

KARAFUTO

Furui
HOKKAIDO
Sapporo
Oshima

NTJ

HONSHU

REF ID: A67239

INDEX NO. X-38(N)-7

~~THIS DOCUMENT CONTAINS UNCLASSIFIED INFORMATION~~

MISCELLANEOUS TARGETS

JAPANESE FUELS AND LUBRICANTS - ARTICLE 7
PROGRESS IN THE SYNTHESIS
OF LIQUID FUELS FROM COAL

U.S. NAVAL TECHNICAL MISSION TO JAPAN

"Japanese Fuels and Lubricants, Article 7 - Progress in the Synthesis of Liquid Fuels from Coal", - Index No. X-38(N)-7.

Page 15 Insert following after second paragraph:

"Information obtained from the Imperial Fuel Institute indicated that the design capacity, or intended capacity, of the AGOCHI plant was 50,000 metric tons of "oil" per year. On the basis of the size of the converter given by SHONO, it appears that the figure of 20,000 tons of oil processed per year would apply to a single converter at the AGOCHI plant".

Page 18 In the sixth line of fifth paragraph under "Plant Development", delete "by thermo - syphon action".

Page 256 In third line of eighth paragraph change "pan mill" to "ball mill".

Page 280 Delete text commencing "This represents --- "and ending" --- hydrogenation of coal". Substitute therefor:

"MIYAMA was unable to give accurate figures or product distribution for the FUSHUN plant".

U. S. NAVAL TECHNICAL MISSION TO JAPAN
CARE OF FLEET POST OFFICE
SAN FRANCISCO, CALIFORNIA

18 February 1946

RESTRICTED

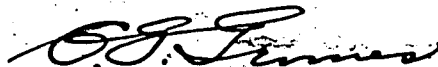
From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Japanese Fuels and Lubricants, Article 7 -
Progress in the Synthesis of Liquid Fuels from Coal.

Reference: (a) "Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report, covering the synthesis of oil outlined by Targets X-09, X-10, and X-38 of Fascicle X-1 of reference (a), is submitted herewith.

2. The investigation of the target and the target report were accomplished by Comdr. G. L. Neely, USNR, Lt. Comdr. C. S. Goddin, USNR, Lieut. W. H. Millet, USNR, Mr. C. O. Hawk, Technical Representative from the U.S. Bureau of Mines, and Ens. E. R. Dalbey, USNR, as interpreter and translator.



C. G. GRIMES
Captain, USN

THIS DOCUMENT HAS BEEN OFFICIALLY
DECLASSIFIED

RESTRICTED

X-38(N)-7

**THIS DOCUMENT HAS BEEN OFFICIALLY
DECLASSIFIED**

**JAPANESE FUELS AND LUBRICANTS - ARTICLE 7
PROGRESS IN THE SYNTHESIS
OF LIQUID FUELS FROM COAL**

**"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945
FASCICLE X-1, TARGETS X-09, X-10, AND X-38(N)**

**THIS DOCUMENT HAS BEEN OFFICIALLY
DECLASSIFIED**

FEBRUARY 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

MISCELLANEOUS TARGETS -

JAPANESE FUELS AND LUBRICANTS - ARTICLE 7 PROGRESS IN THE SYNTHESIS OF LIQUID FUELS FROM COAL

Impelled by the lack of petroleum resources, Japan made a determined effort to develop an industry for converting coal into oil. Paralleling the program in Germany, emphasis was placed on three primary coal conversion processes: high pressure hydrogenation, the Fischer-Tropsch Synthesis, and low-temperature carbonization.

Although the Japanese Navy initiated research on coal hydrogenation in 1925, only two commercial-scale coal hydrogenation plants were installed in the Japanese Empire. These plants were based on the Japanese Navy's 200-Atmosphere process with modifications by the respective operating companies. The actual production of oil from coal was insignificant, since one plant at AGOCHI, Korea, never achieved continuous operation, and the other, at FUSHUM, Manchuria, operated only intermittently. Visits to these plants by the U/ S. Naval Technical Mission to Japan were not feasible in view of the unsettled military conditions in those areas.

The Fischer-Tropsch industry in Japan was based primarily on Ruhr-chemie patents purchased by the KITSUI interests in 1936. Only three plants ever produced oil and the actual output of each was well below design capacity. Two of these plants operated at normal pressure and utilized a cobalt catalyst, while the other operated at middle pressure and used both cobalt and iron catalysts. The iron catalysts were the product of Japanese research, the manufacturing details of which are fully described herein.

The most important source of liquid fuels from coal was the low-temperature carbonization process. Most of the installations were Lurgi or Koppers ovens, and all evidence indicated that no coal carbonization process of Japanese design was successfully operated.

The Japanese "Seven-Year Plan" called for production of 2,000,000 kiloliters of liquid fuels from coal by 1943. Actual production in the peak year, 1944, was only 113,000 kiloliters. The plan was a failure due to stoppage of foreign machinery imports by the war, diversion of critical materials during the war, and technical difficulties encountered with the coal hydrogenation and the Fischer-Tropsch processes. As a matter of interest, the output of oil from shale at FUSHUM, until 1944, exceeded the combined output from all coal conversion processes.

~~THIS DOCUMENT HAS BEEN ORIGINALLY~~
DECLASSIFIED

TABLE OF CONTENTS

Summary	Page 1
List of Enclosures	Page 3
References	Page 5
Introduction	Page 7
The Report	
Part I History	Page 9
Part II High Pressure Hydrogenation	Page 11
Part III Fischer-Tropsch Synthesis	Page 16
Part IV Low-Temperature Carbonization	Page 19

LIST OF ENCLOSURES

(A)	Summary of Research on Conversion of Coal to Oil at the First Naval Fuel Depot, OFUNA	Page 31
(B)	Detailed Reports of Research on Conversion of Coal to Oil at the First Naval Fuel Depot, OFUNA	
(B) 1	The Thermal Cracking of Phenol under High Pressure Hydrogen	Page 37
(B) 2	On the Thermal Change of Aromatic Compounds in the Presence of High Pressure Hydrogen	Page 43
(B) 3	Effect of Size of Coal on Coal Hydrogenation	Page 55
(B) 4	Effect of Viscosity of Paste Oil on Coal Hydrogenation	Page 61
(B) 5	Effect of Ferric Oxide on Coal Hydrogenation	Page 67
(B) 6	Effect of Reaction Temperature on the Hydrogenation of Coal	Page 73
(B) 7	Effect of Reaction Pressure on Hydrogenation of Coal	Page 81
(B) 8	Effect of Reaction Time on the Hydrogenation of Coal	Page 85
(B) 9	Studies on the Hydrogenation of Low Temperature Tar	Page 89
(B)10	On the Coal Hydrogenation Reaction	Page 95
(B)11	Experiments on Various Coals Produced in Japan	Page 105
(B)12	Studies on Tar for Paste	Page 111
(B)13	On the Physical Properties of Paste	Page 117
(B)14	Studies on the Hydrogenation of Mixtures of Aromatic Compounds	Page 127
(B)15	Studies on the Properties of Tar from Coal Hydrogenation	Page 137
(B)16	On the Mechanism of Coal Hydrogenation	Page 149
(B)17	Coal Hydrogenation in a Semi-Commercial Pilot Plant	Page 157
(B)18	Studies on Catalysts for Coal Hydrogenation	Page 165
(B)19	Studies on the Fischer-Tropsch Synthesis	
	Part I Activation of Cobalt Catalyst by Hydrogenation	Page 171
	Part II Studies on Iron Catalysts	Page 179

Part III	Studies on Liquid-Phase Synthesis with Iron Catalyst	Page 183
(B)20	Studies on Coal	Page 187
(B)21	Studies on Shaly Coal Tar	Page 195
(B)22	Studies on Simplified Apparatus for Carbonization of Shaly Coal	Page 203
(B)23	Studies on the Extraction of Coal	Page 211
(C)	List of Japanese Reports on Conversion of Coal to Oil, First Naval Fuel Depot, OFUNA, forwarded through ATIS to the Washington Document Center	Page 219
(D)	Research on the Fischer-Tropsch Process at the Kyoto Imperial University	Page 227
(E)	Research Activities of the Imperial Fuel Research Institute at KAWAGUCHEI	Page 249
(F)	The Coal Hydrogenation Plant at FUSHIMI	Page 275
(G)	Miike Synthetic Oil Company	Page 283
(H)	<u>Nissan Ekitai Nenryo K.K.</u> , Wakamatsu Plant	Page 307
(I)	History of the Synthetic Oil Industry in JAPAN	Page 319
(F)	<u>Taikoku Nenryo K.K.</u> , Ube Works	Page 327

REFERENCES

Location of Target:

First Naval Fuel Depot, OFUNA.
 Third Naval Fuel Depot, TOKUYAMA.
 Army Fuel Research Institute, FUCHU.
 Kyoto Imperial University, KYOTO.
 Imperial Fuel Research Institute, KAWAGUCHI, Saitama Pref.
 TEIKOKU NENRYO KOGYO K.K., TOKYO.
 MIike Synthetic Oil Co., OMIYA.
 NISSAN EKITAI NENRYO K.K., Wakamatsu Works, WAKAMATSU.
 TEIKOKU NENRYO KOGYO Ube Works, UBE.

Japanese Personnel Interviewed:

- S. KOMATSU, Ph. D., Civilian Advisor to the Department of Fuel Research, First Naval Fuel Depot, OFUNA, (formerly Professor of Bio-Chemistry at Kyoto Imperial University).
 K. MITSUI, Ph. D., Engineering Commander Japanese Navy, First Naval Fuel Depot, OFUNA, (key research man on coal hydrogenation research).
 A. NAKAI, Engineering Lieutenant-Commander, Japanese Navy, First Naval Fuel Depot, OFUNA, (key research man on the Fischer-Tropsch Process).
 I. WATANABE, Engineering Rear-Admiral, Japanese Navy, Superintendent of the Third Naval Fuel Depot, TOKUYAMA.
 G. KITA, Ph. D., Retired Professor of the Institute of Physical and Chemical Research, at the Kyoto Imperial University, (pioneered research on the Fischer-Tropsch Process in Japan; especially development of iron catalysts).
 S. KODAMA, Ph. D., Professor in the Institute of Physical and Chemical Research at the Kyoto Imperial University (is now actively in charge of Fischer-Tropsch research at the University).
 Y. BAN, Director of the Imperial Fuel Research Institute, (has been associated with the Institute for 25 years, is competent, and thoroughly familiar with Japanese coal resources and problems of utilization).
 T. MIYADA, Technical Director of TEIKOKU NENRYO KOGYO K.K., TOKYO, (formerly with Manchurian Chemical Industries Co. at DAIREN, working on ammonia synthesis, then became General Manager of the coal hydrogenation plant at FUSHUN from 1937-1942 prior to present assignment).
 N. SHONO, Assistant to Chief Engineer of TEIKOKU NENRYO KOGYO K.K., TOKYO, (formerly Chief Engineer with the Toho Kagaku Kogyo Co. at NAGOYA up to 1944, especially familiar with hydro-cracking).
 N. NAKAHARA, President of the Toa Nenryo (Oil) Co., (especially familiar with catalytic cracking development in Japan).
 T. MITSUI, President of the Miike Synthetic Oil Co., (Dartmouth graduate and closely related to the development of the plant at MIIKE, primarily a businessman, and not highly informed technically).
 M. TAKEI, Head of the Chemical Department of the Miike Synthetic Oil Co., (a graduate chemist, well informed on details of the Fischer-Tropsch Process at MIIKE).
 H. YAMADA, Director of the Nissan Ekitai Nenryo Plant at WAKAMATSU, unusually well-informed on the technical details of the low-temperature process employed at this plant).

continued

IWAROTO, Director of the Ube Works of the TEIKOKU NENRYO KOGYO K.K.,
(well-informed technically on the operations of this plant).

In addition to the key personnel listed above, a number of other plant executives and research assistants were interviewed, and are listed in the enclosures contained in this report.

Referenced Japanese Reports.

"Technical Notes on Research Work, Army Fuel Research Institute,
FUCHU."

INTRODUCTION

Recognizing her critical lack of an adequate domestic or a dependable foreign source of petroleum, Japan has intensively endeavored to overcome this deficiency by developing an industry for conversion of extensive reserves of low grade coals into oil. Three processes for converting coal into oil have been studied and expanded to industrial scale operation:

1. High-Pressure Hydrogenation.
2. Fischer-Tropsch Synthesis.
3. Low-Temperature Carbonization.

This report summarizes the findings of the Petroleum Section of the U. S. Naval Technical Mission to Japan relative to research and industrial developments on the above processes. A general history of the synthetic fuels program in Japan is also presented.

To obtain this information, important Japanese oil research institutions were inspected including the Naval Research Laboratory at OFUNA, the Army Fuel Research Institute at FUCEU, the Imperial Fuel Research Institute at KAWAGUCHI, and the laboratories of Professor KITA at the Imperial University, KYOTO. Typical commercial scale installations visited were the Fischer-Tropsch plant at MIIKE, the low-temperature carbonization works at WAKAMATSU and the low temperature carbonization and high pressure oil hydrogenation units at UBE.

Semi-commercial coal hydrogenation units at OFUNA and KAWAGUCHI were also inspected. Interviews were held with representatives of TEIKOKU HENRYO KOGYO, K.K., (Imperial Fuel Industries Co.), a government agency established to promote development of the synthetic liquid fuel industry in Japan.

Particular attention was devoted to evaluation of the research carried on at the First Naval Fuel Depot, OFUNA. Detailed research reports of the work on coal conversion were prepared (in English) by technical personnel of the Depot and are submitted as Enclosures (B)1 to (B)25, inclusive. Since the original research reports, drawings and documents had been burned in August, 1945, it was necessary to recall Japanese personnel to reassemble this information from laboratory notebooks and miscellaneous records.

It is recognized that the data secured do not completely cover Japan's program with respect to the production of oils from coal. However, it is believed that there is sufficient material to permit at least a rough appraisal of the extent and nature of her synthetic fuel developments.

THE REPORT

Part I - HISTORY

Research on coal conversion was begun in Japan as early as 1921 by the Imperial Fuel Research Institute, which at that time initiated studies on low-temperature carbonization of Japanese coals. The Japanese Navy, in 1925, started laboratory studies at TOKUYAMA on high-pressure hydrogenation and low-temperature carbonization. This work was stimulated by the fact that units of the fleet were then in process of converting from coal to liquid bunker fuels. In 1926, Dr. OGAWA, of the Tokuyama Naval Research Laboratory, visited the I. G. Farben Industries, A. G., at LEUNA, taking with him samples of Fushun and Japanese coals for hydrogenation tests. Upon his return, work on the hydrogenation process was intensified, and in 1930, the decision was made to build the first semi-commercial coal hydrogenation unit in Japan. This unit, of seven tons per day paste throughput capacity, was completed in 1932, and experiments were continued at TOKUYAMA until 1933, when the unit was transferred to OFUNA.

In 1928 the South Manchurian Railway Co. started experiments on coal hydrogenation in their Central Research Laboratory at DAIKEN, Manchuria.

In 1931, the Imperial Fuel Research Institute at KAWAGUCHI also began research on high-pressure hydrogenation of coal, and in 1934 constructed a simplified pilot plant of 3-5 tons per day paste charge capacity. The work, however, apparently did not play an important part in industrial development of the process.

The information obtained by NavTechJap indicates that only two commercial-scale coal hydrogenation plants were ever installed in the Japanese Empire. In 1936 the South Manchurian Railway Co. began construction of a unit of about 10,000 tons per year coal charge capacity at FUSHUN, Manchuria, which was jointly designed by the Navy and the South Manchurian Railway Co. In 1937 the Korean Nitrogen Fertilizer Co. began construction of a plant at AGOCHI, Korea, with a coal charge capacity of 20,000 tons per year. This plant was also based on the Navy process, but with modifications, especially in catalyst design, which reflected the experience of the parent company in ammonia synthesis.

Both these plants commenced operations in 1939. Apparently the Agochi plant was never able to achieve continuous operation on coal, due to excessive coking and plugging difficulties. Experiments were continued on hydrogenation of low-temperature tar and coal until 1942, when the plant was converted to naphthalene synthesis. The Fushun plant is reported to have been somewhat more successful, although many process and design changes to which the Navy and the South Manchurian Railway Co. cooperated, were required. From 1940 to 1942 the plant was alternately operated on coal and hydrocracking of low-temperature tar and in July, 1942, was completely converted to hydrocracking of low-temperature tar and petroleum oils for production of aviation gasoline.

In the meantime other agencies, impatient with delays in development of the Japanese coal hydrogenation process, attempted negotiations with Germany. In 1937 the Ogura Oil Co. reached a price agreement with I. G. Farben Industries for licensing rights to the Bergius Process. However, the Japanese Navy prevented completion of the deal, apparently on the basis that development of a satisfactory Japanese process was imminent. The Japanese Navy, on the other hand, continued negotiations with the German Government until 1945, but it is reported that no actual technical data were secured.

Beginning in 1939, the Japanese Army in its extensive laboratories at OFUNA, conducted research on hydrocracking various oils for production of aviation

gasoline, and constructed kerosene hydrocracking units in its refineries at IWAKUNI and SHIHEIGAI. There is no indication, however, that the Army investigated the high-pressure hydrogenation of coal.

Although a number of oil hydrocracking units were successfully operated for production of aviation gasoline, the production of liquid fuels by the high pressure hydrogenation of coal in the Japanese Empire was negligible.

Research on the Fischer-Tropsch Process for synthesis of oil from carbon monoxide and hydrogen was pioneered in Japan by Professor G. KITA at the Institute of Physical and Chemical Research at the Imperial University, KYOTO. This work was started in 1927, one year after the appearance of Franz Fischer's first paper on the subject, and was centered primarily on development of cheap iron catalysts for use in both normal and middle-pressure synthesis.

The Imperial Fuel Research Institute at KAWAGUCHI also conducted research from 1933 to 1940, especially on nickel substitute catalysts, but made no significant contributions to the industry. Professor MATSUBARA, at the Tokyo Imperial University, also worked on catalysts for this process and developed a natural iron catalyst in 1932-34. Iron catalysts from both Tokyo and Kyoto Universities were tested on plant scale at the Takikawa middle pressure Fischer-Tropsch plant.

In 1936, the Mitsui interests purchased rights to the Fischer-Tropsch Process from Ruhrchemie, and in the same year, commenced construction of a normal-pressure cobalt plant at MIKE, near OMIYA. This plant was designed to have an output capacity of 50,000 tons of crude product per year. Operational difficulties were encountered and actual production was substantially less than this figure. Two other Fischer-Tropsch plants were built in Japan under the joint management of NITSOI and TEIKOKU HENRYO K.K. One of these was the middle pressure plant at TAKIKAWA, employing both cobalt and iron catalysts, which started operations in December, 1942; the other was a normal pressure plant at KAGASAKI, employing a cobalt catalyst, which started in September, 1943. Two other plants in Kancharia, one at CHIELIN and the other at CHINCHU, were under construction at the end of the war.

The Mitsui interests, at their laboratory in TOKYO, conducted some research, especially on iron catalysts and the manufacture of lubricating oils and chemicals from Fischer-Tropsch liquids. The Army and Navy also conducted a small amount of research on the process, but made no significant contributions to the technology.

The most successful method for production of oil from coal in Japan, with respect to volume and cost of production, was low-temperature carbonization. Although studies of the process were started in 1921 by the Imperial Fuel Research Institute, difficulties of marketing the semi-coke prevented any substantial development of the industry under peace-time conditions.

In 1936, the Japanese Government established a petroleum substituted policy as a war measure, which included indemnities for losses suffered in the production of such fuels. With the establishment of this policy, the low-temperature carbonization industry expanded rapidly.

In January, 1938, the Imperial Fuel Industries Co. (TEIKOKU HENRYO KOOYO K.K.) was established under the Japanese "Seven Year Plan" for synthetic oil development. Under this plan, annual production of 1,000,000 kl each of synthetic gasoline and fuel oil was to be achieved by 1943 (See Enclosure I). TEIKOKU HENRYO K.K. was authorized to finance synthetic oil enterprises and to manufacture and sell synthetic oils. Companies engaging in synthetic oil production were exempted from income, import, and profit taxes, and were given subsidies based on oil output. In 1942, however, subsidies were eliminated and the government purchased all oil from the synthetic oil companies at favorable fixed prices.

Under the "Seven Year Plan," the synthetic oil industry was to be developed to include 10 high-pressure coal hydrogenation units, each of 100,000 kl per year oil output capacity, 11 Fischer-Tropsch units, each of 50,000 kl per year capacity, and 66 low-temperature carbonization units, each charging 100,000 tons per year of coal. The actual plants constructed in the empire, and their outputs during the war years, are given in Table I, which is based on data supplied by TEIKOKU DENRYO K.K. It will be noted that the peak annual output of oil from all coal conversion processes amounted to only 114,000 kl compared with the 2,000,000 kl called for in the plan. This performance was due mainly to (1) the effect of the Moral Embargo and declaration of the European War in 1939 which stopped shipment of equipment from the United States and Germany, (2) the curtailment in the plant construction program in Japan after the attack on Pearl Harbor, due to diversion of critical materials for more pressing military requirements, and (3) the operating difficulties and low outputs from both Fischer-Tropsch and coal-hydrogenation plants.

Part II HIGH PRESSURE HYDROGENATION

A. DIRECT HYDROGENATION OF COAL

1. General Remarks. Studies on the direct hydrogenation of coal in Japan began as early as 1925, at the Japanese Naval Research Laboratory at TOKUYAMA (Enclosure (A)). The first experiments were carried out in small high pressure autoclaves for assay purposes, that is, to qualitatively determine the suitability of coal to liquefaction by hydrogenation. In 1926, Shimbara and Oyama coals were sent to Germany for confirmatory assay and for study in a small continuous plant at LEUNA.

The Japanese were attracted to coal hydrogenation as a possible source of liquid fuels because of their extremely poor position with respect to native petroleum. They had acquired some knowledge of low-temperature carbonization (Enclosure (E)) and of the potential usefulness of low-temperature tar as a petroleum substitute. However, the maximum tar yield was only about 10 per cent by weight of the coal, and many Japanese low-grade coals yielded only 6-8 per cent. Furthermore, there was no ready market for the semi-coke, the weight of which was 65 per cent or more of the weight of the coal. Coal hydrogenation, on the other hand, offered the possibility of developing a commercial process for complete conversion of coal to oil.

Coal hydrogenation has probably been studied more thoroughly in Japan, at least on laboratory scale, than in any other country in the world, except Germany. There are records of nearly two hundred hydrogenation assay tests, including ninety tests on coals from Manchuria and China (Enclosure (B)22), and more than one hundred tests on coals from Japan proper (Enclosure (E)).

The Petroleum Section of NavTechJap interviewed research personnel and inspected coal hydrogenation equipment at the First Naval Fuel Depot, OFUNA, and at the Imperial Fuel Research Institute, KANAGUCHI. Both organizations have done work on laboratory and semi-plant scale.

No industrial research laboratories investigating this subject were inspected. One such laboratory, under Japanese control, known to exist, is the South Manchurian Railway's Central Research Laboratory at DAIREN. In this laboratory much of the exploratory and development work was done which culminated in erection of the coal hydrogenation plant at FUSHURI, Manchuria.

The exact position of Japanese Universities in coal hydrogenation research is not known. The Keiji College of Technology near WAKAYAMA, Kyushu, is said to have facilities for this type of work. The Imperial University at

KYOTO has been active in Fischer-Tropsch investigations, but did no work on hydrogenation. The Imperial University at TOKYO is known to have supported fuel research, but the nature of this work has not been ascertained.

2. Coal Hydrogenation Work of the Japanese Navy

a. Laboratory work. The Japanese Navy's interest in coal hydrogenation was motivated by the desire and need to establish a dependable source of liquid fuels for the fleet. Therefore, consideration was given to all coals within, or controlled by, Japan. Assays were made in the Tokuyama laboratories on both Japanese and continental-Asiatic coals. However, in view of the direct co-operation between the Navy and the South Manchurian Railway Co., much of the Navy's earlier laboratory work was concentrated on developing a liquefaction process based on Fushun (Oyama coal (Enclosure (B)1)). Autoclave studies on the effect of catalyst (Enclosure (B)5), reaction temperature (B)6), hydrogen pressure (Enclosure (B)7), time of contact (Enclosure (B)8), viscosity of vehicle (Enclosure (B)4), and to some extent, the size of coal particles (Enclosure (B)3), comprised the nucleus of the early coal hydrogenation work.

The most important results of these experiments were:

- (1) Zinc chloride was found to be the most effective catalyst, although later, (Enclosure (B)18), a mixture of ferric oxide, sulfur, and stannous hydroxide was chosen as the standard catalyst.
- (2) Reaction temperatures near 420°C were found to be the highest practicable without encountering excessive coke and gas formation.
- (3) At pressures below 200 atmospheres, excessive coke formation occurred and liquefaction was incomplete.
- (4) Vehicle viscosity was without effect on the hydrogenation reactions.
- (5) About one hour minimum contact time under conditions described in (1), (2), and (3) was required for complete liquefaction.

Physical properties of coal pastes made with Fushun coal, were also measured to assist in the design of plant equipment (Enclosure (B)13).

Relatively few records were found relating to work on the fundamental aspects of coal hydrogenation. Work of this nature which was done, comprised studies on the hydrogenation of simple compounds (Enclosures (B)1, (B)2, (B)14), the effectiveness of relatively pure compounds when used as vehicles (Enclosure (B)12), the behavior of coal substance and humus (Enclosure (B)10), and mechanism studies (Enclosure (B)16). Although results and conclusions of this work are of general scientific interest, they contributed little to the practical aspects of process development.

One of the most valuable contributions of this laboratory to the general fund of knowledge concerning coal hydrogenation was an extensive survey of the properties of Chinese and Manchurian coals (Enclosure (B)22). Fifty coals from North China and forty from Manchuria were assayed. Only a few experiments were reported on coals from Japan proper, Korea, and Formosa (Enclosure (B)11).

general conclusions were:

(1) The coals of North China (mostly caking varieties) were found to be more suitable for high-temperature coking than for hydrogenation.

(2) Most coals of Manchuria hydrogenated readily. Similarly those tested from Japan, Korea, and Formosa were suitable for hydrogenation.

A list of titles of reports in Japanese relating to coal hydrogenation work at the Navy's research laboratories will be found in Appendix C. These documents have been forwarded through ATIS to the Washington Document Center.

3. Semi-Plant Operation. Erection of a semi-commercial scale plant, the first in Japan, began in 1930 at TOKUYAMA. Construction was completed and preliminary operation began about 1932. The plant comprised a single converter liquid-phase system, with a throughput of about 7 tons of paste (3-3.5 tons of coal) per day. An electric hydrogen preheater was enclosed in the converter (Enclosure (B)17, Figure 1) otherwise the hydrogenation system was conventional. Equipment for stripping volatile liquid hydrocarbons from the converter exit gases was provided, in order that hydrogen recirculation could be effected. Process hydrogen was furnished by electrolysis of water in a Knowles generator, with a capacity of 200 m³ per hour. Heavy oil, containing the ash and unliquefied constituents of the coal, was withdrawn through a manually controlled valve. Attempts to maintain continuous discharge with this system proved troublesome. Solids were separated from the heavy oil by centrifuging.

No written records were available for pilot plant operation between 1932 and 1938; but Japanese personnel estimated that during this period, the unit was actually on stream about one-third of the time.

Enclosure (B)17, summarizes data obtained in 1938-39 during a five-day run on Oyama coal and a one day run on Naibuchi coal from SAKHALIN. It was admitted that difficulties were experienced in these runs in the separation of solids from heavy oil by centrifuging, and in the non-uniform distribution of hydrogen and paste in the reactor. It was also stated that erosion of the heavy oil discharge mechanism was severe, and that the lack of flow control instrumentation made it difficult to maintain uniform operating conditions.

Results of the hydrogenation test on Oyama coal are of particular interest because of its relationship to the full scale operation at the South Manchurian Railway Co. plant at FUSHUN. Oyama coal is mined at FUSHUN and has been described (Enclosure (F)) as "a very high quality brown coal approaching bituminous". An analysis of the coal used in this test is given in Table II.

4. Coal Hydrogenation at the Imperial Fuel Research Institute. Both laboratory and semi-plant-scale hydrogenation of coal were studied by this organization from about 1931 to 1940. The purpose of the work was to carry to full demonstration scale, a process for liquefaction of Japanese coals. This work was done without direct co-operation with the Navy or any industrial group.

In all, over a hundred coals (Enclosure (E)) were hydrogenated in small autoclave tests showing, in general, that practically all Japanese coals are suitable for hydrogenation. Three of the more suitable coals were further studied in a small semi-commercial plant having a throughput capacity of 3 to 5 tons paste (1.5 to 2.5 tons of coal) per day. This plant comprised a double converter liquid-phase system (Enclosure (E)).

Figure 2). It possessed simplified design features intended to insure maximum operability rather than to serve as a means for studying engineering problems connected with economical operation of a high-pressure plant. For this reason, its operation, although reported to be reasonably successful, contributed little to the development of commercial hydrogenation in Japan. It did, however, furnish information of general interest on the behaviour of Japanese coals upon hydrogenation.

5. Industrial Scale Coal Hydrogenation

a. The South Manchurian Railway Co. Plant at FUSHUN, Manchuria. The construction of this plant was undertaken in 1936 (Enclosure (F)), about 10 years after experimentation on coal hydrogenation began on an extensive scale at the Navy's Research Laboratory at TOKUYAMA and the South Manchurian Railway's Central Research Laboratory at DAIREN.

Construction was completed and preliminary operation began in 1939. As a matter of interest, the reactors were made in Japan, and it was stated that there was no cooperation with foreign engineers in designing any of the equipment. Originally, the plant comprised a liquid-phase single converter system of essentially conventional design, at least with respect to material flow. Late in 1939, a second liquid-phase reactor was added, and early in 1940, a vapor-phase reaction system was installed. Between this time and July 1942, operation alternated between liquid-phase coal hydrogenation and vapor-phase treatment of fractions from low-temperature tar or from coal hydrogenation. From 1942 until the end of the war, at the direction of the Japanese Navy, the plant was completely converted to hydrocracking of gas oil and kerosene for production of gasoline.

For coal hydrogenation, operating conditions were 200 atmospheres and 430°C in the liquid-phase step, with a throughput of 4 tons of paste per hour. Ratio of coal to vehicle was 2 to 3 by weight. In the vapor-phase step, the input was 40 kl per day, at 200 atmospheres pressure and temperatures of 430°C and 440°C in the first and second stages respectively. The yield of gasoline obtained by combining liquid and vapor-phase operation was about 35% of the weight of coal charged.

It was not possible to visit this plant and no original operating records were located. T. MIYAMA, Technical Director of the plant from 1937 to 1942, advised that no particular mechanical operating difficulties had been encountered. N. SHONO, Assistant Technical Director of TEIKOKU KENRYO, stated that operating difficulties had been encountered, but he could give no specific information. Dr. H. FUSIMOTO, of the First Naval Fuel Depot at OFURA, recalled that production schedules were irregular between 1939 and 1942, but that at the end of this period, a reasonably successful process had been evolved.

The nominal throughput was about 10,000 tons of Oyama coal per year, according to MIYAMA. He also stated that the approximate total oil output of the plant from 1939 to the present was 15,000 tons, most of which was heavy oil from liquid-phase hydrogenation of coal.

Both MIYAMA and SHONO maintained that, although the Fushun plant was large enough to be considered of industrial scale, it had always been considered an experimental venture rather than a production unit. However, it seems probable, that under the severe stress of Japan's need for oil during the war, it would have operated continuously at rated capacity if the coal hydrogenation process had been successful.

b. The Plant at Agochi, Korea. Information secured on this installation was meager. Interrogation of N. SHONO of TEIKOKU NENRYO revealed that it was installed about the same time as the Fushun plant and the design capacity was about 20,000 tons of coal per year. Dr. K. MITSUI of the Navy's First Fuel Depot at OFUNA, recalled the nominal production as 10,000 kl of heavy oil per year by liquid-phase hydrogenation of Agochi brown coal.

Information obtained on the operation of this plant indicated that it was not able to function as a coal hydrogenation unit, and that during the war, it was finally converted to methanol synthesis. SHONO stated that the plant contained 2 converters, 160 centimeters in diameter and 13 meters long, and that, when operated as a coal hydrogenation unit, there was severe overheating in the reaction zone, resulting in excessive coking. He also recalled that the converter walls were said to be too thin to withstand the design operating pressure (200-250 atmospheres).

All evidence indicated that the Fushun and Agochi works were the only commercial-scale coal-hydrogenation plants installed in the Japanese Empire. Their failure to maintain operation, together with the fact that no other plants were built, is interpreted to mean that Japan did not have a perfected process. Since these plants could not be inspected, in view of the military situation prevailing in Manchuria and Korea at the time of this investigation, the actual progress made in the development of these plants has not been ascertained.

In securing the information for this report, it has been revealed that Japan, in her acute need for oil, plunged into industrial coal hydrogenation without acquiring an adequate background of experience with the intermediate-scale equipment. It has also been revealed that materials, particularly heat-resistant alloy steels, were not available for the construction of suitable equipment, and that manufacturing facilities did not exist for fabricating reaction vessels of proper size.

B. HYDROGENATION OF TAR

1. Research at the First Naval Fuel Depot, OFUNA. As a war measure, the utilization of high and low-temperature tar as raw material for aviation gasoline production was considered an attractive possibility by the Japanese Navy. High-pressure vapor-phase hydrogenation or "hydrocracking" of tar fractions over fixed catalysts was the method chosen for investigation. In this process, the molecular weight of the hydrocarbons in the charge stock is reduced, and the phenols are destroyed.

At the Navy's laboratories, both autoclave and small continuous plant experiments were conducted, which resulted in the development of a tentative process (NavTechJap Report "Japanese Fuels and Lubricants, Article 2 - Naval Research on Aviation Gasoline," Index No. X-38(N)-2, Enclosure (B) 16, Parts I and II). The throughput of the continuous unit was 4 to 5 liters of liquid per hour and the amount of catalyst, 8 to 10 liters.

During this investigation, the field of single component catalysts was rather thoroughly covered. Molybdenum tri-sulfide, either alone, or mixed with acid clay was found to be the most favorable catalyst. It induced the highest hydrogen absorption with the lowest gas loss and best yields of gasoline.

The process was operated in two stages without inter-stage product condensation. Typical results obtained on processing high and low-temperature tars are presented in Table-IV.

2. Commercial Developments. Eight oil-hydrocracking plants were reported to have been installed in the Japanese Empire. Three of these plants were installed specifically for the processing of low-temperature par, and the remaining five for processing petroleum kerosene and gas oil. In addition, the coal hydrogenation plants at FUSHUN and AGOCHI were both operated at times as hydrocracking plants. A tabulation of known hydrocracking plants is given in NavTechJap Report "Japanese Fuels and Lubricants, Article 2," Index No. X-38(N)-2. The low-temperature tar-hydrocracking plants were the TEIKOKU NENRYO plant at UBE, the TOHO KAGAKU plant at NAGOYA, and the NEPPON YUKA plant at KAWASAKI. Of these, the Nagoya plant was converted to the hydrocracking of petroleum oils and the Ube plant was not completed prior to the end of the war. No data were available on the Kawasaki plant.

Part III FISCHER-TROPSCH SYNTHESIS

A. GENERAL REMARKS

Japan has maintained interest in the Fischer-Tropsch synthesis since shortly after the announcement of its discovery in 1926. Like direct coal hydrogenation, this process offers the possibility of essentially complete conversion of coal to liquid fuel. Fischer-Tropsch research work in Japan was pioneered by Prof. KITA, of the Kyoto Imperial University. It was later undertaken by the Imperial Fuel Research Institute, the Tokyo Imperial University, and by others, notably, the Mitsui Bussan Co., which in 1936, obtained licensing rights to the Ruhrchemie patents in Japan.

Just prior to the war, the Navy conducted a few laboratory experiments at the First Naval Fuel Depot at OFUNA. During the war, technologists at the Army Fuel Research Institute at FUCHU carried on pilot plant experiments on the use of an iron catalyst which was developed in KITA'S laboratories at KYOTO.

Since Japan has no resources of the expensive cobalt, much emphasis in Japanese research has been placed on substituting iron or nickel. Although none of this effort has been more than moderately successful, an iron catalyst developed at KYOTO has been used in a Fischer-Tropsch plant at TAKIKAWA, Hokkaido. This plant and two others, one at OKUTA (Miike Works) and the other at AMAGASAKI, were the only Fischer-Tropsch units reported to have been completed and operated in Japan. Two more plants were under construction in Manchuria.

The Petroleum Section of NavTechJap has inspected equipment and interviewed personnel at the Miike plant, the Kyoto Imperial University, the First Naval Fuel Depot at OFUNA, and the Imperial Fuel Research Institute at KAWAGUCHI. Information was also obtained from personnel of TEIKOKU NENRYO and the Nippon Jinzo Sekiyu Co., who managed the plants at MIIKE, AMAGASAKI and TAKIKAWA.

B. LABORATORY RESEARCH

1. Research at the First Naval Fuel Depot, OFUNA. Little work was done on the Fischer-Tropsch Process at the First Naval Fuel Depot. Two reports were obtained relating to studies on iron-oxide catalysts (Enclosures (B)30 and (B)21) and one concerning the reduction of cobalt catalysts (Enclosure (B)19). The work on reduction of the cobalt catalyst is of interest, since it concerns the behavior of fixed catalysts of the type employed in Germany.

2. Research at the Imperial Fuel Research Institute. Experimental work on both laboratory and semi-commercial plant scale was carried on at this institution from 1933 until 1940, with the intention of developing a complete full-scale process (Enclosure (E)). This work was abandoned in 1940 when the Miike plant began operation. Because of the high cost and difficulty of obtaining cobalt, studies on the substitution of nickel were

intensively conducted. Yields above 100 grams total liquid product per cubic meter of synthesis gas were obtained in laboratory tests, but the life of the best catalysts was apparently limited to about a month. In the semi-commercial plant, only a few days activity could be obtained. Iron catalysts were not investigated.

The Institute's largest scale of operation was an intermediate pressure plant with a catalyst charge capacity of about $3/4$ cubic meter (Enclosure (E)). It was designed to produce about 200 kg/day of total liquid product from 100 cubic meters per hour of synthesis gas at a gauge pressure of five atmospheres. The system comprised a single-pass down-flow cylindrical converter, with a product recovery system consisting of air and water-cooled condensers and a pressure-type oil scrubber. Converter temperature control was effected by an intricate system of vertical tubes placed inside the converter shell, through which water was circulated in a closed system containing an external condenser. The catalyst was packed in the interstices between the tubes.

Actual synthesis gas throughput and oil production in this plant never exceeded 30% of design capacity. One of the best runs yielded about 66kg of crude liquid product in 30 m³/hr, using a catalyst whose active constituent was a mixture of 80% nickel and 20% cobalt. This yield corresponded to 85 grams per cubic meter of pure synthesis gas. The poor performance of this plant was attributed to poor catalyst activity and inadequate temperature control of the converter.

3. Research at Kyoto Imperial University. The work at KYOTO is undoubtedly Japan's most important contribution to the field of the Fischer-Tropsch synthesis. Experiments began in 1927 under Prof. G. KITA, with no subjects in the beginning other than to study the scientific aspects of the problem (Enclosure (D)).

In 1937, work was started on iron catalysts for use at normal atmospheric pressure and it was continued through the war, the objective being to develop a substitute for cobalt. From 1937 to 1941, atmospheric pressure experiments were made in a semi-commercial pilot plant, whose throughput was 100 cubic meters of synthesis gas per hour. At the request of the Japanese Army, this plant was transferred to the Army Fuel Research Institute at FUCHU in 1942.

Although extensive work has been done at KYOTO to develop an iron catalyst for the atmospheric pressure synthesis, no catalysts yet discovered have proved equal to the conventional cobalt type. On the other hand, operation at intermediate pressures (10-15 atmospheres) was found to have a favorable influence on the performance of iron catalysts. Under these conditions, one of KITA'S best preparations produced about 120 gm/m³ in laboratory tests (refer to Table IV, Enclosure (D)). A catalyst of this type was manufactured at KYOTO for full-scale tests at TAKIKAWA. KITA and his associates declared that six months' life would be expected from this catalyst.

4. Research at the Army Fuel Research Institute. A brief inspection of the Fuchu laboratory was made by the Petroleum Section of NavTechJap on 12 January 1946. It was ascertained that tests had been made there with a pilot plant, formerly at KYOTO, of 100 m³/hr gas throughput capacity using a natural iron ore catalyst at normal pressure. The yield was reported to be 73 gm/m³, obtained at an operating temperature of 250°C.

This catalyst was discovered by Prof. MATSUDA of the Tokyo Imperial University (Enclosure (D)). Prof. KITA and his associates at KYOTO also contributed their time and laboratory facilities for developmental studies on this catalyst prior to the trial in the Fuchu pilot plant. The catalyst consists mainly of a natural iron ore, sometimes designated ochre of

"yellow mud", obtained from NIWASAKA, Fukushima Prefecture, and also occurring elsewhere in Japan. X-ray studies of this material indicated it to have the crystal structure of alpha ($\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$).

C. PLANT DEVELOPMENT

According to information obtained, only five Fischer-Tropsch plant installations were ever placed under construction in the Japanese Empire. Three were completed and put on stream, namely, the Miike and Amagasaki Works in HONSHU, and the Takikawa plant in HOKKAIDO. Two others in Manchuria, one at CHEILIN and the other at QHINCHU, were under construction at the end of the war.

The Miike Works was the only Fischer plant visited. Some information on the other installations was supplied by Mr. SOGABE of the Nippon Jinzo Sekiyu Co., and Mr. N. SHONO of TEIKOKU HENRYO. The Amagasaki plant had 24 double-tube Ruhrochemie-type converters and utilized a cobalt catalyst at atmospheric pressure. The Takikawa plant had 36 double-tube Ruhrochemie converters, 32 single-tube Ruhrochemie converters, and 4 of a Japanese design, in which internal cooling tubes, carrying circulated water, were arranged in a cylindrical converter shell. All operations at TAKIKAWA were at 10 atmospheres pressure, and both iron and cobalt catalysts were employed. Both the precipitated iron catalyst developed by Prof. KITA, and the natural iron catalyst of Prof. KATSUBARA have been utilized in this plant.

These installations, as shown in Table I, failed to produce in accordance with design figures. It is significant, however, that the Takikawa plant did manage to maintain production using Japan's only contribution to the Fischer-Tropsch process, namely the iron catalyst.

The Miike plant utilized the atmospheric pressure synthesis as licensed by Mitsui Bussan Co. from Ruhrochemie in 1936. Construction on the plant began in November, 1936, and oil production started in May, 1940. Most of the equipment was furnished by the Koppers Co. of Germany (Enclosure (G)).

The catalyst was licensed as part of the Ruhrochemie contract and consisted of cobalt, thorium, magnesia and kieselguhr, in the respective weight proportions 21.2 : 1.2 : 2.4 : 75.2. About 4.5 metric tons of catalyst, containing one ton of cobalt, was charged to each converter. The converters were the well known "fin and tube" type, with water at about $15\text{kg}/\text{cm}^2$ static pressure circulating by thermo-siphon action through the tubes and an external cooling system. The catalyst was packed between the fins, outside the tubes.

The plant was operated as a two-stage system, comprising 30 converters in the first stage and 18 in the second, with total product recovery between stages. Eight additional converters were held in reserve or were "off-stream". The system was designed to operate at a gas throughput of $1,000\text{ m}^3/\text{hr}$ per converter, corresponding to an K.T.P. space velocity of about 75. The actual throughput was about $750\text{ m}^3/\text{hr}$.

The synthesis was effected at $180\text{--}200^\circ\text{C}$, using a synthesis gas of nominal composition $2\text{H}_2 : 1\text{CO}$, made by blending water gas with re-formed coke oven gas. The design yield was 116 grams per cubic meter of inlet gas, whereas the actual yield was 70-85 gm.

The plant produced gasoil (liquified propane and butane), motor gasoline, diesel fuel, and several grades of paraffin wax. A plant to manufacture lubricating oil by AlCl_3 polymerization of paraffin was under construction at the end of the war. Design capacity of the synthesis plant was 30,000 metric tons of crude product per year, but actual production during the peak year (1943) was only 10,000 tons. Low production was said to be due primarily to:

- (a) Low production of synthesis gas, caused by generator difficulties. The coke from Miike coal, used in gas generation, has a low melting point ash, and a high sulfur content, necessitating a low operating temperature. This, in turn, resulted in production of a gas high in inerts, and also a substantial reduction of the gas yield per ton of coke.
- (b) Poor catalyst activity.
- (c) Leakage of the water tubes in the converter.
- (d) Variation of synthesis gas composition.

The synthesis gas generating system consisted of 5 Koppers water-gas generators and a re-forming plant, also designed and constructed by Koppers. The latter comprised two sets of Cowpers stoves and auxiliary equipment. For de-sulfurizing the gases, the Klonne system was employed, comprising separate units for removing inorganic and organic sulfur. This system employed Luxmasse sodium carbonate mixtures as the de-sulfurizing agent. The purified gas contained about 0.004 gm of total sulfur per cubic meter.

The catalyst life was about 120 days, requiring five activations, at intervals of 20 days. The plant contained complete facilities for the manufacture of new catalysts, and the recovery of cobalt and thorium from spent catalysts. Facilities were also provided for reducing new catalysts outside the converters, and storing the reduced product until required for plant service.

As previously stated, the Miike plant began operation in 1940. Steady production was maintained, but at a rate far below design capacity, until the gas generator system was damaged by bombing in August, 1945. Even at reduced production rate, however, this plant was Japan's most successful Fischer-Tropsch plant, as is shown by the production figures of Table I.

Properties of crude products from the Miike and Takikawa plants are presented in Table V, and those of finished products from Miike in Table VI. This information was obtained from TAIKOKU NENRYO in TOKYO. These data should be compared with the values in Table III, Enclosure (G). The high olefin content of the Takikawa product, (Table V), is characteristic of the Fischer-Tropsch process when using an iron catalyst. The low-octane and high-cetane values of the Miike products (Table VI) are typical of the Fischer-Tropsch process employing the conventional Ruhrohemie cobalt catalyst.

Part IV COAL CARBONIZATION

A. GENERAL REMARKS

The study of low-temperature carbonization of coal in Japan began as early as 1921, being a part of the general program at the Imperial Fuel Research Institute for investigating the economical utilization of Japanese coals (Enclosure (E)). The Institute has maintained a leading position in the endeavor to establish a successful carbonization industry as part of Japan's normal economy. The objective of this research has changed from time to time. Early work emphasized the possibility of utilizing the semi-coke from low-temperature carbonization as a domestic fuel, but this product has never been accepted by the Japanese people, who prefer charcoal. In central and southern Japan, charcoal is used almost exclusively in the rural districts, and in most towns of less than 50,000 population. Mr. Y. BAN, present Director of the Institute, states that even in the larger cities, a large proportion of the domestic fuel consumed is charcoal. For example, it is estimated that 40% of the homes in TOKYO use no other fuel.

The tar from low-temperature carbonization is a valuable raw material. As one of its industrial possibilities, it is an attractive substitute for petroleum as a source of gasoline and fuel oil. Japan, having limited natural petroleum resources, has been acutely aware of this possibility for many years. As an outcome of the war, one of her most important sources of oil has been lost, namely, the lean shales of FUSHUN. This circumstance will undoubtedly stimulate further research on carbonization of native coals in the immediate future.

No attempt was made to study Japan's low-temperature carbonization industry and research in a comprehensive manner, but in the course of pursuing field activities, direct contact was made with a number of industrial installations and research institutions related to this field. Japanese technical personnel associated therewith have been interrogated and, in addition, some technical and statistical information has been obtained regarding carbonization installations in areas not visited. The information so obtained forms the basis for this report.

B. COAL CARBONIZATION RESEARCH

1. Research Activities of the Imperial Fuel Research Institute. The utilization of the low-rank non-caking bituminous coals and brown coals, with which Japan is plentifully supplied, has always constituted one of the country's more important problems.

At the Institute, low-temperature carbonization has always been considered an attractive and logical approach to the problem of utilization of such coals, and a continuous program of research has been carried on along this line (Enclosure (E)).

The tar is the most valuable product obtained from coal carbonization, but is produced only in yields of six to ten per cent, by weight, of coal charged, whereas, the semi-coke usually amounts to sixty-five per cent or more of the charge. Tar alone, therefore, cannot carry the cost of process. Table III of Enclosure (E) presents data on tar yields from typical Japanese coals.

The Institute has contributed much general information on the carbonization characteristics of Japanese coals, but no specific commercial process or equipment has evolved from this work. Its technologists are carrying out investigations on both laboratory and assay plant scale, the latter comprising a system of six externally-heated vertical retorts arranged in parallel, and having a total throughput of six tons of coal per day (Enclosure (E), Figures 4 and 5). This system was designed at the Institute and has been in operation, with some modifications, since 1921.

Since the end of the war, interest has revived at the Institute in promoting the use of low-temperature carbonization semi-coke as a domestic fuel, and in particular, the "coalite" obtained from brown coal. If a satisfactory product can be obtained, and commercial exploitation realized, the tar may become an important source of liquid fuels for Japan's peace-time economy. Already it has been determined that "coalite" from brown coal has satisfactory ignition and combustion properties and can be produced at about one half the cost of charcoal. However, all samples as yet prepared burn with a slight, but objectionable odor, which would prevent their ready acceptance.

2. Carbonization Research at the Army Fuel Research Institute. The Army Fuel Research Institute, at FUCHU, investigated the performance of a simplified low-temperature carbonization retort, internally heated, suitable for installation at mine sites. The project was strictly a wartime measure, intended to increase Japan's supply of low-temperature tar for use in liquid fuel production.

To economize on steel, brick was employed for constructing the experimental unit except for critical supporting members. The charge to this retort was 400Kg, and the time of carbonization about 10 hours. It was reported that this equipment was adaptable either to caking or non-caking charge stocks. Results were said to be favorable to the extent that large-scale expansion was contemplated.

Tar yields from several coals tested were as follows:

Ubari coal.....	10-12% (on weight of charge)
Mitsui-Nayoshi.....	10-14% (on weight of charge)
Toban Takahagi.....	6% (on weight of charge)
Takasaki Feat.....	3.5% (on weight of charge)

Carbonization Research in the Naval Research Laboratory, TOKUYAMA. The Naval Research Laboratory at TOKUYAMA installed Thyssen and Davidson retorting systems in 1925. Carbonization work was carried on until about 1932, when it was abandoned. The results of some of this work have been obtained in the form of critical documents not yet translated, except for titles. A list of these documents, which were forwarded via ATIS to the Washington Document Center, is contained in Enclosure (C).

INDUSTRIAL COAL CARBONIZATION

1. General Remarks. Because the war produced could not carry the cost of the process, and no dependable market had been found for the semi-coke, industrial coal carbonization did not comprise an important phase of Japan's peace-time economy. However, under the stimulus of government subsidies, this industry expanded rapidly in recent years, the object being to increase the available supply of tar for use as a source of motor gasoline and heavy fuel oil.

Motor grade gasoline can be obtained from the tar by simple distillation, and it was planned to produce aviation grades by hydrocracking suitable middle and heavy fractions (refer to Part II, Section B, this report). Although the hydrocracking program materialized only to a limited extent, the manufacture of liquid fuels by simple distillation of low-temperature tar constituted a far greater share of Japan's war production than high-pressure coal hydrogenation and the Fischer-Tropsch synthesis combined (Table I).

From information obtained, it appears that growth of the coal carbonization industry began about 1934, with the building of the Chisso Plant at M3. From that time until the present, at least 12 plants have gone into operation throughout the Japanese Empire, and 3 more were under construction at the end of the war, according to information obtained from Mr. N. SHONO, of TEIKOKU ENRYO. Miscellaneous technical information concerning these plants is presented in Table VII.

The Lurgi system is preferred in Japan. According to Mr. BAN, of the Imperial Fuel Research Institute, no Japanese carbonization system has been successful. The Tokyo Gas Co. type plants, installed at the Nagoya and Yokohama works (Table VII), were the only references found as to the commercial use of Japanese equipment. The retort of this system, according to Mr. SHONO, comprises a horizontal rotating steel drum, externally heated. It is provided with a rotating internal scraping device to prevent accumulation of partially carbonized coal on the walls. Six retorts constitute a production unit. The design throughput of each retort is 2.5 metric tons of coal per day. Excessive damage from overheating was suffered, both in the retort vessel and the scraping device, and the plants were abandoned about 1943. The coals charged to these plants possessed some caking properties, which, according to Mr. SHONO, contributed to the operating difficulties experienced.

The Ube, Kawasaki, Wakamatsu, Agochi, and Nanyo plants were originally built to supply tar for hydrocracking. Gasoline manufacturing by this method was never actually realized commercially to a significant extent; therefore, the liquid fuel production figures for these plants (Table I) represent processing of low-temperature tar by conventional distillation methods.

No information other than production figures was obtained concerning the plants at AGOCHI, CHIELIN, KAWASAKI, NAIBUCHI, NAIHORO, HIRAHISHI, TAKIKAWA, MURORAN, KIAN and the Chisso works at UBE. These data were obtained through TEIKOKU NENRYO.

2. The Wakamatsu Plant. Both the Wakamatsu and Ube plants were inspected. The carbonization plant at WAKAMATSU was based on the Himgi patents (Enclosure (H)). German engineers assisted in the construction and acceptance tests of the first units, which were completed in 1941, and production of gasoline, fuel oil and small coke began immediately. The original plan included installation of a research pilot plant for hydrocracking tar oils, and reaction vessels were ordered from the Krupp Corp. in Germany. Deliveries on these vessels and other equipment required were never made, however.

This plant was one of Japan's most important producers of liquid fuels from coal, according to information obtained. (Refer to Table I). Expansion of its carbonization and refining facilities continued, and steady production was maintained until the installation was disabled by a fire-bomb raid in August, 1945. It was stated that the tar yield actually attained was about 90% of the figure predicted by the Fischer-Hempel assay test, namely, about ten per cent, by weight, of the coal. The coal charged was a non-caking or weakly-caking bituminous variety from the nearby Orio district. Personnel interviewed stated that no operating difficulties were encountered, but that actual retort throughput varied somewhat with the properties of the coal charged.

3. The Ube Plant. The Ube plant was also an important producer of liquid fuels during the war, as shown by the production figures of Table I. At the time this plant was founded, in 1939, it was planned to install facilities for an annual production of 10,000 kl of gasoline. This output was to be obtained from Ube lignite coal by combining low-temperature carbonization with hydrocracking to the light tar oils. Synthetic ammonia and methanol were also to be manufactured. (Enclosure (I)).

Construction of the plant began in 1941. The hydrocracking plant, which was never completed, was designed on the basis of the Navy's research at the First Naval Fuel Depot. (Refer to Part II, this report, and to Navyhead Report, "Japanese Fuels and Lubricants," Article 2, Index No. X-38(N)-2, Enclosure (B), Parts I and II). Two Loppars carbonization units, each having a throughput capacity of 500 metric tons of coal per day were completed in February, 1942, and operation began at once. These units maintained production until the plant was severely damaged in bombing raids of July and August, 1945. Of the ten 500-ton Lurgi retorts originally planned, four were completed and in operation, and the remaining six were under construction when the plant was disabled by bomb damage.

Table I
LOCATION AND OUTPUT OF JAPANESE SYNTHETIC OIL PLANTS

Company	Location	Design Capacity	Actual Fuel Output (kl)			
			1941	1942	1944	
Coal Hydrogenation:						
1. Nippon Jisso Sakayu Co., Fushin Works	FURUJI, Manchuria	2.5 T/hr Paste charge	-	770	690	1,720
2. Chosen Jisso Sakayu Co., Araochi Works	LOKCHI, Korea	2 T/hr Paste charge	-	-	-	-
Total Coal-Hydrogenation Oil			-	770	690	-
Fischer-Tropsch:						
1. Nippon Jisso Sakayu Co., Mikuba Works	OMURA, Kyushu	50,000 T/yr. oil output	7,200	9,230	13,870	11,970
2. Nippon Jisso Sakayu Co., Asagasaki Works	AMAGASAKI, Honshu	30,000 T/yr.	-	-	200	130
3. Nippon Jisso Sakayu Co., Fukushima Works	TAKIYAMA, Hokkaido	50,000 T/yr.	-	1,550	1,600	6,610
4. Nippon Jisso Sakayu Co., Chitose Works	CHITOSE, Manchuria	1,000 kl/yr.		under construction		
5. Nippon Gosei Kenkyu Co., Chitose Works	CHITOSE, Manchuria	40,000 kl/yr.		under construction		
Total Fischer-Tropsch Oil			7,200	10,840	15,670	17,810
						4,200

Table I. LOCATION AND OUTPUT OF JAPANESE SYNTHETIC OIL PLANTS. (Cont.)

Company	Location	Design Capacity	Actual Fuel Output*-(kt)			
			1941	1942	1943	1944
Low Temperature Carbonisations:						
1. Nissan Ethical Petro Co., Fukuoka Works	YAMAGUCHI, Yonago	4 Lurgi Units 4 x 300 T/day Coal	8,760	9,620	16,850	21,570
2. Teikoku Petro Co., Ube Works	UBE, Honshu	2 Koppers Units 4 Lurgi Units 6 x 300 T/day Coal		10,400	19,250	18,390
3. Ube Lignite Co., Chilop Works	UBE, Honshu	2 Koppers Units 2 x 300 T/day Coal	11,530	11,850	9,470	10,820
4. Toho Lignite Petro Co., Sagaya Works	MAGUYA, Honshu	Toho Units	550	1,400	1,040	300
5. Nippon Yoku Petro Co., Kawasaki Works	KAWASAKI, Honshu	Knowles Ovens 30x7.5 T/day	320	2,170	4,700	-
6. Tokyo Gas Kagaku Co., Yokohama Works	YOKOHAMA, Honshu	"	310	790	430	-
7. Nippon Seitetsu Co., Wakabayashi Works	WAKABAYASHI, Hokkaido	Rotary-Kiln 4 x 100 T/day	3,120	2,870	3,020	2,530
8. Nippon Jinsu Seikiyu Yokohama Works	YOKOHAMA, Hokkaido	Knowles Ovens 15x12 T/day			under construction	
9. Nippon Yoku Petro Co., Mitsubishi Works	MITSUBISHI, Hokkaido	Knowles Ovens 120x12 T/day			under construction	
10. Taihoku Petro Co., Mitsubishi Works	MITSUBISHI, Sabbalin	Lurgi Units 2x300 T/day 2x200 T/day			3,560	16,770
						8,390

Table I. LOCATION AND OUTPUT OF JAPANESE SYNTHETIC OIL PLANTS. (Cont.)

Company	Location	Design Capacity	Actual Fuel Outputs-(kl)				
			1941	1942	1943	1944	
11. Taihoku Kogyo Kogyo Co., Mitsuboro Works	NAIORO, Sakhalin	Lurgi Units 4 x 200 T/day	14,000	15,330	17,929	12,140	2,950
12. Toppo Caluso Kogyo Co., Kisa Works	SIAM, Korea			4,620	3,760	930	
13. Chosen Jinsu Seiyu Co., Igochi Works	AGOSHI, Korea	Lurgi Units 6 x 150 T/day	6,260	6,090	10,470	11,920	240
14. Mansu Jinsu Seiyu Co., Chitella Works	CHERLIN, Manchuria	Lurgi Units 4 x 150 T/day					
Total Low-Temperature Oil			24,890	65,140	90,470	95,360	25,150
Total Actual Oil From Coal			52,090	76,790	106,140	113,860	29,350
Scale Oils							
Mitsui Manchu Petroleum Co., Fushimi Works	FUSHIMI, Manchuria		137,780	153,280	160,140	83,150	16,530

* Oil output includes only gasoline, kerosene, diesel oil and fuel oil. It does not include items such as naphtha, lubricating oils, creosote, "gasol", etc.

Table II
ANALYSIS OF OYAMA COAL

Proximate				Heating Value	Ultimate				
H ₂ O	Ash	Volatile Matter	Fixed C	Cal/gr	C	H	O	S	N
5.5	7.0	41.1	46.4	7,200	73.7	5.7	12.0	0.5	1.2

Table III
RESULTS OF HYDROGENATION OF OYAMA COAL

Catalyst.....	ZnCl ₂ (amount used not specified)
Operating temperature.....	415°C
Average pressure.....	200 kg/cm ²
Fresh hydrogen input.....	185 m ³ /hr (N.T.P.)
Rate of hydrogen recirculation.....	1,000 m ³ /hr (N.T.P.)
Paste input.....	282 kg/hr
Ratio (vehicle/coal).....	3/2
Hg consumption (wt% of coal).....	7.97
Wt% of coal liquified.....	77.9
Yield of oil, wt% of total oil:	
Oil boiling below 180°C.....	3
Middle oil, boiling 180-280°C.....	40
Heavy oil, boiling above 280°C.....	53

Table IV
HYDROGENATION OF HIGH AND LOW-TEMPERATURE TARS

	Creosote Oil from High-Temp. Tar.	Middle Oil from Low-Temp. Tar.
Catalyst	MoS ₃	MoS ₃
Reaction Temp. - 1st stage, °C	420	350
Reaction Temp. - 2nd stage, °C	470	450
Reaction Pressure, atm.	200	200
Space Velocity (liquid)	0.5 - 0.6	0.5
Aviation Gasoline:		
Yield, % by volume	Ca 25	Ca 50
Octane No., Clear	79	74
Octane No., 0.1% T.E.L.	92	88.5

Table V
 PROPERTIES OF CRUDE FISCHER-TROPSCH PRODUCTS FROM
 MIIKE AND TAKIKAWA PLANTS

		Crude-Condensed Product		Light-Product Adsorbed on Charcoal	
		MIIKE	TAKIKAWA	MIIKE	TAKIKAWA
Plant		Co	Fe	Co	Fe
Catalyst		Co	Fe	Co	Fe
Operating Pressure, atm.		1	10	1	10
I.B.P.		131°C	125°C	75°C	35°C
Vol. distilled:	5%	155	162	48	50
	10%	184	177	53	55
	20%	200	200	62	64
	30%	214	229	71	71
	40%	227	253	80	79
	50%	240	276	92	86
	60%	257	309	103	92
	70%	284	347	115	105
	80%	315	360	139	115
	90%	337	-	158	132
	97%	348	-	173	-
E.P.		373	-	195	152
Paraffins		93-96%	88.1%	88-90%	63.1%
Olefins		4-7%	11.9%	10-12%	36.9%
Iodine Value		-	13	-	92.9
Sp. Gr.		0.768	0.761	0.695	0.682

Table VI
 PROPERTIES OF PRODUCTS FROM MIKE PLANT

Product:		Motor Gasoline	Gas Oil B 1	Gas Oil B 2
Sp. Gr.		0.7081	0.770	0.780
I.B.P.		35°C	143°C	163°C
Vol. distilled	5%	40	171	192
	10%	53	193	216
	20%	62	215	226
	30%	71	225	235
	40%	81	234	246
	50%	92	242	250
	60%	103	252	280
	70%	116	275	322
	80%	129	292	341
	90%	143	301	356
95%	154	320	362	
E.P.		183	-	-
Octane No. (C.F.R. Motor Method)		40	-	-
Vapor Pressure, kg/cm ²		0.6	-	-
Cetane No.		-	75	-
Flash Point		-	56°C	87°C
Freezing Point		-	-4°C	-1°C

Table VII
MISCELLANEOUS INFORMATION ON JAPANESE LOW-TEMPERATURE CARBONIZATION PLANTS

Name of Plant	Name of Operating Agency	Date of Commissioning	Type of Furnace	No. of Retorts	Actual Coal Cap. Per Day	Actual Total Coal Cap. Per Day	Type of Coal Processed	Classification of Coal Processed	Proximate Analysis of Coal			Approx. Tar Yield % of Coal		
									Vol. Matter	Fixed C	Ash			
Yamada Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	6	150	750	Apex	From Coal	120	30.95	35.43	16.66	0.35	5112
Yamada Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	6	150	750	Peak	From Coal	120	29.92	47.79	5.78	0.31	4433
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	2	300	1500	Peak	From Coal	120	29.28	32.06	20.67	0.36	5068
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	30	75	3000	Peak	From Coal	120	32.12	45.65	10.59	0.23	7779
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	2	300	1500	Peak	From Coal	120	31.48	31.31	51.46	0.61	7260
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	2	300	1500	Peak	From Coal	120	31.00	39.80	41.70	0.30	6059
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	4	300	1500	Peak	From Coal	120	32.39	43.08	39.46	0.49	6464
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	2	300	1500	Peak	From Coal	120	32.10	38.28	51.83	0.31	7260
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	11	11	11	Information	Information	See Remarks	See Remarks	See Remarks	See Remarks	See Remarks	See Remarks
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	4	300	1500	Peak	From Coal	120	30.58	38.68	20.57	0.43	6704
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	4	300	1500	Peak	From Coal	120	31.21	37.28	22.18	0.73	595
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	4	300	1500	Peak	From Coal	120	31.21	37.28	22.18	0.73	595
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	4	300	1500	Peak	From Coal	120	31.21	37.28	22.18	0.73	595
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	4	300	1500	Peak	From Coal	120	31.21	37.28	22.18	0.73	595
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	4	300	1500	Peak	From Coal	120	31.21	37.28	22.18	0.73	595
Chama Works	Chosen Iron and Steel Co., Ltd.	Apr. 1943	Large	4	300	1500	Peak	From Coal	120	31.21	37.28	22.18	0.73	595

See (1)
 1. Chama Works
 2. Chama Works