

unreacted coal and catalyst and ash. Eventually it was found that valves with very hard inserts on seats and needles, protected further by downstream orifices made of very hard materials, would give much longer service if the minimum flow was held above 700 g.p.h. (17).

The problem of removing solids from H.O.L.D. was not completely solved. Flash distillation of H.O.L.D. (fig. 55) appeared to have some promise (17). Gasification of the residue from flash distillation appeared an interesting possibility that should be tried; however, time did not permit such trial before the plant shut down.

Products and Costs

Use of Coal-Hydrogenation Gasoline. - Motor vehicles at the demonstration plant were fueled by gasoline produced at the plant from May 1949 to September 1953 (16), and 1 million gallons of the gasoline was fleet tested at an armed services installation. In performance this 78-octane (motor method, unleaded) synthetic gasoline was found equal to or better than petroleum gasoline. There was somewhat shorter life of the fuel-pump diaphragm in vehicles propelled by coal-hydrogenation gasoline, probably owing to the higher aromatics content of the synthetic fuel.

Thermal Efficiency. - During the process design of the hydrogenation demonstration plant information was developed on requirements for heat, power, steam, hydrogen, fuel gas, coal, and catalyst. This information was used later in preparing an estimate of thermal efficiency of the hydrogenation process. The estimated values indicated that 55 percent of the B.t.u.'s in the inbound coal might be available in liquid-fuel product (55). Such efficiency, however, has not been achieved in any coal-hydrogenation plant. Practical experience has been that not over 45 percent can be expected.

Cost Estimates. - Plant information on construction and equipment was used, together with much other cost information supplied by various manufacturers of equipment, to establish capital costs for commercial-size units. As these studies progressed it became possible to provide more realistic estimates on installed costs of commercial-size hydrogenation plants (38). These studies made it evident that some 3 to 4 years would be required from the time of the decision to build before such a plant could be on stream. Yields of gasoline and other products could be predicted realistically from the demonstration-plant work.

Problems of Coal Hydrogenation

Although the production of gasoline from coal by direct hydrogenation is feasible from an engineering standpoint, the economics of the process does not favor commercial application at present. However, production costs might be lowered by reducing hydrocarbon-gas production, by lowering the cost of hydrogen, and by improving techniques for removing solids from the heavy-oil fraction.

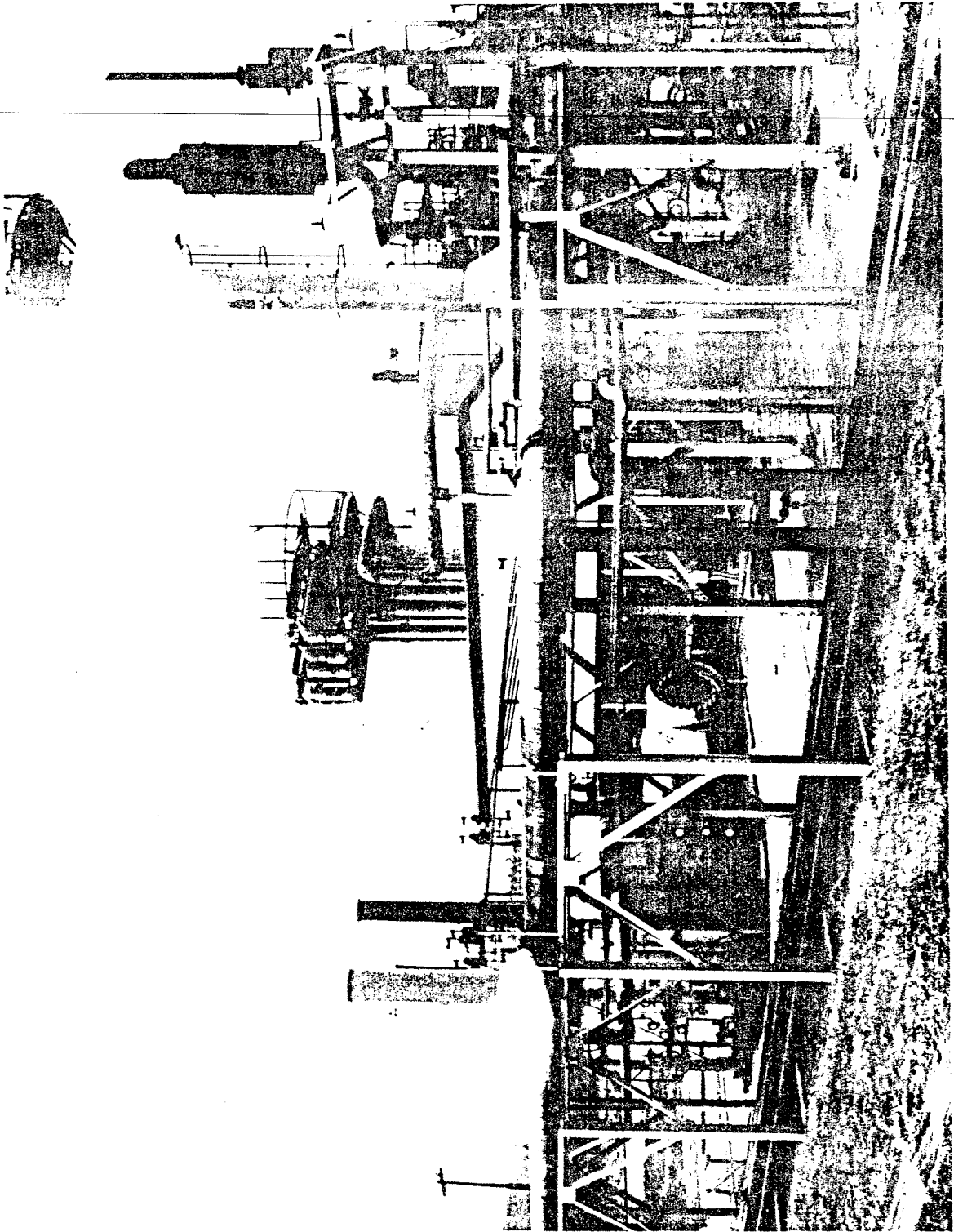


FIGURE 55. - Flash-Distillation Unit at Coal-Hydrogenation Demonstration Plant, Used to Separate Lower Boiling Oils From Heavy-Oil Letdown (H.O.L.D.).

In the Bergius process, 25 to 30 percent of the m.a.f. coal is unavoidably converted to hydrocarbon gases. This uses 2-1/2 times as much hydrogen as is required for the same weight yield of gasoline. Also, the present commercial return from these gases is only one fourth that from an equivalent yield of gasoline. Obviously, then, decrease in gas formation, with an increase in the yield of gasoline, would greatly enhance the possibility of a profitable operation. Such an improvement might be obtained by developing new catalysts of greater selectivity. The importance of the development of more efficient techniques for solids removal becomes evident when it is realized that oil losses in this operation amount to about 10 percent, based on m.a.f. coal.

To achieve additional cost reduction, an overall simplification of the Bergius process should be effected. The probable shift in the Nation's future demand for liquid hydrocarbons away from gasoline toward use of jet, gas-turbine, and diesel fuels may permit simplification of the process and thus expedite application of coal hydrogenation. Previous studies indicate that a jet or gas-turbine oil could be produced in a single-stage coal-hydrogenation unit at moderate pressures. With such pressures, eliminating the conventional high-pressure vapor-phase system and reducing power requirements should contribute to reasonable reduction in liquid-fuel cost. Further simplification may be possible by applying hydrocarbonization. This technique, carbonization in a hydrogen atmosphere, could be conducted at 500 p.s.i. and elevated temperatures with a comparatively small outlay of capital. This process can also produce large yields of high-B.t.u. gas which may be in high demand in the future economy of the United States.

The conventional conversion of coal to gasoline by hydrogenation is accomplished usually in two steps. The first stage is a liquid-phase operation in which a slurry of coal, heavy oil, and a catalyst are treated with hydrogen at elevated pressures (200 to 700 atm.) and temperatures (400° to 500° C.). During this step the coal is converted into lower-molecular-weight material. The middle-oil product is then converted into gasoline in second-stage hydrogenation on a fixed-bed catalyst.

The problems encountered in this vapor-phase step are similar to those in petroleum technology. Although our understanding of how a vapor-phase catalyst works leaves much to be desired, considerable practical progress has been made in vapor-phase heterogeneous catalysis.

The reactions occurring in the liquid-phase step need investigation most urgently. Numerous catalytic studies have been made; these have been mostly empirical tests and have not elucidated the mode of action of the catalysts. Kinetic and product-identification studies have increased our knowledge of the liquid-phase hydrogenation of coal. However, these results are difficult to interpret, because several types of reactions take place concurrently during liquefaction of coal.

Some major basic problems concerned with liquid-phase coal hydrogenation are:

1. Relatively little is known about the structure of coal.
2. There is little information about chemical transformations in catalysts during coal hydrogenation.
3. There is limited information about the behavior even of simple molecules at the elevated temperatures and pressures of hydrogen employed in hydrogenation of coal.

Studies of vapor-phase hydrogenation in small, continuous reactors should provide information about catalytic reactions of coal-hydrogenation oils. Data on the influence of catalysts and operating conditions on the kinetics and relative rates of cracking, of hydrogenation-dehydrogenation, of isomerization, and of nitrogen- and oxygen-elimination reactions would aid in interpreting the mechanism of both vapor- and liquid-phase coal hydrogenation. Fixed-bed catalysts for the hydrogenation of heavy asphaltic oils as obtained from hydrocarbonization should be investigated, since processes utilizing dry coal require conversion of heavy oils to useful products.

Knowledge of the structure and chemistry of coal has increased rapidly in recent years; with continuing study clarification of many of the still unsolved problems is anticipated. Improved methods of X-ray diffraction should develop definitive information regarding the relative amounts of organized and unorganized substance in coal and the size and orientation of structural units. Sorption studies should provide a consistent picture of the pore structure of coal. Infrared studies should be continued to obtain information regarding chemical groups present in coal. Ultraviolet spectroscopy and nuclear and electron magnetic resonance may resolve the problems of free radicals, of color, and of sorption phenomena in coal.

Other desirable chemical studies of coal include extraction by specific low-temperature solvents, titration of coal in ethylenediamine and similar solvents, and applications of powerful new reduction systems. Studies of the charring of organic molecules to yield "coallike" materials may lead to valuable concepts on coalification. Microbial attack on organic substances, usually very specific, promises to provide definitive data on the structure of coal and related materials. Such research results may aid in improving and simplifying processes for obtaining fuel and other chemicals from coal.

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