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Status of the Development of EDS Coal Liquefaction

G. K. Vick and W. R. Epperly

The modern world has a substantial appetite for liquid fuels from petroleum. At present there are some essential energy needs, such as transportation, which are almost entirely met by liquid fuels. In 1979 oil and gas accounted for almost 70 percent of the world's fossil fuel production. However, only 11 percent of the world's estimated fossil fuel resources are oil and gas. Oil shale and tar sands account for about 10 percent, and the rest—nearly 80 percent of the estimated recoverable resource base—is coal (*1*). Barring some sort of breakthrough, it therefore seems almost inevitable that liquids from coal will have a role to play in the eventual transition from fossil sources to renewable sources of energy.

Summary. This article traces the evolution and development of a modern coal liquefaction technology, the EDS (Exxon Donor Solvent) process, over a period of 15 years. During this time the technology has been advanced from laboratory experiments to a pilot plant with a coal feed rate of 250 tons per day, and findings from several areas of science and technology have been important. The process is now in the final stage of development to generate the data needed to design a plant of commercial size.

The production of oils and tars by pyrolysis of coal predates the 20th century, but it was not until the 1920's and 1930's in Germany that there were serious efforts to develop technologies to produce liquid fuels from coal. Two rather different approaches were developed. Indirect liquefaction involves gasifying coal to carbon monoxide and hydrogen and then synthesizing hydrocarbons from the gas. This is the technology used by SASOL in South Africa. Direct liquefaction involves the direct hydrogenation of coal to produce liquids. At the time when research that ultimately led to the EDS (Exxon Donor Solvent) process was started, it was decided to concentrate on direct liquefaction because it was expected to be more thermally efficient and lower in cost than indirect liquefaction in the long term. Recent comparisons of the two suggest that this expectation is still reasonable.

The path by which the EDS technology was first defined and then developed to the point of scale-up was a tortuous and complex one involving process development, elucidation of the chemistry, equipment development, and process scale-up. While a great deal of new knowledge was gained, it appears in retrospect that certain key findings and developments were crucial to advancing the technology. As a result, the advance took place in a series of steps of uneven size and timing in which three main phases can be distinguished: (i) research to define the critical process steps and chemistry (1966 to 1973), (ii) predevelopment to define process conditions, scale-up issues, and the development program plan (1974 and 1975), and (iii) execution of the development program to obtain the information needed to design a commercial-size plant (1976 to 1982).

Research and Predevelopment

At the beginning of the research in 1966, it was clear that to liquefy coal it was necessary to (i) decrease the size of the coal molecules, (ii) increase their hydrogen content, and (iii) separate the resulting liquids from the mineral matter and other unreactive solids. However, equipment and techniques for carrying out the necessary chemistry and separations were not well developed. This led to most of the early R & D being done on an unusually large scale compared to that used in petroleum technology (1/2 ton per day). This size was chosen as a compromise between conflicting needs; it was small enough for easy, low-cost operation and modification, but large enough so that pumps, pipes, and tubing could handle the tarry slurries with their high solids content. Even on the scale of 1/2 ton per day, equipment was small and prone to plugging. For example, the inside diameter of the tubing in the slurry preheater was less than 5 millimeters, leaving little tolerance in the event that deposits of coke formed in the tubes due to the high temperature involved, and the orifice in a critical control valve was less than 2 mm. This hardware problem also led to ambiguous data and uncertain interpretations. In the early days it was difficult to separate the effects of the process variables from effects caused by the hardware behaving in unwanted and unexpected ways.

In the interests of minimizing cost and maximizing the chances for successful scale-up, the initial strategy adopted in 1966 was to obtain liquids at the lowest possible hydrogen consumption, separate them from the unreactive solids and mineral matter, and then upgrade them

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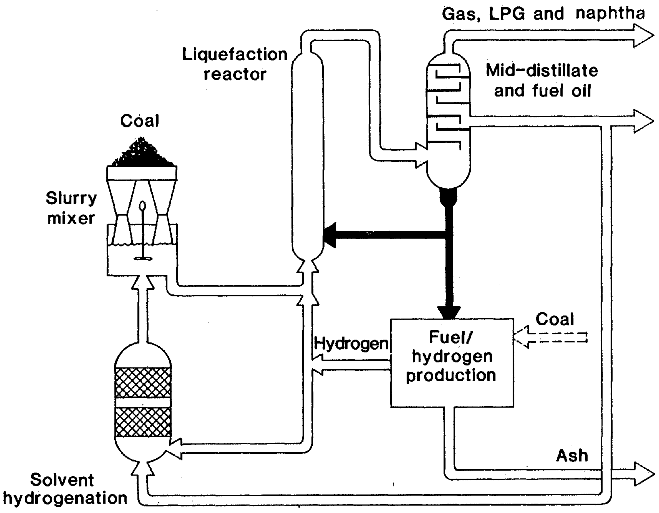

Fig. 1. Simplified flow chart of the EDS process. The recycling of part of the distillation residue (vacuum bottoms) back to liquefaction was a process improvement added during the development program. *LPG*, gas of the composition of liquefied petroleum gas.

by hydrogenation as necessary. The search started at fairly low pressures and temperatures (2.5 to 7 megapascals and 400° to 430°C). A large number of different process schemes within this severity range were tested. These included conventional hydrogenation catalysts in the liquefaction reactor, and solvents that can donate hydrogen to the liquefying coal in both the presence and absence of added hydrogen gas. Various reactor types were investigated, including ebullating catalyst beds, well-stirred and back-mixed reactors, and simple plug flow reactors.

On the separation side, a wide variety of approaches for separating product liquids from the remaining solids were investigated. These included various kinds of filters and centrifuges, solvent precipitation, hydroclones, coking, and distillation (*2*). Some of these approaches (for example, centrifuges and hydroclones) were not scalable to the very large sizes contemplated for a commercial plant and their use would have required a large number of parallel units. However, the first concern was a method that would work, and at that time it was not apparent that scalable approaches would work.

The catalytic approach with a conventional hydrogenation catalyst in the liquefaction reactor was abandoned rather early in favor of a donor solvent approach. In spite of the fact that the yields with fresh catalyst were better, the catalyst life appeared to be too short to be economic. The low-severity results were not particularly encouraging either, and this pushed the program in the direction of higher pressures and higher temperatures. Gradually, the first key finding became clear: temperatures in the range of 430° to 480°C and pressures from 10 to 17 MPa would be necessary. The presence of gaseous hydrogen in the liquefaction reactor was found to be beneficial, even at low severity. Another observation was that some donor solvents were better than others, although it was not yet clear how to relate performance to donor solvent composition.

In addition, none of the separation techniques appeared to be economic at low-severity conditions. Vacuum distillation was not successful because of fouling of the distillation tower. It appeared that the liquids were reactive and were polymerizing in the distillation equipment, giving tars that caused plugging and coking. The move to higher severity conditions with higher hydrogen consumption led to another key finding: if enough hydrogen could be incorporated into the liquids, they became stable and light enough to be distilled. This indicated that a process that combined intermediate severity liquefaction conditions, a "good" donor solvent, and vacuum distillation might be successful.

By about 1969 a promising conceptual process scheme, shown in Fig. 1, had evolved. The scheme involves slurrying coal with a donor solvent produced by hydrogenation of a portion of the liquid product, adding gaseous hydrogen, and subjecting the mixture to pressures of 10 to 17 MPa and temperatures of 430° and 480°C for periods of an hour or so. The resulting liquids are separated by atmospheric and vacuum distillation. This process was appealing because it separated the hydrogenation catalyst from the tars and minerals in the coal, and because the techniques of atmospheric and vacuum distillation and fixed-bed catalytic hydrogenation of the solvent were well developed in the petroleum field. By maximizing the use of conventional petroleum technology, it was hoped to improve the chances for successful development and scale-up and for attainment of a safe, reliable, and easy-to-operate commercial plant. Of all the early German processes, the EDS process as it had evolved to this point was probably most similar to the Pott-Broche process (*3*, *4*). A more complete description of the process can be found in (*5*).

At about the time when the EDS process scheme evolved into substantially its present form, a program of basic research was started to improve the science underlying direct liquefaction. The first part of this program to bear fruit was a study of what happens in the first minutes when coal is heated in a donor solvent (Tetralin) or in a nondonor solvent (naphthalene or dodecane) (*4*, *6*). This work produced another key finding by showing that bituminous coal quickly dissolves in the donor solvent. Until then it had been thought that diffusion into and out of the coal particle was a controlling factor. The results of the dissolution study focused thinking on the chemistry of the process and away from a chemical engineering diffusion model.

In 1972 the accumulated process knowledge and the operating experience with the 1/2 ton per day unit made it possible to construct and operate a small (23 kilograms per day) integrated recycle coal liquefaction unit, RCLU-1. The combination of appropriate conditions of temperature, pressure, and residence time; donor solvent; and gaseous hydrogen in liquefaction, together with distillation, produced an operable system. In 1973 the potential for good yields of distillable products from the EDS process was confirmed in RCLU-1. More important, RCLU-1 made it possible to obtain more data of higher quality, faster, and at lower cost than before. This significantly increased the laboratory's ability to study process variables.

Early in the investigation of the donor solvent approach, it became clear that some solvents were better donors than others. The structural characteristics of a good donor molecule were known. But for solvents derived from the process itself, it was not clear how to measure the hydrogen donating ability. The solvent consisted of material boiling in the range 200° to 425°C. This complex mixture contained hundreds of different compounds that could function as hydrogen donors. The first approach was to use total hydrogen content, but it quickly became obvious that this did not work well. In the period 1970 to 1973, when work on the EDS process was at a low point, the Baytown analytical laboratory developed the ability to use high-resolution mass spectrometry to characterize complex petroleum and coal liquid streams (*7*). As will be seen shortly, this development was crucial to advancing the technology.

Thus the research carried out from 1966 to 1973 defined the key steps of a donor solvent process: liquefaction, solvent hydrogenation, and vacuum distillation. In 1974 the predevelopment program was initiated to define process conditions, scale-up issues, and the development program. In this period, a 1 ton per day pilot plant was built to obtain process data, and engineering studies were carried out to define both a complex process flow plan with all of the process blocks and the scale-up issues to be addressed in a development program. Work to improve the understanding of liquefaction chemistry also continued.

Laboratory predevelopment was oriented toward defining critical process parameters. For example, it was confirmed that the simple, tubular flow liquefaction reactor was preferred. Also, the critical effects of solvent composition and hydrogen gas in liquefaction were determined. Engineering studies identified the Flexicoking process (a proprietary petroleum refining process in which residua are coked to recover additional liquids and the coke is gasified to produce a fuel gas) as a promising approach for utilizing the heating value left in the distillation residue. Hydrogen production by steam reforming of product gas was selected. Finally, process scale-up issues related to heating the coal-solvent slurry before liquefaction, the liquefaction reactor, and product distillation, and equipment scale-up issues related to pumps, valves, heat exchangers, and so on were defined in quantitative terms.

During the development work, progress had been made in learning how to carry out the experimental work on a smaller and smaller scale, from 1/2 ton per day in 1966 to 23 kg per day in 1972. In 1974 this was taken the last step by the development of a new, small-scale, batch technique involving tubing bombs. Up to then, small-scale experiments with hydrogen at high pressures were carried out in autoclaves, but because of the long heating and cooling times involved, they could not simulate the pilot plant very well. With the tubing bomb procedure a large number of variables could be studied quickly and reliably. The technique was quickly used to determine the liquefaction performance of a range of practical donor solvents prepared from creosote oil by catalytic hydrogenation to different levels. These solvents were also characterized by using the newly developed analytical capability, and a relationship was developed between solvent composition and performance. This relationship was used to develop a measure of the hydrogen donating ability of the solvent, which became expressed as the solvent quality index (*8*). The solvent quality index was crucial to the development of the EDS process. It made possible the control of a critical variable which could affect process operability, product yield, and product quality. It also provided another lever with which to manipulate the process, and it provided flexibility in dealing with different feedstocks and making different product slates.

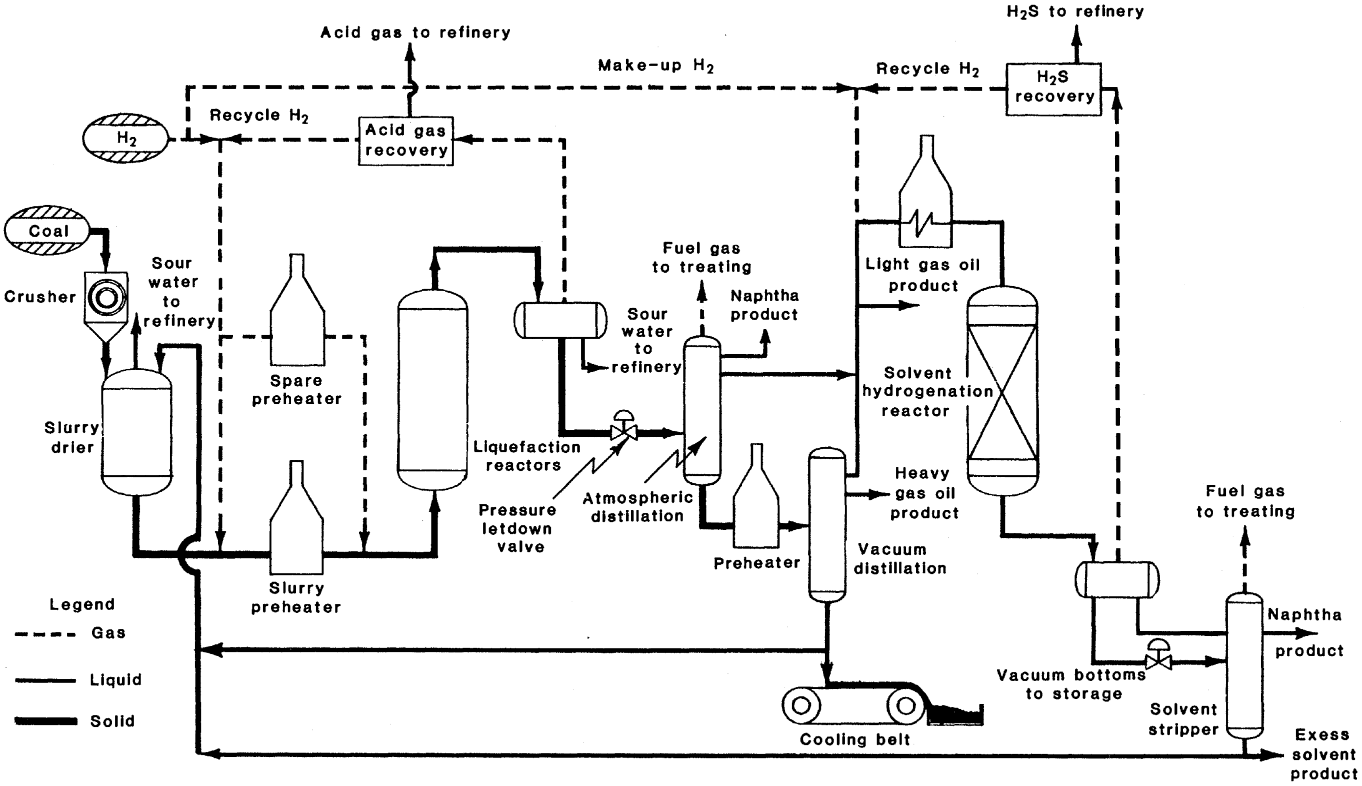

Fig. 2. The EDS 250 ton per day pilot plant (ECLP). Coal is received in 100-ton rail cars and stored in a 5000-ton concrete silo. Raw coal is crushed and dried in a gas-swept rotary mill or crushed in an impact mill and dried as a slurry in recycle solvent. The coal-solvent slurry is pumped to a pressure of about 14 MPa, gaseous hydrogen is added, and the three-phase mixture is heated to about 450°C in one of two slurry preheat furnaces (the other is a spare). The heated mixture flows upward through one or more of four reactors, depending on the residence time desired. The reactor effluent passes through a series of separator drums, is depressured, and is fed to an atmospheric distillation tower, where naphtha and a gas oil sidestream are withdrawn. The atmospheric bottoms are pumped through a preheat furnace to the vacuum distillation tower, where light and heavy vacuum gas oil sidestreams are withdrawn. The vacuum bottoms are solidified on a cooling belt and sent to storage. The atmospheric and the light vacuum gas oils are hydrogenated and distilled. Part of the hydrogenated solvent is recycled to the slurry drier. Excess solvent, naphtha, and heavy vacuum gas oil are sent to tankage. Part of the vacuum bottoms may be recycled in the molten state to liquefaction.

Development Program

As the predevelopment program was being completed in 1975, planning began for a large pilot plant development program. After a thorough analysis of the technical uncertainties, it was concluded that a large pilot plant would be needed to develop the data required to design a commercial-size plant at an acceptable level of risk. However, it was apparent that the effort would be costly (estimates were in the range of $300 million) and would take a considerable amount of time (at least an additional 5 years). At this time, the U.S. government became active in the development of coal conversion technology, with the objective of helping to provide alternatives to imported oil. Accordingly, an unsolicited proposal was offered to the Energy Research and Development Administration (ERDA) and contacts with prospective participants in the private sector were begun. The cooperative agreement that resulted has been described (*9*).

The EDS project employs an integrated approach to the development and scale-up of the technology (*3, 10*). This includes not only the design, construction, and operation of a large pilot plant, but also a continuing program of laboratory and bench-scale research on potential improvements, continuing development in small pilot plants of process know-how and predictive process models, engineering design and economics studies to guide the research and development, and product quality studies aimed at ensuring the acceptability of the products in the marketplace.

Five coals, including bituminous and subbituminous coals and lignite, were studied and successfully processed. It was found that the coals require different liquefaction conditions. For example, subbituminous and lignitic coals contain calcium humates, which form calcium carbonate in the reactor, and a mechanical means of removing these solids was developed. In addition, the lower rank subbituminous coals and lignite were found to yield vacuum bottoms of high viscosity, which adversely affected pilot plant operability. This was controlled by adjusting solvent quality, liquefaction residence time, and distillation cut point, and by recycle of liquefaction bottoms.

During the development program, an important improvement was incorporated into the process. The idea of recycling part of the vacuum bottoms back to liquefaction was suggested by one of the project's sponsors, the Electric Power Research Institute (EPRI). The attempt to apply this idea to the EDS process produced another key finding. It was discovered that it was necessary to raise the pressure in the liquefaction reactor from 10 MPa to about 14 MPa to realize significant advantages from bottoms recycle. At the higher pressure, bottoms recycle improved process operability by lowering the viscosity of the bottoms, increased product yield, reduced the quantity of bottoms, and made possible a lighter product slate. For example, the product slate could be varied from one containing 35 percent naphtha, 40 percent middle distillate, and 25 percent fuel oil with no bottoms recycle to one containing 45 percent naphtha, 55 percent middle distillate, and no fuel oil with recycle of bottoms. The naphtha was found to be an ideal feed for further processing to gasoline. It was also found that the characteristics of the product liquids in a given boiling range were largely independent of the coal and the extent of coal conversion.

Engineering studies showed that thermal efficiency might be improved and cost reduced by generating hydrogen through partial oxidation of coal or liquefaction bottoms instead of steam reforming of gas (*11*). Also, combustion of liquefaction bottoms in a boiler designed to provide process heat and steam was identified as a potential improvement.

Studies of model coal molecules and their behavior under liquefaction conditions had been initiated in the late 1960's. These studies confirmed some conventional wisdom of the time, that pyrolytic cracking of weak bonds in coal (ether bonds and benzylic carbon-carbon bonds) formed free radicals, which abstracted hydrogen from the donor solvent. The development of the tubing bomb technique made it possible to examine the role of gaseous molecular hydrogen in model compound studies. This work showed that the molecular hydrogen entered into the free radical reactions (*11*). Organic free radicals reacted with molecular hydrogen to form hydrogen atoms, which are themselves free radicals. These atomic hydrogen radicals attacked coal molecules and caused the scission of bonds that were too strong to be broken thermally at liquefaction temperatures. This was another key finding because it explained a number of the effects of pressure and molecular hydrogen on yields, gas make, solvent degradation, and so on, which had been observed in the empirical process variable studies.

It is clear that this improved understanding has played a direct role in the continuing exploratory work by providing valuable leads. The applied research program had already moved to gaseous hydrogen and higher pressures, and the model studies gave the applied researchers an after-the-fact understanding and a better framework in which to think about the process, plan experiments, and interpret their results. We believe this framework has improved the ability of the research team to define responses to process variables and to search for economic compromises.

Large Pilot Plant (ECLP)

A key to commercial readiness is the ability to design a commercial-size plant. With a new process technology such as coal liquefaction, there is considerable uncertainty about how to design the commercial hardware. The purpose of the large pilot plant is to generate enough scale-up data and know-how to reduce the technical risk to an acceptable range.

A substantial effort involving both process engineers and engineering technology experts was devoted to deciding on the size of the large pilot plant. The goal was to determine the minimum size (and thus cost) that would generate the needed data. Each process section was studied to define the scale-up problems in that section. The coal slurry preheat furnace, coal liquefaction reactor, and vacuum distillation tower were identified as the limiting pieces of equipment. For example, it was concluded that the liquefaction reactor should be no smaller than 60 centimeters in inside diameter to operate at the same liquid and gas holdups as commercial-size reactors, and to permit inclusion of an inlet distributor with the hardware elements and geometry that could be used in a commercial reactor. The critical dimensions from these studies dictated the coal feed rate to the plant, about 250 tons per day of Illinois No. 6 coal as received (about 200 tons per day of dry coal). The major elements of the Exxon Coal Liquefaction Pilot Plant (ECLP) are shown in Fig. 2. The facilities included are described in more detail in (*12*).

The operating plan for ECLP is shown in Fig. 3. It calls for operation with three different coals—Illinois No. 6 bituminous, Wyoming subbituminous, and Texas lignite—for progressively shorter periods as experience and data are accumulated. A major turnaround is provided at the end of each testing period to inspect test equipment and prepare for the next run.

A formal test program for ECLP was developed by technology experts and process engineers. It involves 89 tests encompassing evaluation of equipment, materials, instrumentation and controls, process performance, and pollution control. It also includes an industrial hygiene program aimed at obtaining data on dust and hydrocarbon emissions, noise, and other health hazards for guidance in the design of a safe commercial plant. This is in addition to an intensive occupational health program to protect the work force at ECLP (*13, 14*).

Illinois coal was introduced into ECLP on 24 June 1980 to begin the shakedown period (*12*), and eight runs were made before shutdown for inspection and turnaround on 10 October 1980. During the shakedown 1245 hours of operation with coal were achieved, for a service factor (percentage of time on coal) of 51 percent. The plant was restarted on 30 December 1980 to begin the test period on Illinois coal (*15, 16*). The test period ended on 2 June 1981, when the plant was voluntarily shut down for a scheduled turnaround. This shutdown terminated the longest continuous run to that date—35 days. Plant operations were markedly better during the test period, as indicated by a service factor of 72 percent. The significance of the knowledge and experience gained during the shakedown and turnaround became obvious early in this set of runs; the operating staff was now running the plant instead of the plant running the staff.

Initially, it was necessary to concentrate on mechanical problems. As these problems were resolved, the service factor improved and attention could be shifted to process considerations. During the shakedown period the main problems encountered were plugging of slurry systems, pump packing leakage, and operation of instrument and control systems.

The plant was very unforgiving with respect to plugging. On five of the eight occasions when the plant was shut down during shakedown the problem was inadequacy of the systems for keeping the slurry lines hot. All the heat tracing systems were checked and upgraded as needed. Taps for lines that were seldom used needed to be relocated to the tops of the lines, and bypass lines tended to plug when a flow increase in the main line caused the flow in the bypass line to fall below the minimum needed to prevent settling.

Initially, the high-temperature reciprocating pumps that move the atmospheric tower bottoms to the vacuum tower averaged only 2 or 3 days of operation with the plant on coal before repacking was required. Each failure was analyzed, a root cause was assigned, and each analysis was documented. In this way a number of contributory factors were identified. The changes made as a result of the failure analysis improved packing life to the range of 15 to 20 days by the end of the Illinois coal test period. Redesigned stuffing boxes were then installed which promise to have the several months' life desired for commercial plant equipment.

The control of slurry flow, measurement of slurry levels, and operation of instrument systems where solids are involved have presented continuing problems. Both liquid and gas flushing of instrument lines have been tried, with only nominal success. On the other hand, level detectors employing radioactive isotopes have worked very well on slurry vessels and additional ones have been installed.

Centrifugal pumps are used in ECLP in several services. Those used as booster pumps for the high-pressure slurry feed pumps have shown good hydraulic performance and less wear than was expected after 2400 hours of operation on coal slurry. On the basis of these results, the booster pumps are considered commercially ready.

Inspection of the plant during the two turnarounds revealed that neither corrosion nor erosion was widespread, but both were significant in localized areas. Corrosion by chloride was found in the upper portion of the atmospheric distillation tower, and the affected carbon steel was replaced with a stainless steel. One area of considerable concern when ECLP was designed was erosion of the high-pressure letdown control valves. These valves control the rate of flow of effluent from the liquefaction reactors. They have to handle a pressure drop of about 13 MPa, which results in very high velocities through the orifice. The slurry passing through the valve contains 10 to 15 percent solids, and the combination of high velocities and high particulate content could cause severe erosion. A substantial amount of experience is available in the petroleum refining industry for handling either a high pressure drop or a high particulate content, but not both at the same time. A special valve was designed for ECLP, using the best valve body design from the standpoint of hydrodynamics coupled with optimum trim materials (*17*). These experimental valves have performed very well. One valve in coal slurry service for 127 days has shown very low rates of wear.

An important element of the test program is the evaluation of four different types of block valves for use in slurry service. Some of the valves have now seen as many as 78 cycles with satisfactory performance. Generally, 100 cycles is considered the life requirement for a commercial plant.

During the shakedown period on Illinois coal, the slurry feed preheater furnaces showed no tendency to coke. As part of the first turnaround, some tubes in one of the furnaces were insulated to raise the heat flux from about 25 to 38 kilowatts per square meter. Hot spots occurred in the tubes of the high heat flux furnace after about 14 days operation on coal due to the formation of coke deposits. The coking became more severe and forced the termination of the run. During the test period on Illinois coal both furnaces showed sporadic episodes of coking and the low flux furnace was just as susceptible as the high flux one. This experience has led to a systematic study of the influence of solvent composition, temperature, furnace design, and other factors on coking. Definitive answers are not yet available, but coking has been reduced by improving solvent quality and furnace design. In contrast to these furnaces, the vacuum distillation tower preheat furnace, which is also operating on a slurry, had no coking problems during the entire operation period on Illinois coal. X-rays of the tubes showed them to be clean and free of coke.

When the test program for ECLP was developed, it was thought that the process was well understood. Early in the test period on Illinois coal, it became obvious that the process was not completely under control. Conversions, yields, and solvent quality were not what

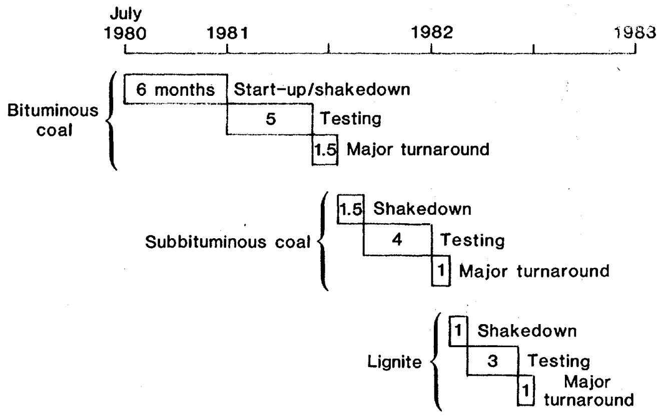

Fig. 3. ECLP operating plan.

they should be. It became evident that there were interactions between the various sections of the process that had not been recognized previously. This problem was investigated through studies in the smaller pilot plants. It was found that the solvent could be overhydrogenated to the point where saturates are produced faster than they are removed by cracking and distillation. High concentrations of saturates reduce solvent quality by diluting the active donor molecules. This showed that both liquefaction and solvent hydrogenation must be carefully balanced to generate the desired quantity and quality of solvent. This was another of the program's key findings and has subsequently been confirmed in ECLP. As a result, process control has been significantly improved.

Coal conversion has been 5 to 10 percent lower in ECLP than was expected from results in the smaller pilot plants. Radioactive tracer studies have shown that the residence time distributions of the reactants change significantly as the reactor diameter is increased to ECLP's 60 cm. Modeling studies are under way to correlate the data and provide a basis for scale-up to commercial size.

Status and Outlook

Our efforts in the last 15 years have demonstrated the advantages of the donor solvent approach to coal liquefaction. The EDS liquefaction process provides feed flexibility, product flexibility, high product yields, and process operability. In addition, it appears that the operability of the commercial equipment will be good, so that there will be reasonable mechanical reliability. Currently we are working on resolving the remaining issues identified in ECLP, developing a process for the liquefaction residue, and maximizing heat utilization and recovery in the preferred plant configuration. Efforts by others to complete the development of coal partial oxidation should provide technology for efficient hydrogen generation.

Note added in proof: A significant technical milestone was reached while this article was in press. It was announced at a Sponsors Management Committee meeting on 27 January 1982 that the EDS coal liquefaction technology has been successfully demonstrated and that the tests have convinced project management that the liquefaction section of a 20,000 to 30,000 ton per day, commercial-size plant operating on Illinois No. 6 coal could be designed when commercially justified. Testing on Illinois coal in the 250 ton per day pilot plant will continue at more severe conditions, including lower solvent-to-coal ratios and higher liquefaction reactor temperatures, aimed at lowering the cost of the coal liquids produced. Demonstration of the technology on Wyoming subbituminous and Texas lignite coals and development of a special boiler utilizing liquefaction bottoms are expected to be completed in 1983.

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18. The work reported here is the result of a team effort of individuals too numerous to name who are or have been part of the following organizations: the Baytown Research and Development Division, the Exxon Engineering Department, and the Petroleum Research Department of Exxon Research and Engineering Company and the Synthetic Fuels Department of Exxon Co., U.S.A.

Transcriptional Control Signals of a Eukaryotic Protein-Coding Gene

Steven L. McKnight and Robert Kingsbury

Transcription of bacterial genes can be regulated by mechanisms operative at two distinct levels. One level of regulation occurs at the initiation step of RNA synthesis whereby RNA polymerase engages a bacterial gene and begins transcription. This process is governed by the interaction of specific proteins with regulatory DNA sequences located close to the site where transcription starts. Such regulatory DNA sequences can be acted on either to repress or to activate gene expression (*1*). A second level of transcriptional control in prokaryotes involves premature termination of an elongating RNA chain. This regulatory mechanism, referred to as attenuation, is mediated by a process involving intrastrand ribonucleotide sequence complementarity (*2*).

The basic physical mechanisms operative in the regulation of bacterial gene expression are likely to be used in the regulation of eukaryotic genes. It will come as no surprise, however, to find protein-DNA interaction and nucleotide sequence complementarity used in novel ways by higher organisms. For example, the phenotypic potential of different cell lineages in developing metazoan organisms become increasingly restricted as a function of embryogenesis. This phenomenon, known as embryonic determination, probably results from a mechanism that affects the implementation of semipermanent patterns of gene expression. It is not clear what specific bacterial regulatory mechanism could account for this phenomenon.

Initial studies of eukaryotic protein-coding genes, the class of genes most

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