REPORT OF INVESTIGATIONS

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

SYNTHETIC LIQUID FUELS 1948 ANNUAL REPORT OF THE SECRETARY OF THE INTERIOR

PART I. - Oil from Coal[1]

PREFACE

This report is submitted in accordance with the provisions of the Synthetic Liquid Fuels Act of April 5, 1944 (30 U.S.C. 321-325, as amended), which require that: "The Secretary of the Interior shall render to Congress on or before the first day of January of each year a report on all operations under this Act."

Owing to the broad scope of the content and the diversity of interests represented, the "1948 Annual Report of the Secretary of the Interior on Synthetic Liquid Fuels" has been divided into three separate publications. Each has been published by the Bureau of Mines as a Report of Investigations, and the respective titles follow:

R. I. 4456, Part I - Oil from Coal

R. I. 4457, Part II - Oil from Oil Shale

R. I. 4458, Part III - Liquid Fuels from Agricultural Residues
Part IV - Secondary Recovery, and Petroleum Chemistry and Refining Research

Identical in each report, the introduction summarizes progress made in 1948 under the entire Synthetic Liquid Fuels program and presents recommendations for the future.

A single copy of any of these publications may be obtained by a written request to the Bureau of Mines, Publications Distribution Section, 4800 Forbes Street, Pittsburgh 13, Pa. The Report of Investigations number and title of the publication desired should be indicated.

1/ Work on manuscript completed December 1948. The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Report of Investigations 4456."

CONTENTS

CONTENTS (Cont'd.)

INTRODUCTION

In 1948 the United States became a net importer of oil. Coupled with an unprecedented domestic production of 5,900,000 barrels daily, imports approximating 500,000 barrels made available a total supply of 6,400,000 barrels a day. Thus, by herculean effort, the oil industry was able to meet an extraordinary demand at home and, in addition, to ship abroad almost 400,000 barrels daily of petroleum and products.

The country's oil position now differs greatly from that prevailing at the beginning of World War II. Then, actual oil production averaged about 4 million barrels a day, and productive capacity probably was greater than 5 million barrels a day. As the demand of the military and industrial machine grew with the rising tempo of the drive toward victory, the United States not only met its own needs but produced about two-thirds of the total oil requirements of the Allied Nations, excluding Russia. As a people, we can be deeply grateful that the Nation's petroleum resources were adequate and sufficiently developed to support such a tremendous effort.

Even in those critical hours when immediate needs were the paramount issues, a prudent Congress paused to contemplate the importance of an assured long-term supply of liquid fuels. From these deliberations came the Synthetic Liquid Fuels Act of 1944, which authorized research and development work on new sources of oil - coal, oil shale, and agricultural and forestry products.

Since World War II, a civilian demand for 6 million barrels of petroleum products has become the order of the day - every day. By drilling as many as 39,000 new wells a year, the production rate has been increased enough to meet domestic requirements by a bare margin. Some imports were necessary, however, to fill both domestic and foreign demands, and these doubtless will increase.

Is this policy of exploration within the United States and the development of oil in foreign countries adequate insurance for the fulfillment of our future national needs? This question has two aspects - one purely civilian and economic in character and the other significant from the standpoint of our national defense.

There are now approximately 4,000 producing oil fields in this country. At first thought, it would appear that production could decline in a considerable number of these fields without materially affecting the over-all daily output. However, 48 percent of the oil comes from only 111 major fields which contain 60 percent of the total proved domestic reserves. It is apparent, then, that the flow from large fields - having proved reserves of 100 million barrels or more each - must be sustained if daily production is to be kept at the present levels.

Essentially, this means that new major fields must be discovered about as rapidly or perhaps more rapidly than the older ones lose productive capacity. From 1940 through 1947, only eight major fields with estimated reserves of more than 100 million barrels each, were discovered and proved - an average of one such field a year. The total estimated reserve of these eight fields was less than 1 year's supply at the present rate of use. As drilling continues, some existing fields ultimately will prove reserves larger than those now known. Without a pronounced increase in the number of major discoveries, however, the prospects for increasing our present productive level are not encouraging.

Any gap that appears between domestic productive capacity and demand could be filled with supplies from proved oil resources abroad. Assuming cheap pipe-line and tanker transportation to the United States, freedom from exorbitant taxes and charges for oil concessions in foreign lands, and the construction of facilities, such oil would provide a quickly available and presumably low-cost supply.

However, from the standpoint of military preparedness, the risks are great if we rely on such sources. The increasingly important Middle East oil fields are supplying more and more oil to Europe and some to the United States. For the remainder of our oil we look to South America and the Caribbean area. In time of war, loss of the Middle East fields could mean the end of any effective western European war effort. It would be exceedingly difficult for the Western Hemisphere to increase its production at a rapid rate, for little reserve productive capacity is available. Interference with tanker shipments from South America during a war would, in fact, create a critical supply situation within our own country.

Our lack of assurance in postwar years concerning the source and adequacy of our future supply of oil contrasts with the broadening vista for its use. A substantial part of this country's transportation system owes its development to oil. Now, however, with the railroads rapidly turning from coal-fired steam locomotives to oil-burning Diesel engines, all transportation - air, land, and water - soon will depend almost wholly upon oil. Home heating is becoming more and more the province of oil and natural gas, where they are available. Oil-driven machinery is one of the major factors contributing to a revolution in American farming. Today only one worker in seven is engaged in agriculture, whereas in 1800 three out of every four were thus employed. Industrial applications of oil are growing as well. It generates power, especially in the Southwest and West; it fires metallurgical furnaces; it drives ships; it supplies a large chemical industry; and it lubricates the machines of all industries.

From these and countless other applications, it may readily be seen not only that the economy of the United States depends upon oil but that this dependence is growing broader and greater. This country, therefore, must have assured oil supplies not for just a few years in the immediate future but for an indefinite period.

The growing feeling of insecurity with respect to oil supply has engendered statements from time to time that the use of oil should be restricted as a conservation measure. If we take the proper steps to meet oil needs, such restrictions are neither desirable nor necessary. If the high living standard of the American people can be attributed to any single factor, it would be the unrestricted use of energy from fuel. Year by year the proportion of power and heat energy supplied by oil and natural gas has grown until in 1947 it nearly equaled that supplied by coal. The large, steady growth in the utilization of oil shows clearly that it is a fuel that particularly meets the needs both of industry and the individual in a modern economy. Furthermore, only now are we becoming aware of the broad field in which oil ultimately will be applied. Restrictions of any duration on the use of oil would block this progress.

Recent achievements in industrial and governmental synthetic fuels research have shown conclusively that our liquid fuel supplies do not depend entirely on petroleum but can be supplemented from our much larger reserves of oil shale and coal. These are ample to meet foreseeable demands for centuries. This progress in technology, plus the increased cost of discovering and producing petroleum, has narrowed the cost differential between synthetic products and those from petroleum.

Highlights of this progress include the development of new mining methods to produce as much as 80 tons of oil shale per man-day underground. New coal-mining machinery, which now essentially is ready for commercial application, promises greatly increased productivity in this field. Large-scale mining operations of the type needed to supply synthetic-fuel plants will benefit greatly by these improved mining methods. In synthetic fuel processing, new developments in the Fischer-Tropsch synthesis have raised output per converter from a few to more than 500 barrels a day. New coal gasifiers now being tested eliminate the dependence on coke ovens and water-gas machines for large volumes of gas. They burn coal of virtually any rank with oxygen, extracted from the air, to produce the special synthesis gas required for the Fischer-Tropsch process. In the direct coal-hydrogenation process, improvements under way are expected to increase the thermal efficiency from a previous level of 30 percent to about 45 percent. These improvements will be reflected not only in decreased costs for plant and products but also in the use of less steel for plant construction. Already the steel requirements for some types of synthetic-fuel plants appear to be no greater per barrel-day of production than those for domestic petroleum exploration, production, transportation, and refining.

There are, however, two important differences between synthetic-fuel and petroleum operations that are unfavorable to the establishment of a new industry. The petroleum industry is divided into two natural phases - production and refining. A petroleum-operating unit can be a single well or a small refinery, and the capital cost may be measured in terms of several hundred thousand dollars, which is comparatively low. On the other hand, in synthetic plants converting coal to liquid fuels, it generally would not be feasible to separate mining, oil synthesis, and refining. For economical operation, these plants must make finished products, such as gasoline and heating oil, in quantities at least approaching 10,000 barrels a day. A single synthetic-fuel plant of this size, using coal, would require an initial investment under present conditions of approximately 80 million dollars. Similarly, oil-shale mining and retorting operations cannot be separated conveniently, but the refining could be done at another location. The capital required for a 10,000 barrel-a-day shale plant might be less than 30 million dollars, but even this is a very large investment.

In the face of the continuing competition from domestic and foreign petroleum, it obviously would be a courageous step for a single corporation to invest such a large amount in a pioneer synthetic fuels plant. There is danger, therefore, that the United States will depend upon petroleum until the supply problem has become critical. Based upon the growth experience of other industries, it then would require from 5 to 10 years to develop a significant productive capacity for synthetic fuels. Again critics and consumers would shout "too little, too late" - and with ample justification.

At this point in the development of synthetic fuels, Government assistance in the form of favorable loans to industry could be most helpful in encouraging construction of the initial plants. Such loans would help assure maximum progress from the research and development stage to commercial production. They could bring into being in this country the pioneer plants of a great new industry that would guarantee our oil supply and benefit our economy greatly. In the East, Midwest, and South, the products could be marketed nearby. In the West, such plants would offer the means for developing vast areas where ample and unused supplies of coal and oil shale now are available. Pipe-line transportation of the product to the consuming centers would permit even isolated areas to play an important role in this new industry.

Two bills (H. R. 5475 and S. 2712) were introduced in Congress during 1948 to clear the way for plant construction initiating a synthetic-fuels industry, but the session was adjourned before their passage was completed. It is hoped that similar legislation will be submitted to the new Congress and that favorable action can be completed at an early date, for synthetic fuels from coal, oil shale, and agricultural products offer an assured supply for hundreds of years from known resources within the borders of the United States - self-sufficiency in peace or war.

A New American Industry

> "The United States is on the threshold of a profound chemical revolution. The next ten years or fifteen will see the rise of a massive new industry which will free us from dependence on foreign sources of oil. Gasoline will be produced from coal, air and water on a scale so huge that it will dwarf even the giant synthetic rubber industry born in desperation during World War II."
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> --New York Times, September 12, 1948

Under the Synthetic Liquid Fuels Act, the Bureau of Mines was directed to supply the scientific, engineering, and economic information required for the establishment of a new American industry - an industry based on the conversion to oil of such materials as coal, oil shale, and agricultural products, all abundantly available within the United States. To obtain this information, the Bureau was authorized to conduct laboratory research and development, and to build and operate demonstration plants.

Progress made by the Bureau of Mines in 1948 toward the development of industrial methods for producing synthetic liquid fuels is summarized as follows:

Oil from Coal

Demonstration Plants, Louisiana, Mo.

As the calendar year ended, two Coal-to-Oil Demonstration Plants - the first units larger than pilot plants in the United States - were under construction at Louisiana, Mo., less than 100 miles above St. Louis on the Mississippi River.

There, on the site of a wartime synthetic ammonia works, made available by the Office of the Quartermaster General of the Department of the Army, the first of these two plants for converting coal into liquid fuels was essentially complete and ready for operation. This, the Hydrogenation Demonstration Plant, is a 200- to 300-barrel-per-day unit built under contract with Bechtel Corp. Early in 1948, a contract was let to Koppers Co., Inc., for the design and construction of the second plant at this site. This, the Gas-Synthesis Demonstration Plant, is a 100-barrel-per-day unit that will gasify pulverized coal with oxygen and superheated steam, purify the gas, and convert it to liquid fuels by a modified Fischer-Tropsch-synthesis process.

The Coal-Hydrogenation Demonstration Plant was designed for operation at pressures up to 10,000 pounds per square inch in two major steps: (1) Liquid-phase hydrogenation, which accomplishes liquefaction of coal; and (2) vapor-phase hydrogenation, which converts the liquefied coal to gasoline and byproducts. Depending on the coal and catalyst used, the output of the plant will range from 200 to 300 barrels daily.

Chemically, crude petroleum contains about twice as much hydrogen as does coal. Thus, to convert coal to finished gasoline, hydrogen is added to the coal catalytically under the proper conditions of temperature and pressure.

By December 1, construction of the Hydrogenation Demonstration Plant was approximately 97 percent complete. All major building structures had been finished by midyear, and the tankage area and plant road system were completed in the fall. Test runs are under way in the distillation unit, oxygen plant, and coal-preparation unit. High-pressure nitrogen made in the readjusted ammonia lines of the former Missouri Ordnance Works was used to test a part of the coal-hydrogenation system. Although some finishing work remained to be done in January, the demonstration plant virtually was ready for operation.

During the year, a basic hydrogenation plant-operating organization was assembled and trained. Plans were worked out and some materials purchased for breaking in the entire plant with coal-tar oils before the first coal run. Coal from Rock Springs, Wyo., will be used in this initial run because it is exceptionally well adapted to the hydrogenation process. Later, when plant operations have become stabilized, coals from other major fields will be tested. A planning group has been organized and is preparing calculating procedures and reporting forms for operating data. By the end of 1949, significant results from the preliminary operations will be available.

This plant incorporates numerous improvements not found in European hydrogenation plants. Full advantage has been taken of all available methods of saving heat, and it is anticipated that a thermal efficiency approaching 45 to 50 percent may be achieved, whereas the German plants obtained only 30 percent. If attained, this higher efficiency will lower the cost of the products - gasoline and oil.

Engineering studies and cost estimates for coal-hydrogenation plants of commercial size have been made by Bureau of Mines engineers. With the aid of German consultants having years of experience in the field and through the use of reports gathered and assembled by technical missions at the close of World War II, it has been possible to develop process designs and select suitable equipment for the commercial hydrogenation of coal in this country.

Preliminary designs and estimates were completed for constructing a 30,000-barrel-per-day coal-hydrogenation plant operating on different types of coals and lignite. The resulting plant-cost figures were used to arrive at synthetic gasoline prices both with and without taking credit for byproducts at prevailing or anticipated market prices. With credit for liquefied petroleum gas at 8 cents per gallon but without recovery of phenols, gasoline-manufacturing costs would range from 12 to 15 cents per gallon. If credit also is taken for phenols at 10 cents per pound, these gasoline costs would be reduced by approximately 4 cents per gallon. The versatility of this plant is striking. With little or no change, it can be used for producing aviation-gasoline base stock, jet fuel, or a good Diesel fuel.

Another cost estimate was based on the production of heavy fuel oils for the steel industry in a 10,000-barrel-per-day plant in the Great Lakes area. The cost figures indicate that, with the assumption of reasonable process improvements, synthetic-fuel prices are nearing competitive levels. In a larger plant of some 30,000-barrel-per-day capacity and with pipe-line or water transportation, it is estimated that heavy fuel oil could be delivered within a radius of 150 miles for as little as $3.10 per barrel. This estimate is based on coal at $3.00 per ton and is the actual cost without profit.

At the request of the United States Department of the Interior, the Army Corps of Engineers is conducting a nationwide survey to determine general areas where requirements for one or more synthetic-liquid-fuel plants can be met. For use in this survey, the Bureau of Mines assembled and provided data on the basic requirements of cost, construction materials, raw materials, water, and construction and operating manpower for commercial plants of different sizes and types.

The contract for the design and construction of the 100-barrel-per-day Gas-Synthesis Demonstration Plant at Louisiana, Mo., was signed with Koppers Co., Inc., on March 17. Considerable time and effort were saved owing to the fact that the contractor already had on hand some equipment applicable to the Bureau's project.

Engineering design was begun at once. After the contractor's construction field office was established, grading was started in May and completed in July. Scheduled for initial completion about April 1949, the coal-gasification building has been erected, and most of the equipment is now in place. Process piping and architectural service installations are under way. With the synthesis units to be erected later, the demonstration plant as a whole now is estimated to be 20 percent completed.

An operational training program has been established at this plant; supervisors and most of the oxygen unit operators now are receiving instruction.

Indexing of the Technical Oil Mission microfilm reels collected in Germany after World War II was continued during the year, and some 185 of the 258 reels now are indexed.

Twenty additional housing units for employees were finished in April, and all were occupied by May.

Laboratories and Pilot Plants, Bruceton and Pittsburgh, Pa.

Radical new process improvements under development in the synthetic-liquid-fuels laboratories and pilot plants at Bruceton, Pa., offer promise of advancing the day when the United States can shift a part of the growing burden of oil and gasoline demand to its immense coal reserves.

Coal-to-oil research activities in 1948 were centered on fundamental improvements in the gas-synthesis or Fischer-Tropsch process and on a basically new approach to the direct-hydrogenation or Bergius-I. G. Farbenindustrie process.

In the gas-synthesis process, the required mixture of carbon monoxide and hydrogen, known as "synthesis gas," constitutes 60 to 70 percent of the cost of the liquid-fuel products. Thus, a very efficient conversion of the synthesis gas to liquid products is necessary. Toward this end, two methods were under development by which a high yield of oil and a low yield of hydrocarbon gases are obtained. In one - the internally cooled, fixed-catalyst-bed method, which was improved greatly during the year - the heat of the synthesis reaction is removed efficiently and rapidly by circulating a relatively nonvolatile oil through a bed of catalyst granules. Relatively cheap, durable catalysts were developed for this method. In the other - the oil-catalyst-slurry method now in the pilot-plant stage of development - a powdered catalyst is suspended in an oil that is nonvolatile under operating conditions, and the synthesis gas is bubbled through this suspension. The oil-catalyst-slurry method potentially offers great advantages. Gas production is kept very low, and the yield of the more desirable liquid products is high. Converters using each method are being incorporated in the Gas-Synthesis Demonstration Plant under construction at Louisiana, Mo.

A departure from the conventional high-pressure process for direct hydrogenation of coal was under investigation. The goal is rapid conversion of coal to distillable oil, gas, and coke at moderate pressures and relatively high temperatures. Parallel objectives are reduction in the two major cost items of this process: (1) Hydrogen, which now constitutes 50 percent of the total cost of the liquid fuels, and (2) capital charges on the investment in and maintenance of equipment. Laboratory research disclosed that hydrogen costs may be reduced either by replacing hydrogen with water gas under appropriate operating conditions or by using byproduct hydrocarbon gases for hydrogen production. Another procedure offering both lower-cost hydrogen and economies in equipment consists of passing about twice as much coal through the plant as is hydrogenated. About half of the coal feed is converted to oil and gas and the other half to coke. The latter is burned for steam and power production. In this way, all of the available hydrogen in the half of the coal feed that is converted to coke appears in the oil and gas.

In general, the results of laboratory-scale tests on this new approach to direct coal hydrogenation are encouraging; but the engineering problems are very difficult, and much pilot-plant development work must be done.

Extensive laboratory studies were conducted on the composition of synthetic liquid fuels and on the important physical and chemical factors involved in the processes. Phenolic compounds used in plastics manufacture are industrially valuable byproducts of direct hydrogenation of coal. By ingenious methods, the phenolic fraction has been analyzed quantitatively, and procedures have been developed for separation of the mixture into pure components. The exact isomeric composition of the branched hydrocarbons in gas-synthesis products was determined - a contribution of industrial significance as well as scientific importance because the octane number of the gasoline fraction is markedly dependent upon this factor.

Tests for gasifying powdered coal were conducted in a vortex combustor, a unique device in that the heat evolved per unit of space is about 100 times that of most other combustion chambers. During the year, the coal feeder and other parts of the unit were redesigned and rebuilt. Results obtained thus far are encouraging, but more development work is necessary to determine whether this device can be applied to synthesis-gas production in the manufacture of synthetic liquid fuels.

A critical evaluation of all captured German documents on the gas-synthesis or Fischer-Tropsch process was about 75 percent completed. Results of this analysis and a review of all research work done in the United States on this process will be published in the near future. Meanwhile, similar evaluations of information on coal hydrogenation and coal gasification have been commenced.

Synthesis-Gas Laboratory and Field Tests, Morgantown, W. Va., and Gorgas, Ala.

With active operations scheduled to start early in 1949, the Alabama Power Co., and the Bureau of Mines jointly undertook preparatory construction at Gorgas, Ala., for their second field-scale experiment in the underground gasification of coal. Gases produced by burning unmined coal offer a potential source of fuel for electric power generation and raw materials for synthetic-liquid-fuels manufacture. In addition, underground gasification holds promise as a method for utilizing coal veins now difficult or uneconomic to mine.

Two parallel entries are being driven into the coal bed for 1,200 feet and a single entry for an additional 300 feet. At crosscuts between these entries, the underground workings are being connected with the surface by five large boreholes through which blast air will be admitted or product gases withdrawn. The boreholes, in turn, will be linked by a 20-inch manifold pipeline to an electrically driven air compressor with a capacity of 7,200 cubic feet per minute. The small surface-plant installations will include an office building, a laboratory, a warehouse, and a compressor building.

Among the objectives of the experiment are: (1) To determine the quantity of coal that can be gasified from a given combustion zone and the shape and extent of the burned-out area; (2) to determine the quality and quantity of product gas generated with an air blast; (3) to ascertain whether fixed outlets for product gas are practicable; and (4) to obtain technical and economic facts concerning plant sites, installations, and operating processes.

The underlying purpose of the underground gasification experiments at Gorgas and the laboratory and pilot-plant work at Morgantown, W. Va., is to develop a new coal-gasification process that will reduce significantly the cost of the synthesis gas and hydrogen required for the alternate synthetic-liquid-fuels processes.

At the Synthesis-Gas Production Laboratories at Morgantown, 11 experiments were made in a retort designed to simulate a segment of coal in place underground. A channel was outlined in the coal bed to form a gasification chamber. Two brick-filled regenerators, a scrubbing train, and two blowers comprised the gas- and air-handling equipment. In operation, the coal was ignited with air preheated by passage through the regenerators. The air-blast rate was brought to a predetermined figure and held constant throughout the experiment. To utilize the heat stored in the regenerators, the direction of the blast was reversed every 1-1/2 hours. Air and gas measurements were made, and gas samples were taken periodically and analyzed. Material and energy balances were calculated. Performance of the retort was studied under various blast rates; and, in general, the indications were that the quality of the gas and the gas-making efficiency increased at higher blast rates.

Small-scale experimental work was started on the use of highly superheated steam in underground gasification.

In the gasification of pulverized fuel, operations were continued with a unit gasifying 20 to 30 pounds of pulverized coal per hour, and the initial runs were made in a new and larger unit gasifying 200 to 300 pounds of pulverized coal per hour.

Steam was heated to unprecedented temperatures approximating 3,600° F. during several months of successful operations in experimental pebble stoves. Ultrasuperheated steam reduces the volume of oxygen required for the gasification process.

A new and improved method was developed for feeding pulverized coal into gas generators, and new methods also were developed and cost estimates prepared for purifying synthesis gas.

Oil from Oil Shale

Experimental Mines, Rifle, Colo.

In the Bureau's experimental oil-shale mining operations near Rifle, Colo., striking advances were made toward developing low-cost methods and equipment for mining the oil-rich Green River shale formation of Colorado, Utah, and Wyoming.

Situated on Naval Oil-Shale Reserve No. 1, the mine workings overlook the Bureau's Oil-Shale Demonstration Plant - only 8,800 feet away but 5-1/2 miles by the zigzag mountain road. The plant site, in turn, is 10 miles from Rifle by access road and U. S. Highway 6. In the Rifle area, this Denver-Grand Junction highway parallels the

Colorado River, the Denver & Rio Grande Western Railroad, and a 66,000-volt public-utility power line.

Additional core drilling during the summer gave firmer status to the estimate that western Colorado's shale beds alone contain 200 billion barrels of recoverable oil - six times as much as the entire world has used since the first discovery well was sunk in 1859. Assays of the initial core samples brought to the surface by both Government and industry drill crews conformed to the geologists' predictions. Funds provided by the Navy enabled the Bureau of Mines to drill on the Naval Reserve, and several oil companies explored their own property holdings in the area. Information acquired is being exchanged. The Bureau also collected further data on the oil-shale resources of other States.

Underground operations were carried on in two sets of workings: The Selective Mine, which supplies the demonstration plant with oil shale; and the Underground Quarry, a cliffside cavern opened to permit investigation of commercial-scale mining problems.

In the small Selective Mine, 13,400 tons of oil shale was mined and delivered to the Bureau's demonstration plant. An additional 1,830 tons was mined and shipped from Rifle to oil companies for retorting tests. Known as the Mahogany Ledge, the oil-shale measure being mined is 70 feet thick and contains an average of 30 gallons of oil per ton, or 100 million barrels per square mile - and it covers 1,000 square miles! The roof stone is strong and an invaluable aid to large-scale mechanized mining, for no roof support is needed in rooms as wide as 60 feet.

As 1-1/2 tons of shale is required to produce a barrel of oil, it has been apparent from the start that mining costs must be unusually low to make a commercial venture attractive.

In the Underground Quarry, unique mining methods and equipment have been developed to assure low-cost production. In a recent 20-day test run under actual commercial operating conditions, an incredible total of 81 tons was produced per man-day underground - as compared to an average of 5.4 tons per man in deep coal mines. Direct-mining costs, excluding depreciation and general office expense, were only 49.7 cents per ton. Ten men and two bosses mined 16,800 tons of shale in the 20-day period.

Using a room-and-pillar system, the 70-foot bed of oil shale is mined in three levels with an advance heading at the top. Horizontal drilling is required to open the top level, but the next two then can be drilled vertically in the same manner as benches in a quarry. Investigations to determine procedures for mining the top or advance level were completed in 1948.

After the oil shale is by dynamite, standard 15-ton Diesel trucks are driven directly into the mine and loaded by an electric shovel with a 3-yard bucket. This shovel, operated by a single man, can handle as high as 300 tons of shale an hour. New equipment developed during the year included:

1. An efficient multiple-drill carriage mounting four drills and operated by only two men instead of eight formerly required for an equal number of conventional wagon drills. Average drilling speed is nearly 90 feet of 2-inch hole per man-hour, using a special hard-surfaced bit also developed at the mine. These bits, used for 2 years, average more than 50 feet of drilling per bit, whereas an ordinary detachable

bit loses gage in 3 to 5 feet and must be replaced. Rotary drills with tungsten carbide bits are being tested.

2. A wooden platform was mounted on a fork-lift truck, enabling blasters to load drill holes 25 feet above the floor in the top level. The truck is powered by a Diesel engine and has a power hoist, controlled from the platform, for raising and lowering the powdermen. This unit has reduced the man-hours required to load a round of drill holes by one-third.

3. A portable crane also was equipped with a platform to serve as a scaling rig for miners trimming loose rock from the roof and the sides of pillars.

4. A movable air compressor assembly was designed and is under construction. Air and water lines will not be required, and the unit will use the same electrical outlets as the shovel.

Experimental work was continued to design the best pattern of drill holes, to determine the most efficient diameter of such holes, and to ascertain the most effective type and quantity of explosive for use in breaking oil shale. Progress was made, but much work remains to be done on these problems. Studies were undertaken to determine the procedures for drilling and blasting on the middle and lower levels or benches.

An estimate of the cost of mining 150,000 tons of oil shale daily disclosed that, as of January 1, 1948, the capital investment required would be $34,000,000 and the total mining cost 37-1/2 cents per ton, excluding interest on capital. Results of the recent test run appear to confirm this mining cost estimate.

During the year, 47,000 tons was mined and stock-piled in the course of the experimental work.

Demonstration Plant, Rifle, Colo.

In addition to experimental operations at the Oil-Shale Demonstration Plant, a new and important chapter was begun in the development of an oil-shale technology. Under cooperative agreements signed with numerous large industrial and educational research organizations, the Bureau of Mines agreed to supply oil shale and shale oil for retorting and refining in exchange for information on the results obtained. The Bureau will assemble this information, correlate it with the findings of its own research, and apply the whole to the problem of determining how our abundant reserves of oil shale may best be converted to useful liquid products.

Under American conditions, with high labor costs and the need for very large commercial plants, it is probable that the only successful retorting methods will be those offering continuous operation and high capacity. Although hundreds of methods have been suggested and used for retorting shale, three now under test appear to offer the greatest promise for meeting these conditions. These are the gas-flow retort of the Bureau of Mines, the fluid-flow retort of Standard Oil Development Co., and an internally fired, underfeed retort developed by the Union Oil Co. of California.

In the gas-flow retort, the shale bed passes downward, and hot gases flow horizontally across the bed. Operation is continuous and the capacity high. Heat for the operation is obtained by burning waste gas and spent shale in a space separated from the retorting area. Although few operating data are yet available on this unit, completed in October, preliminary runs indicate that it will prove successful.

The fluid-flow retort consists of two vessels, one for retorting the shale and the other for burning the spent shale. Hot spent shale is blown from the combustion zone to the retorting zone to provide heat to drive the oil from the raw shale. Using shale provided by the Bureau, a pilot plant employing this process now is being tested by the Standard Oil Development Co. at Baton Rouge, La.

The retort developed by the Union Oil Co. employs a piston arrangement at the base to force a column of shale upward through a vertical cylinder. Spent shale is burned in the upper part of the retort, and the hot gases flow downward to remove the oil from the raw shale. In addition to high capacity and continuous operation, this retort also offers the advantage of relatively low water consumption - an important consideration in the semiarid regions where the best American shales are found. Now undergoing preliminary tests at Los Angeles, Calif., with shale also provided by the Bureau, this unit later probably will be moved to the demonstration plant at Rifle for further experiments.

Test programs outlined for these three types of retorts are expected to show that one or more of the units is suitable for the economical recovery of oil from American shales.

Experimental operation of the Bureau's N-T-U retorts, which was begun in 1947, was continued at Rifle. In planning and conducting the test runs, two objectives were paramount: (1) Determination of the significance of each operating variable and its relationship to the entire operation and (2) ascertainment of the most favorable operating conditions. Periodic engineering analyses of test data led to alterations of equipment, such as changes in piping and instrumentation, which resulted in more reliable data as well as more satisfactory operation. Sampling - a major problem from the outset - was improved greatly. Operation of these N-T-U batch retorts provided technical information useful in designing continuous units and produced a sizable quantity of crude shale oil. Part of this oil was burned successfully as plant boiler fuel; part was used for refining studies by cooperating organizations and the Bureau's Petroleum and Oil-Shale Experiment Station at Laramie, Wyo., and the remainder was stored for use as feed stock in the demonstration refinery.

Technical information on retorting principles other than those of the N-T-U was obtained by operating a pilot plant known as the Royster-process unit. In this retort, gas is heated in pebble stoves and then passed through a bed of shale. Oil vapors, swept out of the retort along with the heat-carrying gas, are condensed and excess gas is flared. During several runs, superheated steam was used in place of gas as the heat-carrying medium. Another phase of the experimental work consisted of operating this retort as an N-T-U, with the fixed carbon on the shale being burned in the retorting vessel to supply the required heat.

Construction of the primary refinery units at Rifle is nearing completion. These include a thermal cracking unit, a continuous low-temperature sulfuric acid treating plant, and a doctor sweetening unit. Preliminary distillation operations were initiated, and cracking operations will be undertaken as soon as possible.

Laboratories and Pilot Plants, Laramie, Wyo.

Efficient use and conservation of heat are important factors in retort operation and design, for approximately 500,000 B.t.u. is required to retort 1 ton of average Colorado oil shale. At the Bureau's Petroleum and Oil-Shale Experiment Station at Laramie, Wyo., determinations have been made of the over-all heat required to retort some grades of Colorado oil shale, and work on additional grades is under way.

There, too, considerable experimental work has been done to evaluate the thermal-solution process for extracting oil from oil shale. The process consists essentially of heating a mixture of oil shale and a shale-oil solvent at a temperature high enough for conversion and then separating the solvent and conversion products from the spent shale. Higher yields are obtained at lower temperatures than in retorting.

The rates at which the organic material or kerogen in oil shale is converted to oil at different temperatures and for different shales have been determined for both thermal solution and retorting techniques. The limitations on the temperature, oxygen content of circulating gas, and time for preheating shale have been established in part. Other factors under study that may influence oil-shale operations include the mineral constituents of raw and spent Colorado shales.

Refining of shale oil into high-grade products presents numerous problems because of the chemical character of the oil. Cracking processes result in high gas and coke formation and products with high sulfur and nitrogen content. Hydrogenation appears more feasible as a method for producing higher yields of more easily treated, higher-quality products.

Shale oil differs from a standard petroleum in that a large proportion of the hydrocarbons is olefinic and the sulfur, nitrogen, and oxygen compounds are present in larger amounts. Low-boiling distillate from shale oil has a hydrocarbon composition similar to cracked petroleum products but includes impurities that are characteristic of tars from coal carbonization.

The olefins in shale-oil naphtha are predominantly of the straight-chain type. The byproduct tar acids contain phenol, cresols, and some xylenols, while the related tar bases contain substituted pyridines and quinolines. Most of the sulfur is in the form of substituted thiophenes.

Preliminary results indicate that good quality crystalline and micro-crystalline waxes can be extracted from shale oil.

Liquid Fuels from Agricultural Residues

Semiworks Plant, Peoria, Ill.

From appropriations authorized by the Synthetic Liquid Fuels Act, the United States Department of the Interior has transferred to the United States Department of Agriculture $510,000 for research and development on the production of alcohol and other liquid fuels from such agricultural residues as corncobs and the hulls of cottonseed, oats, and rice. With these funds, the Bureau of Agricultural and Industrial Chemistry late in 1946 started operations in a small industrial plant at Peoria, Ill., to determine the manufacturing steps and costs of a process of its own development.

The Liquid Fuels plant was located on the site of the Northern Regional Research Laboratory at Peoria to permit coordination of the programs of the two groups and a more rapid evaluation of the possibilities of the process. The Northern Laboratory, therefore, is studying the fermentation of the pentose and dextrose sugars to liquid fuels and is testing the various fuels produced.

Basically, the hydrolysis process under investigation consists of converting one of the fractions of agricultural residues - pentosans - to pentose sugars and subsequently converting the cellulose fraction to dextrose. The pentose sugars may be fermented to the liquid fuels butanol, isopropanol, acetone, and ethanol, or they may be converted to furfural. Dextrose, on the other hand, may be converted to the liquid fuel ethanol. The fundamental economic advantage of this particular process is that pentose sugars and dextrose can be almost quantitatively separated, therefore each one in its turn can be converted to maximum yields of end products.

A large number of experimental runs in the semiworks plant has demonstrated that the first phase of the process, the pentosan hydrolyzation of corncobs, proceeds satisfactorily. The average yield obtained under routine operating conditions conformed with anticipated yields based on the original laboratory investigations.

A survey of Illinois to determine the "average density" of corncobs available in industrial quantities revealed that six possible collection points may be located in the east central part of the State. Each has a potential capacity for supplying more than 250,000 tons of cobs from within a 50-mile radius. Three production areas thus are indicated for the erection of corncob-hydrolyzation plants with a working capacity of 100,000 tons per year.

A study of the decomposition of pentosans and cellulose in corncobs stored outdoors has indicated that a storage period up to 6 months is not detrimental to their industrial use. However, decomposition is noticeable after longer storage and becomes appreciable after 12 months.

Investigation of the second phase of the conversion process - the lignocellulose hydrolysis - has been in progress for several months. Operational experience provided the necessary background for changes in certain steps which will simplify the process and, therefore, lower costs.

A corrosion problem that materially influences the production costs was studied through laboratory testing and plant observation. Definite answers were obtained about the suitability of certain alloys already used in the construction of plant equipment.

The fermentability of pentosan hydrolysates to the liquid fuels as butanol and associated products was studied from the viewpoint of increasing the yield of fuels by treating the process material with burner dust.

Ethanol and other liquid-fuel products desired from the hydrolysates of the process were investigated for their behavior in antidetonant injection. The high octane number of several of the agricultural fuels, in addition to high heats of vaporization and antiknock value, promises great effectiveness in antidetonant injection.

U. S. Patent 2,450,586 was granted covering, with seven claims, the several stages of the hydrolyzation process employed in the semiworks plant.

Secondary Recovery and Refining Research

An amendment to the Synthetic Liquid Fuels Extension Act of March 15, 1948 (Public Law 443, 80th Congress), provided for the use of up to $1,000,000 of the authorized funds for research on secondary-recovery methods as applied to stripper oil fields and for studies relating to petroleum refining.

Although only 6 months have elapsed since funds became available to begin this work on July 2, 1948, a carefully coordinated program has been developed. Work has been initiated on many problems, and specialized equipment and personnel have been obtained for others that will get under way early in 1949.

Correlated with work already in progress, the expanded program of secondary-recovery research has been started at the following field headquarters of the Bureau of Mines: The Petroleum Experiment Station, Bartlesville, Okla.; the Petroleum and Oil-Shale Experiment Station, Laramie, Wyo.; and the Petroleum Field Offices at Franklin, Pa., San Francisco, Calif., and Dallas, Tex. The studies to aid refining marginal crude oils are being conducted at Laramie, Wyo., and Bartlesville, Okla.

When it is generally agreed among oil men that only about half of the petroleum in the average reservoir is recovered by present production methods, the need for improvement is evident. The Bureau's work on secondary-recovery methods falls under three main headings:

(1) Engineering field studies. For the more efficient recovery of petroleum from stripper fields, the Bureau of Mines is undertaking additional complete engineering studies and analyses of selected reservoirs which appear particularly suited for applying secondary-recovery production methods.

(2) Research on special engineering problems. This research will include such subjects as the use of explosives in shooting wells, safety in compressing air-gas mixtures, selective plugging of air-gas injection wells, water flooding, and the development of special tools.

(3) Fundamental research. Under this heading the central problem is to determine the nature of the forces that so tenaciously hold crude petroleum in the underground reservoir rock, curtailing recovery. Modern techniques of physics and chemistry are being applied in studies of the permeability of oil sands to the flow of oil and water and of the interfacial tension of oil-water systems.

In its petroleum chemistry and refining studies under this program, the Bureau of Mines is concentrating on the development and correlation of technical data that will aid refiners in one of their major current problems - the processing of high-sulfur crude oil. Decreased supplies of available petroleum have made it necessary to refine low-grade oils having a high sulfur content. The properties and chemical behavior of sulfur compounds must be determined so that suitable separational and analytical procedures can be developed.

If these parallel research programs on secondary recovery and petroleum refining are as successful as expected, many millions of barrels of oil now considered economically unrecoverable can be converted to "proved recoverable reserves," and additional millions of barrels of low-grade crude oils will be available for making better-grade products through improved refining processes.

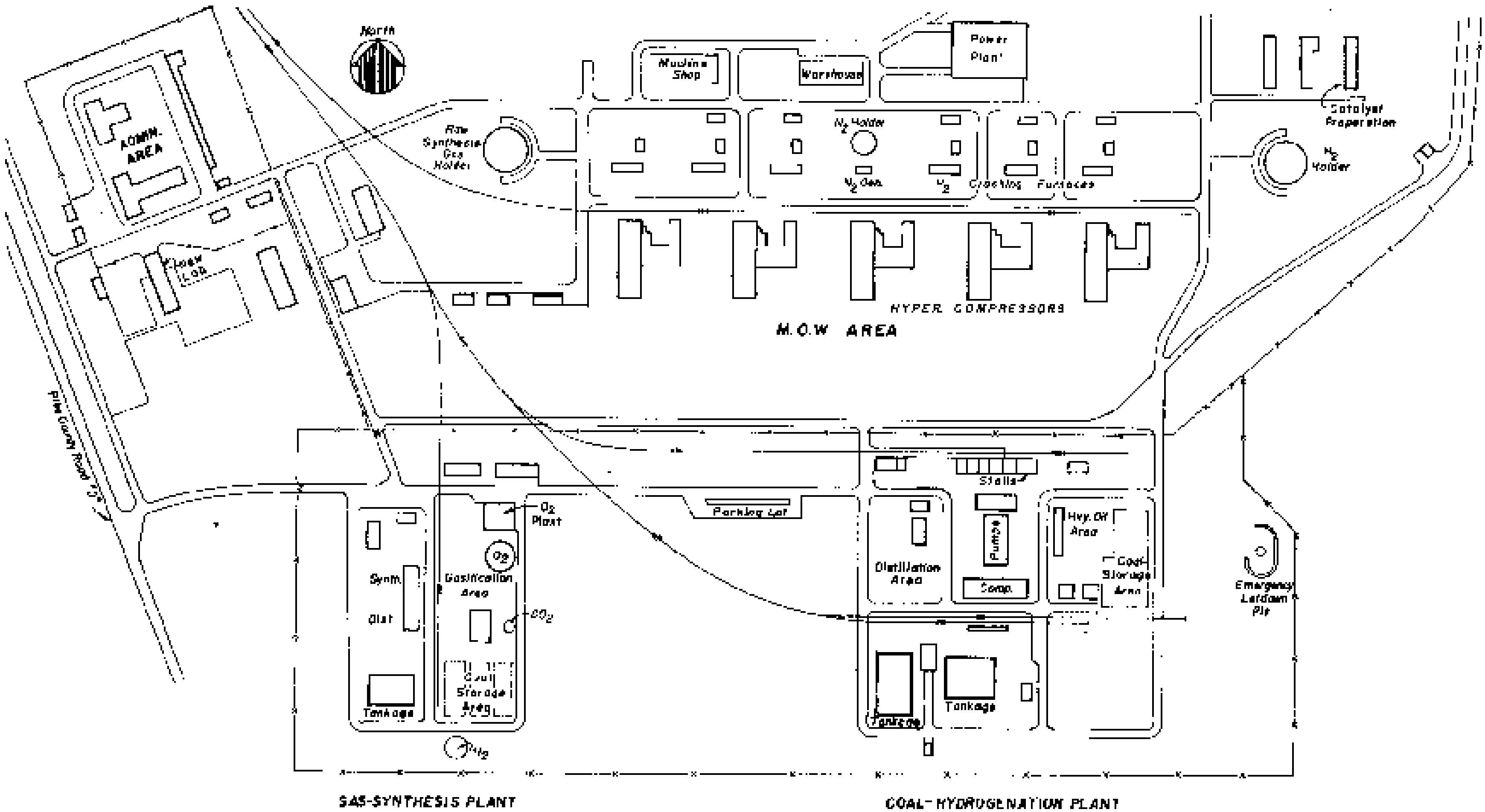

Figure I. - Plot plans, Coal-to-Oil Demonstration Plants.

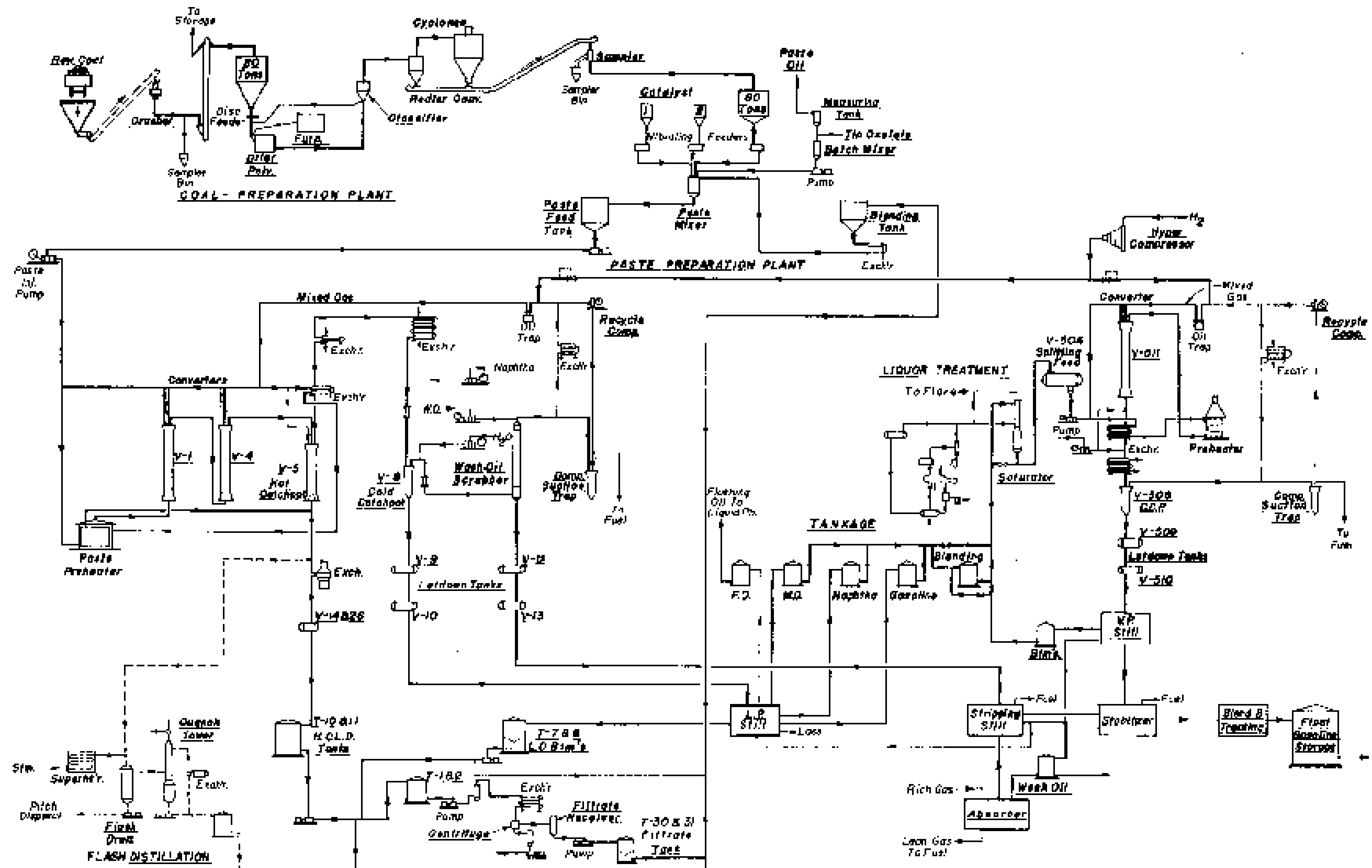

Figure 2. - Process-flow diagram of Coal-Hydrogenation Demonstration Plant.