EXXON DONOR SOLVENT COAL LIQUEFACTION PROCESS
ECLP OPERATING EXPERIENCE II

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ECLP Operating Experience

This is the second in a series of presentations covering operations of the Exxon Coal Liquefaction Pilot Plant, commonly known as ECLP. The first presentation was to the May meeting of the American Petroleum Institute[1] and covered the first 9-1/2 months of operations. This presentation covers all of the operations, through the end of the testing period, as well as the results of our second turnaround. On June 2 we shut down the plant for a scheduled turnaround and thus ended our test program with Illinois coal, as well as testing of operations in a once-through mode. Exxon Research and Engineering (ER&E) has completed studies that show that recycling vacuum fractionator bottoms to the reaction section increases process flexibility and is the preferred method from an economic standpoint. Therefore, bottoms recycle facilities were installed during our recent turnaround, and plans are to operate in the bottoms recycle mode for the duration of our operations on sub-bituminous and lignitic coals.

The Process and The Plant

The operation of the Exxon Coal Liquefaction Pilot Plant (ECLP) is the keystone of an integrated program to bring the Exxon Donor Solvent (EDS) process to commercial readiness. The status of this developmental program has been presented in a series of progress reports[2-6]. The program is sponsored by the U. S. Department of Energy, Exxon Company, U.S.A., Electric Power Research Institute, Japan Coal Liquefaction Development Company, Phillips Coal Company, Arco Coal Company, Ruhrkohle AG, and AGiP.

The simplified flow of the EDS process is shown in Figure 1. The five-part process provides for liquefaction of the coal, distillation of products, processing of bottoms, generation of hydrogen, and hydrogenation of the donor solvent. The Exxon Coal Liquefaction Pilot Plant facilities include only the liquefaction, distillation, and solvent hydrogenation units. The plant was erected in 26 months at a cost of $118 million. Operating costs, including raw materials, total about $3 million monthly.

In the process, mined coal is transported to the plant in a unit train of 30 cars, each carrying 100 tons. Coal is stored in a 5,000-ton silo and is prepared for liquefaction in a gas-swept mill where it is crushed to minus 30 mesh and dried to less than 4 percent moisture. An impact mill serves as a spare and crushes the coal to minus 12 mesh. Ground coal is slurried with solvent oil in a mixing drum and is pumped by two pump stages to 2,000 pounds pressure. Recycle and makeup hydrogen are added to the slurry before it is heated in a pipe still type furnace to a coil outlet temperature of 780 to 820°F. The hot slurry moves upflow through open reactors where 40 to 80 minutes residence time is provided, depending on coal rank.

After liquefaction, pressure is reduced to about 20 pounds and the reactant slurry is charged to an atmospheric and vacuum pipe still. Naphtha overhead, distillate sidestreams, and vacuum bottoms are produced. The middle distillate is directed to the solvent hydrogenation section and is fractionated after catalytic hydrogenation to prepare a solvent recycle, the "donor solvent," for donation of hydrogen to the reaction. Gases produced in the process are scrubbed for sulfur removal and are burned in the process furnaces, providing a large part of the plant energy requirements. The vacuum tower bottoms with a viscosity of about 30 to 50 poise are solidified and cooled from 650°F to 150°F on a solidification belt. The solid material is stored for future use in studies of bottoms processing options. Vacuum bottoms and heavy vacuum distillates can be recycled to increase conversion and selectivity to light products.

The plant is located on a 55-acre site adjacent to Exxon's Baytown Refinery. This location was chosen to utilize the manpower, utilities, and environmental capabilities of the nearby Exxon complex. The ECLP facility is operated as a separate entity and has its own administrative and staff organization. Process operators are on loan from the Baytown Refinery, and maintenance craftsmen and security personnel are provided by outside contractors.

The process block of the plant is reminiscent of a miniature refinery, except for the coal preparation section. The plant is complex and highly integrated, containing more than 52 miles of two inch and larger pipe; over 13,000 valves are utilized; and there are 107 miles of instrument tubing and electrical conduits. More than 1,500 feet of conveyors are operated; 15 towers, 68 drums, 148 pumps, 76 heat exchangers, 5 furnaces, and 17 tanks are employed. Figure 2 is a photo of the plant showing the Liquefaction/Distillation Units.

Plant Purpose and Operating Plan

The Exxon Coal Liquefaction Pilot Plant is a test facility to obtain information so that a pioneer plant could be designed with acceptable risk and reduced equipment cost. Operating know-how on three different coals will be obtained. Equipment problems and design technology information will be determined by an extensive test program. Overall process operability, reliability, and flexibility will be determined. Scale-up data and information for correlation and engineering guidelines will be developed. A fundamental understanding of the process and of the plant limitations will result from its operation.

The plant will operate for 24 months on three different coals--bituminous from Illinois, sub-bituminous from Wyoming, and lignite from Texas. An operating plan is presented in Figure 3. Each coal will be processed through a start-up and shakedown period to determine the know-how necessary for the following sustained run, then inspection and repairs are made before processing the next coal. The second coal run will be about 6-1/2 months, half as long as the first; and the third coal run will be about five months applying the learnings from each run to make the shorter time possible. The mechanical and operating test program for the plant covers 10 major areas, with maximum attention directed toward solving problems of machinery, materials, instrumentation, and heat transfer. All areas of concern are shown in Figure 4, along with the key learning needs of each. In all, about 90 different tests will be conducted, and the knowledge obtained will be used to optimize design and ensure plant service factor.

Operating Summary

We have been pleased with our operating experience and test program progress to date. Onstream time with coal-in is about what we expected, and learnings about design and operation gained along the way have permitted us to steadily increase the operating time between coal outages. Our two longest runs, each lasting more than one month, took place during the last three months of the Illinois test program, giving an overall coal-in factor of over 82 percent for that operating period. Figures 5A and 5B summarize the coal-in operations for the entire Illinois program of 368 days.

Component and Systems Design, Operations, and Maintenance

The key difference between coal liquefaction processing technology and petroleum refinery technology is the presence of solids in our liquid streams. What makes the problems created by the presence of these solids more difficult is that coal solids are abrasive and many coal liquid streams that are processed are sticky and/or have melting points well above ambient temperatures--in the case of vacuum bottoms, as high as 500°F.

A look at the schematic flow diagrams on Figures 6A and 6B illustrate the areas and types of equipment where the problems presented by these slurries are encountered. Some of our operating experiences and learnings, both for improved operation and future designs, for these sections of the plant are discussed in this presentation. Piping arrangements, in general, need careful consideration of fluid flow, block valve and check valve design, and the selection and use of erosion-resistant materials. Considerable knowledge has been gained in the operation of the centrifugal circulation pumps, and criteria for the use and design of the two sets of reciprocating pumps have been advanced. Instrumentation has presented many challenges and they have been met with varying degrees of success. Coking of the reaction section preheat furnaces has been reported previously, and good progress toward understanding the unusual coking phenomenon has been made. It is interesting to note that the vacuum fractionator furnace has shown no signs of coking.

Slurry Flow-Plugging of Process Lines

During early operations, there was a multitude of plugging problems due to solidification of slurry in process lines. These problems have been brought under control and are now in the nuisance category rather than having a significant effect on the coal-in factor.

The first step taken to help alleviate these problems was a systematic program to check out all the heat tracing in the plant including jacketed, steam, and electric systems. This program ensured that all tracing was properly designed and commissioned. One result of this work was a sixfold expansion of the jacketed system. A second finding was that when lines were shut down and flushed, flushing was not long enough. That is, lines that were thought to be clean were later discovered to be plugged. Increased monitoring of line flushing has greatly reduced this problem. A third find was that seldom-used lines, such as bypasses and taps for instruments and drains, must come off the tops of lines to prevent plugging. We continue to modify piping to eliminate problems caused by improper location of takeoffs and taps.

Minimum flow bypass lines in slurry service have also been a source of plugging. When flow increases are called for in the main line, the recycle or bypass line is robbed of the minimum flow required to prevent settling out and subsequent plugging. The design experience gained from investigating this problem was applied to the bottoms recycle project. Recycle around the pumps was sized to handle very high rates, and the control valve in the recycle line was specified to have a minimum port size that would prevent any particles from being caught. The net effect should be that changes in bottoms recycle rate will have a minimal effect on pump recycle and, therefore, promote smooth operation.

In future designs of systems involving slurry service, the number of lines (piping configurations) will be minimized. Having the capability for several different operating modes, as is provided at ECLP, is useful, but service factor penalties for increased line plugging tendencies must be weighed against the flexibility advantages.

ECLP Slurry Block Valve Operability

Four types of block valves are used in slurry service at ECLP. The valve types used are the wedge-type gate valve, through-conduit-type gate valve, lubricated-tapered plug valve, and the Trunnion-mounted ball valve with spring preloaded metal seats. Before discussing the specific experience with each valve type in detail, it should be noted that the overall experience with block valves in slurry service at ECLP has been satisfactory. Figure 7 presents a summary of services for the four types of valves being tested.

Two wedge-type gate valves are used as the inboard block valves (closest to pump) on the suction of the P-204 atmospheric bottoms pumps. The valves are not flushed with each cycle but do close on a diluted slurry because the outboard block valves, which are flushed with each cycle, are closed first. No operational problems have been encountered with these valves during ECLP's first year of operation. These valves have accumulated about 78 cycles on coal and have passed recent leakage tests. A hundred cycles are considered the life requirements in a commercial plant. To further define the reliability of wedge-type gate valves in slurry service, valves of this type have been installed in the P-101 slurry pumparound loop and bottoms recycle.

Through-conduit-type gate valves, which are flushed with each cycle, are used throughout ECLP in slurry service. These valves are used on the suction of the P-101 slurry pumparound circulation pumps, the high-pressure side of the L-106CV high-pressure letdown valve, the outboard block valves on the suction of the P-204 atmospheric bottoms pumps, and the suction of the P-210 vacuum bottoms pump. These valves have been cycled from between 12 times around the high-pressure letdown valves and 78 times around the atmospheric bottoms pumps. The operational experience and leakage test results have been satisfactory, provided the valves were adequately flushed with each cycle.

Lubricated-tapered plug valves are used to isolate the discharge of the P-101 slurry pumparound circulation pumps, P-102 high-pressure slurry feed pumps, discharge of the P-216 atmospheric bottoms test pump, and L-206CV vacuum bottoms feed to the Sandvik belt valve. Sticking and seizing problems were encountered early in plant operation until a suitable valve lubricant/sealant was found and a routine maintenance schedule established. Since that time, the valves have accumulated from 10 to 70 cycles on coal with no operational problems--the one exception being the outboard discharge block valves on the P-102 high-pressure slurry feed pumps.

The Trunnion-mounted ball valves with spring preloaded metal seats are used in the solids withdrawal system, low-pressure side of the L-106CV high-pressure letdown valves, and the suction of the P-216 atmospheric bottoms test pump. Problems with solids buildup in both the spring and body cavities have caused one valve to seize on the suction of the atmospheric bottoms test pump and the valves on the low-pressure side of the high-pressure letdown valve to fail leakage tests. However, the valves on the low-pressure side of the letdown valve performed satisfactorily enough to enable isolation and removal of the letdown valve due to a double block and bleed arrangement. The valve on the suction of the atmospheric bottoms test pump is being replaced with a modified valve that has grease connections to the spring and body cavity to prevent solids buildup. Metal-seated floating ball valves are being installed in bottoms recycle and the slurry pumparound loop to obtain data on this other type of ball valve.

Corrosion/Erosion

From the standpoint of erosion and corrosion, the overall performance of equipment and materials at ECLP has been favorable. Valuable information concerning erosion and erosion-corrosion has already been obtained. For instance, general guidelines have been developed to select slurry piping based on temperature, velocity, and geometry. Piping systems have been redesigned to eliminate or minimize flow disturbances since these have a pronounced effect on metal loss.

One of the most erosive services in the plant is in the vacuum tower transfer line. With a solids content of 30 weight percent and velocities over 200 feet per second, this slurry severely eroded the original five-chrome transfer line. This line was partially replaced during the first turnaround with pipe lined with a fiber-reinforced, high alumina refractory. After approximately 120 days of on-coal service, minimal wear has occurred.

Another area of accelerated erosion during shakedown operations was in the mixing chamber downstream of the main letdown valve. The original five-chrome vessel lost over one-fourth inch of metal. Again, this was replaced with a refractory-lined vessel which experienced only minor attack by the high temperature abrasive slurry. Refractory spalling did occur, but this was due to improper installation of the refractory anchoring. The refractory anchors were modified during the recent turnaround and the vessel was reinstalled.

The atmospheric fractionator experienced erosion-corrosion, which ultimately resulted in a pinhole leak in the tower shell. The attack was concentrated in a section of the tower which operates in the 420-480°F range, which corresponds to the experience of other coal liquefaction plant operators. Maximum metal loss occurred on the carbon steel tower shell where the manway trays rest on the tray support rings. Turnaround inspection found that the manway/tray fit-up created a small, highly turbulent area which resulted in localized metal loss as shown in Figure 8. More generalized attack was noted on a circumferential band approximately six inches above each tray, while the 316 stainless steel downcomers and trays were unaffected. The 12-foot section of the tower affected has been replaced with a 321 stainless steel-lined section. Six corrosion racks, containing a range of alloys, and one corrosion probe were installed in this new section for monitoring corrosion. Samples of process liquid were also collected from this section of the tower for laboratory corrosion testing and chemical analyses.

Centrifugal Pumps

After approximately 2,400 hours of operation on coal slurry, the P-101A and B feed booster pumps, which operate in series, show less wear than was anticipated--primarily due to the conservative impeller tip speed selected for initial operations. These 400-gpm, 1250-rpm centrifugal pumps had an overall service factor of about 95 percent after the November 1980 turnaround. Throughout the entire operation, no performance deterioration was detected, indicating low wear of the critical components (impellers and liners). During the June 1981 turnaround, both pumps were pulled and inspected. The inspection confirmed the low wear rates indicated by the satisfactory hydraulic performance of the pumps. As shown in Figure 9, the volute (casing) liners show the most wear at the cutwater -- the dividing point between centrifugal and straight flow. Since the geometry of the cutwater is critical to the pumps' hydraulic performance, the new volute liners will have a modified cutwater for wear reduction.

As part of the pump test program objectives, the major wear components of these pumps were replaced in order to obtain wear rates from the next coal operation. However, the difference in coal per se is not likely to significantly change the wear rates of the pumps. It is likely that the speed of these pumps could be increased for increased performance without a major reduction in the useful life of the wear components. This will be investigated during the Wyoming coal operations using the P-101C spare pump.

The high-speed (3,560 rpm) P-101E coal slurry test pump has operated for approximately 600 hours on coal in a test loop around the slurry drier. This pump, which was designed for the same service conditions as the other P-101 pumps, suffered a much higher wear rate than the P-101A and B process pumps, as illustrated in Figures 10 and 11. This higher wear rate confirmed that high impeller tip speed is not attractive for slurry operation--at least with currently available materials. In spite of the high wear rate, the liners will be replaced with new ones of the same material for testing at a lower speed with Wyoming coal.

During the Illinois coal run, the P-216 atmospheric bottoms centrifugal test pump logged about 1,100 hours on slurry. Just prior to the June turnaround, this 1800-rpm, 50-gpm pump was pulled and inspected. The pump showed very little wear. As a result, the speed was increased to 2400 rpm in order to accelerate wear (for test purposes).

Reciprocating Pump Packing Experience

Although reciprocating pump packing life was not a concern before operations, it quickly became a major factor in plant operability. Major packing problems were initially experienced with the P-204 atmospheric bottoms pumps.

The atmospheric bottoms pumps operate at about 650°F with a differential pressure of 475 psi and a design flow rate of 40 gpm, with the pumped fluid containing about 30 weight percent solids. A schematic diagram of a typical cylinder is presented in Figure 12. The current stuffing box packing is of the adjustable type. Clean flush oil is injected into the top of the throat bushings on the suction (upward) stroke of each cylinder using a reciprocating flush pump that is synchronized with the main pump. Packing lubrication is provided by a force feed lubricator, and a leakoff line is located below the secondary packing to dispose of any leakage that passes the primary packing.

During initial plant operations, these pumps averaged only two or three days on coal before repacking was required. Each failure was documented in a pump failure analysis report and a root cause assigned. Through this analysis system, a number of items were identified as causing or contributing to the short packing life. The most important of these were plunger alignment and coatings, reliable flush and packing lubrication systems, packing materials and prompt packing adjustment, and clear leakoff lines. A steam quench has been added to the stuffing box and the leakoff lines have been steam traced to prevent bottoms solidification.

Improvements in operating and maintenance procedures, as well as packing and plunger material changes, have dramatically extended the packing life in the atmospheric bottoms pumps. The latest data indicate an average packing life of 15 to 20 days, and 22 days in service with no indication of pending failure, had accumulated just prior to turnaround. This service life is still not considered acceptable and redesigned stuffing boxes, the ones depicted in Figure 12, are now being installed. These new stuffing boxes incorporate longer throat bushings in an attempt to prevent the slurry from contacting the packing, as well as a significant increase in the length of the packing area. This will allow testing of various packing schemes that are not possible with the present design. Figure 13 shows the old and new stuffing boxes side-by-side.

The main slurry feed pumps P-102A/B operate at less than 300°F and have a design flow rate of about 80 gpm and a differential pressure of 3175 psi. The pumped fluid can contain up to 50 weight percent solids with normal operations in the 40 to 45 weight percent range.

All of the factors found to be important for the atmospheric bottoms pumps are also important for these pumps, except steam quench and steam tracing of the leakoff lines are not required since solidification of the pumpage is not a problem. However, due to the high differential pressure, the flush injection system is of critical importance. With our present injection system, which injects flush on the suction stroke only, small amounts of slurry get into the packing on the discharge stroke. This results in eventual premature packing and plunger coating failure. A system modification is presently in design which will allow the testing of two alternative flushing schemes with the objective of finding a way to prevent the incursion of slurry into the packing.

Slurry Furnace Coking

The shakedown period on Illinois coal was a favorable experience from a coking standpoint with little evidence of long-term coking and no hot spots in the slurry preheat furnace. Because of this favorable experience, it was decided to insulate some of the tubes in the spare furnace to achieve a heat flux in excess of 12,000 Btu/hr ft^2. This furnace became known as the "high-flux" furnace with the original furnace, which operates at a heat flux of 7,000 to 8,000 Btu/hr ft^2, the "low-flux" furnace. Hot spots first occurred in the high-flux furnace on January 19, three days into Run 11 and 14 total days on coal. Coking became more severe on January 30 and necessitated termination of Run 11. Subsequently, the low-flux furnace coked after only 49 hours of operation. Both furnaces continued to coke periodically through the Illinois No. 6 run with the low-flux furnace just as susceptible as the high-flux furnace. The coke formed in this service is soft and has been easily removed by standard Exxon decoking procedures.

The coking that has occurred has been highly localized in the peak flux region of the furnace box and has occurred very rapidly. After a coking incident on March 22 ended the second longest coal-in period (Run 14--738 hours), a section of the tube containing the deposit was removed. A photo enlargement of a cross section of the deposit found in this tube is shown in Figure 14. Analysis of the deposit revealed that it formed quickly--probably in one coking episode.

Several furnace tests were carried out prior to turnaround to determine if changes in flow rates and temperature had any effect on this type coking. No coking occurred as the result of changes to slurry and gas flow rates or temperature. However, a hot spot did occur--with a 30°F rise in tube metal temperature observed in over a ten-minute period. This rise in tube metal temperatures was simultaneous with a flow meter and pump speed spikes on the slurry feed to the furnace. The conclusion drawn from this is that the coking may be related to nonhomogeneous slurry flow. Slugs of material, perhaps high coal concentration in a gel state, pass through the system causing pump speed variations and in the extreme, rapid coking in the furnace. Further investigation into events and operating data for the time period preceding the coking incident is continuing.

In contrast to the reaction section preheat furnace, the slurry vacuum furnace did not exhibit any coking problems throughout the Illinois No. 6 run. X-rays show the tubes to be clean and free of coke. However, minor erosion has taken place in the return bend of the last tube in the slurry vacuum furnace.

To Be Continued

The third report in this series will be presented next Spring after completion of the Wyoming coal run and the turnaround inspection that follows it. Main objectives for the Wyoming run include: 1) repeat of most of the hardware test program; 2) demonstration of bottoms recycle technology; 3) maintenance of at least 70 percent coal-in service factor; 4) completion of critical test operations not performed during the Illinois coal run; and 5) demonstration of various conversion levels.

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LIST OF FIGURES

FIGURE I

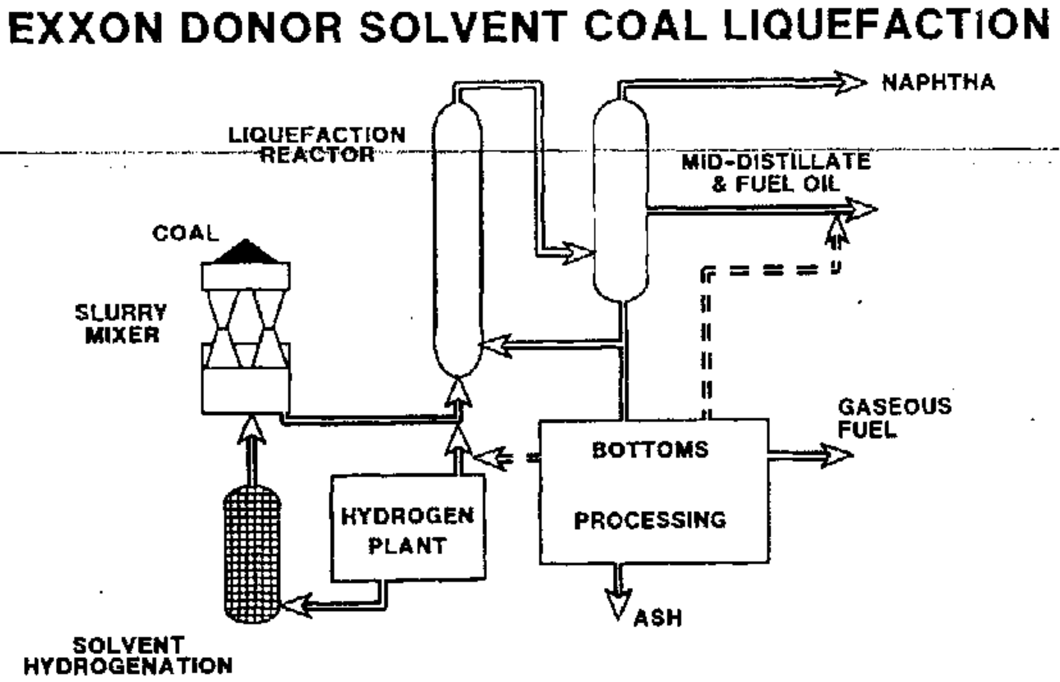


FIGURE II

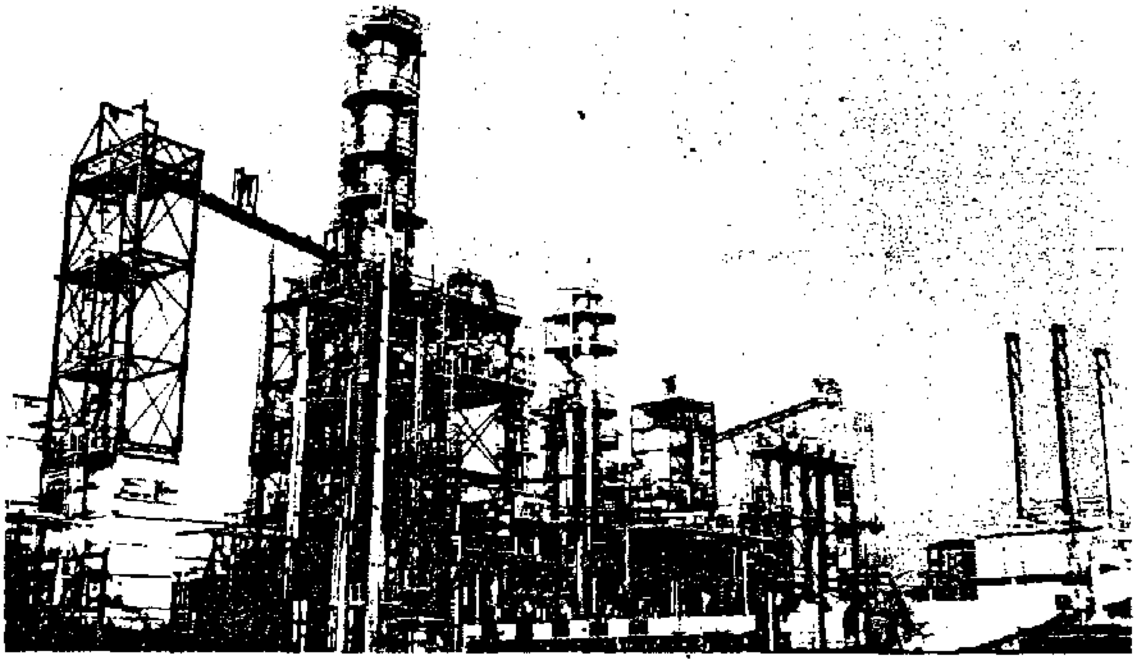
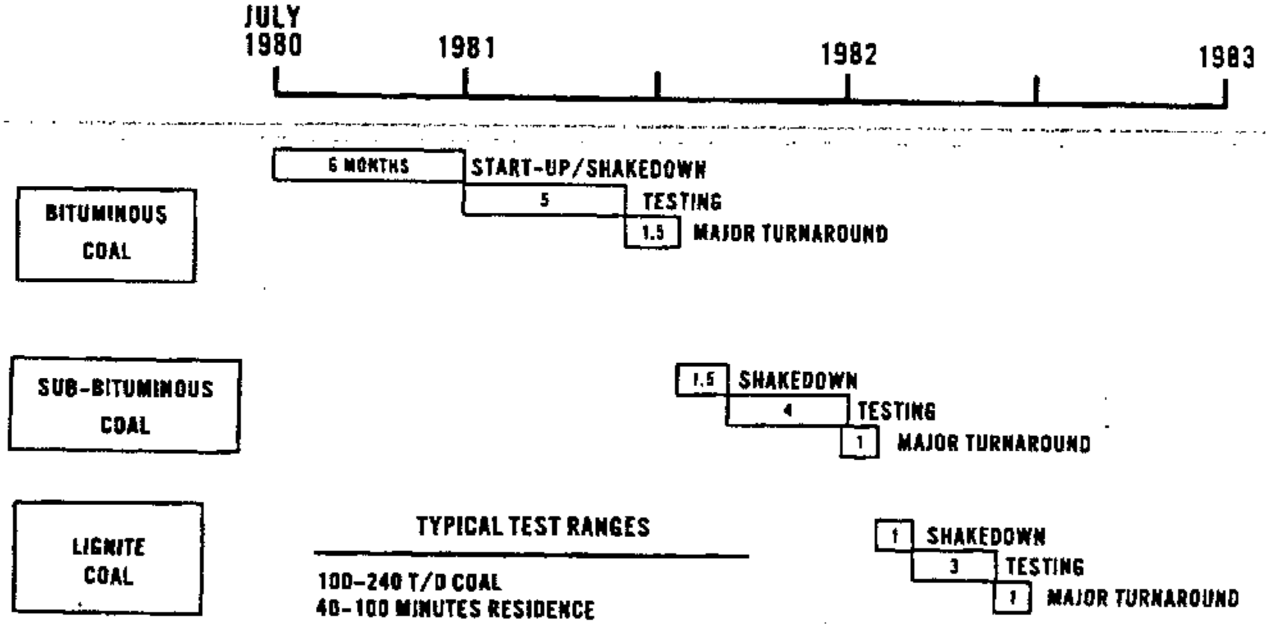


FIGURE III

ECLP TEST PROGRAM PLANS



TYPICAL TEST RANGES

100–240 T/D COAL
40–100 MINUTES RESIDENCE
800–860°F
1900–2500 PSIG PRESSURE
ONCE-THROUGH/RECYCLE CONFIGURATION
50–70% COAL-IN SERVICE FACTOR

FIGURE IV

MAJOR AREAS OF TECHNICAL CONCERN

TECHNOLOGY	PRIMARY CONCERN
• FURNACES	• COKING/DESIGN METHODS
• REACTORS	• PROCESS SCALE-UP/DISTRIBUTOR TESTING/SOLIDS WITHDRAWAL
• SOLIDS HANDLING	• OPERATING EXPERIENCE
• TOWERS	• FRACTIONATION/ENTRAINMENT
• INSTRUMENTATION • VALVES • PUMPS	• OPERABILITY/EVALUATION OF ALTERNATIVES/DESIGN DATA FOR ABRASIVE SLURRIES
• ENVIRONMENTAL • WASTE TREATMENT	• SAMPLING/AREA MONITORING
• CONSTRUCTION MATERIALS	• EROSION/CORROSION

FIGURE Va

ECLP COAL-IN SUMMARY
ILLINOIS #6 SHAKEDOWN

RUN	HOURS IN	HOURS OUT	% SERVICE FACTOR	SHUTDOWN PRIME SOURCE
1	128	242	35	PLUGGING – HEAT TRACING
2	509	233	69	EROSION
3	32	187	15	PLUGGING – JACKET HEATING
4	134	223	38	FEED CONVEYOR AND PLUGGING – JACKET HEATING
5	77	112	41	PLUGGING – JACKET HEATING
6	77	109	41	PLUGGING – HEAT TRACING
7	173	129	57	HYDROGEN COMPRESSOR, FEED SYSTEM
8	115	T/A	-	SLURRY CARRYOVER
	1,245	1,235	51	

FIGURE Vb

COAL-IN SUMMARY -- TESTING PERIOD
DECEMBER 30, 1980 - JUNE 2, 1981

RUN	HOURS IN	HOURS OUT	% SERVICE FACTOR	SHUTDOWN PRIME SOURCE
9	29	58	33	SOLIDIFICATION BELT STOPPAGE/DAMAGE
10	226	128	64	LEAKING BLOCK VALVES AROUND SLURRY FEED PUMPS
11	317	67	83	PREHEAT FURNACE (F-102B) COKING
12	49	254	19	PREHEAT FURNACE (F-102A) COKING
13	6	92	6	REFRACTORY IN BOTTOMS PUMPS
14	738	244	75	SOLIDIFICATION BELT REPLACEMENT, FURNACE COKING
15	398	161	71	ATMOSPHERIC FRACTIONATOR CORROSION
16	39	43	48	REFRACTORY IN BOTTOMS PUMP
17	856	2	100	INSPECTION/TURNAROUND
	2,658	1,049	72	

FIGURE VIa

SCHEMATIC FLOW DIAGRAM
LIQUEFACTION UNIT

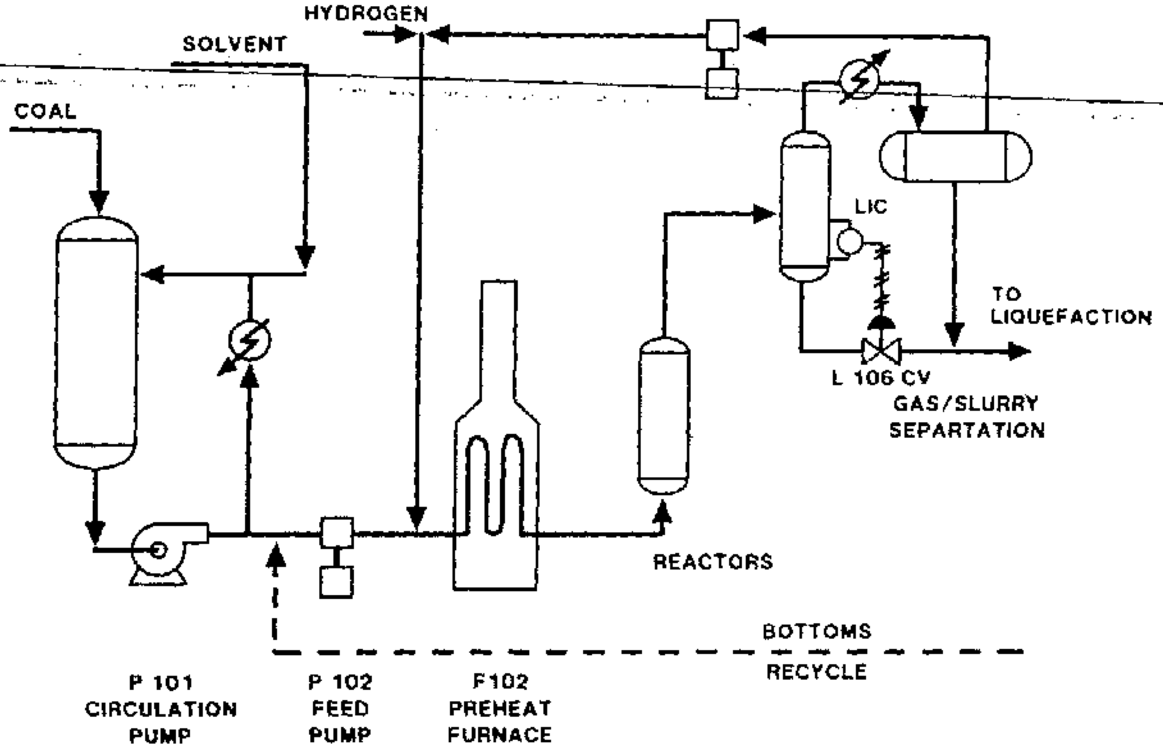


FIGURE VIb

SCHEMATIC FLOW DIAGRAM
DISTILLATION UNIT

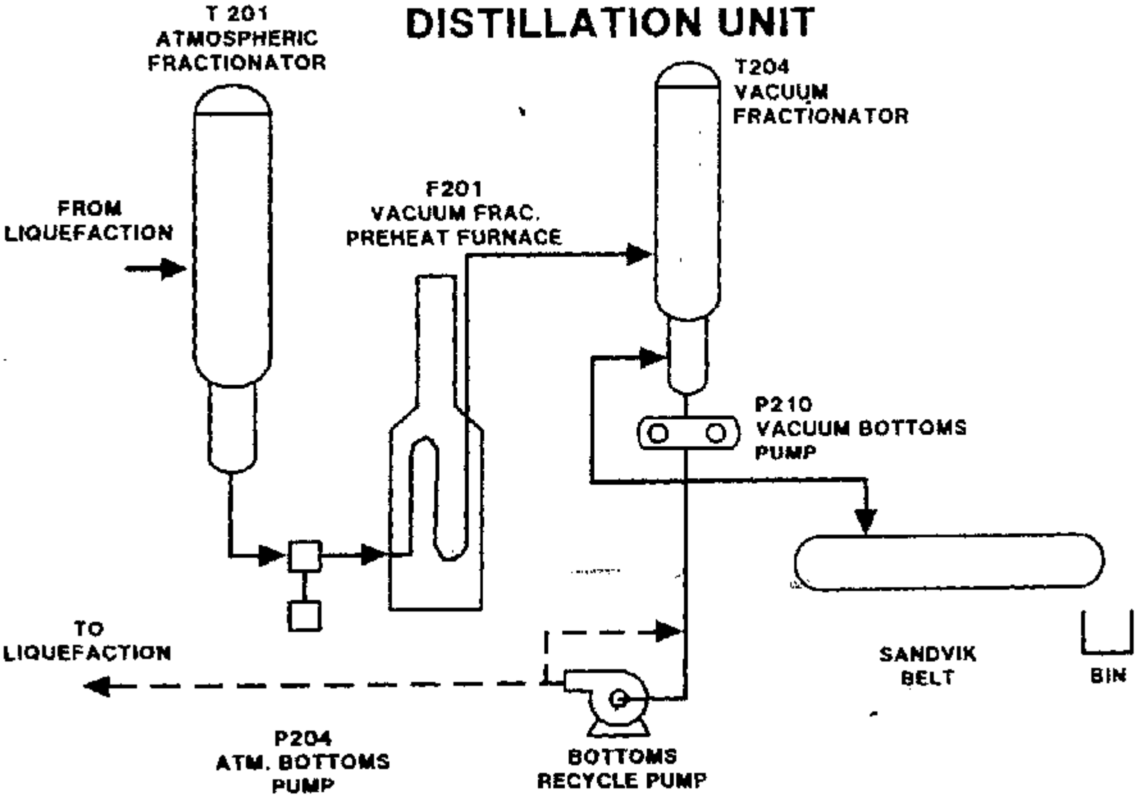


FIGURE VII

BLOCK VALVE TYPES BEING TESTED AT ECLP

UPSTREAM VALVES			DOWNSTREAM VALVES	
OUTBOARD	INBOARD	FACILITIES BEING ISOLATED	OUTBOARD	INBOARD
	THRU CONDUIT	P-101 FEED SLURRY CIRCULATION PUMPS	PLUG	
	PLUG	P-102 HIGH-PRESSURE SLURRY FEED PUMPS	PLUG	PLUG
THRU CONDIUT	THRU CONDUIT	L-106CV HP SLURRY LETDOWN VALVES	BALL	BALL
THRU CONDUIT	WEDGE	P-204 ATMOSPHERIC BOTTOMS PUMPS	THRU CONDUIT	THRU CONDUIT
BALL	BALL	P-216 ATMOSPHERIC BOTTOMS TEST PUMPS	PLUG	
THRU CONDUIT	THRU CONDUIT	P-210 VACUUM BOTTOMS PUMP	PLUG	

LEGEND

BALL -- TRUNNION-MOUNTED BALL VALVE
THRU CONDUIT -- THROUGH-CONDUIT-TYPE GATE VALVE
PLUG -- LUBRICATED-TAPERED PLUG VALVE
WEDGE -- WEDGE-TYPE GATE VALVE

FIGURE VIII

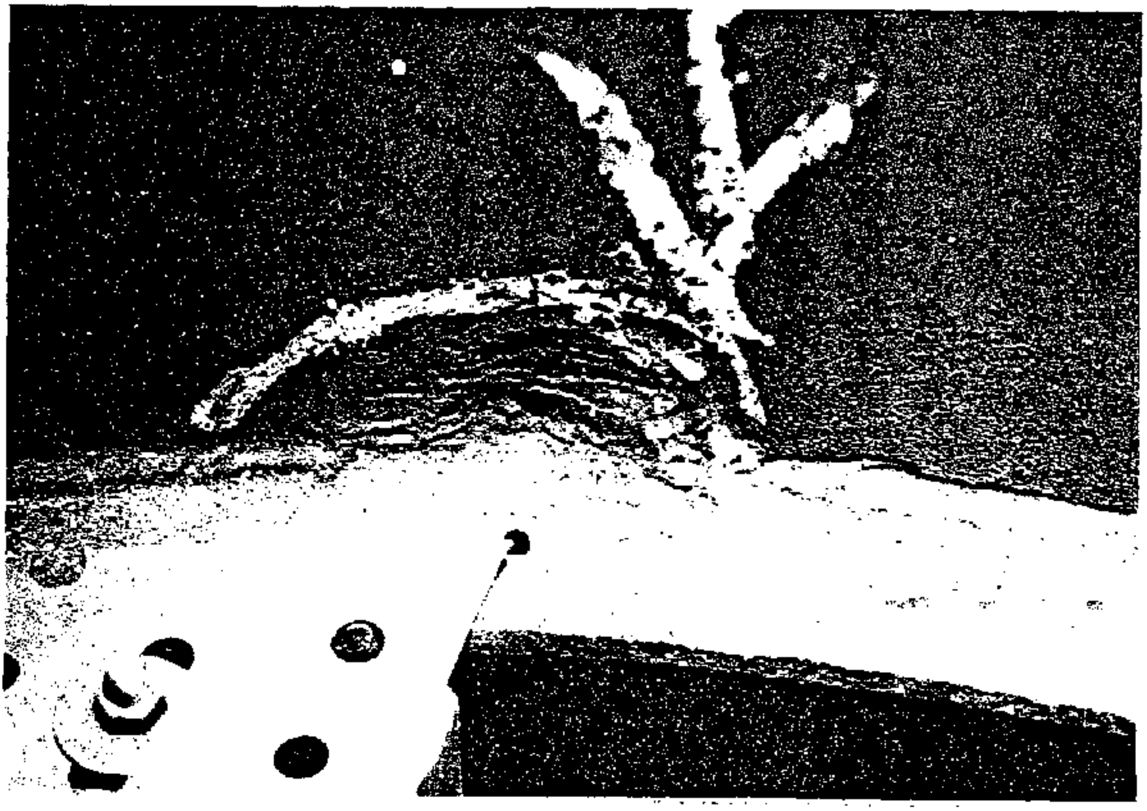
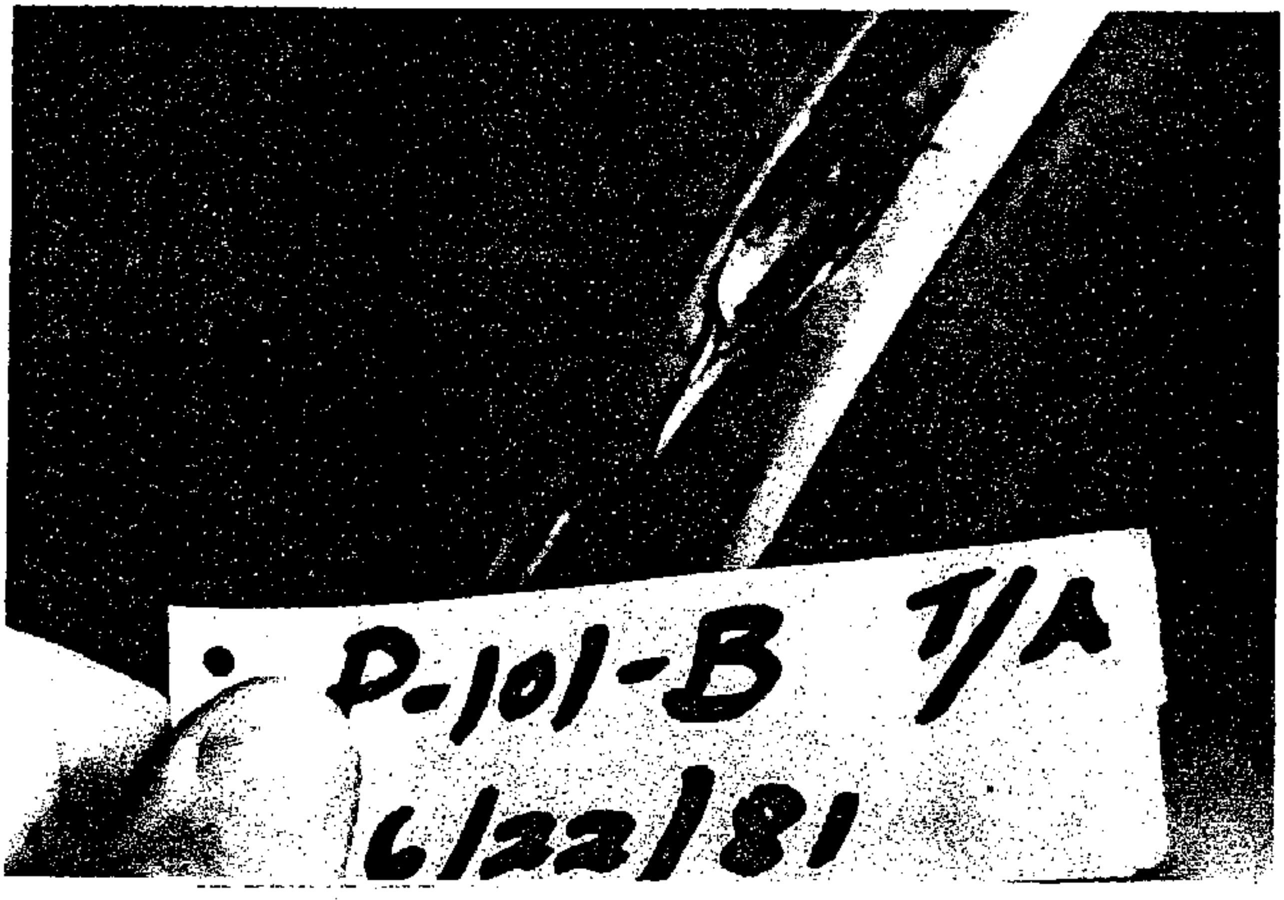


FIGURE IX

FIGURE X



D-101-B T/A
6/22/81

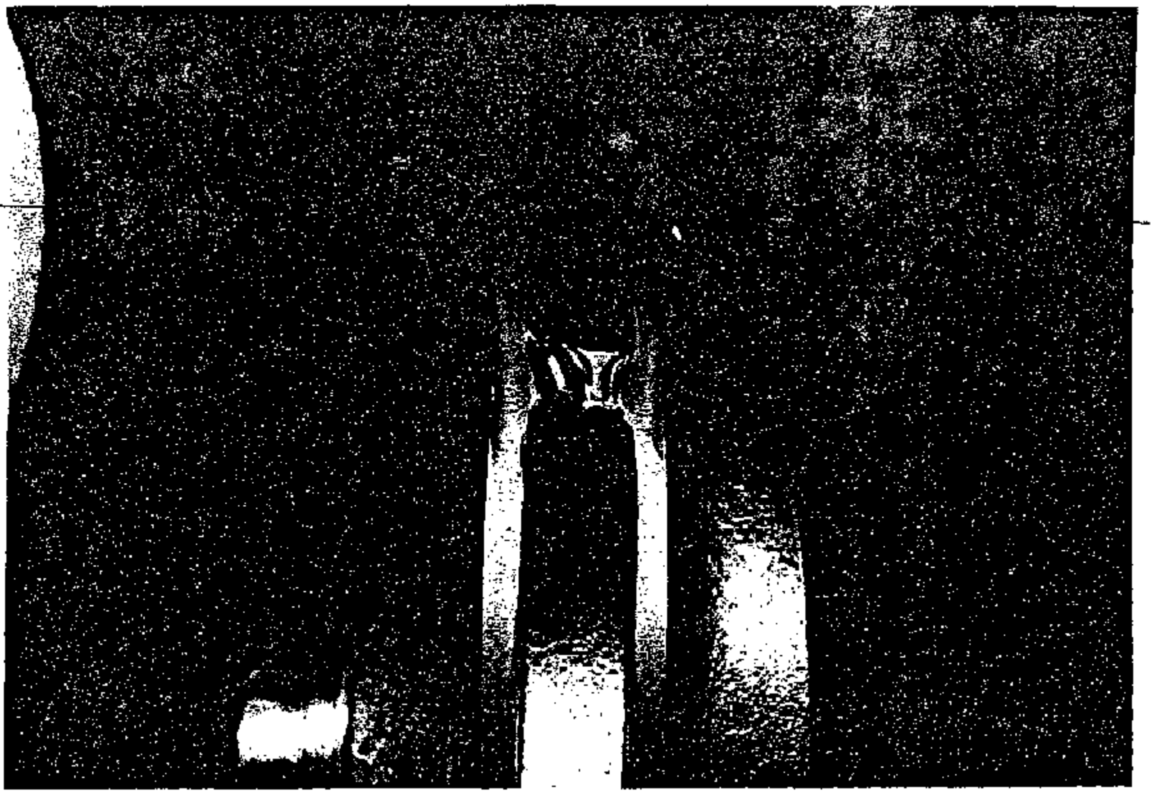


FIGURE XII

RECIPROCATING PUMP ARRANGEMENT

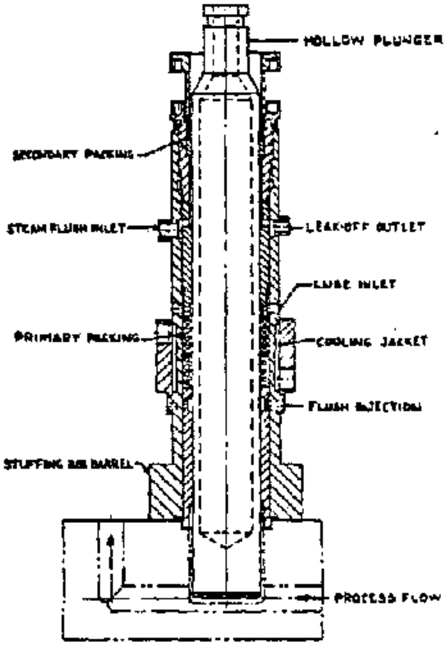


FIGURE XIII

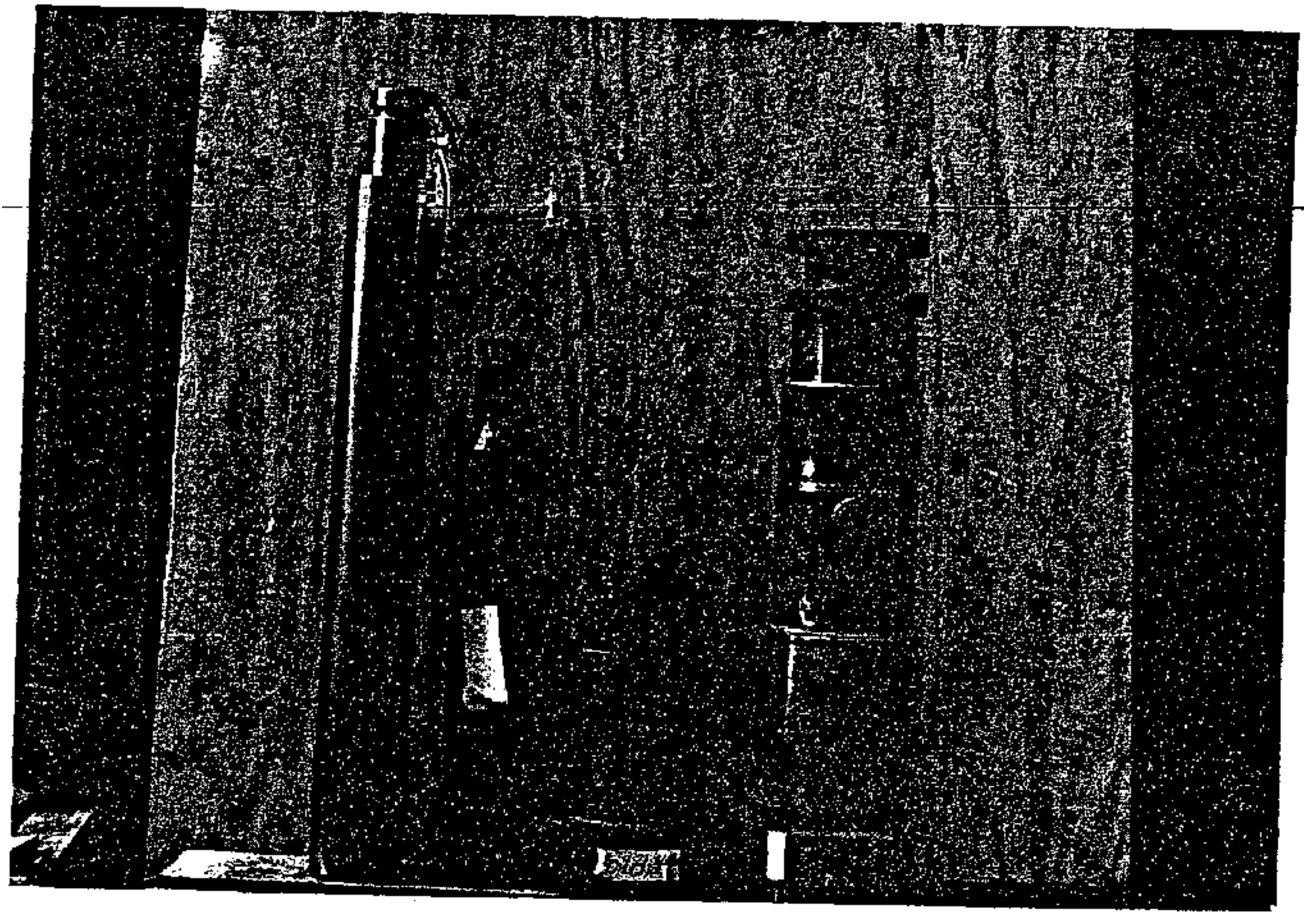
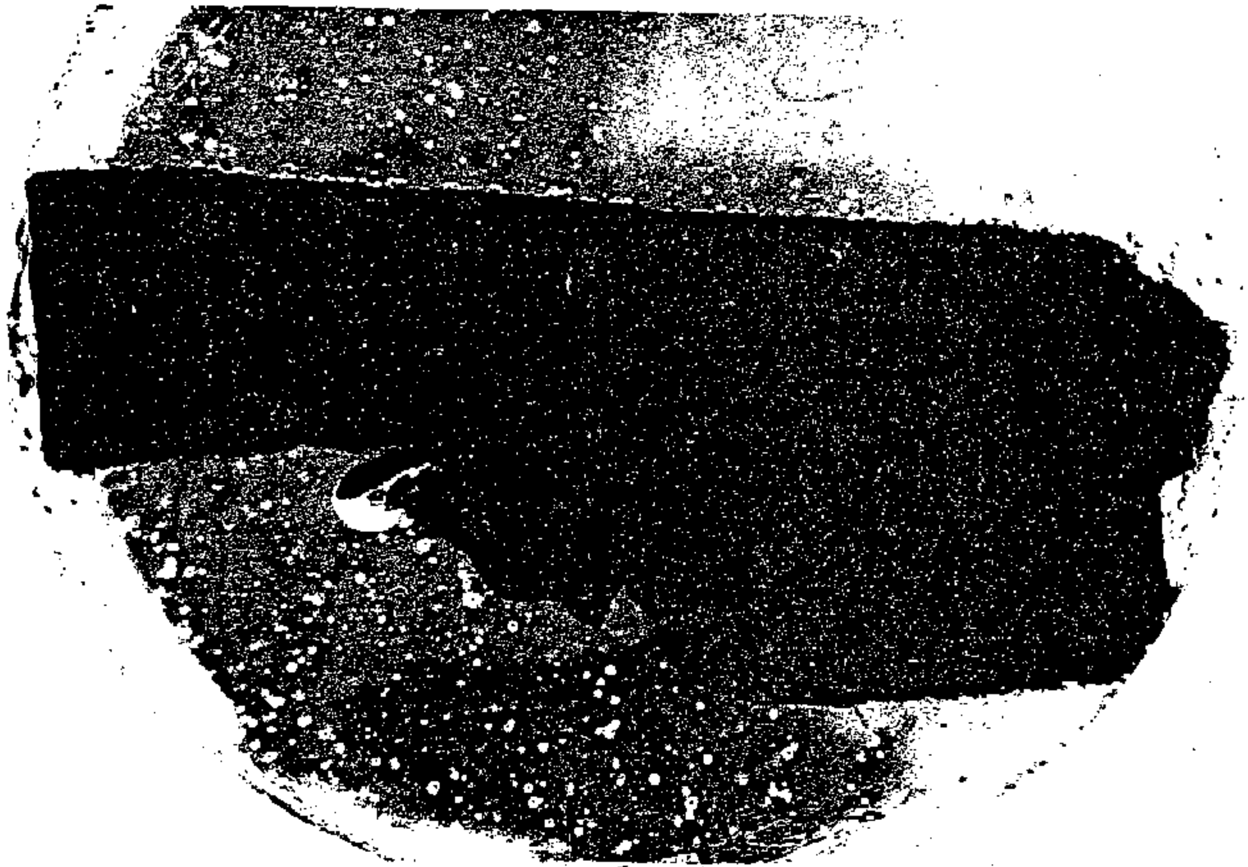


FIGURE IVX



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