

EDS COAL LIQUEFACTION PROCESS DEVELOPMENT

PHASE V

EDS Commercial Plant Study Design Update
Onsite Design Basis - Wyoming Coal Case

Interim Report

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EDS COAL LIQUEFACTION PROCESS DEVELOPMENT-PHASE V
COMMERCIAL PLANT STUDY DESIGN UPDATE
ONSITE DESIGN BASIS
WYOMING COAL CASE

Abstract

This report is an Interim Report for U.S. Department of Energy Cooperative Agreement No. DE-FC01-77ET10069 for EDS (Exxon Donor Solvent) Coal Liquefaction Process Development-Phase V. This report covers the Onsite Design Basis for the Wyoming Coal Case of the EDS Commercial Plant Study Design Update. Funding is shared by U.S. Department of Energy, Exxon Company, U.S.A (a division of Exxon Corporation), Electric Power Research Institute, Japan Coal Liquefaction Development Company, Philips Coal Company, ARCO Coal Company, Ruhrkohle AG and Agip S.p.A. The agreement covers the period January 1, 1977 through December 31, 1982. The Laboratory Process Research and Development studies was conducted at various Exxon Research and Engineering (ER&E) facilities: Research and Development Division at Baytown, Texas; Products Research Division at Linden, New Jersey; and the Exxon Research and Development Laboratories at Baton Rouge, Louisiana. The engineering research and development studies were performed at the Synthetic Fuels Engineering Department and Exxon Engineering Technology Department at Florham Park, New Jersey.

The Wyoming Coal Case will utilize partial oxidation of about one half of the vacuum pipestill bottoms for hydrogen generation and FLEXICOKING* of the remaining bottoms to make low Btu gas (LBG) for use as plant fuel. This configuration is essentially the same as used in the Illinois Coal Market Flexibility Sensitivity Case. The methane/ethane product will be sold as high Btu gas (HBG). HBG will also serve as backup fuel for the onsite area. The Wyoming Coal Case is being developed as a sensitivity to locating a commercial EDS plant in a northeast Wyoming location.

The report is to serve two purposes. First to present the design bases for the study, (i.e., feed rate, product yields, configuration, etc). Second, to summarize and reference the laboratory and engineering studies carried out in setting the design bases. These studies cover the development of the liquefaction operating conditions and the configuration of process units within the EDS plant.

*"Service Mark"

EDS COMMERCIAL PLANT STUDY DESIGN UPDATE
ONSITE DESIGN BASIS
WYOMING COAL CASE

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EDS COMMERCIAL PLANT STUDY DESIGN UPDATE
ONSITE DESIGN BASIS
WYOMING COAL CASE

This report documents the onsite design basis for the EDS Commercial Plant Study Design Update - Wyoming Coal Case. The report is to serve two purposes. First, to present the design bases for the study, (i.e., feed rate, product yields, configuration, etc.). Second, to summarize and reference the laboratory and engineering studies carried out in setting the design bases. These studies cover the development of the liquefaction operating conditions and the configuration of the processing units within the EDS plant.

Two study design cases have already been developed for Illinois No. 6 Bituminous Coal from the Monterey No. 1 Mine (Monterey coal); the Illinois Coal Base Case and the Market Flexibility Sensitivity (MFS) Case, (References 1, 2, 3, 4). The Illinois Coal Base Case is a maximum C₄⁺ liquids case including FLEXICOKING to process vacuum bottoms and steam reforming of C₂⁻ gas to supply hydrogen. The Illinois Coal MFS Case is a higher thermal efficiency case where partial oxidation of part of the vacuum bottoms is used to produce hydrogen. A FLEXICOKING unit is employed to process the remaining vacuum bottoms and C₂⁻ is sold as high Btu gas.

The plant feed coal is Wyoming subbituminous coal. The dry coal feed rate to liquefaction is to be 25.0 kST/SD (36.3 kST/SD of "as received" coal); the same dry feed basis as in the Illinois Coal Base and MFS cases. The process configuration is to be identical to that of the Illinois Coal MFS Case, i.e., the use of FLEXICOKING and partial oxidation to produce plant fuel and hydrogen, respectively. However, the operating conditions have changed as a result of differences in the properties of Wyoming vs. Illinois coal.

The quality of the onsite design will be comparable to the Illinois Coal Base Case and MFS Case. Wherever possible, the previous designs will be used to develop the onsite design for the Wyoming Coal Case while maintaining the same design quality.

Wyoming Coal Feed
Properties Affect Onsite Design

Feed properties for Wyoming subbituminous coal are given in Table 1. Wyoming coal is lower in rank than Illinois coal and has different characteristics which affect the design of the onsite facilities. These differences are outlined below:

- Based on operational and yield advantages a higher liquefaction severity, was selected for Wyoming coal relative to Illinois coal to achieve about the same level of conversion. As a result, a 60 minute residence time and 1.6 solvent-to-coal (S/C) ratio (vs 40 minutes and 1.2 S/C for Illinois coal) were chosen as liquefaction conditions for Wyoming coal. Thus, the liquefaction reactor volume will be about twice that for Illinois coal.

- The ash content of Wyoming coal is 7.2 wt%, which is lower than cleaned Illinois coal at 9.1 wt%. Thus, a lower ash rejection rate from bottoms processing is achievable with Wyoming coal. However the viscosity of vacuum bottoms from Wyoming coal is significantly higher than from Illinois coal.
- The moisture content of Wyoming coal is about twice that of Illinois coal. Therefore, the slurry drying facilities are substantially larger than those of a plant using Illinois coal. This additional slurry drying capacity may be reduced somewhat by increasing drier temperature.
- Wyoming coal is considerably lower in sulfur than Illinois coal which results in less H₂S and lower sulfur content in the liquid products. Thus, excess spent solvent and 350/400°F naphtha need not be hydro-treated before blending them into the fuel oil, as in the Illinois Coal Base Case and MFS Case. The 350/400°F naphtha is being blended into the fuel oil to reduce its viscosity.
- The calcium content of Wyoming coal is about seven times greater than for Illinois coal which leads to CaCO₃ deposition in the reactors, a potential problem that is not present in Illinois coal. This requires changes in design and operational procedures.

Process Configuration

Screening economics based on the EDS Process Alternatives LP Model (PAM) were used to select the process configurations for the Illinois and Wyoming coal cases. A grid of PAM-LP model cases were developed for the Wyoming coal SDU process configuration study. These cases considered the following process alternatives to generate H₂ and fuel for the EDS plant.

- To generate hydrogen
 - + Steam reforming of C₁, C₂ and C₃.
 - + Partial oxidation of vacuum bottoms.
 - + Moving-bed gasification of coal
- To generate fuel
 - + FLEXICOKING of vacuum bottoms (produces LBG fuel)
 - + Partial oxidation of vacuum bottoms (produces IBG fuel)

The economic basis for the study was a 1985 startup and operation in Wyoming. Liquefaction conditions for this study were 840°F, 40-80 minutes residence times, 1500 psi nominal hydrogen partial pressure, and a 1.6 solvent-to-coal ratio. These conditions were found to be attractive in a liquefaction process variables study (Reference 5) and were chosen to provide a basis for comparison of the above process alternatives. For all cases, high Btu gas, when available, was sold in Btu parity with petroleum distillate. The study also included deep-cut fractionation in the vacuum pipestill upstream of partial oxidation; thus minimizing the 1000°F- content in the vacuum bottoms and maximizing liquid recovery. Cutting deeper is limited by the increases in the viscosity of the bottoms as the 1000°F- content decreases and its adverse effect on pump performance. Other factors which affect bottoms viscosity are liquefaction severity, storage time and storage temperature.

The results for the best three cases from this screening study are compared at various liquefaction residence times in Figure 1. Figure 1 shows the configuration using FLEXICOKING for fuel and partial oxidation for hydrogen to be the most economically attractive. This configuration was therefore chosen as the basis for the Wyoming Coal Case. Thus, the configuration for the Wyoming Coal Case is essentially the same as that in the Illinois MFS Case except for the operating conditions.

The process configuration for the major processing blocks is shown in Figure 2. Cleaned coal, received in coal preparation, is crushed to the desired size, and is sent to the slurry driers. In the slurry driers, the coal is dried and slurried with solvent. The slurried coal is processed in a plant consisting of two onsite trains, each containing two lines of liquefaction furnaces, reactors and separators with common treat gas facilities. The two liquefaction lines in each train share common fractionation facilities to separate coal liquids into spent solvent, raw product streams (C₂-, C₃/400°F and VGO), and vacuum bottoms. A major portion of the spent solvent is sent to solvent hydrogenation to produce hydrogenated recycle solvent; the remaining spent solvent is blended into the fuel oil. Each train has a single solvent hydrogenation section consisting of a furnace, several hydrogenation reactors, separators, a fractionator and H₂ treat gas facilities. Solvent hydrogenation produces the hydrogenated (hydrogen donor) recycle solvent and raw product streams (C₂- and C₃/400°F). Hydrogenated solvent is recycled back to the slurry driers.

The vacuum pipestill (VPS) bottoms cut point is different for each train in the plant, since each train feeds a different bottoms processing step. In Train No. 1, the vacuum bottoms cut point is 850°F. The 850°F+ vacuum bottoms stream is sent to two FLEXICOKING units to produce low Btu gas (LBG), raw product streams (C₂-, C₃/400°F and coker liquids) and an ash residue sent to waste disposal. The LBG is utilized as plant fuel. In Train No. 2, the vacuum bottoms cut point is 900°F. The 900°F+ vacuum bottoms stream is sent to the four partial oxidation units in the plant to

produce hydrogen. The hydrogen produced is utilized as makeup to liquefaction and solvent hydrogenation. Oxygen required by the partial oxidation units is produced in oxygen plants by cryogenic fractionation of air.

Each train has a H₂ recovery section where H₂ purge gas from liquefaction and solvent hydrogenation and C₂- gas are processed in a cryogenic fractionation system to recover hydrogen and C₁/C₂ product gas. Some C₃+ material is also recovered and sent to the light ends unit. Each train also has a light ends unit where C₃ LPG, C₄ LPG, C₅/350°F naphtha, and a 350/400°F heavy naphtha are recovered from all the C₃/400°F material. The heavy naphtha is blended into the fuel oil product along with the spent solvent, vacuum gas oil (VGO) and coker liquids. Not shown in Figure 2 are the Gas and Water Treating facilities.

A coordination flow plan for the Wyoming Coal case is shown in Figure 3. This simplified diagram shows many of the flow paths for the different streams in the plant and depicts the configuration of the plant and individual units. No attempt has been made to distinguish the number of units, lines, and trains in the coordination flow plan.

Liquefaction Operating Conditions

The liquefaction operating conditions for a commercial EDS plant feeding Wyoming coal were chosen as a result of extensive laboratory and engineering studies. These studies were based on operation of the 50 pound-per-day Recycle Coal Liquefaction Unit (RCLU-1) and the one ton-per-day Coal Liquefaction Pilot Plant (CLPP). The following is a summary of the findings from these studies:

- + Conversion of Wyoming coal to liquids show a greater dependence on nominal residence time and solvent-to-coal ratio than Illinois coal.
- + The liquefaction vacuum bottoms viscosity is a strong function of conversion for Wyoming coal (viscosity decreases with increasing conversion). As a result, a minimum liquefaction severity may be required to obtain a vacuum bottoms product with a pumpable viscosity. This limits the choice of liquefaction operating conditions to maintain an operable EDS plant.
- + Liquefaction operating conditions of 1.6 solvent-to-coal (S/C) ratio, 840°F reactor temperature and 60 minutes residence time meet the viscosity criteria and were selected for the Wyoming Coal Case.

● Liquefaction Process Variables Studies

Yield data for the liquefaction process variables studies were developed from RCLU-1 operations. The objective was to determine the effects of processing conditions on yield structure and conversion for Wyoming coal.

The process variables investigated parallel those studied earlier with Illinois coal. Of the process variables studied, the following were found to have a significant impact on yields:

- + Solvent Quality Index (SQI)
- + Liquefaction residence time
- + Liquefaction reactor temperature

Solvent Quality Index (SQI) was found to have a major impact on the conversion and yields for Wyoming coal (Reference 6), as shown in Figures 4 and 5. SQI, a function of S/C ratio and solvent donatable hydrogen content, is a measure of the donatable hydrogen available for the liquefaction reaction. Figures 4 and 5 show the effect of SQI on conversion and liquid yield, respectively. The liquid yield drops significantly when the SQI is reduced below 4. Above 4 SQI, there is no significant increase in liquid yield as shown by the data at 8 SQI. Thus, at 840°F, 1500 psig, and 25 to 60 minutes residence time, the preferred operating region for Wyoming coal would be at an SQI \geq 4. Operating at lower SQI than this would result in lower liquid yield. This break in the SQI curve may shift somewhat at other liquefaction conditions, but a similar response to SQI would be expected. Illinois coal also exhibits this relationship between SQI and conversion. However, the critical SQI for Illinois coal is about 3. Thus, Wyoming coal requires a higher SQI than Illinois coal.

The RCLU-1 results favor maintaining a Solvent Quality Index (SQI) of 4.0 for Wyoming coal operation. An SQI of 4.0 maximizes coal conversion, thus, minimizing the viscosity of residual vacuum bottoms. In addition, there is a marked increase in liquid yields when SQI is increased to 4.0. For the typical donatable hydrogen content of recycle solvent, a solvent-to-coal (S/C) ratio of 1.6 is required to achieve an SQI of 4.0. Therefore, a 1.6 S/C ratio was chosen for Wyoming coal operation.

The effects of liquefaction temperature and residence time on Wyoming coal yields were investigated in RCLU over ranges of 800°F to 880°F and 15 to 100 minutes, respectively (Reference 6). Other liquefaction conditions were 1500 psi. nominal H₂ partial pressure, 1.6 S/C ratio, and 4.0 wt% molecular hydrogen treat rate.

The effect of liquefaction residence time on liquid yields from Wyoming coal is shown in Figure 6. For comparison, results for Illinois coal are also included. Wyoming coal liquid yield increases continually as liquefaction residence time is increased from 15 to 100 minutes. However, the increase is very marginal after about 60 minutes. For Illinois coal, a maximum liquid yield occurs at about 40 minutes time at 3.0 SQI, 840°F and 1500 psig. For Wyoming coal, somewhat higher severity, at least 60 minutes at 4.0 SQI, is required to approach maximum liquid yield at equivalent temperatures/pressure conditions.

The EDS process is limited to an operation that is self-sufficient in recycle solvent. Pilot unit solvent balance has been maintained during Wyoming coal operations on RCLU-1 and CLPP. The effect of residence time on 400-1000°F liquid (solvent) yield, shown in Figure 6, indicates that at equivalent conditions Illinois coal yields more 400-1000°F liquid than Wyoming coal. The decrease in solvent yield with increasing residence time

is due to cracking the heavier liquid to lighter liquid (naphtha) and gases. Eventually a solvent balance limitation will be reached because of continued cracking to naphtha. The criteria to maintain solvent balance is a minimum predicted solvent yield of 5 wt% on dry coal. For Illinois coal a critical solvent balance is reached at about 130 minutes residence time at 840°F and 1500 psig. Because Wyoming coal produces less 400-1000°F liquid than Illinois coal, solvent balance limitations occur at a lower severity, approximately 100 minutes residence time, according to RCLU-1 data. However, yields from CLPP indicate that solvent balance limitations may occur at less than 100 minutes for Wyoming coal.

RCLU-1 operations on Wyoming coal identified potential operability problems in handling the residual bottoms material. The residual bottoms material is made up of unconverted coal, heavy hydrocarbon products, and mineral matter. At typical Illinois coal operating conditions, the residual bottoms from Wyoming coal were significantly more viscous than those from Illinois coal. During these operations, both RCLU-1 and CLPP experienced difficulties in removing the bottoms from the vacuum tower. However, further studies showed that the difficulties were alleviated by increasing conversion in the reactor. Results of these studies indicate that Wyoming bottoms viscosity drops dramatically with increased conversion, leveling off at a value about equal to Illinois bottoms viscosity (Reference 7). In contrast, Illinois bottoms viscosity is relatively independent of conversion.

The RCLU yields provided the database for liquefaction and solvent hydrogenation yields used in the EDS Process Alternatives LP Model (PAM). As indicated earlier, PAM results in turn provided the basis for economic evaluation of the effects of liquefaction temperature and residence time. The economic studies selected 840°F and 40 to 80 minutes as the most attractive liquefaction conditions (Reference 5).

● CLPP Confirmation Runs

Yields from the larger Coal Liquefaction Pilot Plant (CLPP) unit are felt to more closely approximate those from a commercial scale plant. Four CLPP yield periods were completed on Wyoming coal at liquefaction conditions of 1.6 S/C ratio, 840°F and 60 minutes residence time. Overall C₄/1000°F liquid yield in CLPP are comparable to RCLU-1 yields at the same conditions. RCLU-1 data show that the 400/1000°F yield decreases with increasing residence time above 40 minutes, indicating that 60 minutes is near the maximum residence time for maintaining solvent balance at the chosen liquefaction conditions.

CLPP measurements of the vacuum bottoms viscosity indicate a viscosity somewhat greater than in the Illinois MFS case and approaching the demonstrated pumping capability of 60 poise. Vacuum bottoms viscosity is

also affected by adjusting the vacuum pipestill cutpoint. RCLU-1 data show a sharp increase in vacuum bottoms viscosity when residence time is decreased from 60 minutes. Thus, the data indicate that 60 minutes is near the minimum required residence time to produce a pumpable vacuum bottoms stream at the chosen liquefaction conditions. These results led to using 60 minutes as the liquefaction residence time.

- Chosen Liquefaction Operating Conditions

Laboratory data on Wyoming coal display a limited range of liquefaction conditions that maintain unit operability. The choice of liquefaction severity is limited to maintain solvent balance and a pumpable vacuum bottoms viscosity. In conclusion, based on operability considerations and PAM economic screening studies, the liquefaction operating conditions for the Wyoming Coal Case are as follows:

Average Reactor Temperature	840°F
Solvent/Coal Ratio	1.6
Residence Time	60 minutes

In addition to the above conditions, a nominal inlet H₂ partial pressure of 1500 psig at a H₂ treat gas rate of 4 wt % on dry coal (same as the Illinois Coal Base Case and MFS Case) was chosen for the Wyoming Coal Case.

Liquefaction/Solvent Hydrogenation Yields

Coal Liquefaction Pilot Plant (CLPP) runs are used to develop the liquefaction and solvent hydrogenation yields for the Study Design Update (SDU). Based on process variables studies, the operating conditions for the liquefaction reactor have been set at 1.6 S/C ratio, 840°F and 60 minutes nominal slurry residence time. Four CLPP yield periods using Wyoming coal were completed at these conditions. Elementally balanced yields for liquefaction and solvent hydrogenation are presented in Table 2. The yields are given for operation at start-of-run (SOR) and end-of-run (EOR) in solvent hydrogenation. The yields of 700/1000°F material are based on microlube determination of 1000°F- content of vacuum bottoms from CLPP.

Table 3 presents a comparison of the SDU overall liquefaction/solvent hydrogenation yields for Wyoming coal vs. Illinois coal. The hydrogen consumption and 1000°F- conversion values are comparable for the two coals at the chosen conditions. However, Wyoming coal yields less liquid and that produced is weighted toward the naphtha boiling range.

Temperature Considerations for Liquefaction Reactor Design

Laboratory data have shown that liquefaction of Wyoming coal is an exothermic reaction. CLPP data indicate the reactor exotherm will be approximately 15-80 °F for the Wyoming Coal Case. Exact definition of the

exotherm is difficult to obtain due to large heat losses which occur in CLPP operation. A better definition of reactor exotherm will be obtained from operation of the 200 ton/day Exxon Coal Liquefaction Pilot Plant (ECLP).

Due to the uncertainty in the reactor exotherm, the commercial design uses an "average" reactor temperature of 840°F.

Calcium Carbonate Deposition in the Liquefaction Reactors

Laboratory runs on RCLU and CLPP have identified the formation of CaCO₃ scale in the liquefaction reactors operating on Wyoming coal. This deposition problem is a result of relatively high calcium content in Wyoming coal. Extrapolation of RCLU/CLPP data indicate wall scale growth will be about one inch per year. Left unchecked, the scale will continue to build up on the reactor internals and cause operational problems, such as the following:

- Distributor bubble caps may plug if scale is formed on them
- Pieces of scale may spall and fall onto the distributors.
- CaCO₃ deposits may cause maldistribution of flow increasing pressure drop in the reactors.
- CaCO₃ scale buildup may cause reactor instruments to be less responsive.

In order to minimize the effect of CaCO₃ deposition in the liquefaction reactor, some design and operational changes are to be included in the Wyoming Coal Case. Solids withdrawal nozzles are to be provided inside the reactors from both the side and through each distributor tray. Solids will be periodically withdrawn to remove particles accumulated on the distributors. These nozzles are part of the design for the Illinois Coal Base Case and MFS Case although CaCO₃ deposition is not a problem; solids withdrawal is to be less frequent in these cases. For the Wyoming Coal Case, screens are to be installed above each distributor to prevent large scale particles (too large for solids withdrawal nozzles) from falling onto the distributors. The spacing between distributors and screens assures good distribution even if the screens are partially plugged. Y-type strainers are also to be placed upstream of the slurry letdown valves that control the reactor separator bottoms flow to the atmospheric fractionator.

To prevent long-term scale build-up, the reactors are to be periodically cleaned with dilute phosphoric acid. The chemical cleaning operation is to be carried out during slurry furnace decoking operations so that no additional downtime is needed.

VPS Cut Point Set by Viscosity Limitations

The configuration for liquefaction fractionation will be identical to the Illinois Coal MFS Case. However, the bottoms cut points for the vacuum pipestill (VPS) units are lower relative to the Illinois Coal MFS Case. The VPS units upstream of the FLEXICOKING and partial oxidation units are to be designed for a 850°F and 900°F cut point, respectively. VPS feed preheat furnaces will not be required for either unit to achieve these cut points.

Screening studies indicated an incentive to maximize liquid recovery by cutting as deeply as possible in the VPS upstream of partial oxidation. The major constraint to cutting deeper is a corresponding increase in viscosity of the bottoms and its effect on pump performance. Figure 7 shows the relationship between vacuum bottoms viscosity and 1000°F- content. Cutting deeper reduces 1000°F- content and thus increases viscosity. A 900°F cut point produces a bottoms stream with about 2.1 wt% 1000°F- (Microlube basis). This yields a viscosity of 60 poise after 2 hours at 600°F, the conditions in the partial oxidation feed surge drum. Presently, 60 poise is the maximum viscosity for which there is demonstrated pumping capability.

The cutpoint of the VPS upstream of FLEXICOKING is set to achieve 8 wt% 1000°F- content (Microlube basis) in vacuum bottoms leaving the VPS unit. Since 1000°F- liquids are recovered in the FLEXICOKING scrubber, it is acceptable to leave some 1000°F- in the feed for ease of pumping and feed injection. From Figure 7, the viscosity of vacuum bottoms after 8 hours storage at 600°F, the conditions in the FLEXICOKING feed surge drum, is 28 poise; within the maximum demonstrated pumping capability of 60 poise. The FLEXICOKING unit feed will also contain some hydroclone underflow recycle and feed pump flushing oil to further reduce viscosity to less than 10 poise. Laboratory studies indicate satisfactory operation of the FLEXICOKING reactor feed nozzles at viscosities of less than 10 poise.

The plant is to have interconnecting lines for atmospheric and vacuum bottoms. The atmospheric bottoms feed to the deeper cut VPS will be set by the partial oxidation feed rate required to meet the makeup hydrogen demand in the plant.

During turnaround operation, one VPS will be operated with a bottoms cutpoint of 850°F; and the two operating partial oxidation units will process 850°F+ vacuum bottoms (instead of 900°F+). Sufficient 850°F+ vacuum bottoms will also be available to provide feed to FLEXICOKING for plant fuel (LBG) production.

Hydrogen Production Via Partial Oxidation

Hydrogen is to be generated in the Wyoming Coal Case with partial oxidation of deep-cut vacuum bottoms. The hydrogen generation configuration is illustrated in Figure 3 (Section 425). Process, utility, and investment information for the synthesis gas (syngas) generation section will be based

on vendor quotes. The investment and utility requirements for facilities to upgrade syngas to hydrogen is to be based on individual equipment design, which will largely be prorated from the Illinois Coal Base Case SDU. The oxygen plant will not be designed in detail.

The process flow scheme for Hydrogen Generation will be identical to the Illinois Coal Market Flexibility Sensitivity (MFS) Case. In the syngas generation section, the partial oxidation reactor will operate at 1000 psig and 2500°F (same as the Illinois Coal MFS Case). For control purposes, a two-hour vacuum bottoms holdup will be provided upstream of the syngas generator as recommended by vendor quotes for the Illinois Coal MFS Case. This is to be operated at 600°F and 50 psig. The characteristics of the vacuum bottoms feed to partial oxidation are given in Table 4.

The Hydrogen Generation Section will be designed concurrently with the Hydrogen Recovery Section to meet a minimum hydrogen makeup purity of 94 mole%. The Hydrogen Generation Section will consist of four trains of partial oxidation-syngas generation and upgrading. This matches the number of liquefaction lines and is within the commercially-demonstrated size of partial oxidation units operating on petroleum feedstocks. Each train is to be sized based on end-of-run (EOR) solvent hydrogenation operation, the maximum hydrogen requirement operation.

The basis for supplying oxygen to partial oxidation is to use three, 33 1/3% oxygen plants sized for EOR solvent hydrogenation operation. The oxygen plants are to produce 99.5 mole% purity oxygen by cryogenic fractionation of air. Storage of three days production of liquid oxygen will be provided for each unit. This storage provides for nine days of 100% EOR solvent hydrogenation operation if one of the oxygen-plants has an unscheduled outage. Current indications from vendors are that cryogenic air fractionation facilities typically demonstrate service factors of about 97%, including both scheduled and unscheduled downtime. This corresponds to a total of 11 days/year for all outages. A single O₂ plant should not exceed nine days. Thus, the planned storage should ensure complete backup availability of oxygen.

Plant Fuel Gas Production

The plant will utilize FLEXICOKING of vacuum bottoms to generate low Btu gas (LBG) fuel for the onsite units. The FLEXICOKING configuration is illustrated in Figure 3 - Section 300. The process flow scheme will be identical to the Illinois Coal MFS Case. A surge drum with 8 hours of vacuum bottoms holdup will be provided upstream of the FLEXICOKING reactor. This is to be operated at 600°F and 40 psig. The characteristics of vacuum bottoms feed to FLEXICOKING are given in Table 5. The database for FLEXICOKING yields and product qualities was developed using the Continuous Stirred Coking Unit (CSCU) (Reference 7).

Preliminary studies have found that the available vacuum bottoms provide enough FLEXICOKING feed to produce fuel for onsite requirements plus sufficient spillover to offsites for fuel system control. Two FLEXICOKING units will be employed with a total capacity of 140% of normal vacuum bottoms feed rate. During a FLEXICOKING unit outage, the remaining onstream FLEXICOKING unit is run at full capacity and excess vacuum bottoms are stored. The additional capacity provides for running off vacuum bottoms which are stored during a FLEXICOKING unit outage. The design capacity will allow for stored vacuum bottoms runoff in about one-half of the available time.

The FLEXICOKING units will utilize hydroclones to reduce the solids content of the scrubber liquids product. Liquids from the reactor-scrubber are to be sent to hydroclones (see Figure 3 - Section 300). Solids, made up of ash and unreacted coal, are concentrated in the underflow which is recycled back to the reactor. Underflow recycle also serves to increase the LBG yield. The recycle rate during "normal" operation will be set to meet the following constraints:

- + To produce scrubber liquids that can be blended into fuel oil with a 0.15 wt% maximum solids specification, (equivalent to 0.1 lb particulate/MBtu fired).
- + To maintain onsite fuel balance and fuel system control with LBG.

The FLEXICOKING units' design will have the flexibility to increase recycle rate over "normal" operation. The design maximum recycle rate is to be sufficient to maintain onsite fuel balance and fuel system control with LBG during all modes of operation except during an unscheduled FLEXICOKING unit outage.

Fuel Oil Product

The fuel oil product of the plant is a blend of 350/400°F heavy naphtha, liquefaction middle distillate (excess solvent), vacuum gas oil and FLEXICOKING unit products (gas oil and scrubber bottoms). The fuel oil product is to have no more than 0.58 wt% sulfur and no more than 0.15 wt% solids. The solids specification is met by controlling the underflow recycle from the FLEXICOKING hydroclones. The fuel oil sulfur specification will be met with the above blendstocks without further hydrotreating.

In the Illinois Base Case and MFS Case, the solvent cut point was set at 350°F. All solvent, including that in excess of the recycle solvent requirement, is processed in solvent hydrogenation. The purpose is to desulfurize the excess solvent before blending it into fuel oil. By cutting at 350°F, the 350/400°F heavy naphtha is desulfurized. These steps are necessary for the Illinois Coal Base Case and MFS Case in order to meet fuel oil sulfur specification.

Wyoming coal liquids are low in sulfur and thus do not require desulfurization to meet fuel oil sulfur specifications. In the Wyoming Coal Case, excess solvent is to be blended directly into the fuel oil pool without being processed in solvent hydrogenation. Solvent is to be cut at 400°F (instead of at 350°F); a more cost effective way to operate liquefaction and solvent hydrogenation. A naphtha splitter is to be provided in the light ends area to separate out the 350/400°F heavy naphtha cut. The 350/400°F cut is to be blended directly into fuel oil.

High Btu Gas Sales

A C₂⁻ (ethane and lighter) gas is produced in the hydrogen recovery section of the plant. This gas is to be compressed up to 1000 psig (pipeline gas pressure) and sold as high Btu gas (HBG). The hydrogen recovery section is to be designed to minimize the amount of propane and heavier compounds in the C₂⁻ gas product. DEA scrubbers are to be provided in the hydrogen recovery section; as a result, the C₂⁻ product will be low in H₂S content, < 5 vppm.

The C₂⁻ HBG product has a high C₂⁺ content (25 mole% in the Illinois MFS Case), which may pose some marketing problems or debit the value of the gas. However, there is a high probability that there is a market for the C₂⁻ HBG either for pipeline sales or as industrial fuel. The C₂⁺ content may need to be sufficiently diluted in natural gas to make HBG sales acceptable. Thus, the value of the C₂⁻ by-product will depend upon many factors including the transportation system and marketplace.

The C₂⁻ HBG will also serve as backup fuel. A combination of LBG and HBG is to be utilized in the liquefaction slurry furnaces when insufficient LBG is available to satisfy onsite fuel demands.

REFERENCES

- (1) EDS Commercial Plant Study Design Update, Revised Onsite Design Basis - Illinois Coal Base Case, Interim Report FE-2893-32.
- (2) EDS Commercial Plant Study Design Update, Offsite Design Basis - Illinois Coal Base Case, Interim Report FE-2893-33.
- (3) EDS Commercial Plant Study Design Update, Onsite Design Basis - Illinois Coal Market Flexibility Sensitivity Case, Interim Report FE-2893-36.
- (4) EDS Commercial Plant Study Design Update, Offsite Design Basis - Illinois Coal Market Flexibility Sensitivity Case, Interim Report FE-2893-37.
- (5) EDS Coal Liquefaction Process Development, Phases III B/IV Annual Technical Progress Report, July 1, 1977 - June 30, 1978, FE-2893-17.
- (6) EDS Coal Liquefaction Process Development, Phase III B Quarterly Technical Progress Report, October 1, 1977 - December 31, 1977, FE-2893-7.
- (7) EDS Coal Liquefaction Process Development, Phase IV Quarterly Technical Progress Report, January 1, 1978 - March 31, 1978, FE-2893-12.

TABLE 1

EDS COMMERCIAL PLANT STUDY DESIGN UPDATE

ONSITE DESIGN BASIS - WYOMING COAL CASE

COAL CHARACTERISTICS

WYOMING SUBBITUMINOUS COAL ⁽¹⁾

Coal Composition ⁽²⁾

	<u>Dry Wt%</u>	<u>"As Received" Wt% (3)</u>
C	66.92	46.09
H	4.87	3.35
O (By difference)	19.78	13.62
N	0.88	0.61
S	0.37	0.25
Ash (SO ₃ Free)	7.18	4.96
Water	-	<u>31.12</u>
Total	100.00	100.00

Ash Composition ⁽²⁾

	<u>Wt%</u>	
	<u>Dry</u>	<u>SO₃ Free</u>
P ₂ O ₅	0.95	1.16
SiO ₂	29.14	35.55
Fe ₂ O ₃	4.49	5.48
Al ₂ O ₃	14.32	17.47
TiO ₂	0.90	1.10
CaO	25.00	30.51
MgO	5.39	6.58
SO ₃	18.02	-
K ₂ O	0.40	0.49
Na ₂ O	<u>1.39</u>	<u>1.69</u>
Total	100.00	100.00

TABLE 1 (CONT'D)

COAL CHARACTERISTICS

Coal Size Distribution -
"As Received"

<u>Size</u>	<u>Wt%</u>
+4"	0.9
4" to 3"	1.1
3" to 2"	4.0
2" to 1"	16.0
1" to 1/2"	21.0
1/2" to 1/4"	19.0
1/4" to 8 mesh	19.0
8 mesh to 16 mesh	8.0
16 mesh to 30 mesh	5.0
-30 mesh	6.0
Total	100.0

Coal Physical Properties

● Specific Gravity	
+ Ash	2.7
+ Organic	1.4
● Bulk Density, lb/ft ³	45.0-50.0
● Angle of Repose, degrees	40
● Hardgrove Grindability Index	58.0
● Heating Value, Btu/lb (dry)	
+ Higher	11723
+ Lower	11010
● Surface Moisture, %	0-1.0

Notes:

- (1) Coal characteristics are for coal from the Wyodak mine.
- (2) Compositions are average.
- (3) Coal "as received" from the mining operations.

TABLE 2

EDS COMMERCIAL PLANT STUDY DESIGN UPDATE

ONSITE DESIGN BASIS - WYOMING COAL CASE

LIQUEFACTION/SOLVENT HYDROGENATION YIELDS⁽¹⁾

START-OF-RUN

All values are lb/100 lbs dry coal.

	<u>Liquefaction</u>	<u>Solv. Hydro.</u>	<u>Overall</u>
Hydrogen	(2.13)	(1.55)	(3.68)
CO	0.41	-	0.41
CO ₂	5.98	-	5.98
H ₂ O	12.84	1.03	13.87
NH ₃	0.28	0.12	0.40
H ₂ S	0.20	0.01	0.21
HCl	0.02	-	0.02
C ₁	2.90	0.13	3.03
C ₂	2.29	0.05	2.34
C ₃	2.00	0.01	2.01
C ₄	1.05	-	1.05
C ₅	1.36	-	1.36
C ₆ /400°F	0.98	18.79	19.77
400/700°F	16.29	(14.62)	1.67
700/1000°F ⁽²⁾	9.02	(3.97)	5.05
1000+°F	24.18	-	24.18
Pyr. Solids	15.15	-	15.15
Ash	<u>7.18</u>	<u>-</u>	<u>7.18</u>
Total	100.00	0.00	100.00

TABLE 2 (Cont'd)

LIQUEFACTION/SOLVENT HYDROGENATION YIELDS⁽¹⁾

END-OF-RUN

All values are lbs/100 lbs dry coal.

	<u>Liquefaction</u>	<u>Solv. Hydro.</u>	<u>Overall</u>
Hydrogen	(2.13)	(1.75)	(3.88)
CO	0.41	-	0.41
CO ₂	5.98	-	5.98
H ₂ O	12.84	1.29	14.13
NH ₃	0.28	0.12	0.40
H ₂ S	0.20	0.01	0.21
HCl	0.02	-	0.02
C ₁	2.90	0.20	3.10
C ₂	2.29	0.15	2.44
C ₃	2.00	0.03	2.03
C ₄	1.05	-	1.05
C ₅	1.36	-	1.36
C ₆ /400°F	0.98	18.77	19.75
400/700°F	16.29	(14.83)	1.46
700/1000°F ⁽²⁾	9.02	(3.99)	5.03
1000+°F	24.18	-	24.18
Pyr. Solids	15.15	-	15.15
Ash	<u>7.18</u>	<u>-</u>	<u>7.18</u>
Total	100.00	0.00	100.00

TABLE 2 (Cont'd)

LIQUEFACTION/SOLVENT HYDROGENATION YIELDS

Notes:

- (1) Yields are based CLPP yield period numbers 267, 268 and 270.
- (2) Yield of 700/1000°F is based on microlube determination of 1000°F-content in vacuum bottoms.

TABLE 3

EDS COMMERCIAL PLANT STUDY DESIGN UPDATE

ONSITE DESIGN BASIS - WYOMING COAL CASE

LIQUEFACTION/SOLVENT HYDROGENATION YIELD COMPARISON

	<u>Wyoming</u> <u>Coal</u>	<u>Illinois</u> <u>Coal</u>
<u>Nominal Liquefaction Conditions</u>		
Average Reactor Temperature, °F	840	840
Solvent/Coal Ratio	1.6	1.2
Residence Time, minutes	60	40
Nominal Inlet H ₂ Partial Pressure, psig	1500	1500
<u>Overall Yields, lbs/100 lbs Dry Coal</u>		
H ₂	-3.7	-3.6
CO _x	6.4	1.5
H ₂ O	13.9	9.4
NH ₃	0.4	0.5
H ₂ S	0.2	3.3
C ₁ -C ₃	7.4	6.7
C ₄ /400°F	22.2	19.8
400/1000°F(1)	6.7	14.6
1000°F+	46.5	47.8
C ₄ /1000°F(1)	28.9	34.4

Notes:

(1) Based on microlube determination of 1000°F- content in vacuum bottoms.

TABLE 4

EDS COMMERCIAL PLANT STUDY DESIGN UPDATE

ONSITE DESIGN BASIS - WYOMING COAL CASE

CHARACTERISTICS OF VACUUM BOTTOMS FEED TO PARTIAL OXIDATION

Temperature, °F	600
Pressure, psig	40
Viscosity @ 600°F and 200 sec ⁻¹	52
<u>Elemental Composition, wt% (ash-free)</u>	
Carbon	87.8
Hydrogen	5.0
Oxygen	5.6
Nitrogen	1.2
Sulfur	0.4
Ash Content, wt%	14.2
1000°F- content, wt% ⁽¹⁾	2.1

Notes:

(1) Based on microlube distillation.

TABLE 5

EDS COMMERCIAL PLANT STUDY DESIGN UPDATE

ONSITE DESIGN BASIS - WYOMING COAL CASE

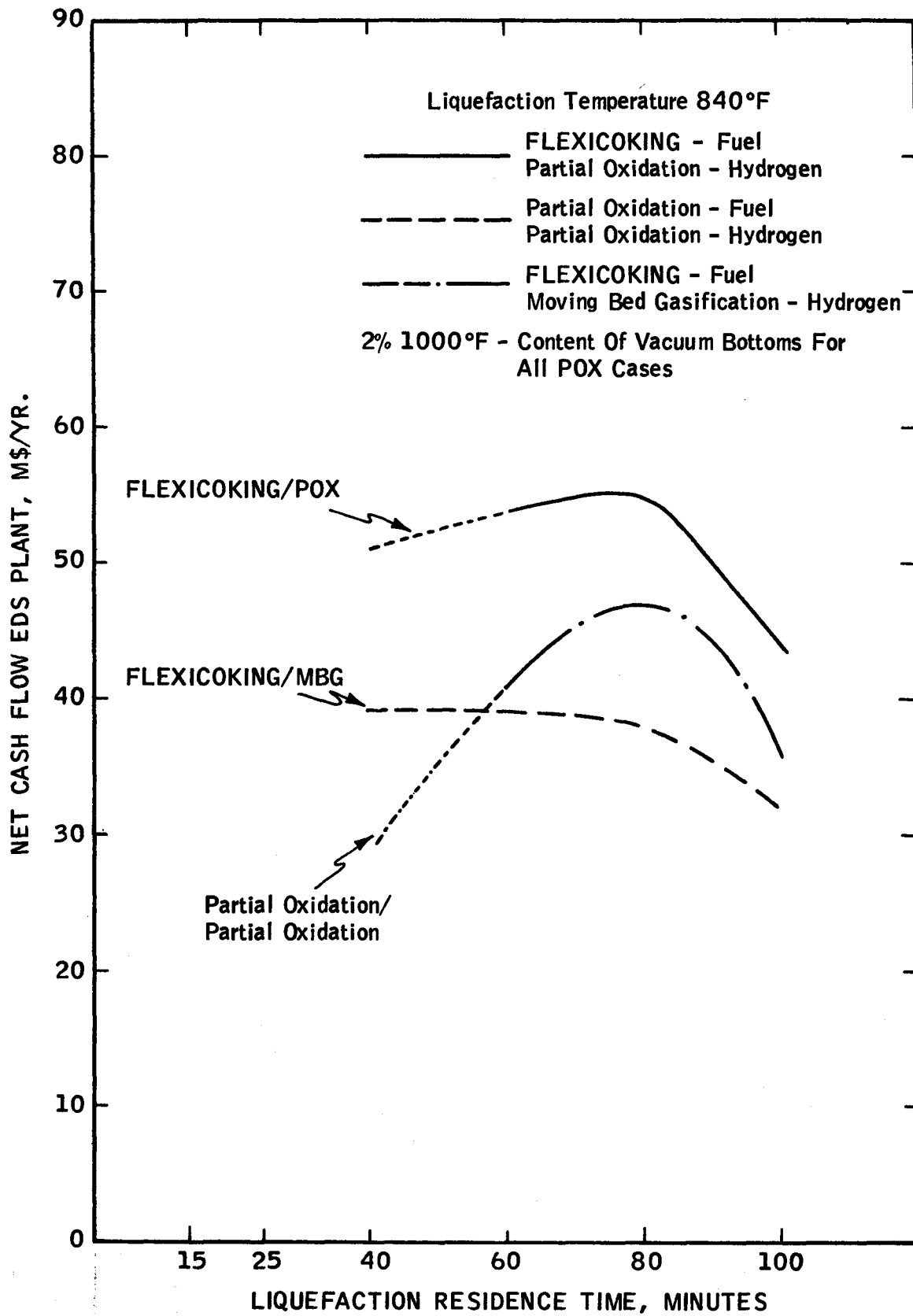
CHARACTERISTICS OF VACUUM BOTTOMS FEED TO FLEXICOKING

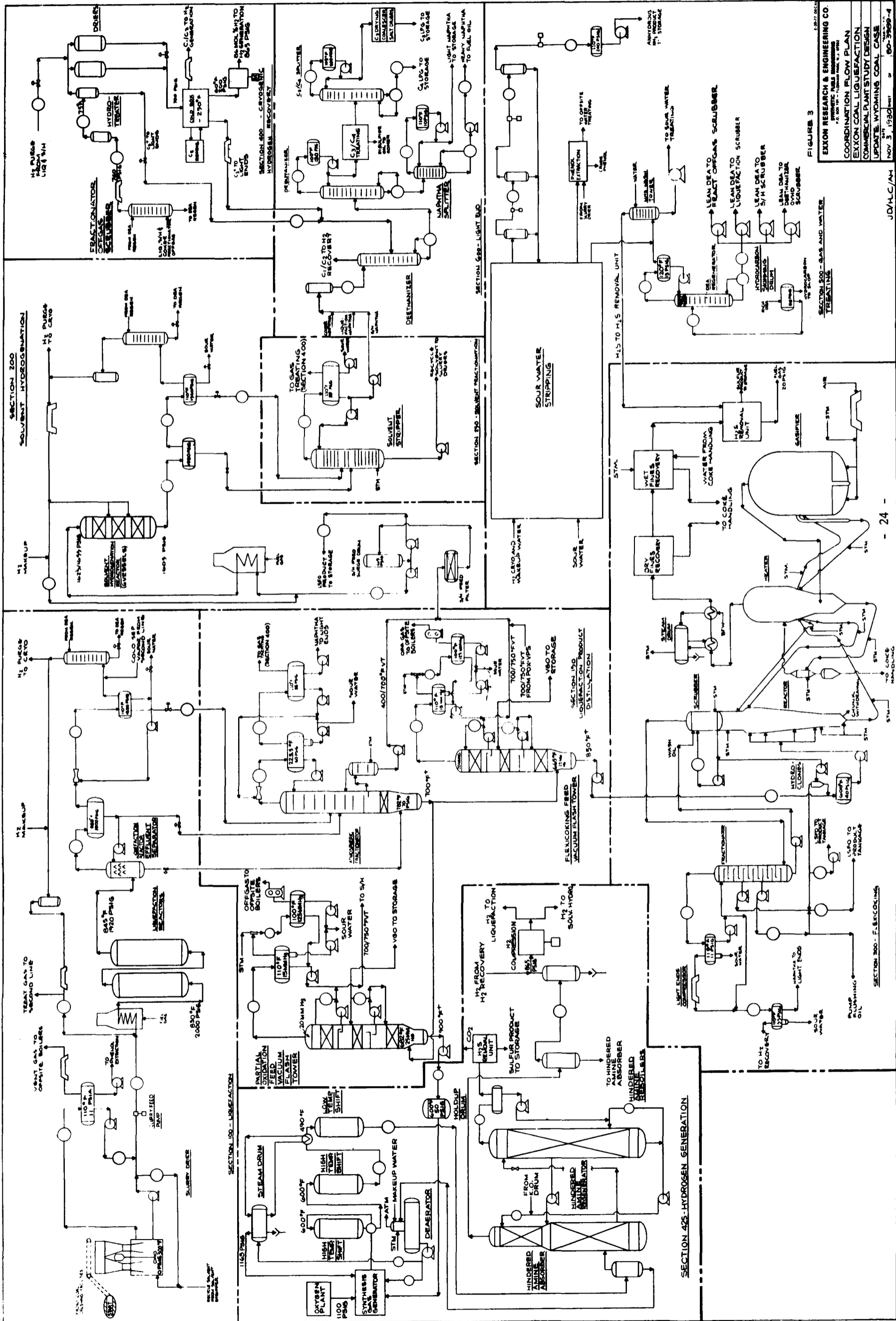
Temperature, °F	600
Pressure, psig	40
Viscosity @ 600°F and 200 sec ⁻¹ , poise	<10
<u>Elemental Composition, wt% (ash-free)</u>	
Carbon	87.8
Hydrogen	4.8
Oxygen	5.8
Nitrogen	1.2
Sulfur	0.4
Ash Content, wt%	15.2
1000°F- content, wt% ⁽¹⁾	8.0

Notes:

(1) Based on microlube distillation.

Figure 1
EDS COMMERCIAL PLANT STUDY DESIGN UPDATE
ONSITE DESIGN BASIS - WYOMING COAL CASE
PROCESS CONFIGURATION STUDY RESULTS





EXXON RESEARCH & ENGINEERING CO.
 COORDINATION FLOW PLAN
 EXXON COAL LIQUEFACTION
 COMMERCIAL PLANT STUDY DESIGN
 UPDATE - WYOMING COAL CASE
 NOV 3, 1980

FIGURE 3
 SECTION 200 - GAS AND WATER TREATING

SECTION 300 - FLYCKING

SECTION 400 - CRYOGENIC HYDROGEN RECOVERY

SECTION 500 - SOLVENT FRACTIONATION

SECTION 600 - LIGHT ENDS

SECTION 700 - SOUR WATER STRIPPING

SECTION 800 - H₂S REMOVAL UNIT

SECTION 900 - GAS AND WATER TREATING

Figure 4

EDS COMMERCIAL PLANT STUDY DESIGN UPDATE
ON-SITE DESIGN BASIS - WYOMING COAL CASE
EFFECT OF SQI ON CONVERSION IN LIQUEFACTION

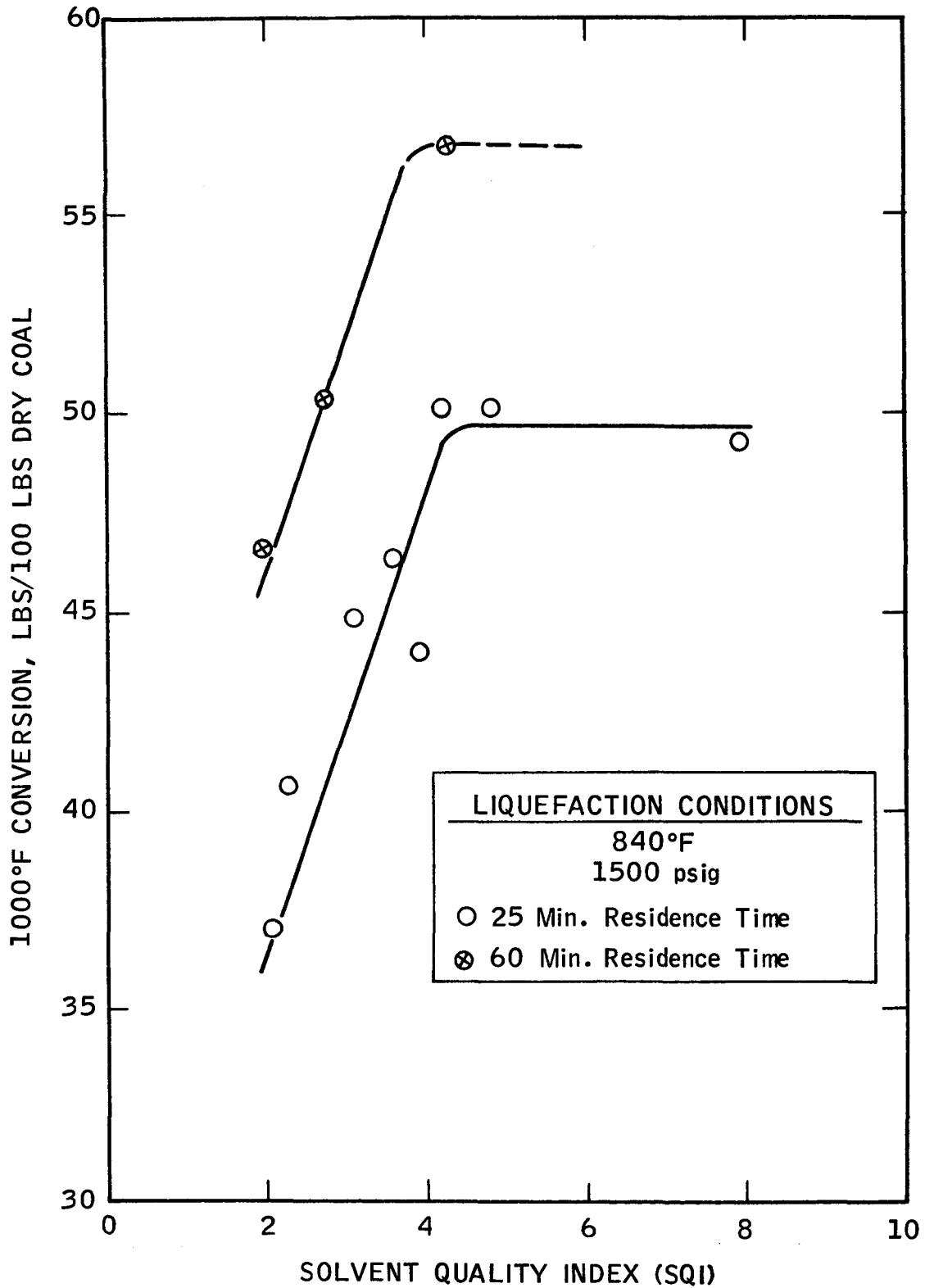


Figure 5

EDS COMMERCIAL PLANT STUDY DESIGN UPDATE
ONSITE DESIGN BASIS - WYOMING COAL CASE
EFFECT OF SQI ON YIELDS IN LIQUEFACTION

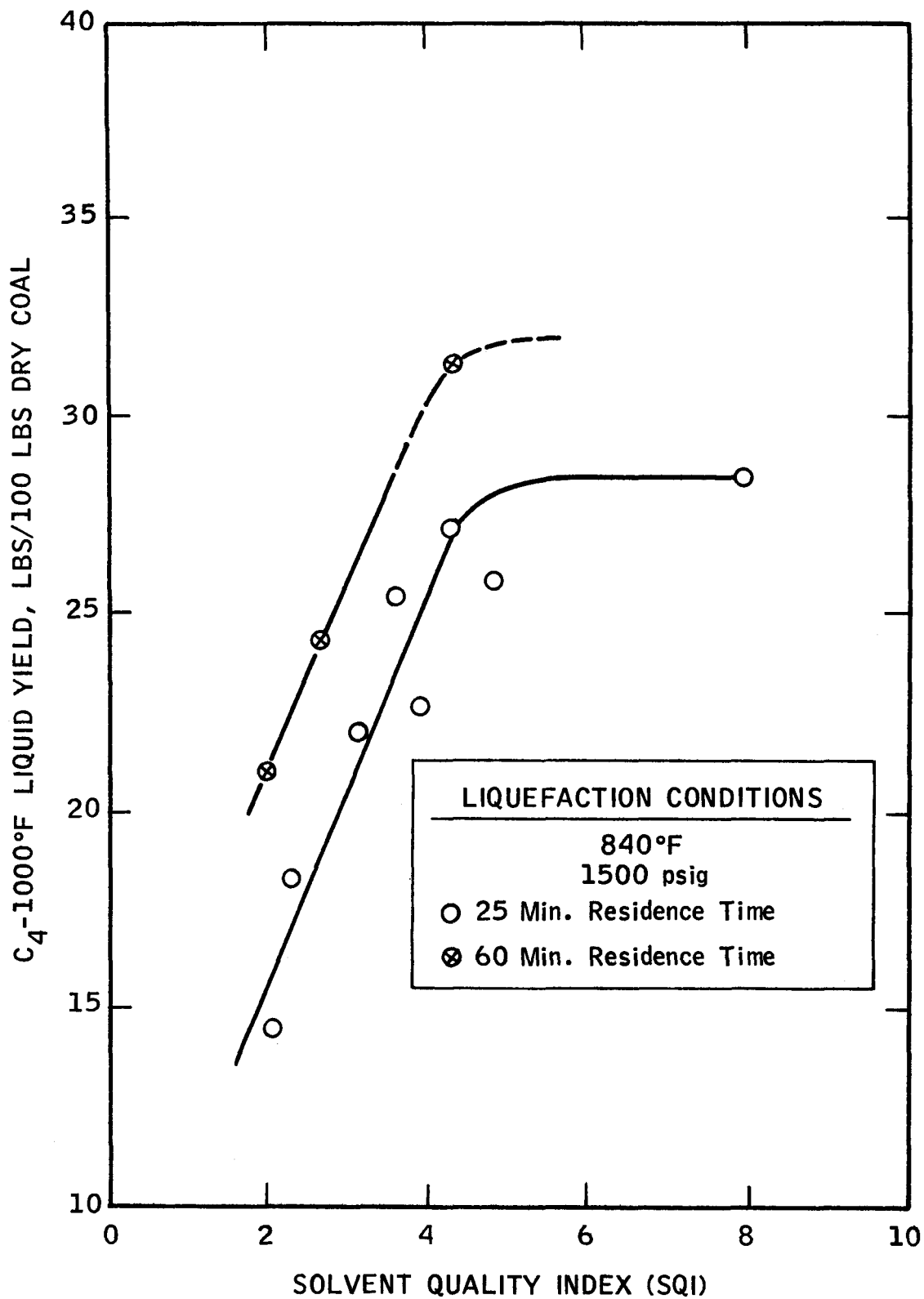


Figure 6
 EDS COMMERCIAL PLANT STUDY DESIGN UPDATE
 ONSITE DESIGN BASIS - WYOMING COAL CASE
EFFECT OF RESIDENCE TIME ON LIQUEFACTION YIELDS

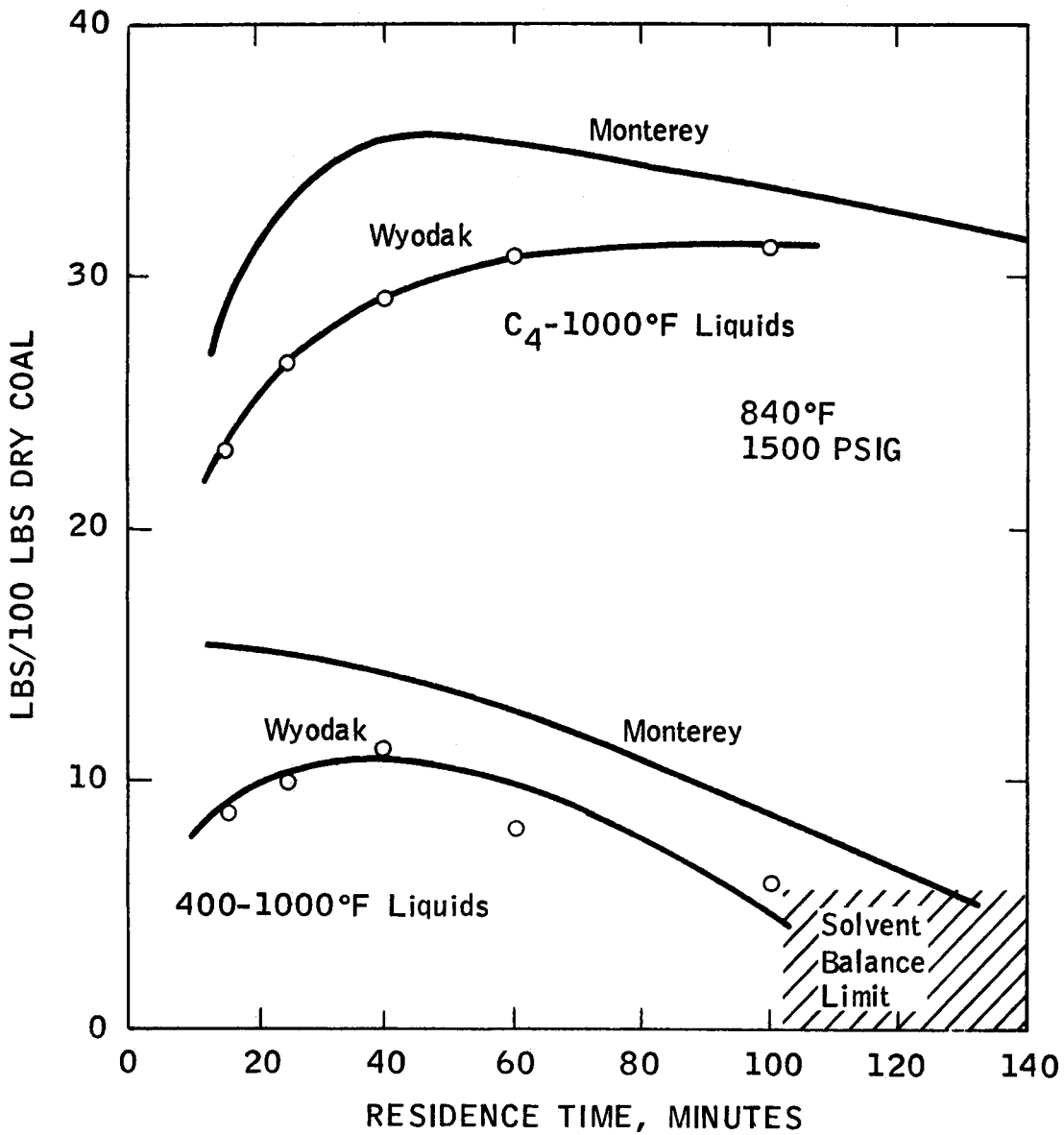
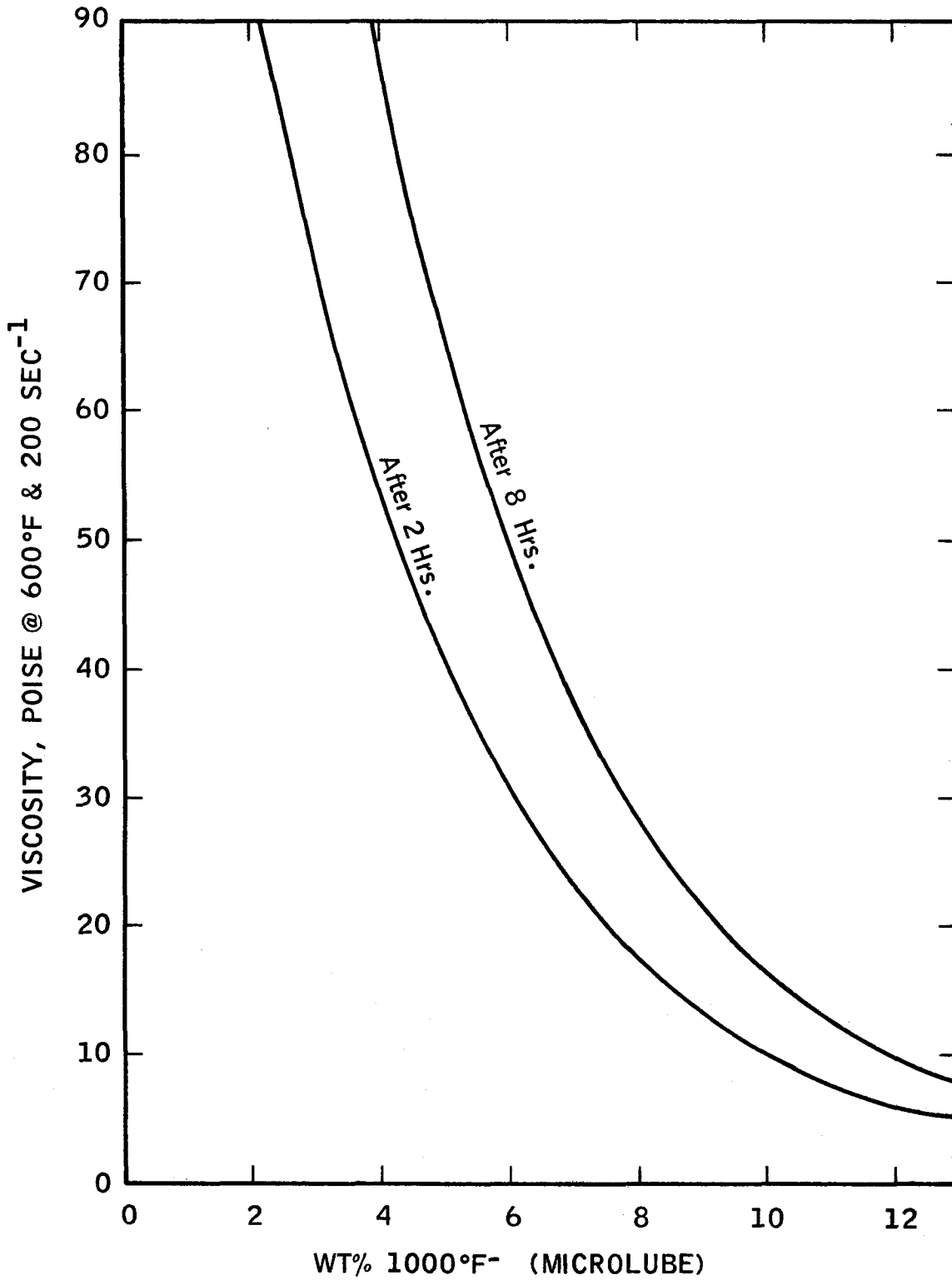


Figure 7

EDS COMMERCIAL PLANT STUDY DESIGN UPDATE
ONSITE DESIGN BASIS - WYOMING COAL CASE
VACUUM BOTTOMS VISCOSITY VS. 1000°F⁻ CONTENT



LIST OF ABBREVIATIONS

APS	Atmospheric Pipestill
B	Barrel
BHP	Brake Horsepower
Btms	Bottoms
Btu	British Thermal Unit
Cond.	Conditions
D	Day
EDS	Exxon Donor Solvent
EOR	End-of-Run
HBG	High Btu Gas
k	Thousand
LBG	Low Btu Gas
LPG	Liquified Petroleum Gas
M	Million
max	Maximum
min	Minimum
MW	Molecular Weight
RVP	Reid Vapor Pressure
SCF	Standard Cubic Feet
SCFM	Standard Cubic Feet Per Minute
SD	Stream Day
SDU	Study Design Update
SOR	Start-of-Run
ST	Short Ton
S/U	Startup

LIST OF ABBREVIATIONS (Cont'd)

T	Ton
T/A	Turnaround
VGO	Vacuum Gas Oil
VPPM	Volume Parts Per Million
VPS	Vacuum Pipestill
w/o	Without
wppm	Weight Parts Per Million
ρ	Density