The results of all of our latest calculations have been forwarded to the Corps of Engineers.

Gas-Synthesis Demonstration Plant

Design

In December 1947 ideas concerning the design and construction of the Gas-Synthesis Demonstration Plant were just being formulated. A tentative contract was drawn around preliminary flow diagrams (fig. 18) and material balances and were sent out to six selected bidders.

On January 15, 1948, bids were received from several contractors for the architectural services, design, and construction of the 100-barrel-per-day-Gas-Synthesis Demonstration Plant. Bids included provisions for the design and construction of the following units: Coal gasification, synthesis-gas purification, Fischer-Tropsch synthesis, product recovery, with treating, and general services and utilities. On March 17, a contract was signed with the Koppers Co., Inc., Pittsburgh, Pa. One of the factors influencing the award was the familiarity of the contractor with coal, its handling and gasification. The contractor had intended to build a similar gasification plant and already had on hand many designs and some purchased equipment applicable to the Bureau of Mines project, which saved considerable time and effort. The contract entitles the Government to inventions made by the contractor, his employees, or agents directly in the performance of the work.

In order to obtain sound technical advice in setting up a gasification and gas-synthesis program, a number of oil and coal companies engaged in synthetic-fuel programs were consulted.

Immediately after the contract was signed, work was begun on the flow diagrams, tentative plot plans, and equipment specifications. A staff was assembled to carry out the planning functions, and the respective duties of the planning sections were defined.

The process accepted for the demonstration plant may be described as follows:

The coal-gasification plant comprises the oxygen-production unit, which was installed under the Coal Hydrogenation Plant contract, coal-handling equipment, process-steam superheater, and the gasifier proper, with its appurtenances.

The oxygen unit is a 1-ton-per-hour Linde-Frankl plant which was brought from Germany, where it had been operated for about 4 years. It has been overhauled, the motors adapted to our power supply and the unit reassembled substantially as it had been installed in Germany.

The coal-handling facilities will dry run-of-mine coal and reduce it to approximately 200-mesh. The pulverized coal will be conveyed pneumatically to storage bins, from which it will be fed to the process. The steam for the process will be superheated to reaction temperature by passage through a bed of refractory pebbles that have been heated by combustion of natural gas.

The gasifier proper is an American modification of a unit partly developed by the Heinrich Koppers Co. in Germany before and during the war. It is a horizontal, steel-cased refractory cylinder 6-1/2 feet inside diameter by 9 feet length. The coal will be fed from the hoppers, picked up by an oxygen stream and the mixture introduced

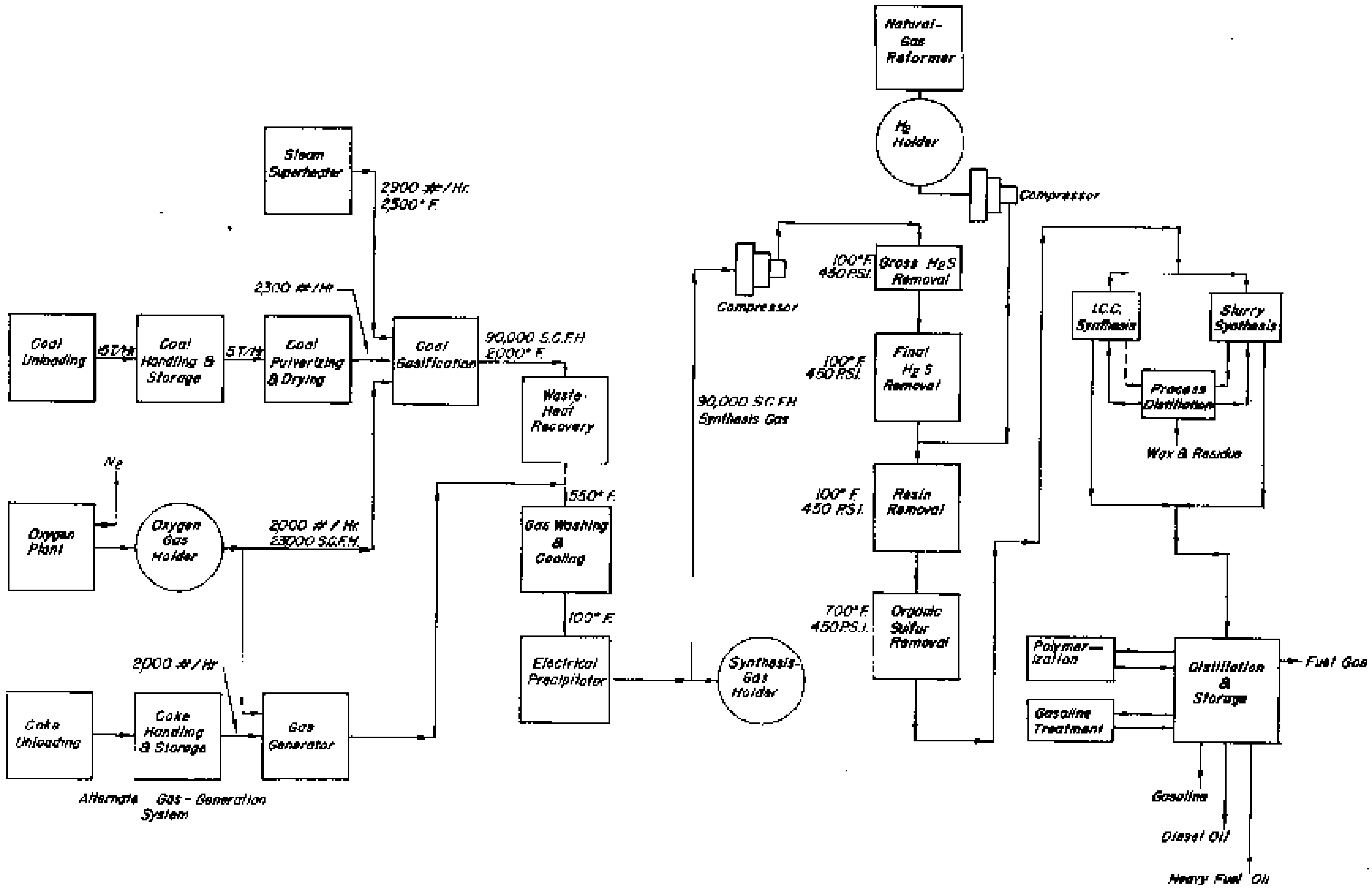

Figure 18. - Block diagram of flow, Gas-Synthesis Demonstration Plant.

into the gasifier through central nozzles at each end. Steam at temperatures up to 2,500° F. will be introduced separately in an annulus surrounding each of the coal nozzles.

After the reaction, the gases will leave through a connection in the top center of the shell. Any ash particles too heavy to remain suspended will fall into water-sealed dust legs and will be removed by sluicing with water.

In this plant, the hourly design rates are 2,300 pounds of coal, 2,000 pounds (23,000 cubic feet) of oxygen, and about 2,900 pounds of superheated steam. This should lead to the production of about 90,000 standard cubic feet per hour of a raw synthesis gas containing 12 to 15 percent carbon dioxide and between 40 to 45 percent each of hydrogen and carbon monoxide.

Effluent gases will pass through a waste-heat boiler, then through a cyclone separator for the removal of most of the fly ash and dust (about 75 percent) and to a washer-cooler for cooling and removal of all but small quantities of dust. The cooled gas will be blown through electrical precipitators for the removal of the final traces of dust (see fig. 19 for simplified flow diagram).

A Kerpely gas producer has been installed and adapted to operation with oxygen. This unit will use coke to make a gas high in carbon monoxide that can be blended with hydrogen from methane re-forming to produce a substitute gas for synthesis when for any reason the Koppers gasifier is not operating.

Dust removed from the gas at the various points is expected to be extremely finely divided and perhaps difficult to handle. It will be washed from each collecting point and the water collected in slow-sand filters. The filtered water will be returned to the system and the accumulated ash removed periodically for final disposal.

The gas then will go either to a storage holder or to the synthesis-gas compressors. As the gas must be compressed for synthesis, it is economical to compress it before the removal of sulfur compounds to permit purification under pressure. The bulk of the hydrogen sulfide present will be removed by scrubbing under pressure with ethanolamine solution. Scrubbed gas then will pass down through beds of iron oxide for final clean-up of hydrogen sulfide.

To provide effective means of making any desired adjustments in the synthesis-gas composition, there are provisions for adding up to 50,000 cubic feet per hour of hydrogen-rich gas from the existing catalytic natural-gas reformer at the Missouri Ordnance Works plant. This may be added after the synthesis gas has passed through the iron oxide towers. The combined stream then will pass through beds of active carbon in which any thiophene, hydrocarbons, carbon sulfides, or gum formers that may be present are removed. As a final purification step, the gas will be passed through heated beds of granular alkalized iron oxide to remove any organic sulfur compounds still present. Complete sulfur removal is essential to the successful operation of the synthesis step because all of the active catalysts known and available at present are extremely sensitive to sulfur poisoning.

Two types of converters will be installed in the synthesis plant - an internally cooled unit and a slurry-type unit - which may be used alternately in order to study the performance of each (see fig. 20). Both units are designed for pressures in the range of 300 to 600 pounds per square inch and temperatures up to 600° F. In the first, or internally cooled converter, a fixed bed of granular catalyst is submerged in coolant oil. The converter, about 5 feet in diameter with a depth of 25 feet, will

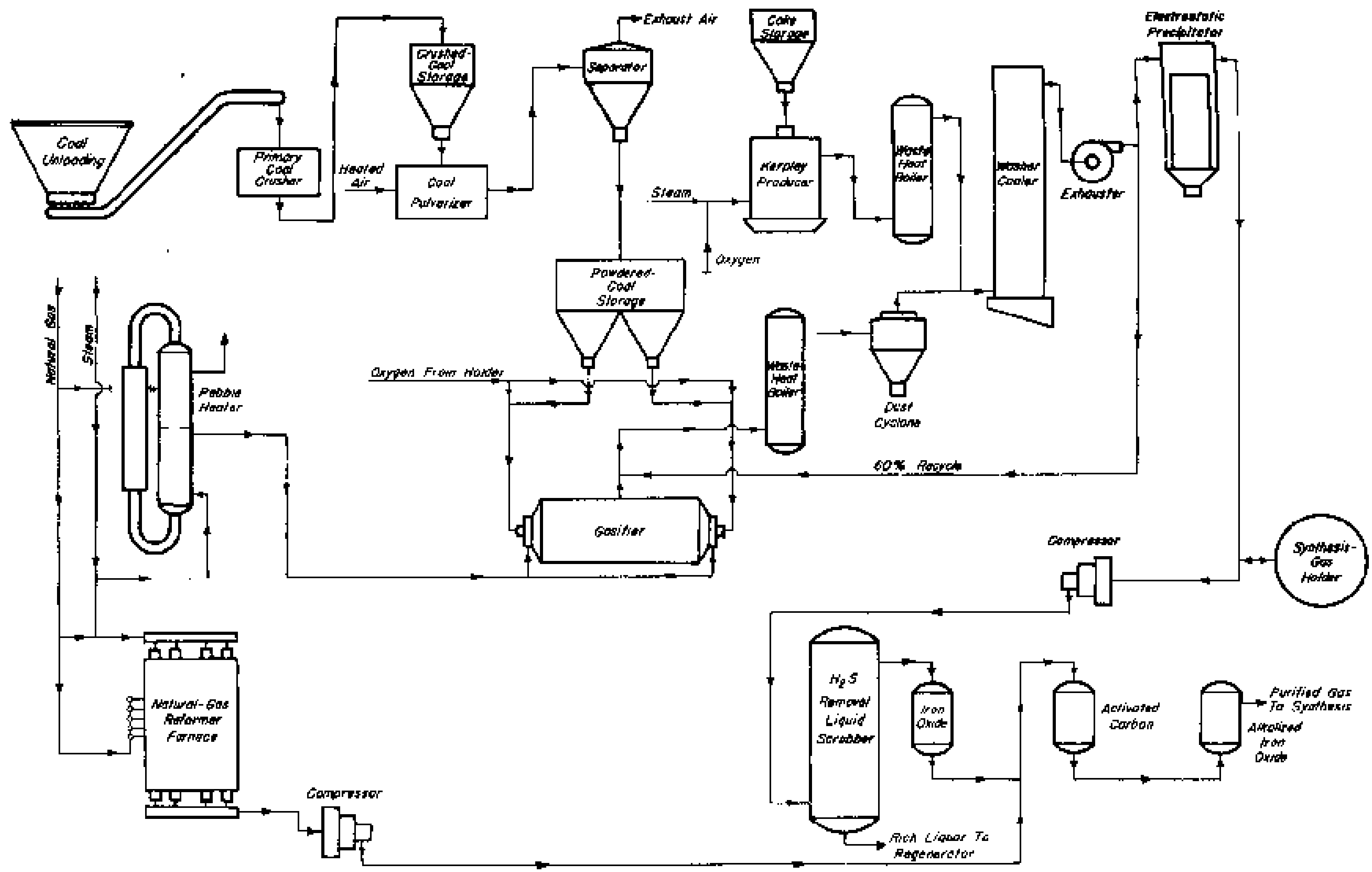

Figure 19. - Simplified flow diagram of coal gasification and purification, Gas-Synthesis Demonstration Plant.

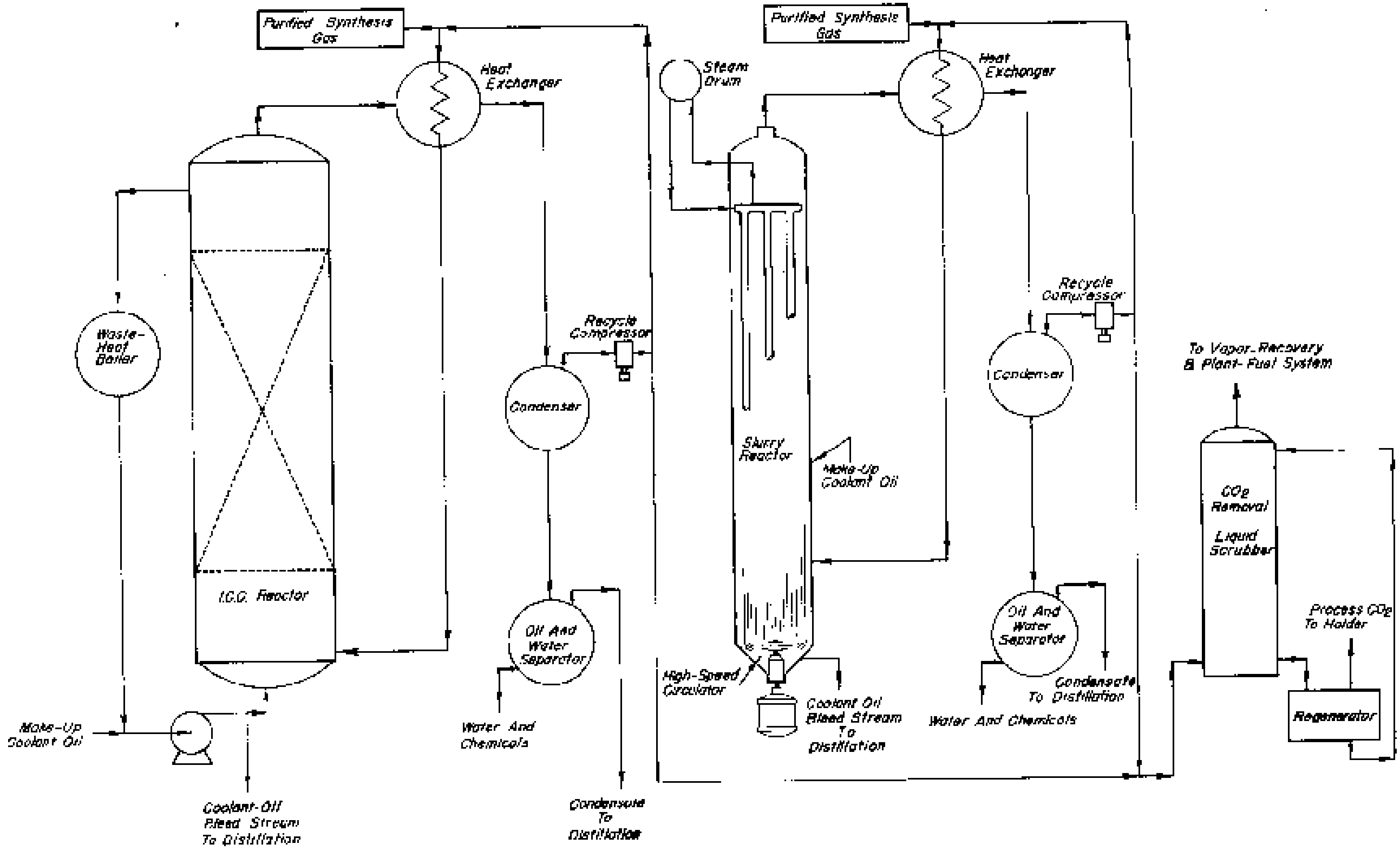

Figure 20. - Flow diagrams of synthesis units, Gas-Synthesis Demonstration Plant.

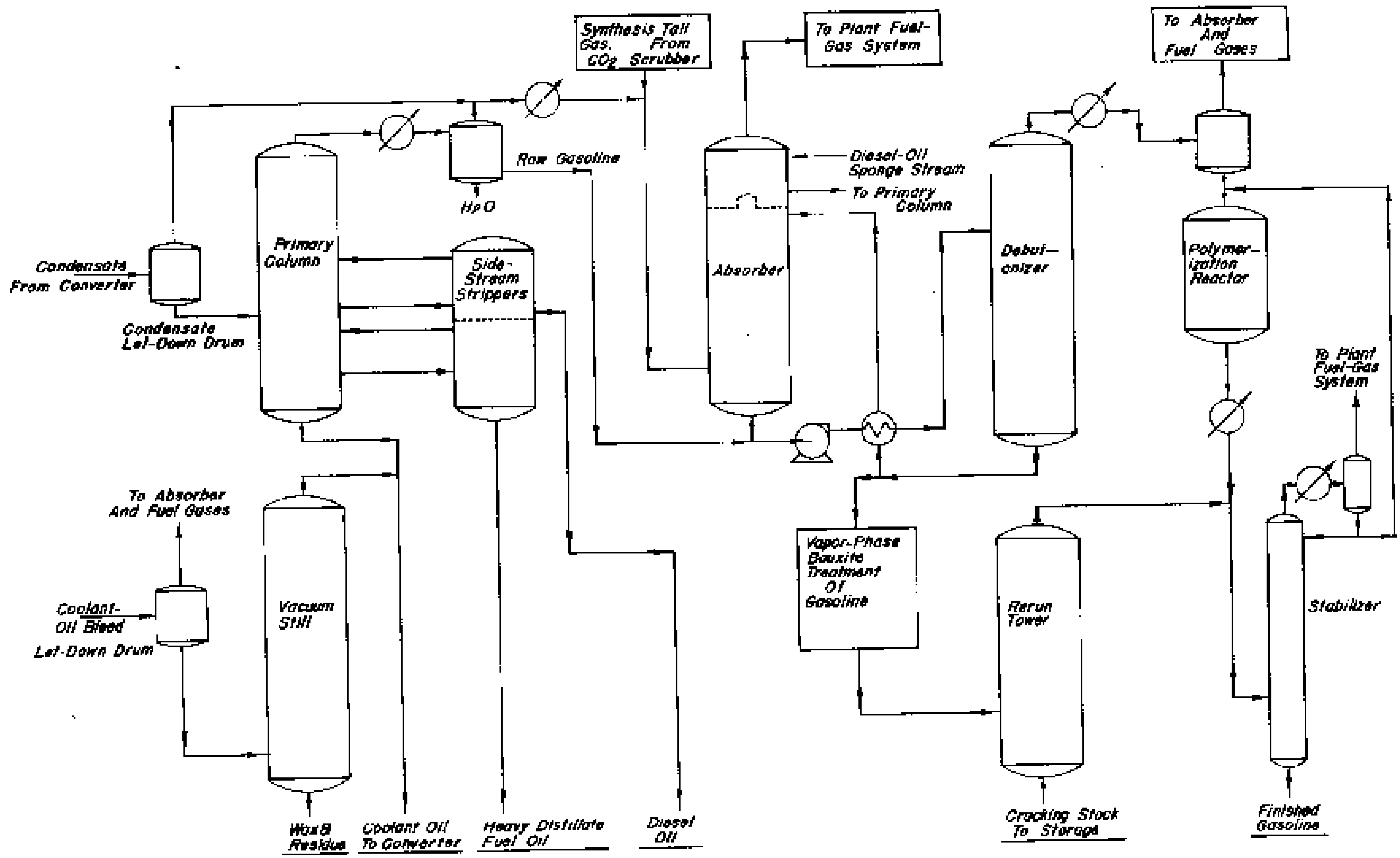

Figure 21. - Flow diagram of product recovery and treatment, Gas-Synthesis Demonstration Plant.

hold about 40 tons of catalyst and will produce perhaps 80 barrels per day of liquid product. Coolant oil will be circulated through the bed at the rate of about 1,000 gallons per minute, then through a waste-heat boiler to remove the heat of reaction, and back to the converter. The fresh purified synthesis gas will be combined with recycle gas, then heated to reaction temperature (500° to 600° F.) by heat exchange with the gases leaving the converter. This heated gas and the coolant oil will pass together up through the catalyst bed and will be separated in a drum at the outlet of the converter. After being partly cooled by heat exchange with the incoming gas, off gas then will pass through a water-cooled condenser. Liquid products from this condenser will be sent to intermediate storage or to the distillation section. The required volume of gas will be recycled to the converter. The excess will be scrubbed first to remove carbon dioxide and then passed through an absorption system to recover the hydrocarbon vapors. The stripped gas then will go to the plant fuel-gas system.

The second converter, a slurry-type unit, will contain a finely divided iron catalyst suspended in coolant oil. Provisions will be made for circulating this slurry within the reactor at extremely high rates (about 3,000 gallons per minute) to maintain the catalyst in suspension and to allow a high rate of heat transfer to the steam generating tubes submerged in the reaction space. As before, the gas will be admitted at the bottom and will flow up through the oil-catalyst slurry. The feed-gas heat exchange, the condensation of products, and the gas recycle will be similar to those used in the internally-cooled converter. To eliminate from the system the high-boiling waxes formed, it is necessary in both cases to send a relatively small bleed stream from the coolant oil to the distillation system. These waxes, if not removed, would concentrate in the coolant oil, accumulate on the surface of the catalyst, or crack and deposit carbon.

The coolant-oil bleed stream from the converters will be fed to a still, where the waxes and associated materials are separated as residue, and the cleaned coolant-oil distillate returned to the converter. Liquid condensed from the gases leaving the converter will go to the primary distillation column, from which gasoline will be recovered as an overhead product, Diesel oil and heavy distillate fuel oil as side streams, and additional coolant oil as the bottoms product (see fig. 21). Diesel oil and heavy distillate fuel-oil side streams will be sent to storage and may be used directly or treated further. Unstabilized gasoline recovered as primary distillate will be sent to a debutanizing column for removal of C_3 and C_4 hydrocarbons. The stabilized gasoline is to be heated and passed over a bed of bauxite to convert oxygenated compounds to hydrocarbons and to change the structure of the unsaturates. Both of these changes result in increased stability and a higher octane number for the treated gasoline. About 95 percent of the raw gasoline is expected to be recovered as finished product.

C_3 and C_4 hydrocarbons scrubbed from the gas and recovered from the debutanizer amount to as much as 15 barrels per day and will be polymerized into high-quality gasoline. The polymer product and the treated gasoline will be combined to produce a stable, sulfur-free gasoline of standard boiling range and about 75 clear A.S.T.M. octane number.

The Diesel-oil fraction recovered from the primary column will require treatment to improve its stability and ignition qualities. No process for this treatment has yet been selected, pending the results of research and development work in this field.

The basic design, detailed engineering, and construction of the plant have been broken down into the various sections, and work is proceeding on each simultaneously.

General specifications have been written on each section by the contractor. These specifications, together with the appropriate flow diagrams, are the technical guides for equipment procurement. Considerable study was given these specifications, and many modifications suggested by Bureau engineers were incorporated before final approval was given. Substantially all general specifications have been completed and approved.

Agreements have been made with the Universal Oil Products Co., for the catalytic polymerization unit and with the Phillips Petroleum Corp., on the cycloversion unit for upgrading. An agreement for the construction of a slurry-type contactor and accessory equipment for a synthesis-gas conversion unit is pending.

It was felt that the most urgent part of the gas-synthesis program is the demonstration of the pulverized-coal gasifier. The construction program has been planned so that the gasifier proper will be ready for operation in March 1949. During the early operations, any gas made will be sent through the washer-cooler to a flare stack, and it will not be necessary to wait for completion of the waste-heat boiler or the dust-removal apparatus. As these items of equipment are made ready, the gas flow will be changed to permit their operation.

As sulfur purification is carried out under pressure, no operations can be undertaken until the compressor house is finished. The functions of the various compressors have been fixed, and orders have been placed with delivery scheduled for early spring. It is planned to schedule construction of the various purifying units so that they will be completed and tested by the time the compressors are available. Synthesis, product-recovery, and treating plants will follow later.

The general services - power, steam, water, cooling towers, sewers and the like - must be completed in part before any plant operations are possible. This work is being scheduled so that the facilities necessary for the gasification step will be available before the anticipated operation; those peculiar to later sections have been deferred.

Engineering-design drawings and material procurement for the coal-gasification step are substantially completed. Lay-out work is complete, and design is well under way on the gas-purification step. The synthesis step is in the lay-out stage, and the flow diagrams of the distillation section are nearing completion. Drawings for general plant services are approximately 50 percent complete.

It is estimated that the engineering work as of December 1, 1948, is 53 percent complete.

Construction

Late in April the contractor established his field office at Louisiana, and surveys for locating fence lines and establishing grading levels were begun early in May. By the end of May, boundary fencing was mostly installed and grading half done.

Grading work continued the first half of June, but was not completed because of heavy rains during the second half of the month. Temporary construction buildings were erected, and materials for construction began to arrive. Excavation, form work, and placing of reinforcing steel for the warehouse were finished, and the same work was begun on the change house.

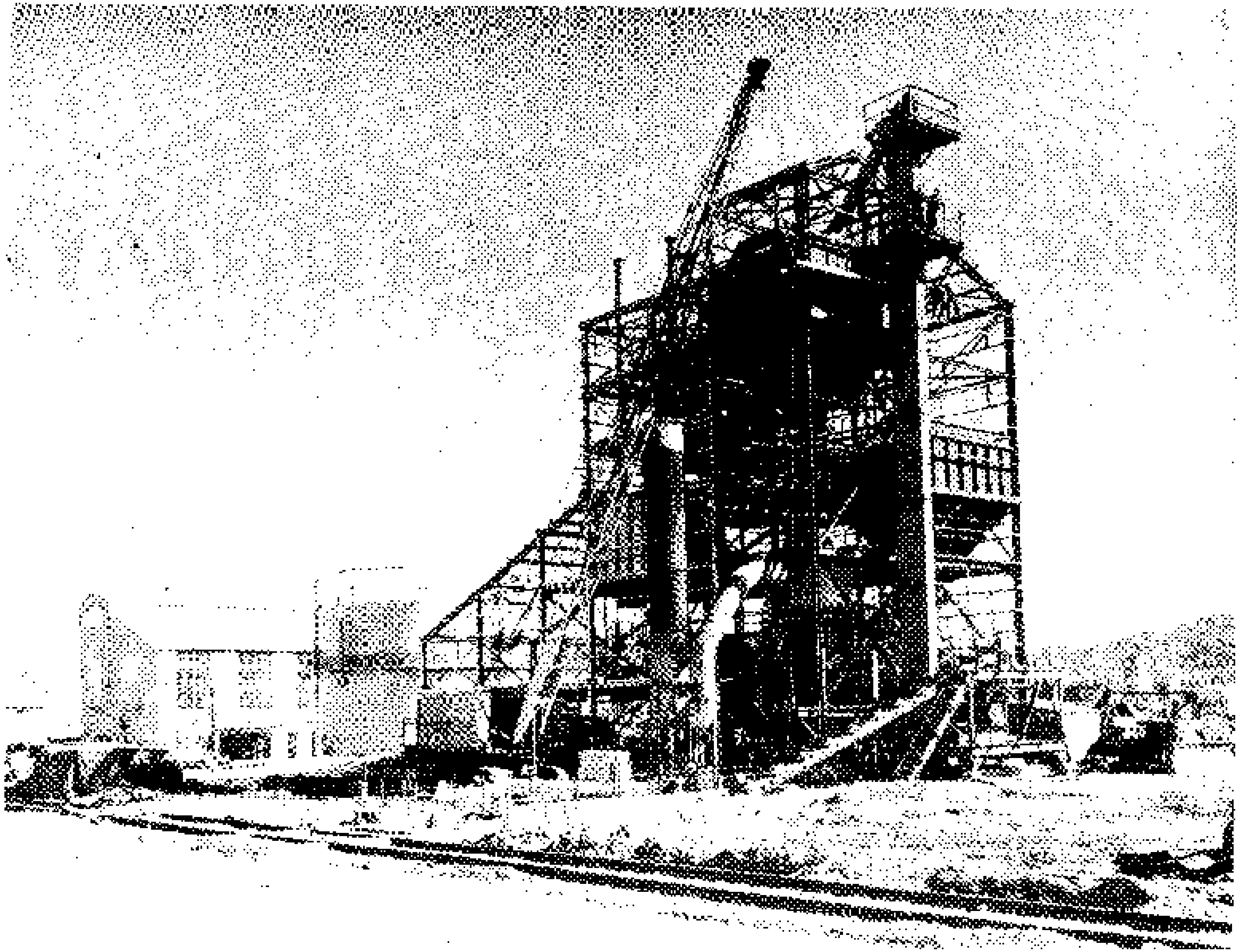

Figure 22. - Coal-gasification building under construction. Oxygen holder and building, left background.

Foundations for the warehouse and change house were completed in July. Excavation of the gasifier building was completed, and most of the footings were poured. A subcontract for plant roads was negotiated. The gasifier shell arrived at the site.

The foundation for the gasifier building and some equipment foundations were completed in August, and the gasifier shell and supports were put in place. Structural steel work on the gasifier building showed good progress. Concrete work was finished for the cooling-tower foundation, carbon-dioxide-gas holder, hydrogen holder, and coal elevator. The railroad siding was completed to the track hopper. The Kerpely gasifier arrived at the site after being dismantled and shipped from St. Louis. Excavation for the filter beds was started.

During September work was pushed on the gasifier building and equipment. The remaining equipment foundations were finished, and the tract hopper foundation was completed. Most of the structural-steel work for the building was finished, and elevator casings and the dust-collector system were erected. Pipe sleeves under roadways were put in place. The change house and warehouse were completed; and the flare stack and cooling tower were erected.

In October, closing in of the gasifier building and equipment setting was brought near completion (fig. 22). Building steel work was painted, and most of the roofing and siding were applied. Coal conveying, crushing, drying and pulverizing equipment, pebble heater, Kerpely gasifier, duct work, and filters were in place. Satisfactory progress was made in lining the gasifier. The storm sewers were placed under the roadways, the sanitary sewer system was completed, and the fire lines and storm sewers were laid. Plant-road grading was complete, and subbase rock was applied. Excavation for the filter beds was completed, and concrete work was finished early in November.

On December 1, estimated completion of the construction work was 20 percent, and the following tabulation indicates the relative size and status of its components:

Unit	Estimated percentage of total project	Estimated percentage complete to December 1	Estimated percentage complete of each item to total project
Gasification	24.8	55.8	14.0
Purification	12.1	-	-
Synthesis	13.5	-	-
Distillation	17.1	-	-
General utilities	18.1	18.7	3.0
Catalyst preparation	3.1	-	-
Subcontracts	11.3	24.0	3.0
	100.0		20.0

Operation

Working out an operational training program and start-up procedure for the gas-synthesis plant was somewhat simplified by the progressive sequence of the process and the estimated stepwise completion of construction. This will permit concentration on the task of eliminating start-up difficulties in each unit as it is completed. When smooth operation has been achieved in one unit, the next should be ready for trial operation.

Organization planning for the operating force of the whole plant has been completed. The supervisors and some operators for the oxygen plant have been employed.

A general training course of lectures and demonstrations has been developed which is to be given to all new operators as they are employed. This is intended to provide indoctrination into the synthetic-liquid-fuels work. Physical and chemical principles involved in the processes are discussed and practical illustrative examples cited. The operator's duties and responsibilities and required techniques in the performance of these duties are outlined. Information is given on the instruments to be used; and a general summary is given of the start-up operation, method of control, and precautions to be observed in each unit of the plant. First aid, fire prevention and fighting, and the care and use of plant safety equipment are treated extensively. This degree of preliminary training is necessary because the operating force must be recruited largely from people without previous industrial experience in this or any related field.

Preparations were completed recently for operating the oxygen unit (see flow diagram, fig. 23). These included extensive tests to assure that all process equipment was free of leaks; turn-over of all moving machinery and running-in of the air blowers, air compressors, and ammonia refrigeration equipment (fig. 24). Detailed operating procedures were prepared covering the characteristics of each piece of major equipment, instructions for starting each piece and group, maintenance of normal operations, and the carrying out of scheduled and emergency shut-downs. The operators were trained in these procedures by instruction and actual trial operations during the run-in period.

It is anticipated that the oxygen unit will be producing its rated output of 1 ton per hour before installation of gasification equipment is completed and made ready for operation.

Plans are ready for assembling groups of operators for the other sections of the gas-synthesis plant in time to permit thorough preliminary training in advance of operations. Operating procedures for the gasification unit have been prepared in collaboration with the contractor, and preparation of procedures for the other units will follow as required.

Engineering Studies and Cost Estimates

Almost every phase of the Gas-Synthesis Demonstration Plant design has required special studies to evaluate factors affecting design or to permit the selection of the most efficient or economical processes.

Studies have been made and are continuing on the thermochemistry of the gasification step. Heat and material balances and equilibrium studies were necessary to explore the effect of varying operating temperatures, oxygen:coal ratio, steam rate and steam temperature, and the addition of carbon dioxide to the gasifier. The effect of the coal characteristics on the quantity and composition of the synthesis

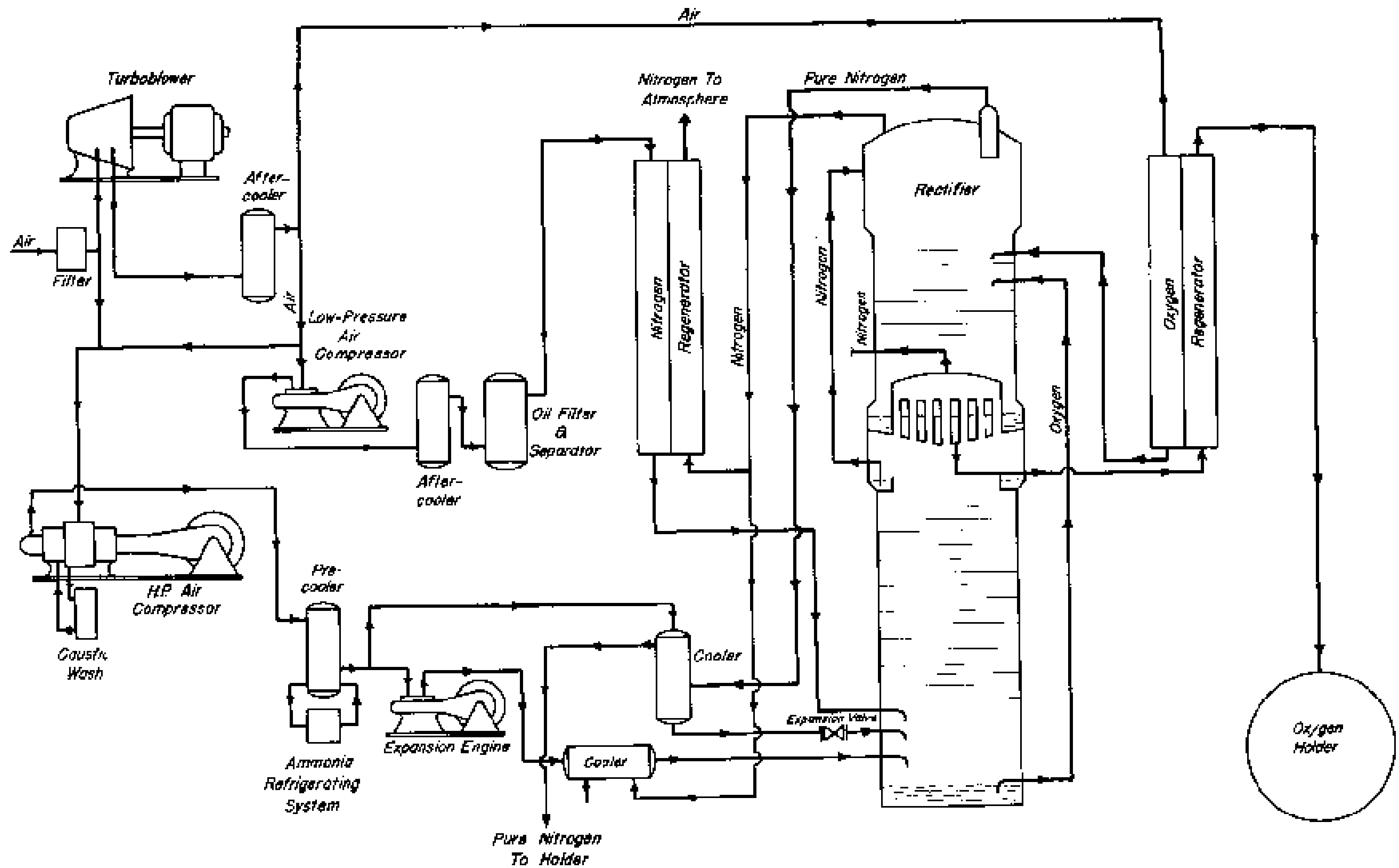

Figure 23. - Simplified flow diagram of Linde-Frankl oxygen plant.

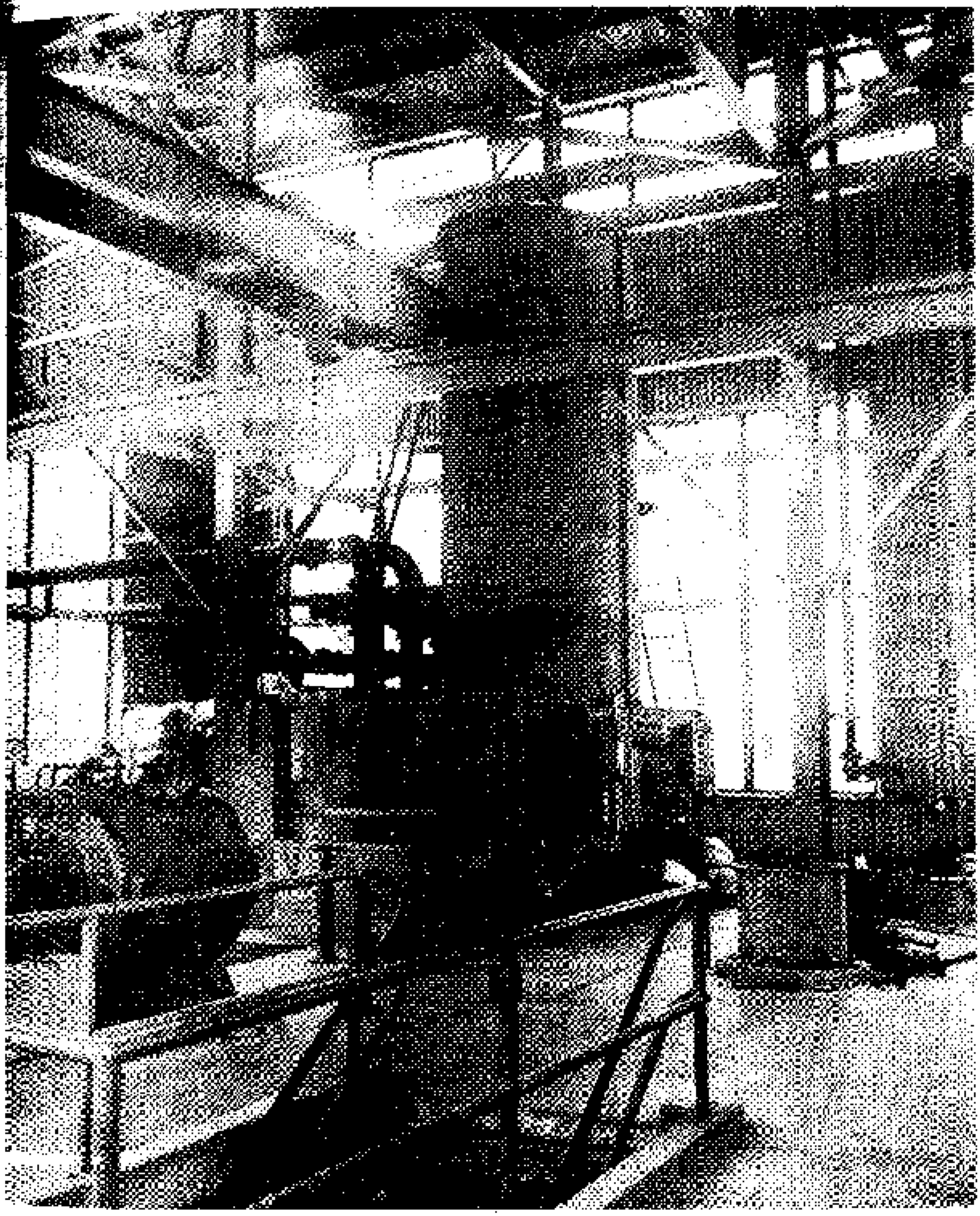

Figure 24. - Interior of oxygen building, showing operating floor with oxygen rectification column in center background and air compressor in left foreground.

gas, the extent of steam utilizations, and process control also were studied. This work leads to the selection of the most favorable operating conditions.

The effect of pressure on the removal of sulfur compounds from the gas and the anticipated cost of sulfur purification, both on demonstration-plant and commercial-scale operations, was studied. Various purifying agents have been investigated in order that the most suitable might be selected. A study was made of the relative values of water and ethanolamine solutions for the removal of hydrogen sulfide, carbon dioxide, and organic sulfur under pressure. The relative power and heat requirements, equipment costs, and losses of process materials had to be closely evaluated. It was decided that, for the demonstration plant, the chemical solution was preferable to water for removing both hydrogen sulfide and carbon dioxide and that scrubbing for removal of organic sulfur was not desirable.

Potential processes for the preparation and reduction of the synthesis catalyst have been examined, and a unit has been designed. Two forms of catalysts were included, one granular for use in the internally cooled-converter process and the other finely powdered for use in the slurry process. The possible contaminants in the gas used for reduction and the effect of each on the product were considered. Maximum limits and methods of purification were determined and the results then translated into process design.

All of the known processes for converting carbon monoxide and hydrogen to synthetic liquid fuels have been examined. Comparisons were made for design requirements, cost of installation, reliability of operation, yield, and throughput. The results of this work justified use of the internally cooled synthesis process and indicated the desirability of including a second type, namely the slurry process, in the demonstration plant.

The selection of a coolant oil suitable for all anticipated operating conditions was based on the results of extensive calculations of the vaporization characteristics and thermal behavior of available materials. These calculations have indicated that the boiling-range characteristics of the coolant oil may be very important to the best operation of the process. For this reason, it was necessary that the distillation be so designed as to permit the recovery of any selected one of a variety of coolant oils.

The demonstration plant is designed to operate with iron catalysts. However, in order to evaluate the potentialities of commercial operation with cobalt catalysts in the making of special products, a survey was made of the world production of this metal, and calculations were made on the theoretically attainable rate of production of synthetic fuels. This study confirmed the necessity of basing commercial operations on a catalyst made from iron or other readily available materials.

Work was begun on a preliminary design and an estimate of plant and operating costs for a commercial-size coal-gasification and gas-synthesis plant to produce 10,000 barrels per calendar day of liquid hydrocarbon products. The main product will be motor gasoline with a yield of Diesel fuel as high as practicable.

After the product yield was established the following basic processes were tentatively agreed upon:

1. Pressure gasification of pulverized coal utilizing the Koppers-type reactor.
2. Superheated steam and oxygen feed to the gasifier.
   Steam and oxygen are heated by exchange with the hot gaseous products leaving the gasifier.

3. Synthesis of hydrocarbon gas by the slurry process, probably in a two-stage operation.

With these basic processes decided upon, process calculations are being made and flow diagrams developed. A specific coal and plant site for the initial work has been selected. Subsequent calculations for different coals will be made on the same basis. Plants to use several representative coals will be estimated.

When the size of major equipment has been determined, quotations from manufacturers capable of fabricating such equipment will be requested. Equipment prices will be established by a comparison of quotations. Using these equipment costs as the starting point, plant costs then will be calculated. Costs will be compared with studies already completed.

General

Plant maintenance consisted primarily of the upkeep, repair, and partial operation of the former Missouri Ordnance Works, the completed portions of the two demonstration plants, and 51 residence units (see fig. 25). This covers a built-in area of some 165 acres, with all utility services. Even with curtailed operations during plant construction, the filter plant processed 90,000,000 gallons of water, and the power plant burned 20,000 tons of coal to produce 270,000,000 pounds of steam for heat and for the generation of 6,000,000 kw.-hr. of electricity. Maintenance and repair of 109 motorized equipment units and vehicles required 5,000 man-hours, painting 7,000, carpenter work 5,000, plumbing repair 3,000 and electrical repair 3,000. Reactivation of hyper units 3, 4, and 5, hydrogen furnaces 5 and 6, and the gas holders was begun in June and required 7,000 man-hours. Storm damage in May necessitated the largest repair job, replacement of 1,200 panes of glass and construction of new roofs on the warehouse and filter plant being the principal items. In addition, the machine shop spent 20,000 man-hours in producing machined parts, piping specialties, and 5,000 lens rings of the 10,000 pounds per square inch working pressure class for the hydrogenation demonstration and oxygen plants.

An active safety, accident-prevention, fire-protection, and health and sanitation program was continued. Accident prevention was maintained with construction contractors on an advisory basis. Safety procedures for operating the coal-hydrogenation plant were established and incorporated in the operating manuals; similar procedures are in preparation for the gas-synthesis-plant operation. All maintenance, operating, and power-plant supervisors have completed the National Safety Council's 20-hour course in "Safety Management for Foremen." Physical qualification standards were set up for all classifications of employees and used for proper placement. A first-aid station was maintained with two nurses on duty. For construction work, the accident-frequency rate (number of injuries per million hours of exposure) was 6.3 and severity rate (actual time lost per 1,000 hours worked) was 0.04. For Bureau activities, the rates were: Frequency 4.9 and severity 0.13.

Cost-accounting procedures were established to conform with standard commercial practice. Bureau operating costs from April 1947 to current status were assembled in monthly statement form. A new work-order procedure for plant operations was developed. A comprehensive guide for making cost estimates for chemical-type operations was completed.

Fiscal accounting was concerned chiefly with reimbursement of the two construction contractors for materials and services. The field audit plan has been continued

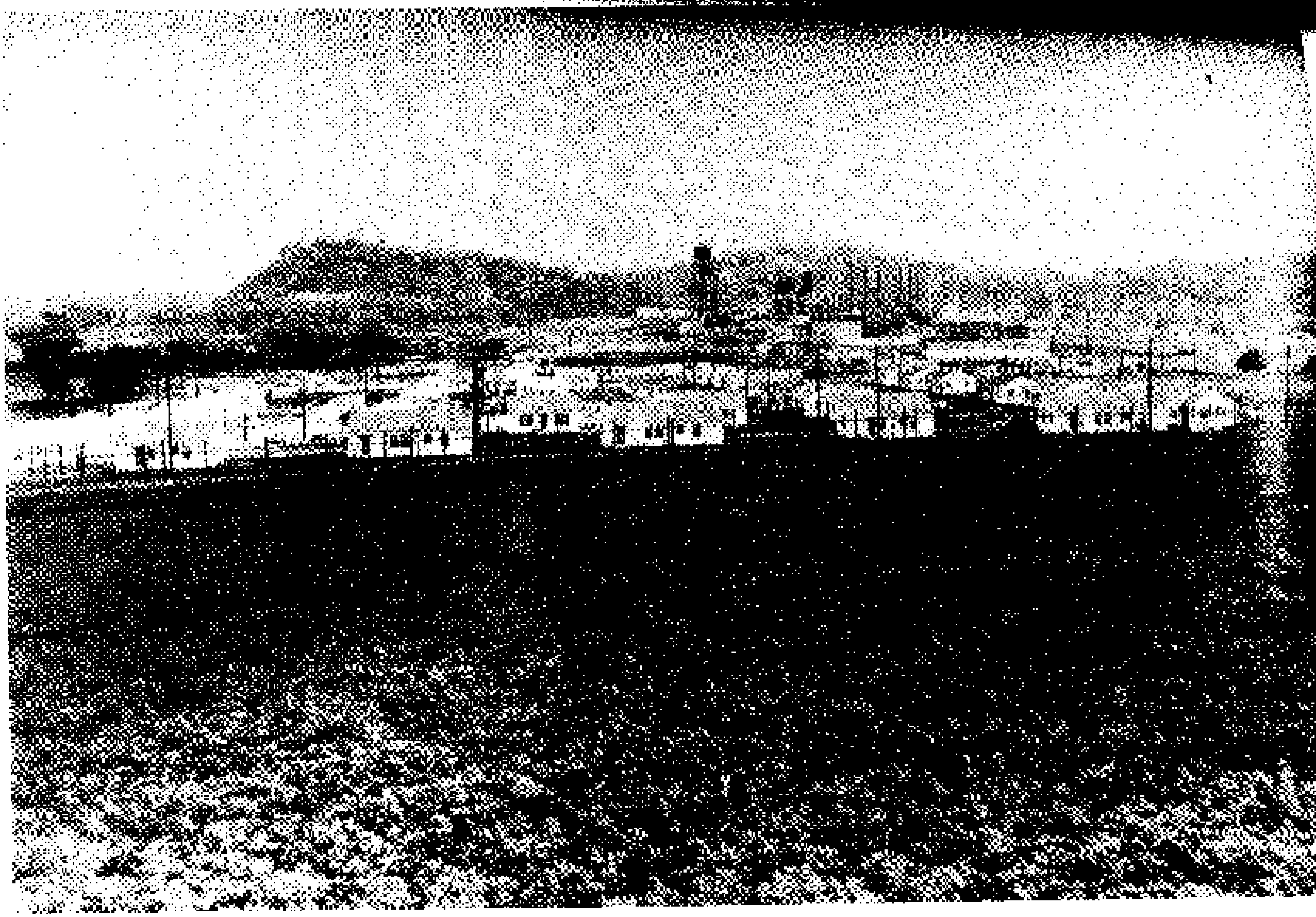

Figure 25. - Panoramic view, looking southeast. Ordonia housing project in foreground; Missouri Ordnance Works and Coal-to-Oil Demonstration Plant in middle background.

satisfactorily. Routine claims for services, transportation, travel, and miscellaneous purchases were approved for payment; more than 3,000 vouchers were processed. Approximately 1,200 Bureau purchase orders were issued.

A property accounting section was established to properly administer former Missouri Ordnance Works plant equipment valued at $11,000,000, a $2,000,000 inventory, and the two new demonstration plants. Two of the five Missouri Ordnance Works ammonia lines have been transferred to the Ordnance Department and will be dismantled and moved. Stock records have been prepared to conform with the cost-accounting system.

The Civil Service Board, which was established late in 1947, announced examinations for 12 general classifications of positions in the CAF, CPC, and SP services. The number of employees increased from 140 to 275 during the year.

Manuscript

A paper entitled "The Thermal Efficiency of Coal Hydrogenation - Present and Future," by L. C. Skinner, R. G. Dressler, C. C. Chafee, S. G. Miller, and L. L. Hirst, is scheduled to be published by the American Chemical Society in the December issue of Industrial & Engineering Chemistry.

In this paper the thermal efficiency of an improved coal-hydrogenation plant is discussed in detail, and the efficiencies are compared to a typical German hydrogenation plant. The new ideas and processes discussed are incorporated into a plant designed for improved thermal efficiency. The over-all heat efficiency of this plant is calculated to be 55.0 percent as compared to 28.9 percent for a typical German plant. The calculations are divided into three sections - hydrogenation proper, hydrogen manufacture, and power plant. Detailed data are presented to verify the results for each section. A comparison is made with the German efficiency for the individual sections with the following results, in percent:

	Improved plant	German plant
1. Hydrogenation proper.........	73.2	51.1
2. Hydrogen manufacture	61.7	27.0
3. Power plant	39.9	42.0
4. Over-all heat efficiency	55.0	28.9

The calculations are based on 100 tons per hour of moisture and ash-free coal to hydrogenation proper with the following material quantities involved:

Total coal charged (as received)	tons per hour	235.8
Total coal charged (m.a.f.)1/	do.	198.0
Total coal to hydrogenation (m.a.f.)	do.	100.0
Total coal to H_2 production (m.a.f.)	do.	41.8
Total coal to power plant (m.a.f.)	do.	56.2
Gasoline produced	do.	62.0
Liquefied fuel gases	do.	13.3
Residuum fuel	do.	11.0
Elec. energy required	kw.-hr.	88,379
Steam required (net)	lb./hr.	389,750

1/ Moisture and ash-free.

Flow sheets are included for each section showing complete heat and material balances.

The favorable increase in heat efficiencies shown, being accompanied by a considerable decrease in plant costs, indicates the necessity for an aggressive coal-hydrogenation development study as a part of our national economic and security program.