix III, page 96) revealed that the wires would elongate on heating, allowing the unit to slide down the side of the ration can.

Effort was then directed toward the use of fiber glass cord. Studies with Owens-Corning Company Fiberglas cord, Types EC-9-3-U or EC-9-3-N, indicated that these materials have excellent tensile strength, withstand repeated bending and flexing without rupture, are stable to reasonably high temperatures, and the elongation is less than that of wire. Although the tensile strength is sharply reduced by exposure to the high temperature incurred during combustion of the briquets, the unit remains in place throughout the combustion period. (Refrasil, a similar product, lacked sufficient tensile strength to hold the unit intact through the combustion period).

Fiberglas Type EC-9-3-U is uncoated whereas Type EC-9-3-N has a light coating of Neoprene. Both products are 0.034 in. in diameter. The Neoprene-treated material is easier to handle as the fiber does not fray when it is cut. The Neoprene coating does not add noticeably to the odor or the smoke of the burning units. The product is quoted at $1.38 per pound and there are about 300 yards to the pound. Both coated and uncoated Fiberglas cords were incorporated in the production units, the majority with the Neoprene-coated material.

In the final design, two Fiberglas cords were embedded within the briquets and served to connect the 11 briquets* together in a unit. The exact design of the final unit is shown in the next section.

Final Link Belt Design.

Originally the units were designed to heat 12-ounce ration-containers. For this purpose, 10 briquets, 2 cm. 6 cm. x 0.5 cm. were linked together. To enable the units to be used with assault rations, the briquets were reduced to a size approximately 25/32 in. x 1-9/16 in. x 3/16 in. One more briquet was added to the unit to give better heating performance at low temperatures. The molded length overall is therefore 8-19/32 in. (8.6-in.). For heating standard C-ration containers at low temperature, the can height permits two units to be wrapped around the upper and lower halves of the can (See Figure 1).

As discussed earlier, maximum heating efficiency requires that secondary air be available between each briquet and the ration can and hemi-spherical

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* At various stages of development 10-, 11- and 12-briquet heating units were used. The final design carries 11 briquets although some of the photographs indicate other numbers..

protrusions approximately 1/4 inch in diameter were accordingly incorporated into the briquet design.

Two 12-inch lengths of Fiberglas cord, either Owens-Corning Type EC-9-3-U or Type EC-9-3-N, 0.034 inch in diameter, were embedded in the fuel briquet near the ends. A third 11-inch length of asbestos cord for the igniter was also embedded in the briquets near the inner surface between and parallel to the two Fiberglas cords. Figure 2 is a drawing showing the structural details.

SELECTION OF FUEL FORMULATION.

The fuel formulation studies reported in the earlier sections were aimed at finding substitutes for wood charcoal fuel and the copper chromite catalyst. In both cases, less expensive and less critical materials were sought. Disco and Char Feed were shown to be reasonably satisfactory alternates for wood charcoal and manganese dioxide in its various forms was shown to be a suitable replacement for copper chromite. In general, however, wood charcoal-copper chromite formulations are slightly superior to other combinations tested as indicated by data and experience at Wyandotte and tests conducted by the Quartermaster Corps (see Appendix III). The advantages, however small, of the charcoal-copper chromite formulations are as follows:

1. Smoke emission is less.
2. Duration and extent of odor during ignition are less.
3. Ignition is faster and fewer and less violent sparks are produced.
4. Burning characteristics are smoother and more uniform.
5. Disintegration during burning is less.
6. Heating efficiency is as good or slightly better.

While items 1 and 2 are subjective in their evaluation and the differences in the other cases are relatively small (and subject to modification by design factors), the decision was reached jointly with Quartermaster Corps personnel to employ, for the final manufactured units, the charcoal-copper chromite formulation CR-1036-I-4, the composition of which is almost identical to the original formulation on a starch-free basis (compare formulas on pages 12 and 47).

Iron powder is included in the final formulation. Iron powder adds to the strength of the briquet. This is an important feature of the link belt design and appears to be essential in the present case. The presence of iron powder also results in a firmer ash.

IGNITER STRIP.

A strip for the propagation of ignition around the unit was incorporated in the design as a means of rapidly utilizing the full heating capacity of the units. The igniter strip was deemed especially important for low temperature use. The composition of a suitable igniter strip is given in Table 11, page 3 . The igniter formulation was originally painted on an asbestos cord embedded on the outer surface of the unit. In this position, when the unit was wrapped around the container, there was a tendency for the cord to break free from the fuel. To overcome this difficulty, the cord was embedded near the interior (side adjacent to the can) surface of the briquets, the cord being exposed in the space between the briquets. The wet igniter formulation is applied by brush as a narrow strip approximately 3/8 inch wide over the embedded cord and on the cord between briquets. The belt is then turned over and an igniter spot approximately 3/8 inches in diameter is applied between the fifth and sixth briquets. The units are then air dried for two hours and then rebaked at 105° C. for two hours.

ATTACHMENT OF THE HEATING UNIT TO THE RATION CAN.

In work under initial contract DA44-109-qm-433, the link belt units were secured to the ration cans by twisting the ends of embedded wires together. The low temperature (-40° F.) evaluation of these units by the Quartermaster Corps, however, as reported in Appendix III, revealed that the wire would elongate and permit the unit to slide down the sides of the ration can.

The following methods of preventing slippage of the unit were considered:

1. Projections from the briquets: wire or preformed protuberances.
2. Wedges to slip under the unit prior to ignition.
3. Suspension of unit from top of container.
4. Spring to provide enough tension to prevent slippage.

As indicated before, Fiberglas cords embedded in the briquets were selected to link the units together. It was decided to tie the ends of these cords together in two loops, one at each end of the linked briquets and secure the two ends circumferentially around the ration can by means of a spring to provide sufficient tension to prevent slippage of the unit down the can. While this technique was incorporated in the final design, it was recognized that hand-tieing of the ends of Fiberglas cord is unsuitable for a mass production process.

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PRE-MANUFACTURING STUDIES

Having established a basic design, attention was directed toward the selection of methods and equipment for manufacturing the units. While the present contract required delivery of but 1000 units, consideration was given to the possible future large scale production of the units. In selecting the link-belt circumferential design, it was recognized that fabrication of the units would present certain difficulties.

The following sequence of operations was tentatively established:

1. Preparation of the starch paste.
2. Milling of the fuel formulation components.
3. Mixing of the fuel formulation.
4. Formation and linkage of the briquets.
5. Baking of the briquets.
6. Application and baking of the igniter strip.
7. Attachment of spring fastener.
8. Packaging.

Pre-manufacturing studies described below were carried out for each step in the sequence of operations listed above. Various pieces of equipment available in the Wyandotte research laboratories and Pilot Plant were tested for utility, and troublesome operations were studied until the technical difficulties were surmounted. Techniques and procedures were established. The amounts and grades of materials, equipment and other operational details finally used for the production operation will be summarized later in the Manufacturing Section of this report.

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PREPARATION OF STARCH PASTE.

The potato starch paste previously selected as binder for the dry ingredients composing the fuel formulation was prepared by adding nine parts of cold water by weight to one part of potato starch. The mixture was then heated with stirring on a steam bath until a nearly transparent paste was formed. The paste should then be chilled to room temperature and if not used the same day stored in a refrigerator prior to use to prevent bacterial deterioration. Preservatives which would be non-hazardous during fuel combustion may be added if necessary.

A total of 700 g. of a 10% paste was required per unit operation, as discussed below under the mixing operation. The equipment required for these operations include a steam bath, stirring motor and a suitable container (2.1 beaker) for the paste. A conventional double boiler could serve. For large scale operations a jacketed steam-cold water kettle of appropriate size would be indicated.

MILLING OF FUEL FORMULATION COMPONENTS.

Certain components of the fuel formulation required a reduction in particle size to produce readily a good working fuel formulation paste: potassium nitrate, sodium nitrate, sodium acetate trihydrate and ammonium bicarbonate. A Raymond Hammermill was available and this rapidly and efficiently produced fine powders of these materials. Over 95% of the powder passed through a 100 mesh screen in one pass through the unit. This mill and maximum mesh size were standardized for the 1000 unit operation.

MIXING THE FUEL FORMULATION

Initial mixing of the fuel formulation components was studied with a one-quart dough mixer. The unit proved satisfactory and a Readco six-quart dough mixer, shown in Figure 3, was used for the final operation. These studies led to the following composition for the final production operation.

1. The following ingredients were dry-blended for 30 minutes:

Component	Wt., g.
Wood charcoal, air float	954.0
Iron powder	189.0
Potassium nitrate	261.0
Sodium nitrate	165.6
Sodium acetate trihydrate	93.6
Copper chromite	68.4
Ammonium bicarbonate	68.4
	1800.0

2. To the above, 350 grams of 10% potato starch were added and the blending continued for 10 minutes.

3. An additional 350 g. of 10% potato starch were added and the blending was continued for 10 minutes.

After 30 minutes of dry blending (step 1), the powders were not always thoroughly dispersed (this type mixer is very inefficient for dry blending). However, mixing for 10 minutes with a portion of the potato starch paste, as indicated, resulted in good dispersion in all cases.

The amount of starch paste needed for the desired consistency was found to vary with the type of mixing employed, period of mixing and, to a lesser extent, the age of the paste. Predicted from hand mixing, 930 g. of starch paste would have been required for a standard batch of fuel formulation containing 954 grams of charcoal. Predicted from studies with a one-quart dough mixer, 810 grams would have been required. From the studies with the six-quart mixer, the value of 700 grams shown above was established. This leads to the principal difference between the old standard formula of Table 1 and the final formula.

Its composition, calculated in various ways, is shown in Table 12.

TABLE 12

COMPOSITION OF THE FINAL FUEL RECIPE

Component	Production Formula Parts by Weight	%	Wt. % Excluding Starch	With Starch
Charcoal	954	38.16	53.0	51.02
Iron Powder	189	7.56	10.5	10.11
Potassium Nitrate	261	10.44	14.5	13.96
Sodium nitrate	165.6	6.62	9.2	8.85
Sodium acetate trihydrate	93.6	3.74	5.2	5.00
Copper chromite	68.4	2.74	3.8	3.66
Ammonium bicarbonate	68.4	2.74	3.8	3.66
Starch)	70.0	2.80		3.74
Water)	630.0	25.20		
	2500.0	100.00	100.0	100.00

FORMATION AND LINKING OF THE BRIQUETS.

Professional opinion relating to the manufacturing operation, with particular reference to step 4, the formulation and linkage of the briquets, was solicited by a letter request for information forwarded to three equipment companies and discussions were held with a fourth company. These were:

1. H. W. North Company, Erie, Pennsylvania
2. Arthur Colton Company, Detroit, Michigan
3. Chambers Brothers Company, Philadelphia, Pennsylvania
4. Sprout-Waldron and Co., Inc., Muncy, Pennsylvania

The primary problem, indicated in the request for information, was a means of forming the briquets with the Fiberglas cords embedded therein. The information received from these machinery and equipment companies indicates that they believe standard equipment can be adapted to the production of the units. The reply from the Chambers Brothers Company was particularly informative and is reproduced in full in Appendix IV (page 100). Thus confirmation of the feasibility of mass production was obtained and a certain amount of useful information was secured.

Because of the limited funds available, however, the approach to the immediate production problem of 1000 heating units was limited to available or low cost equipment. In the light of the information received and a consideration of the problem, two methods were evaluated for forming the fuel briquets. These are as follows:

1. Extrusion of the fuel paste.
2. Casting the briquets in pre-formed molds.

Fuel Paste Extrusion Studies.

Attempts to extrude the fuel paste by means of a Royles rubber extruder were not successful. The following problems were encountered:

a. Loading the extruder was a slow and labor-consuming task with the type of paste used in the fuel formulation.

b. An increase in the fluidity of the paste during extrusion increased the difficulty of forming the briquets.

c. The paste cannot be met at the point of extrusion by conventional conveyors.

An investigation was made of the possibility of producing the units by means of a cylinder and piston using a hydraulic jack to supply the power for extrusion. As the fuel was extruded by this method, cracks developed along the sides of the ribbon of paste. Nozzles of various shapes were evaluated in an attempt to avoid crack formation. A straight taper at the end of the nozzles as well as straight taper with outward flaring failed to prevent the cracking. The drag of the paste on the surface of the cylinder probably accounted for at least a portion of the cracking.

In view of the above results, work with the extrusion technique was dropped and effort was concentrated on casting procedure. However, an extrusion process is desirable for large scale manufacturing and further studies would probably resolve the technical problems shown above.

Casting the Briquets in Pre-formed Molds.

Exploratory work to determine the feasibility of using molds to produce the units was carried out with wooden forms. The work indicated that this method of forming the briquets and embedding the connecting fibers was a promising one for the production of 1000 units.

A brass form was then constructed from which molds were cast for the production of the units. These molds were cast from a polyvinyl chloride, Plastisol, No. 370-102 yellow, obtained from the B. F. Goodrich Company (American Anode). The thickness of the Plastisol forms depended on the temperature to which the brass form was heated and the length of time it was left in the Plastisol. The design of such a brass form is shown in Figure 4 and a photograph in Figure 5. In producing the Plastisol forms the following procedure was used:

1. The brass form was heated for 30 minutes at 325° F. and then dipped into the Plastisol for 2 minutes. A photograph of the dipped form is shown in Figure 6.

2. The coated form was then baked at 325° F. until cured; approximately 30 minutes were required.

3. After being cooled in cold water, the Plastisol mold was freed from the brass form by cutting along the edges of the form with a sharp knife or razor blade.

Notches were cut in the Plastisol mold for the purpose of embedding the connecting fibers and for the emplacement of the igniter strip. A photograph of the mold is shown in Figure 7. The briquets were then formed by loosely filling the mold (with supporting sides) with fuel paste and then working the formulation firmly into the mold with a spatula. The fibers linking the briquets were kept under tension to position them at the proper depth.

A number of experiments were conducted to determine the best method of freeing the briquets from the Plastisol molds. Baking the fuel in the molds permitted ready release from the forms, but the tendency of the fuel to emit sparks upon ignition was increased.

In the case of freeing the wet briquets from the mold, directing a blast of air at the back of a mold perforated with a number of small holes gave poor release results. This experiment, however, was carried out with available laboratory air pressure directed at a small area of the surface. Using higher pressure applied over the entire surface of the mold, it is believed that this method might successfully release the paste.

Experiments revealed that when the paste had the right consistency, the units release readily from the molds. If too much paste was inadvertently used, the tendency for the briquets to distort when released by manual flexing was greatly decreased by slowly stripping back the form while directing a low-pressure current of air against the form at the point of release.

Based on the results obtained with Plastisol forms, the decision was reached to use this method of forming the briquets and embedding the connecting fibers in the manufacturing process. For the construction of the contract units two forms were assembled and filled simultaneously. The amount of paste was regulated to enable the units to be released directly from the molds on to a wire screen for insertion into the baking oven. Additional details are presented in the Manufacturing Section.

Compression Molding.

The effect of compression molding upon the strength of the fuel briquets was investigated. Formulations of Charcoal, Disco and anthracite coal were molded in a Carver press at pressures varying from 100 to 2500 psi. Breakage tests were conducted using an Instron Compression Testing machine. Data for the charcoal briquets are reported in Table 13 which shows that maximum resistance to breakage was found at approximately 2000 psi. Similar results were obtained with the Disco briquets, the anthracite briquets being somewhat weaker.

TABLE 13

STRENGTH OF COMPRESSION-MOLDED
CHARCOAL-FORMULATED FUEL BRIQUETS

Molding Pressure, Psi.	Break Point, Psi.
None	6.8 - 11.5
1000	7.5 - 11.25
1250	10.0 - 15.5
1500	6.5 - 13.75
2000	10.5 - 20.5
2500	9.5 - 15.0

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Although compression molding increased the strength of briquets as much as 50% in some cases, the resulting unfavorable burning characteristics made the use of pressure in briquet formation undesirable. Sputtering, flashing, and disintegration of the formulations occurred during the initial combustion period in all briquets formed by compression molding. The addition of ammonium bicarbonate to the formulation normally leads to a porous product which permits free escape of the gaseous products of combustion. Apparently this desirable porosity is largely eliminated by compression molding.

Other Methods of Forming.

The use of a finned drum designed to simultaneously form the briquets and embed the connecting fibers was given consideration. Because of the cost of constructing the equipment and the uncertainty of its capabilities, this method was not investigated experimentally.

BAKING OF THE FUEL BRIQUETS.

Optimum baking conditions had already been established, as reported earlier (page 26). For the production operation 36 fuel units, with embedded Fiberglas cord, were supported on hardware cloth after release from the mold. The loaded screen was then dried for one hour at 70° C. and then baked for four to fifteen hours at 105° C. in a Model CW 32 Blue Line Air Circulating Oven.

PREPARATION OF THE IGNITER STRIP.

The igniter formulation and its method of application have been discussed sufficiently before (page 42).

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ATTACHMENT OF THE SPRING FASTENER.

As discussed on page 43, the use of a small coil spring, attached to the looped ends of the embedded Fiberglas cords, was selected as the means of securing the link belt heating units to the ration can. The springs used for the manufacture of the final units were obtained from the American Spring Company, Holly, Michigan.

The springs are 3/4 inch in length overall and 5/32 O.D. in diameter and have a 3/8 inch body of music wire, as shown in Figure 12. They were manually attached to the Fiberglas cords linking the fuel briquets just prior to packaging the units.

PACKAGING.

Studies under contract DA44-109-qm-433 had shown that exposure of the fuel briquets to 75% relative humidity for 24 hours at 77° F. caused serious impairment of the heating efficiency of the fuel. Efforts under the present contracts were unsuccessful in finding an otherwise suitable moisture-resistant binding material (see page 25). Further, the fuel contains other water-soluble components which add to the problem. Some form of packaging is required in any event, and it was decided to consider moisture-resistant packaging after the final design of the unit had been established.

A study of packaging materials was accordingly undertaken. As a rigorous test of protection the packaged units containing indicating-Drierite were placed in a desiccator partly filled with water.

Effort was primarily toward utilization of heat-sealed polyethylene pouches and heat-sealed aluminum films. The polyethylene pouches were not sufficiently effective, the Drierite turning red due to moisture in a few days and within two weeks the unit could not be ignited. In addition, the pouches were somewhat difficult to open.

Attention was given to heat-sealable aluminum foil laminates using information secured from Reynolds Metals Company. Tests were performed with Reynolds RM-112 material consisting of a thin layer of aluminum backed with cloth. This laminate was heat-sealable at 425° F. but was withdrawn from commercial production. Units packaged in this manner were subjected to the desiccator test for three months, followed by 24 hours at 50 mm. (reduced) pressure, without deterioration.

These tests indicate that a properly designed hermetically-sealed package will give excellent shelf-life characteristics. Storage for one year in a dry atmosphere did not result in noticeable deterioration, and low temperature ignition tests were satisfactory. After exposure of the packaged unit for 24 hours at a temperature of -65° F., ready ignition was obtained at -5° F. Similarly after a 24-hour exposure at -40° F., ready ignition was secured at -40° F. (See Appendix III, page 99 , for the -40° F. studies). However RM-112 is no longer available commercially and only a few of the production units were ultimately packaged with this material.

As a replacement for RM-112, Reynolds Metals Company supplied Barrier Material RM-245. This consists of 40 pound Kraft paper laminated to 0.001 inch aluminum foil backed by 0.001 inch plastic film (apparently polytheylene) which permits heat sealing. Tests on RM-245 indicated equivalent moisture resistance to that attained by the RM-112 material and most of the production units were packaged with this material. The packaged unit is considered to possess the following characteristics:

1. Not adversely affected by high or low humidity or low atmospheric pressure.
2. Stable and usable until consumed.
3. Long storage life; duration unknown but probably greater than one year.
4. Non-friable when subjected to normal military shipping of handling.

Attention should be called to the desirability of vacuum pouch packaging since pouches may be exposed to low pressure conditions in air transport. Machines which can accomplish this are available from Bartelt Engineering Company of Rockford, Ill. and probably others. Facilities were not available to us for vacuum packaging the 1000 units produced. The removal of unnecessary air should diminish the size of cartons and cases needed, and prevent their rupture or distortion by expansion of the pouches when subjected to reduced pressure conditions.

MANUFACTURE

With the establishment of a design and the finalization of procedures for all steps in the manufacturing process, actual production of the 1000 units was undertaken. All details of the design and the manufacturing steps have been covered in previous sections except those related to the assembly of the unit. However, pertinent details related to the manufacturing operation will be included below. The subject matter will be presented under the following headings:

1. Raw Materials.
2. Operational Sequence and Equipment Employed.
3. Description of the Manufacturing Process.

RAW MATERIALS.

All raw materials, except water, which entered into the production of the 1000 fuel units are itemized in Table 14.

TABLE 14

MANUFACTURING RAW MATERIALS

Materials	Description	Source
	A. Fuel Formulation Components	
Potassium nitrate	Granular, commercial grade	Allied Chemical and Dye Corporation
Sodium nitrate	Imported, commercial grade	Allied Chemical and Dye Corporation
Copper chromite		Harshaw Chemical Company
Sodium acetate trihydrate	Commercial grade	Allied Chemical and Dye Corporation
Ammonium bicarbonate		Fisher Scientific Company
Charcoal	Air Float, 90-95% passing 300 mesh	Hardwood Charcoal Company
Iron plastic sponge, powder	- 325 mesh	Plastic Metals, Inc.
Potato starch		Paisley Starch Company
	B. Other Items	
Fiberglas EC-9-3-N*	0.034 inch diameter	Owens-Corning Glass Works
Asbestos cord	Cat.No. 1-455, 1/16 inch	Fisher Scientific Company
Springs	3/8 inch body - Music wire	American Spring Company
Moisture-proof packaging material	RM-245 ** 40 lb. Kraft/ .001 Foil/.001 plastic laminate	Reynolds Metals Company

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** RM-112, no longer available, was employed for a few units.

* EC-9-3-U was used in some units.

MANUFACTURING OPERATIONAL SEQUENCE AND EQUIPMENT

The eight major steps in the production of the units, together with the equipment requirements, are listed in Table 15.

TABLE 15

MANUFACTURING OPERATIONAL SEQUENCE AND EQUIPMENT

Operation	Equipment Employed
1. Preparation of Starch Paste	Steam bath, laboratory stirring motor, stirrer and container (2 l. beaker).
2. Milling of Fuel Formulation Components	Raymond Hammermill, 100 mesh screen
3. Mixing of Fuel Formulation	Readco Six-Quart Dough Mixer
4. Formation and Linkage of the Fuel Briquets	Plastisol forms, wood supports for forms, table, oven and hardware cloth
5. Baking of the Briquets	Model CW 32 Blue Line Air Circulating Oven
6. Application of the Igniter Strip	Beaker and spatula, paint brush, oven
7. Attachment of the Spring Fastener	Pliers
8. Packaging	Doughboy Belt Type Hand Sealer, Model PHS-B

DESCRIPTION OF THE MANUFACTURING PROCESS.

The unit design, methods and technique are those established in the design and pre-manufacturing studies. A flow diagram for the porcess is shown in Figure 8 and important details of the process and equipment are illustrated by photographs.

1. Preparation of the Starch Paste.

Seven hundred grams of potato starch paste were required per batch of 34 heating units. Slightly larger batches were prepared by adding nine parts of cold water to one part of potato starch in a 2 l. beaker. The mixture was heated on a steam bath and stirred with a laboratory stirring motor until a nearly transparent paste was formed. The paste was cooled and stored in a refrigerator if not immediately used. The operation required about one hour.

2. Milling of the Fuel Formulation Components.

The following components were passed separately through a Raymond Hammermill and sifted through a 100 mesh screen: potassium nitrate, sodium nitrate, sodium acetate trihydrate, and ammonium bicarbonate.

3. Mixing of the Fuel Formulation.

The components of the fuel formulation were blended and mixed in the Readco six-quart dough mixer (Figure 3) according to the following batch recipe:

a. Dry-blend the following ingredients for 30 minutes:

Component	Weight, grams
Charcoal	954
Iron powder	189
Potassium nitrate	261
Sodium nitrate	165.6
Sodium acetate	93.6
Copper chromite	68.4
Ammonium bicarbonate	68.4
	1800.0

b. Add 350 grams of 10% potato starch and blend for 10 minutes.

c. Add 350 grams of 10% potato starch and blend for 10 minutes.

The wet formulation was placed in a 2 l. beaker until required for casting in the molds. The above batch was sufficient for the production of 36 units containing 11 briquets each, including some wastage.

4. Formation and Linking of the Fuel Briquets.

Two Plastisol forms were placed in recessed wooden supports on a work table as shown in Figure 9. The asbestos cord and the two Fiberglas cords were placed in the grooves in the form, and tension applied to the cords to hold them taut.

The wet fuel-formulation paste was placed in the Plastisol forms and leveled in the forms to the height established by the wooden supports.

The connecting Fiberglas cords between the two forms were cut and the two forms released at once on to the oven screens. This operation was repeated until 36 (usually) units were prepared. The oven screens, loaded with units prior to baking, are shown in Figure 10. The units shown contain 12 briquets of which one was removed prior to drying and baking.

5. Baking of the Briquets.

The loaded oven screens were placed in an air-circulating oven as shown in Figure 11. The units were baked at 70° C. for one hour and then at 105° C. for a minimum of four hours.

6. Application of the Igniter Strip.

The units were placed on a second screen with the inner surface of the briquets face up. The igniter paste was applied with a paint brush following the asbestos cord from end to end and across the face of the 11 briquets in a strip about 3/8 inch wide. The units were then inverted and an igniter spot painted on the outer surface between the fifth and sixth briquets. The units, on the screen, were then baked in the oven for two hours at 105° C.

7. Attachment of the Spring Fastener.

The units were removed from the oven. The ends of the glass cords were tied in a square knot and the connecting spring was manually attached to each unit. A view of the final unit showing how the spring was attached is seen in Figure 12.

8. Pouch Packaging.

In production the Reynolds Metals Company Barrier Materials RM-112 or RM-245 were cut from roll stock into 6 inch by 7 inch sheets and formed into 3 inch by 7 inch pouches by heat sealing the long edges together and one end. The operation was carried out at a sealing temperature of 500° F. using the Doughboy Belt Type Hand Sealer, Model PHS-D shown in Figure 13. The spring-linked heating unit, once folded between the fifth and sixth briquets, was insered in the pouch followed by sealing on the remaining edge. The final packaged unit is seen in Figure 14.

RAW MATERIAL AND MANUFACTURING COSTS

Estimates of raw material and total manufacturing costs for the ration heating units are detailed in the following sections. The effect of some variations in fuel formulas upon the raw material costs will be shown.

In computing production costs the following principal assumptions will be used:

1. A production of 48,000 fuel units per day, equal to 11,520,000 units per year of 240 eight-hour working days.
2. An investment of $80,000 in essential production equipment, not including buildings.
3. Investment money available at 5 percent interest rate.
4. Five year amortization of production equipment investment.
5. Material costs at the levels indicated in Tables 17 and 18.
6. Utilities charges of $225 per month.
7. A labor complement of five persons fully employed in handling all production work.
8. An average labor rate of $1.80 per hour and no overtime work.
9. Overhead costs (to include indirect labor costs, investment in real estate or rentals, maintenance, taxes, insurance, office, accounting, travel and administration expense, carrying charges on materials inventory, etc., but without profit) - 200 percent of direct labor.

10. Continuous full time employment of personnel and machines.

11. No changes in labor rates, materials or other costs.

12. No changes required in product or method of production adopted requiring additional (net) time or capital.

13. No investment in research or development, either to improve the product or its manufacturing process (this stage of development has not yet been attained).

14. An average freight cost of $2.00 per 100 pounds from f.o.b. points for chemicals and materials used.

15. A three percent allowance over purchase price to cover freight from f.o.b. points and wastage onother materials used (springs excepted - losses and freight assumed negligible).

16. A loss of 3 percent of the chemical raw materials purchased as a result of spillage, dust losses, powdering and breakage of fuel briquettes.

17. All ammonium bicarbonate in the formula volatilized during baking.

18. Each finished fuel unit to carry an average of 45 grams fuel.

19. No costs have been estimated for printing, cartoning, casing or boxing the fuel units for shipment as the requirements have not been indicated.

RAW MATERIALS COSTS.

Cost quotations for all chemicals and other materials, obtained from suppliers or from 6 September 1954 listings in "Oil, Paint, and Drug Reporter", appear in Table 16.

The l.c.l. cost for Idaho potato starch is not quoted by Oil, Paint and Drug Reporter but c.l. and l.c.l. quotations given for Maine potato starch show a difference of $0.015 per pound. The c.l. price of Idaho potato starch has been increased by this difference to obtain the estimated l.c.l. cost of $0.078 shown.

To the full extent practicable the quotations cited are for the procurement of a 1-2 month supply of each material for the indicated production schedule of 48,000 units daily. Manufacturers prepared to make firm committments or purchase in larger units should obtain better prices on some items.

Using the figures of Table 16, raw material costs for the fuel components (chemicals) have been calculated in Table 17 for the formula employed in manufacturing the 1000 test units. The cost is based on 100 lbs. of raw materials, corrected for freight charges and finally by ammonium bicarbonate (3.66 percent) and wastage losses (3 percent) estimated. The data indicate a chemical raw material cost of $14.13 per 100 pounds of useable fuel plus $0.20 for igniter.

For a single link belt unit containing 11 briquets carrying 45 grams of fuel (0.0992 pounds), the unit raw material cost is $0.0140. Individual component costs are itemized in Table 18 and the total cost for a single unit is shown to be $0.0469 as follows:

	Unit Cost	Cost/100 lb. Packaged Fuel	Percent of Material Cost
Fuel and igniter components	$0.0142	$14.33	30
Springs	0.0220	22.18	47
Other components	0.0107	10.79	23
Totals	$0.0469	$47.30	100

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TABLE 16

COST QUOTATIONS FOR HEATING UNIT COMPONENTS

BASIS: F.O.B. WORKS

A. Chemicals		Cost
Wood charcoal, Airfloat grade		$77/ton
Iron plastic sponge - 325 mesh powder		0.185/lb.
Potassium nitrate, granular, bbl., 20 ton lots	*	9.75/100 lbs.
Sodium nitrate, imported, bags, c.l.	*	53.00/ton
Sodium acetate trihydrate, commercial, dr., l.c.l.	*	0.125/lb.
Ammonium bicarbonate, dr., l.c.l.	*	0.075/lb.
Copper chromite, Harshaw Chemical Company		1.25/lb.
Potato starch, Idaho, bags, c.l.	*	0.063/lb.
l.c.l., estimated		0.078/lb.
B. Other Materials		
Asbestos cord, 5 lb. at $2.60/lb., less 10%		2.34/lb
Fiberglas (315 yards/lb.)		1.28/lb.
Springs (lots of 10,000)		22.00/1000
RM-245 Aluminum Barrier Material		0.21/sq.yd.
C. Alternate Chemicals		
Disco (from low temp. dist. of coal) Pittsburgh Consolidation Coal Co.		9.25/ton
Manganese dioxide, African, 84-87% paper bags, 5-20 ton lots	*	91.00/ton
Potato starch, Maine, bags, c.l.		0.0725/lb.
l.c.l., spot		0.0875/lb.

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* Quotations from Oil, Paint and Drug Reporter, 6 September 1954

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TABLE 17

COST OF RAW MATERIALS PER 100 LBS. OF FINISHED FUEL FORMULATION

Material	$/Lb.	Dry Fuel Formula		Dry Igniter Formula	
		Lb.	Cost	Lb.	Cost, $
Charcoal, Airfloat grade	0.0385	51.02	1.96	23	0.89
Iron powder - 325 mesh	0.185	10.11	1.87	-	
Potassium nitrate, commercial grade, granular	0.0975	13.96	1.36	41	4.00
Sodium nitrate, imported, commercial grade	0.0265	8.85	0.23	27	.72
Sodium acetate, trihydrate, commercial grade	0.125	5.00	0.63	4.5	.56
Ammonium bicarbonate	0.075	3.66	0.27	4.5	.34
Copper chromite	1.25	3.66	4.58		
Starch (dry weight)	0.078	3.74	0.29		
Totals		100.00	11.19	100.0	6.51
Allowance for freight from f.o.b. point			2.00		2.00
Cost/100 lbs. chemicals purchased			13.19		8.51
Cost/100 lbs. fuel, after losses: $13.19/(1 - .0366 - .03)			14.13		

TABLE 18

UNIT COST OF RAW MATERIALS

Fuel Unit: 45 g. or 0.0992 lbs.; 1008 Units/100 lb.

Material	Cost/Unit, $	
Fuel ($14.13/100 lbs.)	0.0140	
Igniter ($8.51/44,000 units, estimated)	0.0002*	0.0142
Spring ($22.00/thousand in 10,000 lots)	0.0220	
Asbestos igniter strip ($2.35/lb.; 0.001 lbs./unit)	0.0024*	
Fiberglass ($1.28/lb.; 315 yards; 2 ft./unit)	0.0028*	
Reynolds RM-245 Packaging Material ($0.21/sq. yd. 5.5 x 6 = 33 sq. in./unit)≠	0.0055*	0.0327
Total Cost		0.0469

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* Includes allowance of 3% to cover freight from f.o.b. point and wastage.

≠ It is believed that stock used for packaging each unit may be reduced from the 6 x 7 inches previously used to 5.5 x 6 inches.

Effect of Possible Lower Copper Chromite Costs.

Copper chromite has been quoted at $1.00 to $1.25 per pound, and the preceding calculations were made on the $1.25 basis. This is the most costly chemical ingredient but the effect of a cost reduction to $1.00 per pound is not large as seen by comparison of the last and the following tabulations.

	Unit Cost	Cost/100 lb. Packaged Fuel	Percent of Materials Cost
Fuel and igniter compounds	$ .0132	$13.35	29
Springs	.0220	22.18	48
Other components	.0107	10.79	23
Totals	$ .0459	$46.32	100

Effect of Use of Manganese Dioxide Instead of Copper Chromite Catalyst.

Replacement of copper chromite in the same formula by manganese dioxide (African) at 4.55 cents per pound would lower the formula cost considerably but might not be as satisfactory in service. The results follow:

	Unit Cost	Cost/100 lb. Packaged Fuel	Percent of Materials Cost
Fuel and igniter components	$0.0095	$ 9.61	22
Springs	0.0220	22.18	52
Other components	0.0107	10.79	26
Totals	$0.0422	$42.58	100

Materials Costs for Disco-Manganese Dioxide Formula LS-14.

Calculations based on Formula LS-14 (Table 8) for a Disco-African Ore manganese dioxide composition gives a further opportunity for cost reduction at some sacrifice in desirable burning properties (compared with the copper chromite formula) already discussed. The results follow:

	Unit Cost	Cost/100 lb. Packaged Fuel	Percent of Materials Cost
Fuel and igniter components	$0.0061	$ 6.13	15.7
Springs	0.0220	22.18	56.7
Other components	0.0107	10.79	27.6
Totals	$0.0388	$39.10	100.0
Copper chromite (at $1.25/lb.) formula	0.0469	47.30	
Difference	0.0081	8.20	

It is seen that (1) the fuel components contribute but 15.7 to 30% of the materials cost of the units, and (2) the greatest opportunity for saving lies in the spring component used which contributes from 47 to 56.7% of the materials cost.

MANUFACTURING COSTS FOR A MASS PRODUCTION PROCESS.

In Appendix IV a letter from the Chambers Brothers Company is reproduced which indicates that present day equipment could be adapted for the forming and linking operation. It is indicated that, if extrusion characteristics are good, a single machine could extrude a 100 ft. column per minute. This should produce at least 100 units per minute or 48,000 units per eight-hour day. Problems associated with incorporating the Fiberglas linking cords and asbestos igniter were also considered by the Chambers people. While the mass production process would require a certain amount of additional research effort with the fuel formulation to obtain an extrudable mix and considerable problems of machine adaptation for carrying out several unique operations must be met, it is believed that actual manufacturing costs can be held within the levels to be indicated, after meeting the further necessary development costs.

TABLE 19

UNIT COST ESTIMATE FOR A MASS PRODUCTION PROCESS

Basis: 48,000 units per day for a 240 day
working year - 11,520,000 units annually

Item			Cost, $/Year
Standard equipment	$30,000		
Special equipment	50,000		
		$80,000	
Amortization			$ 16,000
Interest, average during amortization			2,400
Material cost ($0.0469/unit)			540,288
Utilities - steam, heat, power, light			2,700
Direct labor, (five operators at $1.80/hr.)			17,280
Overhead at 200% of labor			34,560
		Total	$613,228
Unit cost, $			0.0532
Unit cost, without spring			0.0312

On the basis of Table 19, a unit cost of 0.0532 is indicated. If the spring is omitted, the unit cost is reduced to $0.0312 (slightly higher if wire replaces the spring. These costs may be subdivided as follows:

Item	With Spring, $/Unit		Without Spring, $/Unit	
Materials cost	0.0469	0.0469	0.0249	0.0249
Manufacturing Cost				
Equipment Investment Costs	0.0016		0.0016	
Utilities	0.0002		0.0002	
Labor	0.0015		0.0015	
Overhead	0.0030	0.0063	0.0030	0.0063
Charcoal-Copper Chromite Formula, Total		0.0532		0.0312
Disco-Manganese Dioxide Formula		0.0451		0.0231
Difference		0.0081		0.0081

ANALYSIS OF THE RATION HEATING UNIT IN TERMS OF THE CONTRACTUAL DESIGN OBJECTIVES. RECOMMENDATIONS FOR FUTURE WORK

As stated in the introduction, this final summary report covers work performed under two contracts: DA44-109-qm-1278 and DA44-109-qm1518. The "Statement of Work" for each of these contracts has been reproduced in Appendix I of this report.

Under contract DA44-109-qm-1278 the six following studies in particular were to be performed: Work on compression molding methods, binding materials, fuel catalysts, fuels other than wood charcoal, new linking materials, and methods of commercial production of the fuel units. Reference to the Summary and Conclusions (page 4) and to the body of the report show that each of these phases was investigated and definite conclusions were reached. Compression molding of the fuel briquets improved the strength moderately but reduced the porosity necessary for smooth combustion. Three binding materials other than potato starch were tested and found to be inferior to potato starch; a moisture-resistant binding agent was not found. Moisture-proof packaging appears practicable and is recommended. Manganese dioxide was found to be an acceptable and less expensive combustion catalyst, but not quite as satisfactory as copper chromite. Disco and Char Feed (derived from coal) could be used in place of charcoal but in their present form would not be equally satisfactory. Various types of wire and other materials were investigated for linking the briquets and Fiberglas glass cord was found to be the most satisfactory. Finally commercial production of the unit was investigated and a detailed analysis of estimated costs was performed.

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Under contract DA44-109-qm-1518, as set forth in Article 1, "Statement of Work", the contractor was required to furnish labor, services, personnel, materials, tools, equipment, facilities and supplies, as well as perform all the necessary investigations toward the manufacture of 1000 acceptable fuel units. Commercial packaging was to be studied and a pilot plant was to be designed for the production, packaging and packing of small quantities of the units. Reference to the Summary and Conclusions and to the body of the report indicate that these contractual requirements were met. The 1000 fuel units were manufactured, packaged and delivered and a pilot plant design was furnished in the Manufacturing Section of this report.

RATION HEATING UNITS IN TERMS OF THE DESIGN OBJECTIVE.

The extent to which the ration heating units supplied to the Quartermaster Research and Development Center fulfill these objectives will be discussed below and certain suggestions will be offered.

(2) a. The Ration Heating Unit Shall Offer Means of Heating Rations by Chemical Action Offering Maximum Security.

The units supply heat by the combustion of a fuel containing carbon. Maximum security is considered to include absence of smoke, sparking, sputtering and odor. While these combustion characteristics are interrelated to a considerable extent, an attempt will be made to discuss each property individually.

Smoke. The tendency of the present units to evolve smoke has been noted in the OQMC evaluation of the units (see pages 33-37 and 91-99). Smoke is evolved from the ration heating unit only during the initial combustion period immediately following ignition. During steady state combustion, no smoke is evident, the unit burning quietly with a dull red glow without flame. The amount of smoke evolved has not been quantitatively measured; it

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is considered by Wyandotte observers to be moderate. The duration of smoke emission under average temperature conditions (70° F.) is about 15 seconds, increasing to about one minute at -40° F.

The achievement of an entirely smokeless formulation would require additional research effort. Smoke is associated with incomplete combustion but at very low temperatures cloud formation from moisture condensation might possibly occur. During the initial heating period, when the bulk of the unit is cold, unburned components of the fuel are volatalized and entrained with the gaseous products of combustion. Modification or purification of the charcoal, if practical, might reduce smoking; a reduction of the volatile matter would be one objective. Further improvement of coal-based carbons such as Disco or Char Feed may be possible. Investigation of the organic nitrates currently being studied in the propellant field as formulation components is a possible area of research. Coating of the fuel particles, before or after baking, with a high oxygen content fuel (non-luminous flame) might reduce or eliminate smoking. These means of reducing smoke, if effective, would probably also improve other burning characteristics such as sparking.

<u>Sparking</u>. There is a small amount of sparking associated with the present unit, immediately following the ignition period and roughly paralleling the smoking period. As discussed under the initial contract No. DA44-109-qm-433 report of 15 November 1951, reduction of sparking was achieved by the incorporation of low-melting components to effect a liquid phase during combustion.

Formulations containing sodium chromate, for example, sparked markedly less than when sodium chromate was absent. Due to its reported toxicity, sodium chromate was eliminated from consideration and sodium acetate trihydrate was employed as an acceptable substitute. Although sparking was not eliminated by an increase in the sodium acetate content, a further search for low-melting phase components which are also oxidizing agents, would appear to be desirable. As stated, effort aimed a reduction of smoke content along the lines suggested above would quite likely also improve the sparking characteristics.

Some reduction in sparking was also achieved as a result of the improved milling and blending achieved in the pre-manufacturing studies; this also minimized a tendency to sputter as noted in the next section. Efficient mixing reduced the amount of starch paste required. The decreased water content of the wet formulation led to decreased migration of salts during the baking period and reduced sparking. This is correlated with the evident increase in sparking caused by an increase in nitrate oxidizer content.

Sputtering. Sputtering is used to describe erratic and rough burning with hot fragments being emitted from the surface of the unit. Although some of the earlier formulations suffered from this deficiency, the final contract units are considered to be satisfactory in this respect. Reduction of sputtering with resultant smooth combustion was achieved, it is believed, by a more thorough milling and blending of the fuel components.

Odor. There is a certain amount of odor during the initial combustion of the unit, roughly paralleling the emission of smoke. The odor has been defined as acrid by OQMC observers (See Appendix III). On the basis of tests conducted at Wyandotte in open laboratory areas, it ic concluded that the odor is not objectionable even when standing next to burning units. In a confined area, with a number of units operating, the odor might be objectionable. As with smoking, odor is associated with incomplete combustion and elimination of smoke would also probably eliminate odor. On the other hand the development of objectionable odor might possibly serve to indicate conditions under which objectionable concentrations of carbon monoxide gas might accumulate. See section (2) g.

(2) b. The Ration Heating Unit Shall be Easily Ignitable With One Book Match from 125° F. to Temperatures as Low as Minus 65° F.

Match ignition has been successfully applied from ambient (70° F.) temperature to -40° F., as shown by the OQMC evaluations reported in Appendix III. It is believed that match ignition will be successful over the desired temperature range of -65° to +125° F.

(2) c. The Ration Heating Unit Shall Not be Adversely Affected by Exposure to Water, High or Low Humidity or Low Atmospheric Pressure.

Experimental data reported in the body of the report indicate that the packaged unit is stable to exposure to water, high or low humidity and to low atmospheric pressure. Vacuum pouch packaging is recommended for consideration.

(2) d. The Ration Heating Unit Shall be Stable and Usable Until Consumed.

The ration heating unit is a stable solid product containing components which are not mutually reactive prior to ignition.

(2) e. The Ration Heating Unit Shall Have a Storage Life of Not Less Than Five Years.

Storage life studies of over one year indicate no detectable deterioration or loss of efficiency. It is believed that the storage life will be five years or more.

(2) f. The Ration Heating Unit Shall be Non-Toxic.

The ration heating unit is considered to be non-toxic in manufacture and handling. During combustion, the only known primary toxic product is carbon monoxide. The question of carbon monoxide evaluation was discussed in considerable detail in the final report under contract DA44-109-qm-433 dated 15 November 1951, as applied to the formulation used in the present units. It was calculated that the combustion of four 37 g. units in a volume of 1000 cubic feet produces a concentration of less than 400 parts per million of carbon monoxide. The present unit weighs 45 g.; the calculated concentration under the same conditions is between 400 and 500 ppm. This concentration can be inhaled for one hour without appreciable effect according to Patty ("Industrial Hygiene and Toxicology". Vol. II, Interscience Publishers, Inc., New York, 1941, p. 616). It was concluded that there would be little or no danger in use of these fuel units out of doors or in reasonably well ventilated dwellings. It is conceivable that in unventilated caves, dugouts, cellars, or gas-tight tents that dangerous carbon monoxide concentrations could be built up, particularly if several fuel units were burned. Therefore, as with any carbon fuel, these must be considered potentially dangerous and care and judgment should be exercised in their use.

(2) g. The Ration Heating Unit Shall be Non-Friable When Subjected to Military Shipping or Handling.

The heating unit in its pouch, when further properly cartoned and boxed or cased, is believed to be satisfactory with respect to military shipping and handling. Pouches can be dropped without breaking pouch or fuel unit. The briquets can be broken by hand and an increased briquet strength would be a desirable but not an essential feature.

(2) h. The Ration Heating Unit Shall Not be Easily Extinguished by Gusts of Wind.

The ration heating unit burns smoothly without failure in the presence of gusts of wind.

This discussion has centered primarily on the desirability of improving the combustion characteristics of the fuel as related to smoking, sparking and odor. The required degree of improvement is small and the objectives of future research along these lines have been stated in relation to an ideal ration can heating unit.

Other possible improved characteristics may be considered. Thus, improved resistance to moisture absorption and water repellency of the unpackaged unit would be a desirable although not an essential objective. New binding agents might be considered for this purpose including sodium silicates of several $Na_2O:SiO_2$ ratios, gum guar, gum acacia, polymerizable emulsion resins, and nitro polymers.

Another approach to the problem would be the investigation of suitable spray coatings for the final unit. Various spray systems could be investigated and studies in this area would be aimed at the following objectives:

1. Moisture resistance and water repellency.
2. Reduction in smoke and sparking during the ignition period.
3. Elimination of dusting during handling.

The investigation would include solvent solutions and aqueous emulsions of vinyl polymers such as polyvinyl alcohol, polyvinyl acetate, polystyrene and others. Nitropolymers and various additives could be incorporated in the spray system. Low molecular weight water insoluble soaps, Silicones and many other approaches should be considered.

Possible improvements in the igniter formulation and its application to the units was discussed above in connection with the smoking problem. Additional research into this problem was indicated to be desirable to attain an igniter formulation which will give still more rapid ignition at very low temperatures and a minimum amount of smoke and light at normal temperatures.

With respect to the mechanical features of the unit, it is felt that the Fiberglas cord is suitable as the linking agent and that the asbestos cord is an essential feature of the igniter strip. A spring appears to be the most desirable means of holding the unit to the can although it is the most expensive component of the system. A suitable spring may very well be available at a unit price less than the 2.2¢ quoted for the present spring.

Certain problems associated with projected mass production of the unit have been discussed in the Pre-Manufacturing and Cost Sections of this report. Quantity production of units will require the use of an extrusion or other mass production technique. It seems certain that further study could develop a mix possessing the necessary flow properties for an extrusion process. Improvement of the wet mix used in the manual operations employed for the contract units is also desirable. The present briquets lack a finished appearance and each briquet is not sharply cut to a uniform shape. An improved wet mix would have as another objective the elimination of surface cracks, possibly through improved milling and blending and a reduction of the water content. Reduction of the present tendency of the wet mix to adhere to the molds occasionally would also result in an improved appearance of the finished product.

RECOMMENDATIONS.

The following areas of future research are suggested as a means of achieving certain improvements in the present unit with respect to physical characteristics and ease of production.

A. Studies of the Reduction in Smoking, Sparking and Odor of the Fuel During the Initial Combustion Period.

1. Modification of the charcoal.
    a. Special purification.
    b. Reduction of the volatiles content.
    c. Coating of the charcoal particles: high oxygen content material, polymeric nitro compounds.

2. Further modification of coal-based fuels.

3. Fuel formulation studies.
    a. Evaluation of low melting components which may be oxidizers to provide an improved liquid phase relative to that from sodium acetate trihydrate. Examples: perborates, persulfates, perchlorates.
    b. Search for binary nitrate eutectic depressants other than sodium chromate.
    c. Incorporation of additive quantities of polymeric organic nitro compounds, polyaminoethyl cellulose perchlorate and other new products associated with the solid propellant field.

4. Study of the effect of improved milling and blending on the combustion characteristics of the fuel briquets.

5. Studies of spray coating of the finished product.
    a. Solvent solutions or aqueous suspensions of polymeric compounds.
    b. Incorporation of polymeric nitro compounds or other additives into the solvent or aqueous suspensions.

6. Studies of igniter formulations.

B. Studies to Improve the Moisture Resistance, Friability and Handling Properties of the Final Unit.

1. Investigation of new binding agents and their mixtures with potato starch.
    a. Solvent solutions of various substituted vinyl and other polymers (vinyl chlorides and agents forming toxic or irritating agents on ignition excluded).
    b. Aqueous emulsions of substituted vinyl and other polymers.
    c. Incorporation of additives in aqueous polymer emulsions to improve smoking and other properties.
2. Spray coating of the finished product with a solvent solution or aqueous suspension of vinyl polymers, silicones, metallic soaps.
3. Effect of extrusion methods upon the strength and friability of the briquets (See below).

C. Studies of Improved Manufacturing Methods.

1. Studies of the wet paste characteristics to acquire a plastic mass capable of extrusion and handling in production equipment.
    a. Studies of the effect of improved milling and blending.
    b. Studies of the effect of additives to improve the extrusion (and molding) characteristics of the plastic mass, such as sodium or potassium silicates of several $R_2O:SiO_2$ ratios, low molecular weight water insoluble soaps, inclusion of talc, etc.
2. Studies of small scale extrusion equipment with special reference to working out problems relating to incorporation of the Fiberglas and asbestos cords.

a. Methods of incorporating the cords, cutting fuel unit and cords to length, and mechanical handling of fuel units.

3. Development of means for applying igniter spot and strip.

4. Development of means to eliminate hand-tying of the Fiberglas cords, folding the units and attaching the springs.

D. Study of Means of Attaching the Unit to Ration Cans.

1. Search for less expensive spring attachments.

E. Packaging Studies.

1. Much more extensive studies including both accelerated and long time tests of alternate laminates are recommended.

All modifications of the fuel composition, application of coatings which show promise of improved characteristics, eventually should be subjected to finished unit performance tests under normal and adverse test conditions. The effects of prospective methods of manufacture similarly should be ascertained before making heavy investments in equipment.

APPENDIX I

SCOPE OF CONTRACTS. STATEMENTS OF WORK.

The scope of the two contracts under which the work presented in this final detailed report was done is reproduced below from Article I of each of the two contracts. Sections related to reports are omitted.

CONTRACT NO. DA44-109-qm-1278

"ARTICLE 1. Statement of Work.

(a) Scope. Contractor shall, commencing on the 22nd day of October 1952 and continuing until the 21st day of October 1953, furnish labor, materials, services, personnel, machinery and equipment, tools, facilities and supplies necessary for and shall conduct studies, experimental investigations and tests on the Solid Heating Units (Carbon) to improve the characteristics of the fuel units developed under previous Contract No. DA44-109-qm-433 and to investigate means and methods for low cost commercial production of the fuel units, and in particular shall:

(1) Investigate compression molding methods to increase the strength characteristics of the fuel blocks.

(2) Study binding materials for use in both compression and non-compression molding techniques with a view toward improving moisture resistance and strength.

(3) Investigate fuel catalysts with the objective of finding one which involves use of less critical and less expensive material than the copper chromite presently used.

(4) Study the use of less critical materials, such as powdered coal, in lieu of charcoal as the heat source.

(5) Study the use of wire or other less critical material in place of asbestos for linking the fuel tablets together.

(6) Investigate means and methods for commercial production of the fuel units, including the preparation of a detailed cost analysis.

CONTRACT NO. DA44-109-qm-1518

"ARTICLE 1. Statement of Work.

(a) Scope. Contractor shall, commencing on the 8th day of July 1953, and continuing until the 7th day of January 1954, furnish necessary labor, services, personnel, materials, tools, machinery and equipment, facilities and supplies and do all other things necessary for and conduct studies, experimental investigations and tests with a view toward:

(1) Development of equipment to furnish 1000 acceptable fuel units, packaged and packed in suitable material which will comply, in as far as practicable with the design objectives, in paragraph 2 and shall, to the extent practicable:

a. Investigate commercial packaging and packing materials and means for use in the packaging of resultant product.

b. Design a pilot plant for the production, packaging and packing of small quantities of the heating units.

c. Produce and furnish 1000 acceptable units properly packaged and packed to be used for further laboratory and field evaluation.

(2) The resultant fuel units shall comply with the design objectives enumerated below to the maximum practicable extent:

a. Shall offer means of heating rations by chemical action offering maximum security.

b. Shall be easily ignitable with one book match from 125° F. to temperatures as low as minus 65° F.

c. Shall not be adversely affected by exposure to water, high or low humidity or low atmospheric pressure.

d. Shall be stable and useable until consumed.

e. Shall have a storage life of not less than five years.

f. Shall be non-toxic.

g. Shall be non-friable when subjected to military shipping or handling.

h. Shall not be easily extinguished by gusts of wind.

APPENDIX II

STUDY OF MINOR COMPONENT VARIATIONS INVOLVING THREE FUELS AND TWO GRADES OF MANGANESE DIOXIDE

Some results of preliminary fuel formulation studies aimed at establishing satisfactory compositions involving charcoal, Disco and Char Feed fuels and copper chromite and manganese dioxide combustion catalysts have been presented (pages 17-20).

The fuel formulation studies reported here aimed at optimizing formulations involving the components listed above with respect to rate of heating, satisfactory formulations having already been developed. These satisfactory formulations upon which the studies are based are compositions A, B and C of Table 6, page 19.

In view of the large number of component variables, it was decided to utilize a Latin Square experimental design to reduce the number of experiments needed. The experimental design used is shown in Table 20. Three ingredients, the eutectic mixture of nitrates, sodium acetate and manganese dioxide, were investigated at four weight levels while other factors such as weights of the ingredients, mixing time, mixing technique, and drying time were held constant. To illustrate the operation of the design, Formula 14 of Table 20 involves the use of 21.3 g. of nitrate eutectic, 6.0 g. of sodium acetate, 5.0 of an unspecified grade of manganese dioxide. The overall composition of Formula 14 of Table 20, is shown on page 87 on both a weight and weight percent basis.

TABLE 20

EXPERIMENTAL DESIGN FOR FORMULATION EVALUATION

Fuel: 53.0 g.
Ammonium Bicarbonate: 5.0 g.
10% Potato Starch: 21.5 g.
Component and Weight in Grams

A. Disco and Char Feed Fuels

	Sodium acetate 4.0	Sodium acetate 6.0	Sodium acetate 8.0	Sodium acetate 10.0
Nitrate Eutectic 22.6 gms.	MnO_2 5.0 No. 1	MnO_2 7.0 No. 2	MnO_2 9.0 No. 3	MnO_2 11.0 No. 4
Nitrate Eutectic 23.7 gms.	MnO_2 7.0 No. 5	MnO_2 9.0 No. 6	MnO_2 11.0 No. 7	MnO_2 5.0 No. 8
Nitrate Eutectic 24.9 gms.	MnO_2 9.0 No. 9	MnO_2 11.0 No. 10	MnO_2 5.0 No. 11	MnO_2 7.0 No. 12
Nitrate Eutectic 21.3 gms.	MnO_2 11.0 No. 13	MnO_2 5.0 No. 14	MnO_2 7.0 No. 15	MnO_2 9.0 No. 16

B. Airfloat Charcoal Fuel

Charcoal: 53.0 g.
Ammonium Bicarbonate: 3.8 g.
10% Potato Starch: 52.0 g.

	Sodium acetate 4.0	Sodium acetate 6.0	Sodium acetate 8.0
Nitrate Eutectic 22.6	MnO_2 5.0 No. 1	MnO_2 7.0 No. 2	MnO_2 9.0 No. 3
Nitrate Eutectic 25.9 gms.	MnO_2 9.0 No. 7	MnO_2 5.0 No. 8	MnO_2 7.0 No. 9

Component	Wt., g.	Wt., %
Disco	53.0	57.3
Nitrate eutectic	21.3	23.0
Sodium acetate trihydrate	6.0	6.5
Manganese dioxide	5.0	5.4
Ammonium bicarbonate	5.0	5.4
Potato starch (dry basis)	2.2	2.4
	92.5	100.0

Iron powder was not included in the design, but was added later to certain selected compositions as shown in the tables giving the results of heating studies. The experimental procedure employed in the preparation of the fuel pellets and the rate of heating tests are described in the next section.

EXPERIMENTAL PROCEDURE.

The dry ingredients were thoroughly mixed and then kneaded with the 10% starch paste to make a homogeneous mass. The paste was then spread on a 1/16 in. screen to a depth of approximately 1/16 in. This was scored and put in a drying oven for 24 hours. During the first hour, the fuel was heated at 70° C. The temperature was then raised to 100° C., and maintained at that temperature for the balance of the period. Gentle flexing freed the pellets, approximately one sq. cm. in size, from the screen after cooling.

The rate of heating tests involved 300 ml. of water at 25° C. contained in a twelve ounce ration can. Sixty grams of fuel were used for each test. Ordinary fly screen folded together held the fuel pellets firmly against the can of water. The following data were recorded: time required to reach 50° C., time required to reach boiling point, duration of boiling, and time required for the temperature to fall from 100° C. (after boiling had stopped) to 95° C.

DISCO-MANGANESE DIOXIDE FORMULATION STUDIES.

Sixteen formulations of the composition designated in Table 20, Group A, were evaluated using Disco as the fuel ingredient and technical grade manganese dioxide as the combustion catalyst. Six of these compositions achieved boiling of the water and complete data for these six tests are shown in Table 21.

A similar series of tests was performed in which African Ore replaced the technical grade of manganese dioxide. In the latter case, four formulations without iron powder and three with iron powder achieved boiling of the water; data for these seven formulations are shown in Table 22.

CHAR FEED-AFRICAN ORE MANGANESE DIOXIDE FORMULATIONS STUDIES.

Sixteen formulations of the compositions designated in Table 20, Group A, were evaluated using Char Feed as fuel and African Ore grade manganese dioxide as combustion catalyst. Four of these formulations without iron powder and five containing added iron powder achieved boiling of the water; data for these seven formulations are shown in Table 23. Formulation LS-14 without iron powder and formulation LS-6-I with 10 g. of added iron powder gave the best heating characteristics.

WOOD CHARCOAL-MANGANESE DIOXIDE (TECHNICAL GRADE AND AFRICAN ORE) FORMULATION STUDIES.

Nine formulation studies with Airfloat Charcoal as fuel and technical grade manganese dioxide as combustion catalyst were carried out according to the Latin Square experimental design shown in Table 20, Part B. No iron powder was added. The results were disappointing in that none of the formulations achieved boiling. On this basis, it appears that manganese dioxide is not as effective a catalyst as copper chromite for charcoal-based fuels. With 10% added iron powder, as shown in Table 24, the results (LS-1-I) were considerably improved. This is in contrast to formulations based on Disco and Char Feed in which the addition of iron powder had only a minor effect, if any, on the rate of heating.

TABLE 21

HEATING STUDIES WITH DISCO FUEL AND TECHNICAL GRADE MANGANESE DIOXIDE CATALYST FORMULATIONS

Iron Powder: None
Test: 300 ml. of water at 25° C.
Formulation Wt.: 60 g.

Formulation No.	Time to Reach Boiling, Min.	Time at Boiling, Min.	Time from B.P. to 95° C., Min.
LS-2	17.5	10.0	5.3
LS-3	20.5	11.0	6.8
LS-4	16.5	9.0	6.0
LS-6	20.5	9.0	6.3
LS-8	17.8	5.7	7.0
LS-14	20.7	4.3	7.0

TABLE 22

HEATING STUDIES WITH DISCO FUEL AND AFRICAN ORE MANGANESE DIOXIDE CATALYST FORMULATIONS

Formulation No.	Time to Reach Boiling, Min.	Time at Boiling, Min.	Time from B.P. to 95° C., Min.
		A. No Iron Powder Added	
LS-6	12.5	9.0	5.5
LS-8	19.0	6.5	4.0
LS-11	16.7	4.7	4.5
LS-14	11.5	15.5	3.5
		B. 10 g. Iron Powder Added	
LS-3-I	24.0	7.0	6.0
LS-8-I	16.0	8.3	3.3
LS-11-I	15.3	9.0	4.7

TABLE 23

HEATING STUDIES WITH CHAR FEEDFUEL AND AFRICAN ORE GRADE MANGANESE DIOXIDE FORMULATIONS

Test: 300 ml. of water at 25° C.

Formulation No.	Time to Reach Boiling, Min.	Time at Boiling, Min.	Time from B.P. to 95° C., Min.
		A. No Iron Powder Added	
LS-4	17.0	11.0	6.5
LS-8	20.7	4.25	5.5
LS-11	19.0	8.5	8.5
LS-14	15.0	13.5	5.0
		B. 10 g. Iron Powder Added	
LS-2-I	21.0	4.5	7.0
LS-4-I	17.25	14.7	4.25
LS-6-I	15.7	13.7	5.0
LS-11-I	19.0	8.5	8.5
LS-14-I	27.5	5.0	8.5

TABLE 24

HEATING STUDIES WITH WOOD CHARCOAL AND AFRICAN ORE GRADE MANGANESE DIOXIDE FORMULATIONS

Test: 300 ml. of water at 25° C.
Iron Powder: 10.5 g.

Formulation No.	Time to Reach Boiling, Min.	Time at Boiling, Min.	Time from B.P. to 95° C., Min.
LS-1-I	16.0	8.5	4.5
LS-2-I	14.5	9.5	4.5

APPENDIX III

EVALUATION OF FUEL FORMULATIONS

BY THE
QUARTERMASTER RESEARCH AND DEVELOPMENT LABORATORIES
CHEMICALS AND PLASTICS DIVISION
Philadelphia Quartermaster Depot, U. S. Army
Philadelphia 45, Pa.

Three memorandum reports, covering the evaluation of various fuel formulations submitted by Wyandotte, contain the following:

MEMORANDUM REPORT OF 10 JUNE 1953.

SUBJECT: Ease of Ignition of Fuel, Ration Heation

A. PURPOSE

To determine relatively, the ease of ignition, and amount of sparking, sputtering and smoking of three samples of fuel, ration heating.

B. MATERIALS

Samples were compounded by the Wyandotte Chemical Corporation. Samples were identified as:

A. Char Feed, African Ore MnO_2

B. Wood Charcoal, African Ore MnO_2

C. Wood Charcoal, Copper Chromite

C. PROCEDURES

1. The fuel was ignited at temperatures of 0° F. and room temperature (amb. 70° F.). Five portions, measuring approximately 3/4 inch in length were tested from each sample at each temperature. All figures are an average of the five portions tested.

2. The ease of ignition was determined by measuring the time that it took each sample to ignite after a flaming match was put to it. The time was measured with a stopwatch.

3. The amount of sparking and sputtering is a subjective evaluation. At room temperature the samples were laid on a copper wire screen measuring 3/4 inch in diameter and suspended 1/2 inch above a large white sheet of paper. The distance that the residues of the sparking and sputtering landed from the samples was measured and averaged. This gave some idea of the intensity of the spark. This could not be done at 0° F. due to the strong draft present.

4. The amount of smoke produced was also a subjective evaluation by three individuals.

D. CONCLUSIONS

1. The sample composed of wood charcoal and copper chromite (Sample C) was superior to the other two since it ignited quicker, produced fewer and less violent sparks, and emitted the least amount of smoke.

2. Sample A, Char Feed and African Ore MnO_2, was the next best type. The sample produced the most smoke and largest sparks but burned readily.

3. Sample B, Wood Charcoal and African Ore MnO_2, was the least acceptable since it either flew apart violently or merely fell apart at the boundary of the burning section and the non-burning section.

E. DATA

See chart below (Note: Chart slightly condensed).

FUEL	TIME OF IGNITION, SECS.		SPUTTERING/SPARKING		SMOKE EMISSION	
	0° F.	R.T.	0° F.	R.T.	0° F.	R.T.
A	7 - 18 Avg. 11.3	4 - 7 Avg. 5.25	Most	Most; pieces flew out to 10 in.	Most	Most
B	4 - 14	3 - 5	Violent, flys apart	Violent, flys apart	Less than A but more than C	Less than A but more than C
C	3 - 7 Avg. 5.0	3 - 4 Avg. 3.5	Least, even burning	Least, sparks fly to 4 ins.	Least, very little	Least, very little

MEMORANDUM REPORT OF 18 DECEMBER 1953.

SUBJECT: Ration Heating Units

I. PURPOSE

To determine the thermal efficiency of Ration Heating Units and Trioxane at -40° F.

II. MATERIALS

1. Ration Heating Units - Charcoal
   - a. CR-1036-A-1
   - b. CR-1036-B-1
   - c. CR-1036-B-2
2. Trioxane   Van Brode Milling Company, Inc., Clinton, Mass.

III. CONCLUSION

The thermal efficiencies of the fuels arranged in descending order are: Trioxane, CR-1036-A-1, CR-1036-B-1 and CR-1036-B-2.

The carbon wrap-around fuels sputtered and pieces broke off. Approximately 10-15% of the fuel broke away from the main body of the fuel due to sputtering. The smoking was not excessive. Odor will probably play an important part in acceptance of this fuel. These formulations seem to produce an acrid unpleasant odor while in the process of ignition. Once ignited, however, the odor and smoke disappear.

IV. TEST PROCEDURE

One hundred and fifty mls. of water were placed in each of four 6 oz. assault cans; the water, cans, fuels and remaining test apparatus were conditioned at -40° F. until the water became solid (overnight). The carbon ration heating units were wrapped around the cans. They were then ignited between the fifth and sixth briquets and the time for complete ignition was noted. The water was stirred constantly until a maximum temperature was reached. This was recorded along with the time taken to attain that temperature.

The procedure for trioxane was similar to that noted above. The can of ice, however, was melted by placing it above a burner fabricated from a 12 oz. ration can containing one fuel bar.

V. RESULTS.

I. Table 1. - 40° F. efficiency test

Type of Fuel	Condition Temp. of	Time for complete ignition	Maximum temp. reached °F.	Time to reach maximum temp.	Smoke	Sputtering	Odor
CR-1036-A-1	-40	2' - 45"	129	21' - 30"	Yes	Yes	Acrid
CR-1036-B-1	-40	1' - 57"	83	27' - 30"	Yes	Yes	Acrid
CR-1036-B-2	-40	5' - 8"	31	11' - 10"	Yes	Yes	Acrid
Trioxane	-40	0' - 5"	130	8' - 5"	None	None	CH_2O

MEMORANDUM REPORT OF 28 MAY 1954.

SUBJECT: Circumferential Fuel, low-temperature efficiency

I. PURPOSE

To obtain the relative efficiencies of several different formulations of circumferential fuel and common methods of heating.

II. MATERIALS

A. Circumferential Fuel, three formulations

1. Fuel marked MnO_2, 3rd lot charcoal, 39.5 gms.

   1 hr. at 80° C.
   4 hr. at 105° C.
   1 hr. at 105° C.

2. Fuel labeled CR-1036-H-3

3. Fuel labeled CR-1036-I-4

4. 550 watt, 800 ml. flask heater, 110 V., Wm. Boekel & Son, AHT 6128-A

5. 5 gal. pot containing water and maintained at a boil by use of three (3) Meker Burners

6. Combat Rations, Meat Can

Corned Beef Hash	2 ea.
Lima Beans & Ham	1 ea.
Pork & Beans	1 ea.

7. Bunsen Burner
8. Calibrated Rochester Dial Thermometers

III. SUMMARY AND CONCLUSIONS

A. Fuel CR-1036-I-4 appears to have the best characteristics. The fuse ignited rapidly and smoothly. It burned with the least objectionable odor and smoking.

B. The time necessary to heat the water to 130° was 16-18 minutes.

C. Some objectionable points are the amount of smoking of all circumferential fuels during the ignition; the fuse is not secured well enough; the wire binding is not adequate for upon heating it expands and the fuel slips down from the ration can.

D. This type fuel appears to be more adequate for heating food cans at very low ambient temperature where the food in the can is frozen throughout. Other types of fuel which heat only the bottom of the can will burn the food before it can be loosened - - with some type of utensil.

IV. RECOMMENDATIONS

A. Another type of binder other than metal wire should be employed, possibly glass rope or glass tape.

B. The igniter fuse strip must be embedded in the fuel farther to prevent it from coming loose and thus impairing its efficiency.

C. The fuel should be made at least one section longer in order that it will leave less of a space around the ration can. This can be done by adding one more section or by making the sections smaller and adding several more.

V. PROCEDURES

A. Low ambient temperatures (-40° F)

The fuels and items to be heated were conditioned for at least 24 hours before testing. Then the fuel was tightly bound around the can and ignited. A match was held against the fuel or igniter until either the fuel ignited or the match burned too low, and then another match was used. The ice and water formed was stirred with the thermometer.

The electric heater was used with a special well-covering which enabled practically all the heat to be concentrated on the bottom of the ration-containing ice. The bottom of the ration can was at a distance of 3/4 of an inch from the heater.

B. Room temperature ambient (70°)

The electric heater was used in the same manner as it was for low ambient temperature studies.

The bunsen burner was placed so that the cone of the flame was approximately 3/4 inch below the bottom of the ration can containing ice.

The five (5) gallon pot, with three (3) Meker Burners underneath, was used - - - so that when the frozen ration cans were suspended in them the water would continue to boil uninterrupted.

The ration cans were removed from the freezer and within 10-15 secs. were placed in the boiling water. A wire was fastened around the can and the can was suspended about halfway in the boiling water.

VI. RESULTS

The three circumferential fuels were listed in the table in the order of their degree of ease of ignition, smoking during ignition, and production of an acrid odor during ignition. The fuel listed first was most objectionable on all points, the third fuel listed was the least objectionable on all points.

The temperatures in column 7 (Maximum temperature) is the temperature of the food after it had been mixed. The temperature in parenthesis is the temperature as close as could be gotten near the center, especially if the center were still frozen.

TABLE 25

HEATING STUDIES WITH CHARCOAL-BASED FUELS, ELECTRICITY AND BOILING WATER

Fuel	Ambient Temp. ° F.	Initial Temp. of Item ° F.	Ignition Time Min.	Time to Thaw Min.	Temp. at Thaw °F.	Time to Max. Temp. or heating time, min.	Max. Temp.	Item	Remarks
Circumferential Fuel, ordinary Charcoal - MnO_2	-40	-40	2-1/2 11 matches	11	70	18	131	Ice 180 gms.	Difficult to light, smoking during ignition, acrid odor
CR-1036-H-3 (Charcoal - MnO_2)	-40	-40	1	10	68	17	130	Ice 180 gms.	Easy to light, smoking, acrid odor.
CR-1036-I-4 (Charcoal-CuChromite)	-40	-40	<1	9	70	16	133	Ice 180 gms.	Easiest to light, smoking, acrid odor
Electric Heater 550 W	-40	-40	--	12	71	19	130	Ice 180 gms.	
Boiling Water	70	-5 to -10	--	10	--	10	84 (60)	Corned Beef Hash	Still mostly frozen
Boiling Water	70	-5 to -10	--	--	--	20	155 (148)	Lima Beans & Ham	Unfrozen
Boiling Water	70	-38 to -46	--	--	--	20	118 (109)	Pork & Beans	1/2 in. cube frozen in center
Electric Heater 550 W	70	-5 to -10	--	--	--	7.5	132	Ice 180 gms.	
Boiling Water	70	-45 to -50	--	--	--	25	132 (62)	Corned Beef Hash	1/2 in. cube frozen in center
Bunsen Burner	70	-5 to -10	--	--	--	5	132	Ice 180 gms.	

APPENDIX IV

REPLY TO LETTER REQUEST FOR MANUFACTURING INFORMATION FROM THE CHAMBERS BROTHERS COMPANY

Fifty-Second Street Corner of Media
Philadelphia 31, Pa.

August 31, 1953

Wyandotte Chemicals Corporation

Wyandotte, Michigan

Attention: Mr. Arthur L. Austin

Dear Sir:

We certainly appreciate receiving your inquiry of August 21st for a special machine to make the briquet unit shown on the drawing that you sent us.

From the description of the general consistency and plasticity of the material that you describe, we believe that there is no major problem in handling the manufacture of this unit by extrusion in a lengthways direction. This, of course, involves a relatively small extruding machine that would have inserted in the die a bridge with three core stems through which the glass fiber thread would be lead into the column as it was extruded. Outside of the die we visualize a flanged roller running over the column with 45 degree projections from the face of the roller that would indent the column as specified. If extended threads on both ends of the unit are not required, every tenth projection would be a cutting blade which would sever the fibers and deliver the pieces to a conveyor belt as individual units. If the fibers must be extended for tying this heater around a can, we believe that it would be simpler to devise the mechanism that would strip the material from two extra lengths than it would to manufacture the unit with the strings exposed.

With a relatively small and inexpensive machine, these units could be produced at an extremely high rate of speed, in fact beyond our conception of any type of handling device to stack them on a dryer or handle them subsequently until hardened.

The extruding machine could be built with a small mixing tub or not as desired. The mixing tub does offer one advantage of an efficient feed to the extruding augers and we have designs of such a machine prepared. Under no circumstances can the manufacturing machine be a large extruder making these in multiples at least as far as we can se.. A rather high volume production would be obtained through a battery of small units that might even successfully feed a very wide drying oven in a continuous stream.

We have not worked out anything with respect to stripping material to leave threads at each end exposed, but wanted to write you first so that you could have our reactions to the problem that you propose to us. We would also like to know the relative strength of the glass fibers to know whether they would lead through the bridge and stem assembly simply by the enclosing friction of the extruded column.

If extrusion characteristics are good, a small extruder could very readily exceed a production rate of over 100 ft. of column per minutes. This is a matter of actual past experience and it is quite easy for us to visualize that this rate might very possibly be exceeded substantially. We do want you to know that our firm is distincly interested in this development and if there is anything further that we can do, please let us know. The enclosed bulletins illustrate primarily, special extruding machines that we have successfully applied to other than the clay or refractories industry and our experience in this field indicates that your problem can be solved.

Yours very truly,

CHAMBERS BROTHERS COMPANY

/s/

L. S. Bettison, Pres.

FIGURE 1

12-OUNCE C-RATION WITH TWO HEATING UNITS

OF THE LATEST DESIGN IN PLACE

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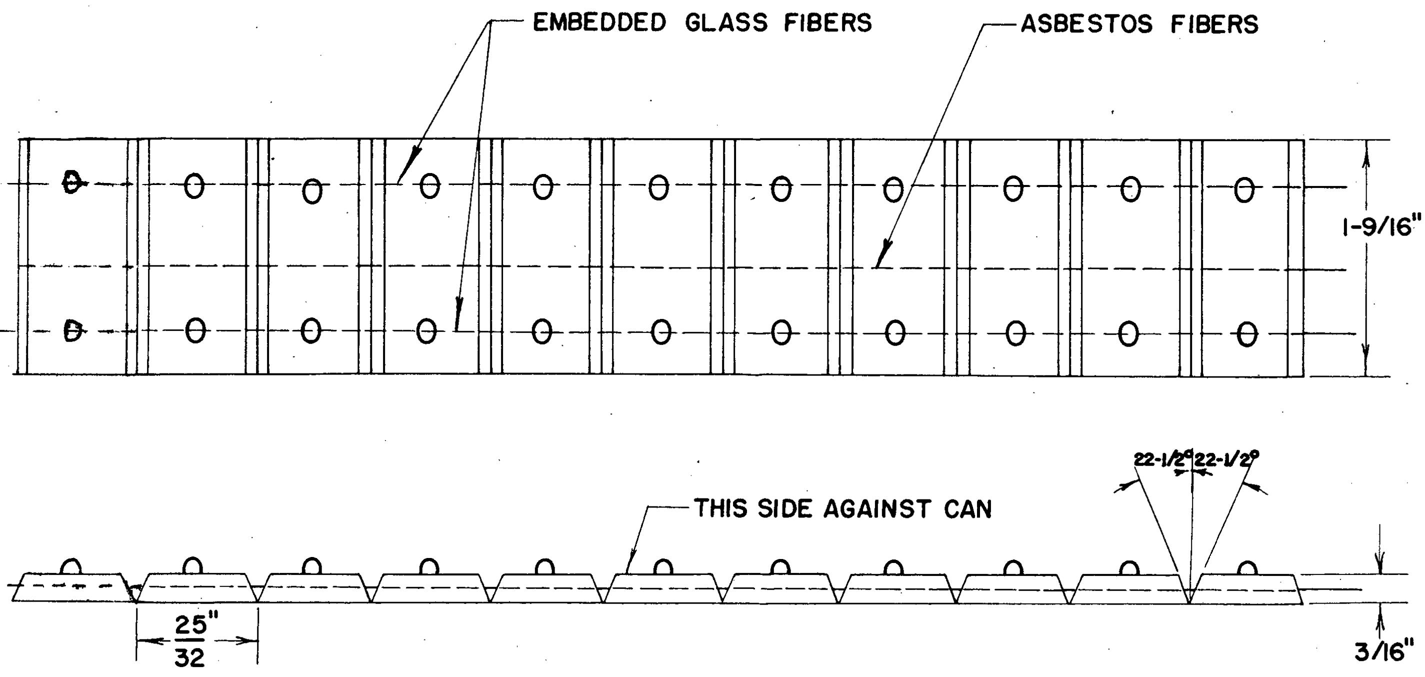

FIG. 2. RATION HEATING UNIT
BEFORE ASSEMBLY

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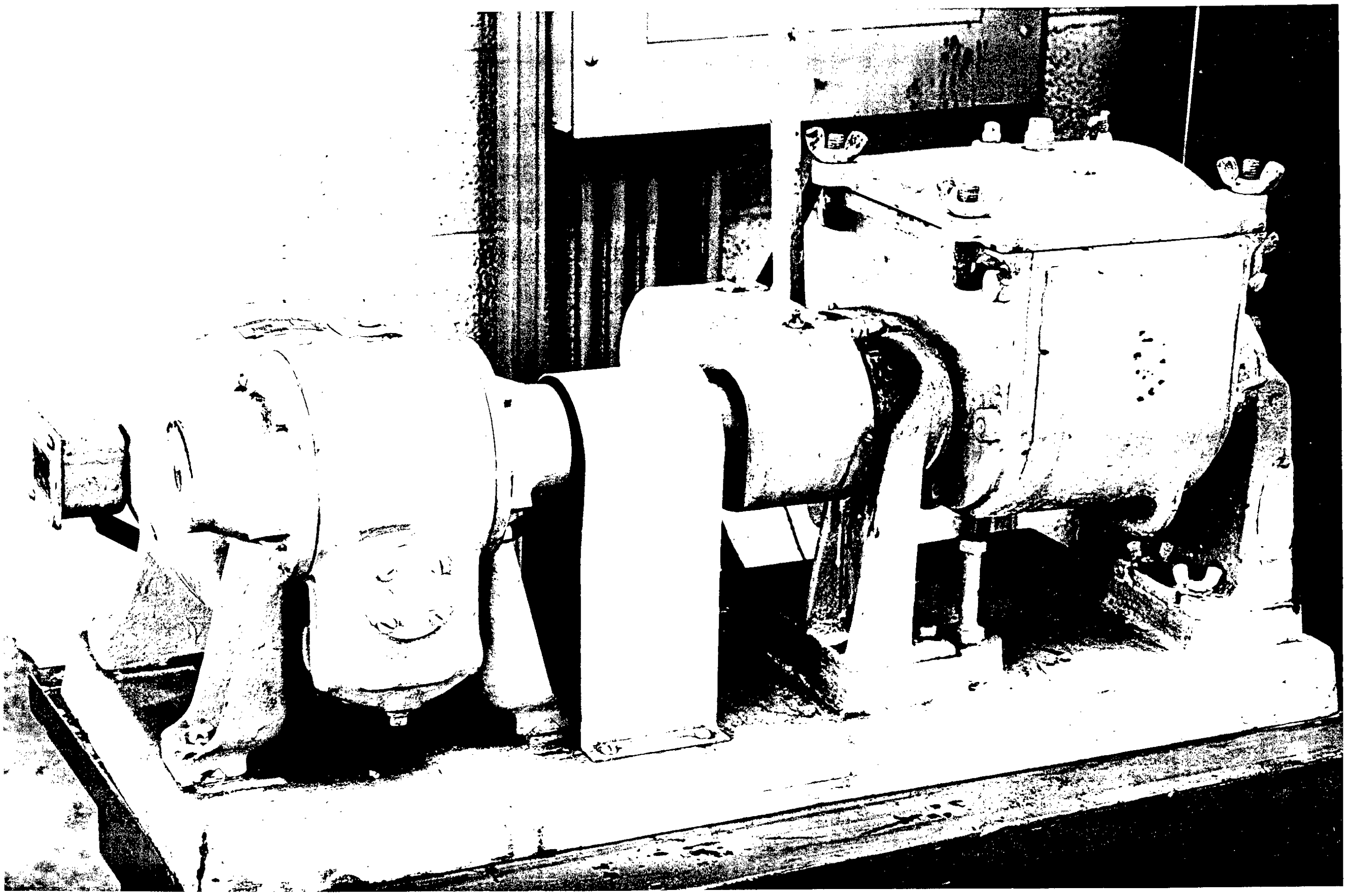

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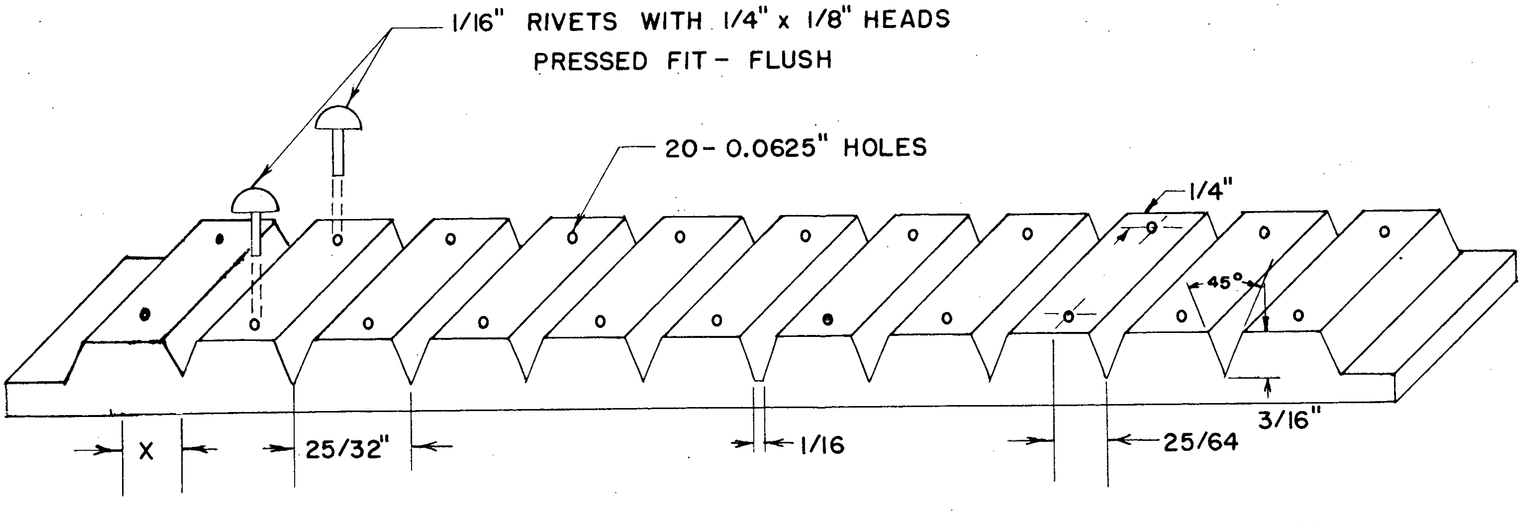


MATERAL - BRASS

FIG. 4. MOLD FOR CASTING PLASTISOL FORM

FIGURE 5

BRASS FORM FOR MAKING PLASTISOL FUEL UNIT MOLDS

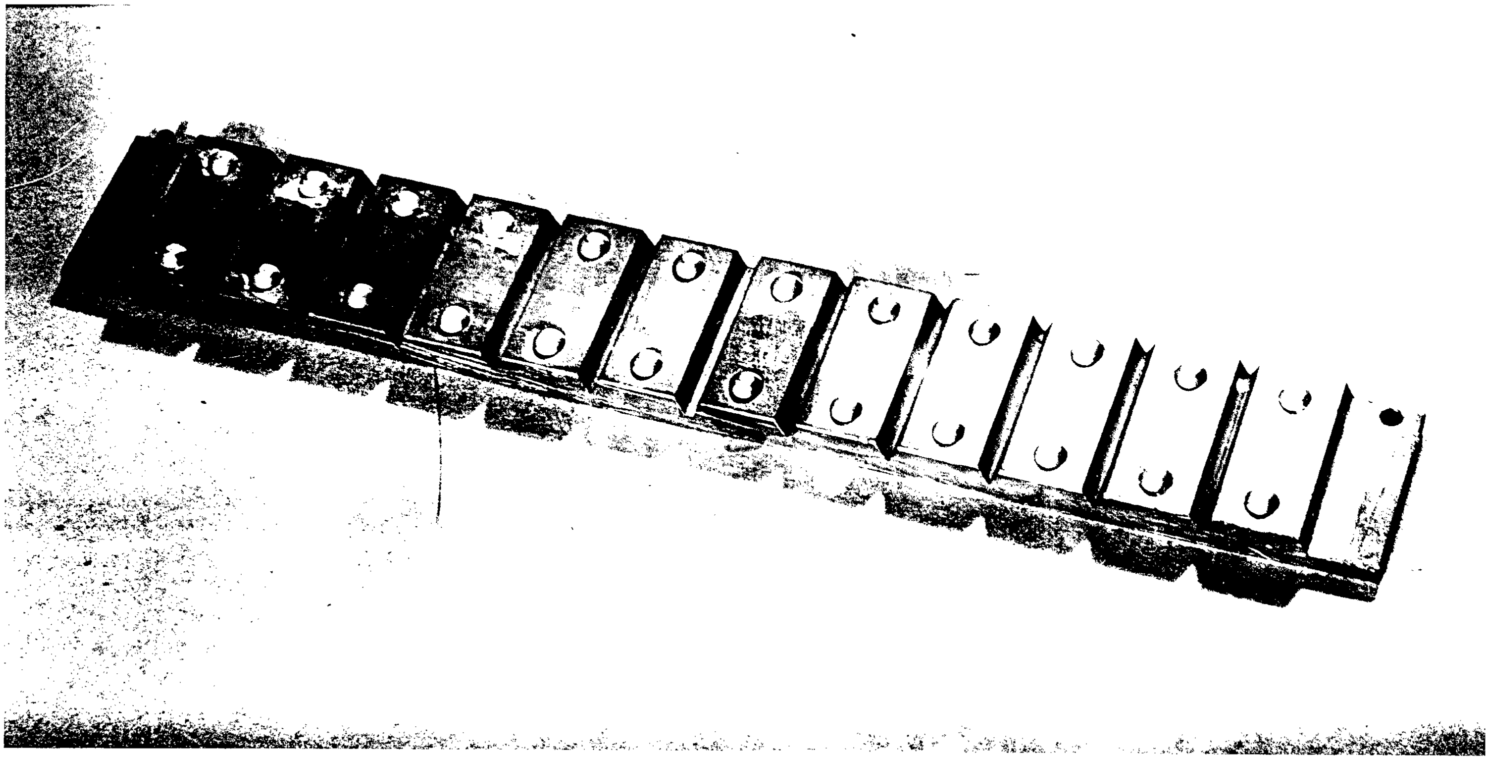
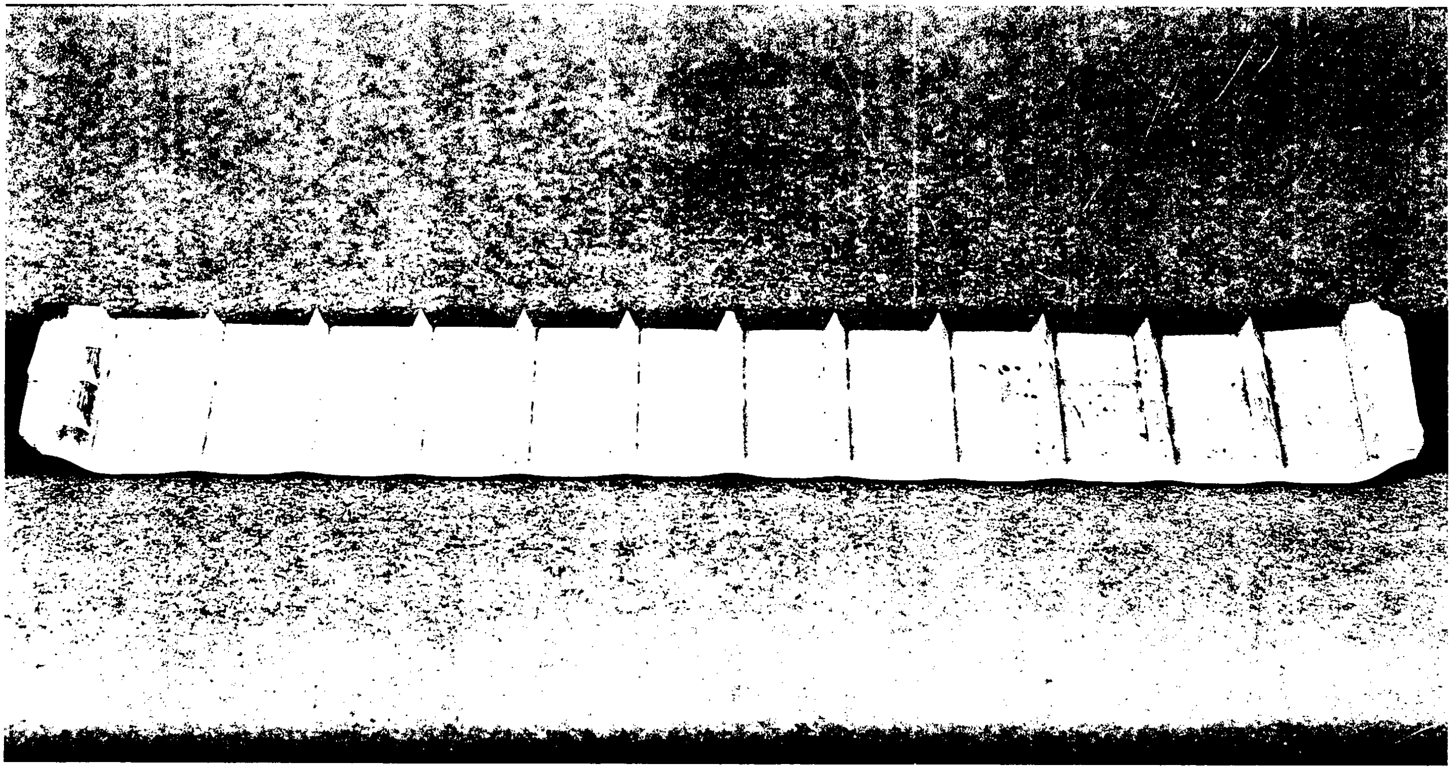


FIGURE 6

BRASS FORM AFTER DIPPING IN PLASTISOL FOR MAKING PLASTISOL FUEL UNIT MOLDS

FIGURE 7

PLASTISOL FUEL UNIT MOLD



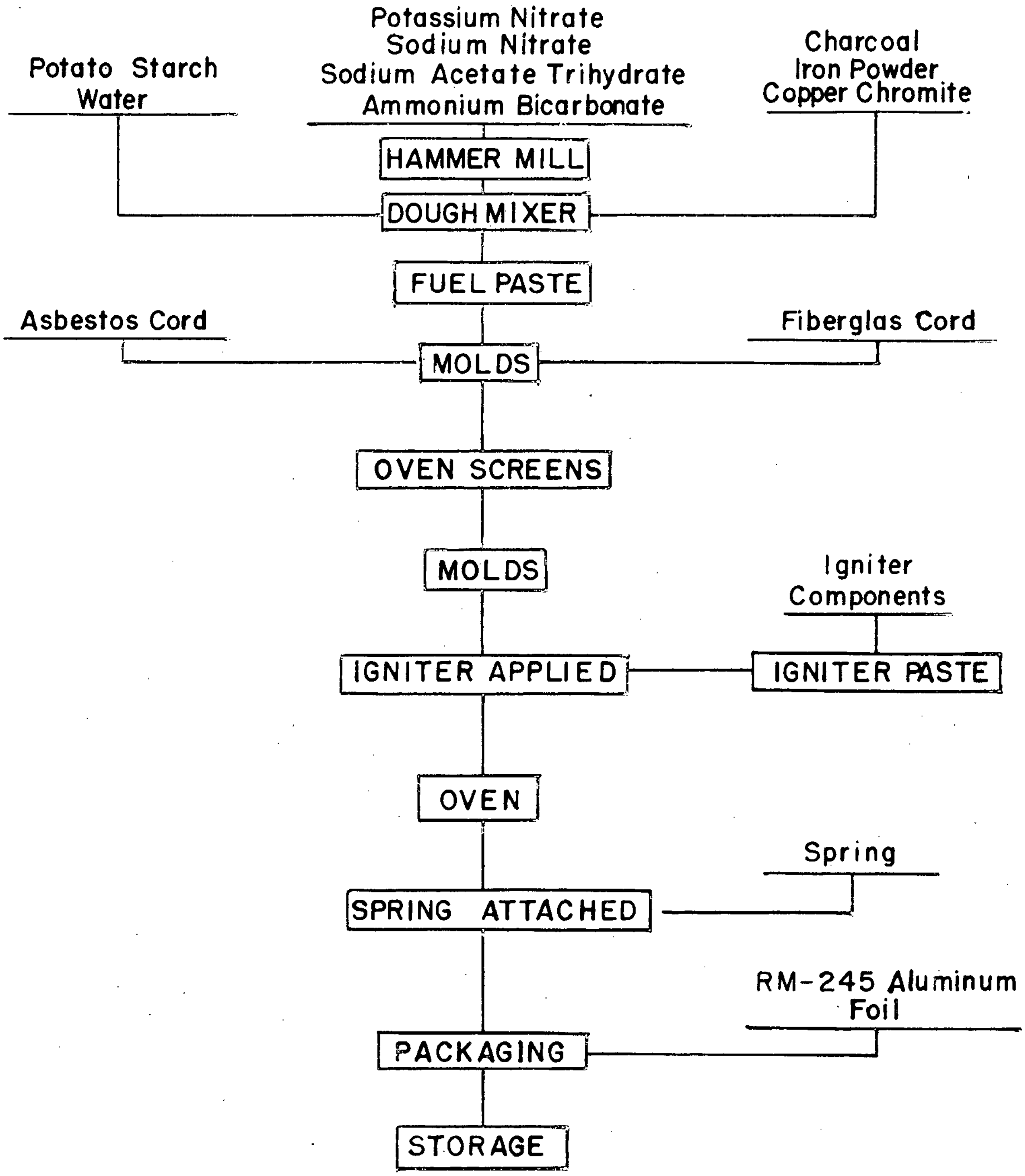


FIG. 8. FLOW DIAGRAM OF THE MANUFACTURING PROCESS

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FIGURE 9

PLASTISOL FUEL UNIT MOLDS IN RECESSED WOODEN MOLD SUPPORTS

FIBERGLAS CORDS AND ASBESTOS IGNITER CORD IN PLACE PREPARATORY TO FILLING FUEL UNIT MOLDS

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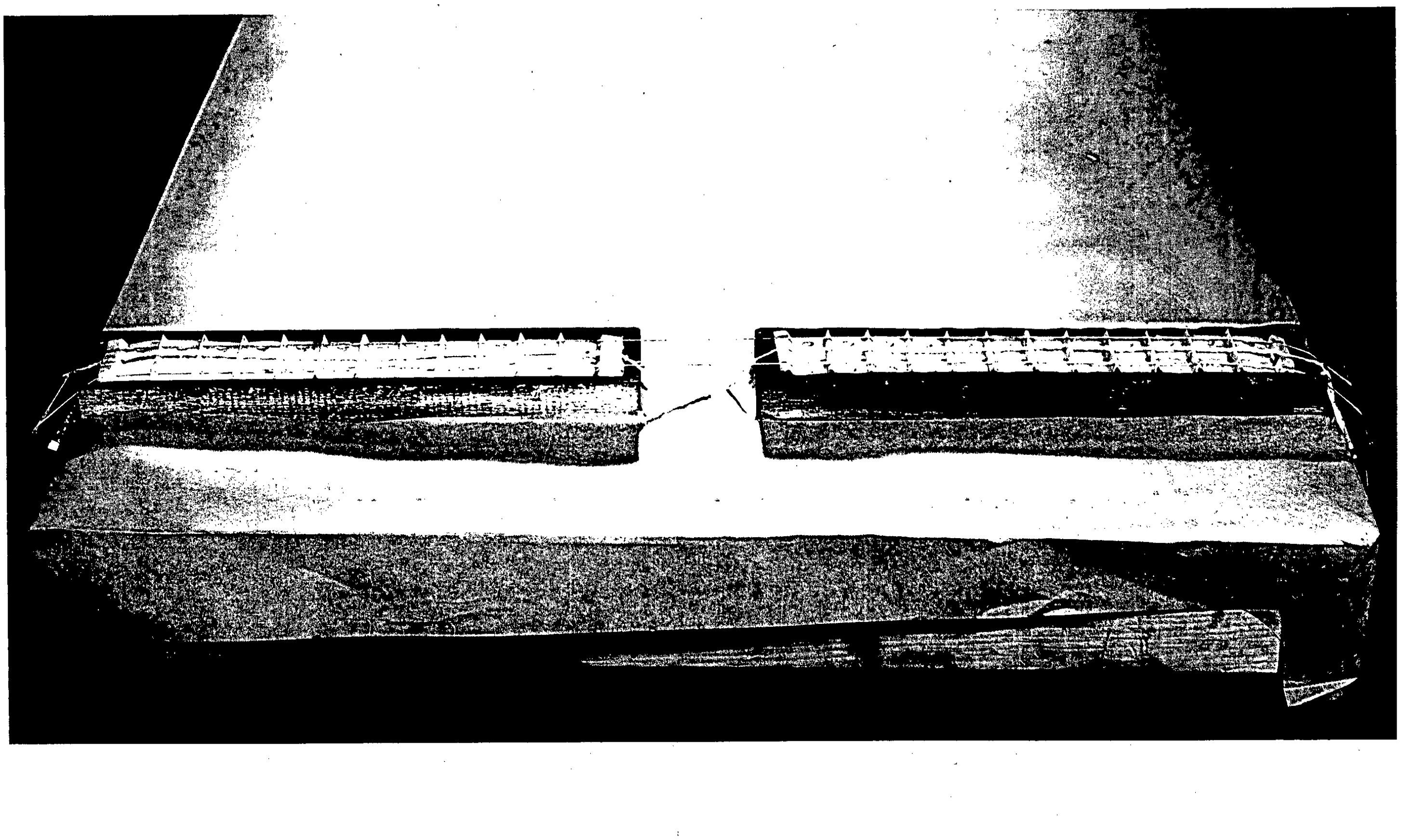

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FIGURE 10

SCREENS LOADED WITH FUEL
UNITS PRIOR TO BAKING

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FIGURE 11

SCREENS LOADED WITH FORMED FUEL UNITS IN AN AIR CIRCULATING OVEN FOR DRYING AND BAKING

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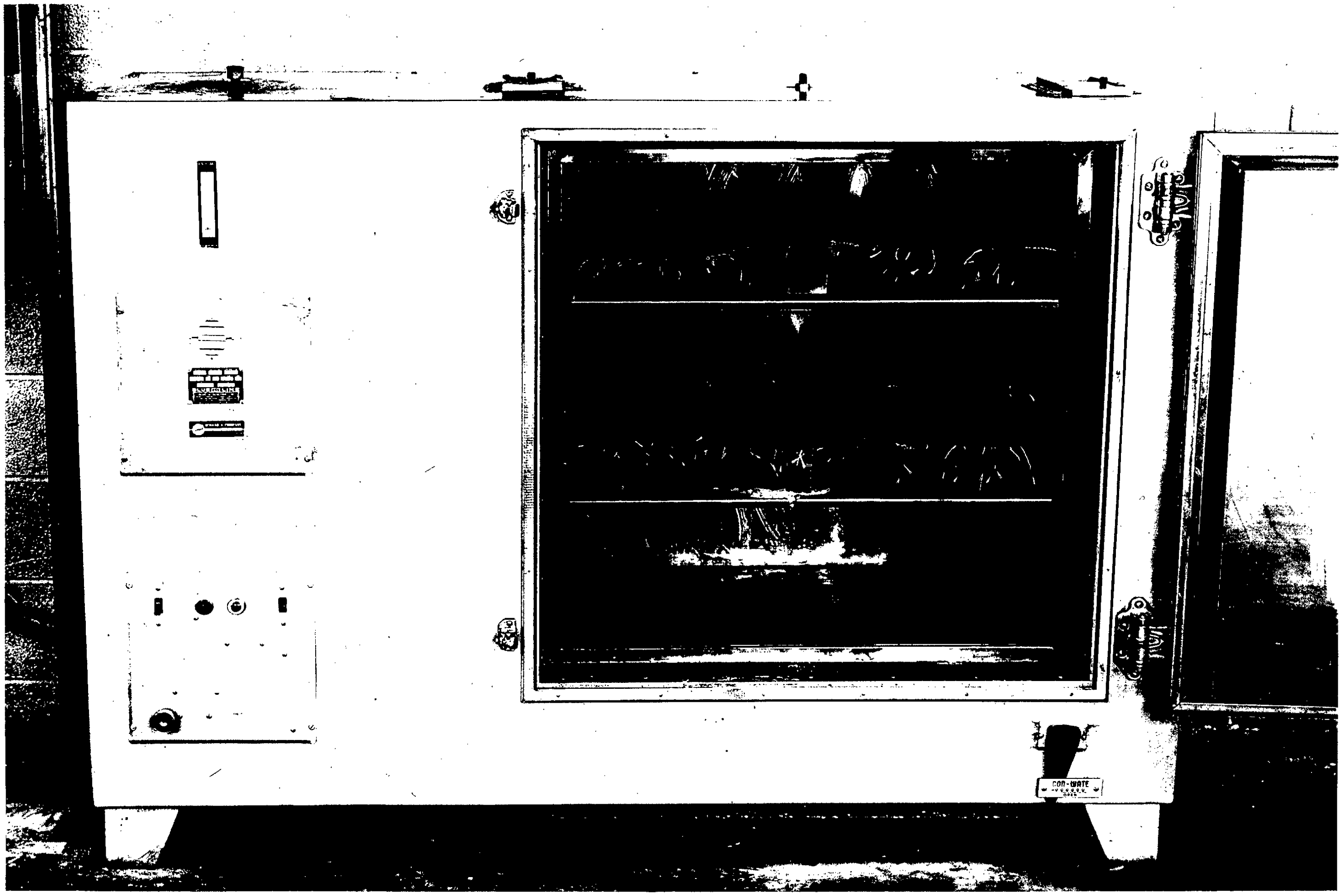
CON-WATE

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FIGURE 12

RATION CAN HEATING UNIT SHOWING COIL SPRING AND METHOD OF ATTACHMENT

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FIGURE 13

DOUGHBOY BELT TYPE HAND SEALING MACHINE

MODEL PHS-D

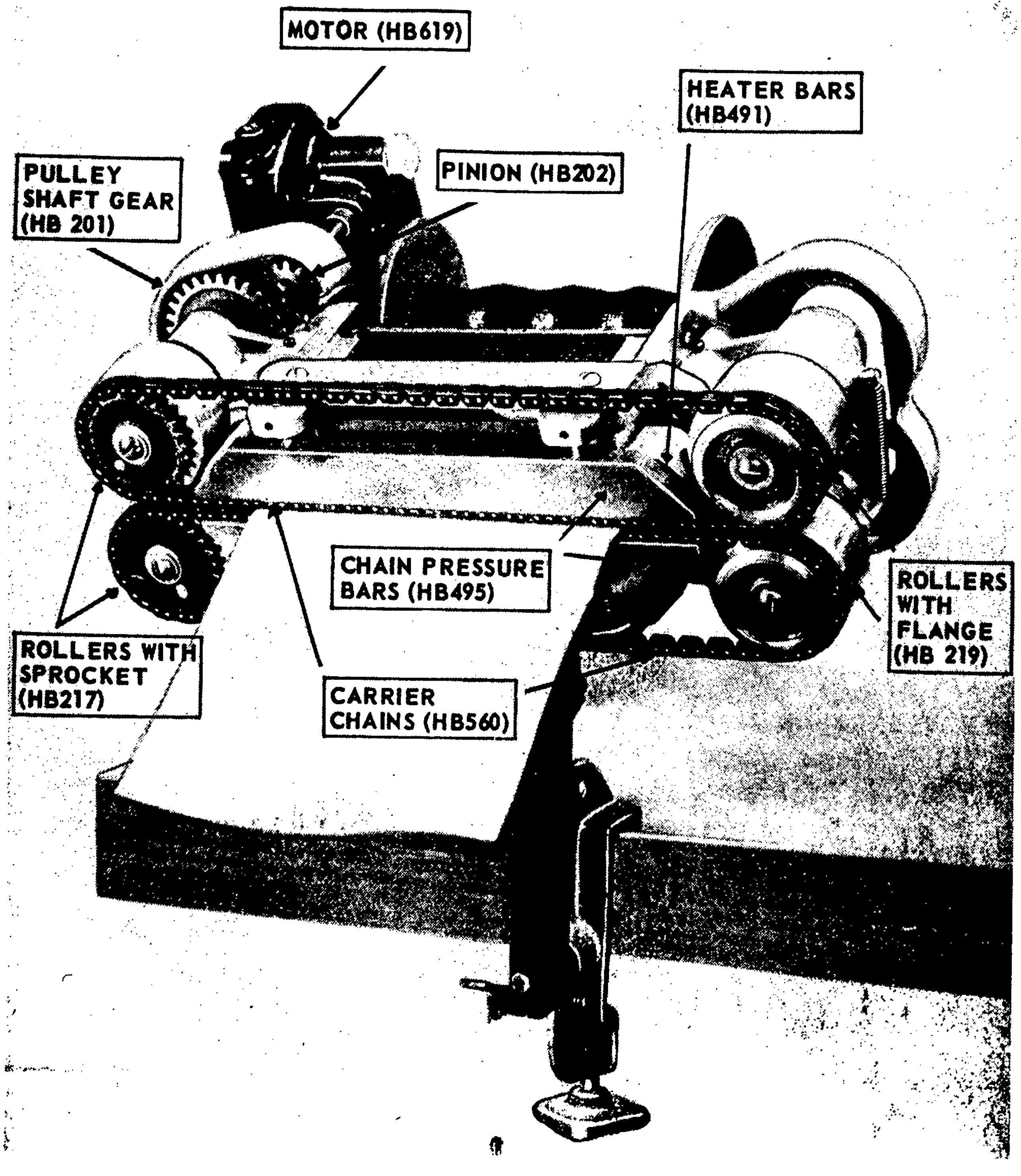
MOTOR (HB619)
HEATER BARS (HB491)
PINION (HB202)
PULLEY SHAFT GEAR (HB 201)
CHAIN PRESSURE BARS (HB495)
ROLLERS WITH FLANGE (HB 219)
ROLLERS WITH SPROCKET (HB217)
CARRIER CHAINS (HB560)

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FIGURE 14

PACKAGED RATION CAN HEATING UNIT

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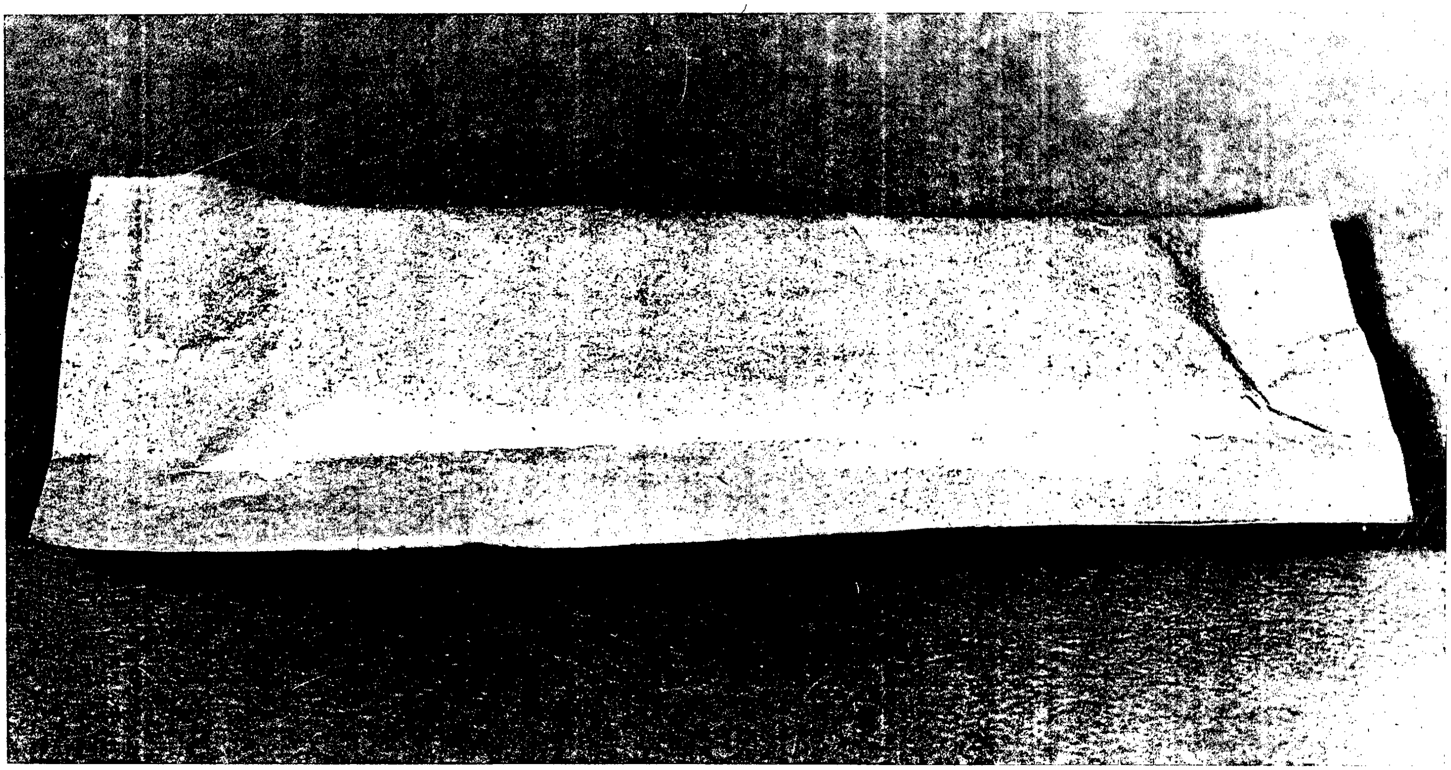

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