SAN-1338-T1

LIQUEFACTION PROJECT AT ALBANY, OREGON

Final Technical Progress Report

April 1978

Work Performed Under Contract No. EG-77-C-03-1338

Research and Engineering Division
Bechtel National, Incorporated
San Francisco, California

U.S. Department of Energy

Solar Energy

NOTICE

Available from the National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161.

Price: Paper Copy $9.50
Microfiche $3.00

SAN-1338-T1
Distribution Category UC-61

FINAL TECHNICAL PROGRESS REPORT

LIQUEFACTION PROJECT
ALBANY, OREGON

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY DIVISION OF SOLAR ENERGY

CONTRACT No. EG-77-CO3-1338

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by Bechtel National, Inc.
Research & Engineering Division

April 1978

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Section 1

INTRODUCTION AND BACKGROUND

1.1 INTRODUCTION

The nation currently faces an ever growing shortage in available energy resources. This shortage is especially severe in the areas of liquid and gaseous fuels. To meet growing demands for these fuels, the United States government has embarked on a wide ranging program to develop alternate sources of energy. While none of the alternate fuel sources appears likely to fill the energy gap alone, they can help in curtailing our current dependence on oil imports.

As part of this program, the U.S. Department of Energy, Solar Energy Division, is developing technologies for the production of gaseous and liquid fuels by the thermochemical conversion of biomass materials. The experiments presently being conducted at the Albany, Oregon test facility are an important part of this program.

The Albany facility is a 3 tons per day biomass liquefaction plant designed for the liquefaction of wood and other cellulosic material. The plant is located within the city limits of Albany, Oregon immediately adjacent to the U.S. Bureau of Mines Metallurgical Research Center. It is set in the middle of a residential area instead of the more isolated setting that one might expect. The location has created a special concern for possible environmental effects. In addition to the process development unit (PDU), the site has a modern control room, an office building for technical and administrative staff, a repair and maintenance shop, a small process control laboratory, and simple pollution control facilities.

The major objectives in the first year's activities at Albany were to verify the original process data, to evaluate the process equipment, and to develop a preliminary conceptual design and economic assessment. This report describes the work performed to achieve these objectives.

Section 1 provides a brief background on the liquefaction of biomass. Section 2 provides a summary and conclusion of the findings in this report. Section 3 describes plant commissioning activities including the original process; the commissioning procedure; and the process, equipment, and safety modifications performed. Section 4 discusses process operating results. Section 5 discusses areas needing further study.

Development of a commercial process design and economic analysis of the present and future status of the biomass liquefaction concept are described in Section 6.

1.2 BACKGROUND

Earliest efforts in the liquefaction of biomass as it is currently practiced at the Albany experimental facility took place during the late 1960's and early 1970's at the U.S. Bureau of Mines' Pittsburgh Energy Research Center (PERC). The study there showed that a wide variety of biomass materials, including wood, municipal solid waste, and cattle manure could be turned into an oil-like material by reaction with carbon monoxide in the presence of an alkaline catalyst and water under conditions of moderate temperature and high pressure. This work was an outgrowth from earlier experiments with coal liquefaction using a similar reaction scheme. On the basis of the PERC results, the flow scheme for both a commercial size plant and what was to eventually become the Albany facility was developed in 1973. Detailed engineering specifications were prepared in 1974 and construction of the facility proceeded soon thereafter. In late 1976 Bechtel National, Inc. was contracted to monitor the completion of construction and the commissioning of the facility. This report describes some of the activities involved. It covers site activities beginning January 1977 through January 1978.

Section 2

SUMMARY AND CONCLUSIONS

2.1 PLANT COMMISSIONING AND MODIFICATIONS

During the commissioning of the plant, a number of difficulties were encountered with the process equipment. This is not unusual in the development of a new process. For example, many modifications had to be made to pump and agitator shaft seals on high-pressure equipment. In addition, there were problems with the feed preparation equipment, the preheater, and the stirred tank reactor.

The feed preparation equipment had few mechanical problems with the exception of the wood grinder and the wood flour weigh belt feeder. The grinder had only one-fourth the capacity specified in the design. As a result, the star feeder valve that controls the grinder feed had to be modified to reduce the feed rate or the grinder would have clogged. The other problem was with the wood flour weigh belt feeder which was equipped with a high temperature, heavy-duty belt, resulting in poor sensitivity. A new lightweight belt was installed and the weighing problem was solved.

The initial operation of the preheater uncovered difficulties with internal coking that caused damage to the scraper blades. The problem was corrected with added temperature monitoring and control.

The stirred tank reactor (CSTR) could not be sealed at the agitator shaft, therefore, it was necessary to bypass it and to introduce all reactants ahead of the preheater.

Significant modifications of the instrument and control systems in the plant were required. In some cases, the instrumentation selected did not provide measurement over the entire operating range; in other cases, instrumentation was improperly installed. Modifications, additions, and rearrangements of existing instrumentation have broadened capability, increased safety, and improved control.

Degradation of polymeric materials caused numerous problems in the plant. The product oil, which contained anthracene and was used for startup, rapidly attacked gaskets, seal parts, and O-rings. Replacement of these parts was required in almost every seal and pressure boundary part.

The centrifuge was unable to separate solids and water from the oil, and was bypassed. Therefore, a pure product sample was unobtainable at this time.

A variety of tests were performed to cover all types of plant equipment. A profile was prepared that contained operating history and the modifications performed. Each unit was checked before the entire system was tested for reliability and stability. Wood was introduced after system stability was established.

2.2 OPERATING RESULTS

During the contract period significant information on process operating variables and equipment performance was obtained. Within the capabilities of the plant, much information was obtained that could be used for process evaluation, scale-up to large-sized equipment, and preliminary economic evaluation. In addition, these results have provided a basis for recommendations concerning continued testing.

The tests examined two major areas — reaction characteristics and equipment performance. In these tests the important parameters that were monitored included rate of biomass conversion, oil yield, heat effects, and product quality.

The results of work to date were used to develop the relationship existing between residence time and conversion. Conversion has been shown to increase with residence time. Residence times of 16 to 18 minutes appear to provide technically acceptable conversion. Longer residence times provide small increases in conversion. Conversion is defined here as the disappearance of wood.

The process oil yield is estimated at 50 percent. Oil yield is defined as the percentage of wood conversion into an oil.

It now appears that as long as the temperature of the slurry leaving the preheater is maintained at $550^{\circ}F$ or higher and CO partial pressure in the exit is kept above 800 psig, there is little effect of either temperature or pressure on conversion. Interpretation of the results of many tests are complicated by the formation of polymers in the product oil.

At room temperature, the product oil has an estimated vapor pressure of 13 mm Hg.

The analytical results of the product oil are summarized in Table 2-1. The reaction product oil shows a sharp decrease in the percent of oxygen over dried wood flour. In addition, the heat content has been roughly doubled on a per pound basis.

Table 2-1

ANALYTICAL RESULTS ON
REACTION SYSTEM PRODUCT

	Wood Flour	Anthracene Oil	Average Product
% Water	1.9		
% C	48.31	89.21	77.2
% H	6.10	5.48	6.5
% N	.13	0.10	.4
% O	40.9	3.03	8.4
Misc. (Inorganics)	2.66	2.18	7.5
Heat Content (Btu/#)	8,196	16,590	15,179

The partial water pressure of the reaction mixture is nonideal oil/water solution as indicated in Table 2-2.

Table 2-2

PARTIAL PRESSURE OF WATER
AT REACTION CONDITIONS

Temp. (^oF)	Observed System Pressure (psig)	Vapor Pressure of Water (psig)
625	560	1850
634	580	1950
650	670	2175

In future studies, these particular results will have a direct bearing on both the function of water in the liquefaction reaction and catalyst solubility in the reaction mixture.

2.3 COMMERCIAL PLANT PROCESS AND ECONOMICS

With the information learned at Albany, a preliminary conceptual design for a commercial plant has been developed. Some of the information that has been incorporated into this conceptual design includes the amount of carbon monoxide consumed, the use of the slurry recycle operation, the technique of CO addition ahead of the preheater, and a knowledge of the slurry and offgas characteristics.

While the carbon monoxide gas is brought in trucks to the Albany plant, a commercial plant will use a synthesis gas containing both hydrogen and carbon monoxide. For this reason, a synthesis gas plant and a product separation system have been added to the commercial facility design. The synthesis gas will be produced in an oxygen blown gasifier and will be treated for removal of water and carbon dioxide. In turn, the synthesis gas will treat the catalyst solution for recovery of the alkali. In a commercial plant about half the wood that is introduced as feed will go for synthesis gas production. The other half of the wood will be treated by drying and grinding and then blending with recycled oil prior to being pumped into the reactor system, as in the Albany plant.

A helical soil preheater and a holdup tank are currently part of the design. The preheater is heated by combustion of system offgases. After pressure letdown from the reactor hold tank, some of the slurry is recycled to the blender while the product portion is routed for purification. Here the product, containing some unreacted wood, water, and catalyst, is diluted with a light solvent. After dilution, the mixture is filtered for the removal of solids. The liquid stream is then further diluted with water to wash out any remaining catalyst. Both the solids and the aqueous waste stream are routed to the synthesis gas reactor for treatment. The organic stream is sent to a fractional distillation column for recovery of the solvent. At this point, the still bottom becomes the product.

A noticeable change in oil viscosity due to apparent polymerization has been observed. Viscosities in the reactor oil recirculation system can increase from a few hundred to several thousand centipoises within a few hours late into an experimental run. The oil is apparently unstable during this period of rapid polymerization and dilution of the process oil stream with anthracene does not prevent it.

Product oil chemical stability is the major problem at this point. All other considerations weigh heavily on this problem. Future experiments will attempt to stabilize the oil by the addition of hydrogen. The result of these tests will determine the next step in proving biomass liquefaction technology.

Overall, investigations to date have led to optimism concerning the possibilities of oil production from biomass. While difficulties in bringing the current facilities on-stream have somewhat limited information, it is felt that a more in-depth analysis can eventually bring about a new source of energy in the form of oil from biomass.

It is important to note that the liquefaction plant can be an environmentally good neighbor. Some of the highlights of the design will serve to illustrate:

- Biomass and air are the only raw materials
- Oil is the only product
- The effluents consist of only water, clean flue gases, and inert ash
- The process is energy efficient

Calculations to date show that overall yield for a commercial plant should be approximately 35 percent wood to oil with an overall energy efficiency of approximately 54 percent.

In order to develop operating and capital costs, several plant sizes were costed out. Due to the plant complexity, the economies of scale were quite evident. Only liquefaction plants in excess of 1,000 tons per day were found to be economical.

For example, the total installed capital costs of 1,000-TPD and 5,000-TPD plants are estimated at $51.85 million and $154 million, respectively; the annual operating costs are estimated at $14.78 million and $46.9 million. The oil production capacity is 800 bbl/day for the smaller plant and 4,000 bbl/day for the larger plant.

Figure 2-1 shows the capital cost breakdown for the various sections of the plant. The largest portion of the capital costs is allocated for the wood handling section and the synthesis gas plant. The portion of the plant capital cost for the high-pressure reaction equipment is only 16 percent of the total. This tends to indicate that future development work should center on reduction in the size of the synthesis gas plant and a simplification of wood handling.

Figure 2-2 shows the annual operating cost breakdown for the plant. The annual operating cost breakdown shows that the amortization of capital is by far the largest factor followed by the cost of feedstock as shown in Figure 2-2. In this instance, wood is assumed to carry a value of $20 per oven-dried ton. Overall, this results in a breakeven production cost of just under $35 per barrel for a 5,000-TPD plant.

The past year's efforts and the development of the first conceptual designs have shown a number of areas for continued refinements. As this program continues, substantial efforts will be aimed at reducing the amount of synthesis gas required, raising overall yield and efficiency, and reducing energy input.

It is expected that continued developments at the Albany facility will yield improvements that should show a reduction in projected product price to approximately $25 a barrel for a 15,000 Btu/lb oil. This should take place over the next 2-1/2 years. At that point, a pilot plant should have all the facilities now envisioned for a commercial plant but of much smaller size. Information gained by the operation of this plant should reduce the product cost, as expressed in constant 1978 dollars, to $20 per barrel. This would take approximately five years. The final step would be the design and construction of a demonstration plant using full-size process trains. Information gained should provide the means to be commercially competitive by approximately 1990 as illustrated by Figure 2-3.

2.4 RECOMMENDATIONS FOR FUTURE WORK

Recommendations for future work are in three general areas:

- Process development studies
- PDU modifications
- Increased analytical capabilities

2.4.1 Process Development Studies

A number of process studies are recommended:

- Study of product separation technique
- Study of hydrogen/carbon monoxide mixtures (syngas) effects
- Upgrading of product
- Use of lower cost materials
- Studies on effluent treatability

The preliminary planning for some of these recommended activities has already started and should be incorporated into the continuing Albany program.

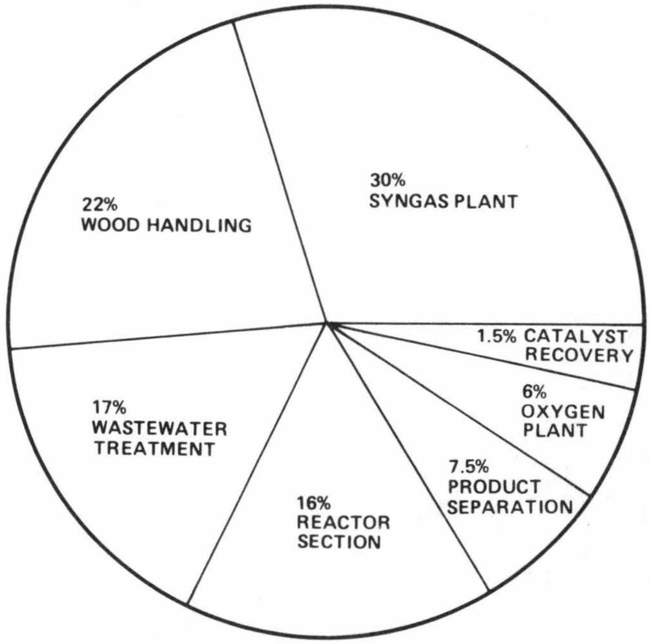


Figure 2-1. Capital Cost Breakdown

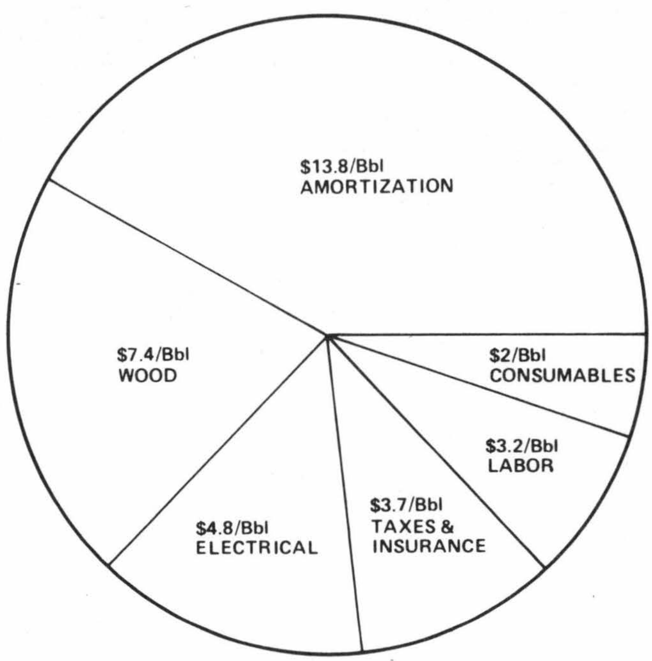


Figure 2-2. Oil Production (Breakeven) Costs

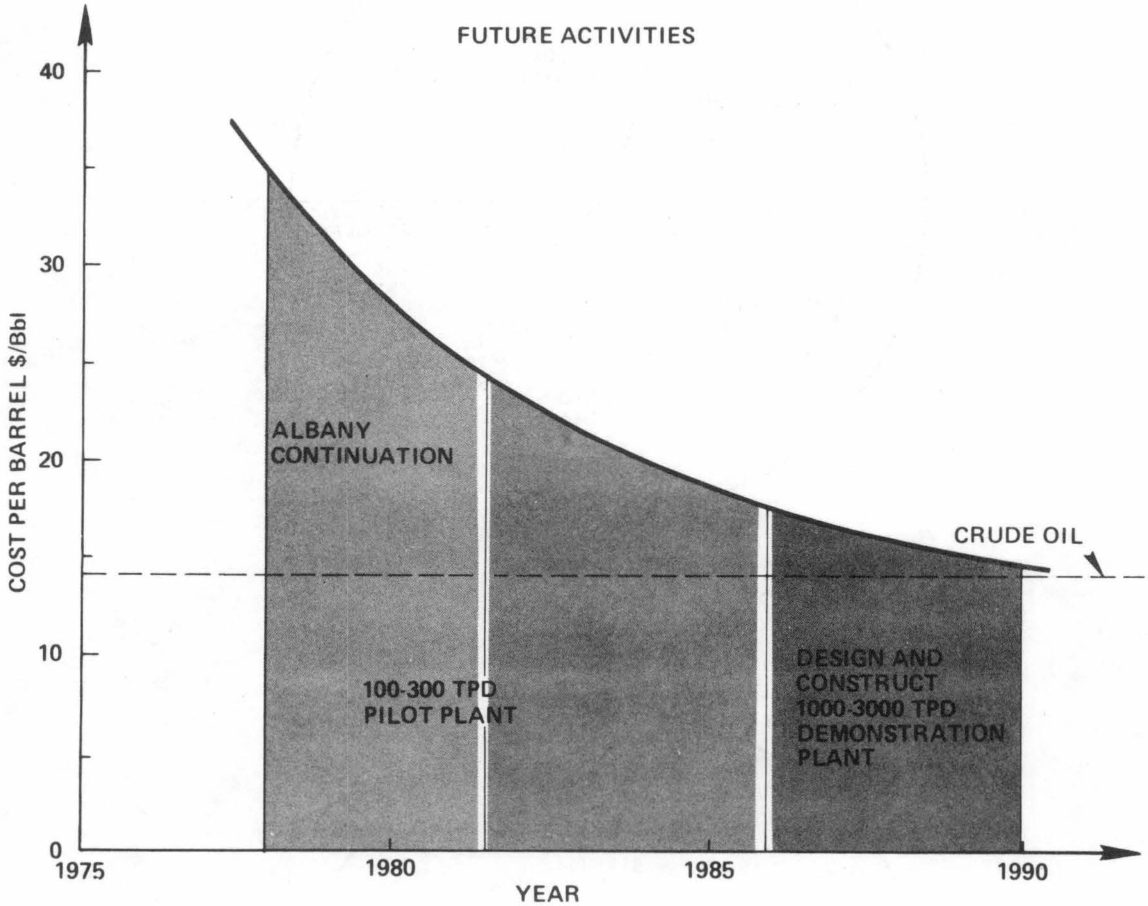


Figure 2-3. Future Activities

2.4.2 PDU Reactor System Modifications

The cost and availability of the critical equipment items have been determined. Installation of the new equipment items at Albany appears possible without long-term interruption of the ongoing tests. A budgetary estimate of $1.1 MM has been obtained, with materials accounting for $0.6 MM.

The major additions or modifications to the Albany PDU are as follows:

- Preheater coil
- Reactor vessels (2)
- Flash tanks (2)
- Gas scrubbers
- Large capacity blender
- Slurry feed pump
- Slurry recirculation pump
- Product incinerator
- Steam boiler for decoking

2.4.3 Increased Analytical Capabilities

A better equipped analytical laboratory is proposed for the Albany facility as the necessity for quick and thorough sample analysis has become apparent due to the complexity of the biomass liquefaction process. Estimates for the cost of equipment and installation for the laboratory were obtained recently from constructors and vendors of equipment and supplies. They represent as definitive an estimate as possible within the schedule limitations. Oral and written bids were submitted.

The proposed laboratory capabilities are as follows:

- Elemental analyzer
- Vacuum distillation
- Gas and liquid chromatography
- Infrared and UV spectrophotometers
- Atomic absorption spectrometer
- Differential thermal analyzer

Section 3

PLANT COMMISSIONING

3.1 PROCESS DESCRIPTION

The wood liquefaction process starts when wood chips are dried and ground into a dry wood flour, as shown in Figure 3-1. This flour is then blended with a carrier oil, and mixed with carbon monoxide and a catalyst solution. The mixture is passed at high pressure through a reaction system where it is heated, held at temperature, and then cooled. The gas phase of the cooled mixture is separated at low pressure and flared. The remaining liquid phase is either recycled as carrier oil or stored in product drums. The following sections discuss each process step in more detail.

3.1.1 Feed Preparation

The wood feed preparation equipment requires partial preparation of the feedstock prior to bringing the material on site. The principal feedstock, wood, has been chipped into small, reasonably uniform blocks approximately 1 in. x 1-1/2 in. x 1/4 in. The wood chips, in this case, Douglas Fir, are brought on site in a live bottom van in lots of 15 to 25 tons. The chips are stored in a covered shed open on one side for easy access. Once on site, the wood is processed and fed to the reaction system by two methods:

- Direct wood drying and grinding
- Partial wood digestion in the preheater

The method more commonly used to produce wood flour is direct wood chip drying and grinding.

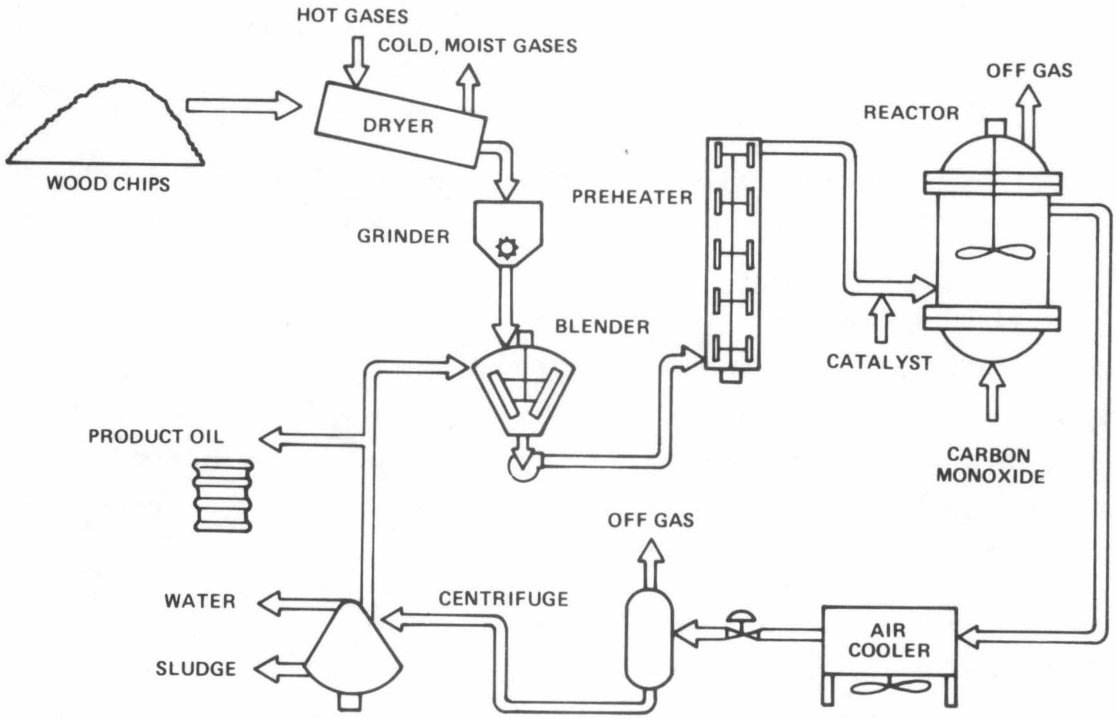


Figure 3-1. Albany PDU Schematic

For direct wood drying, the chips are loaded on a hopper by a tractor equipped with a front-end loader and transferred directly to a surge tank on a conveyor belt. Wood chips are transferred from the surge tank to the dryer via a screw conveyor and a star feeder. Air, heated to 1800^{o}F by burning natural gas, flows cocurrently with the wood, drying it to a nominal one percent moisture.

For grinding, the dried wood chips are transported by bucket elevator to the dried wood surge bin. The bin, equipped with positive flow activation, feeds the dry material by gravity through a variable speed air lock feeder to the wood chip grinder. The grinder is used in combination with the wood flour screen to separate the minus 50 mesh wood from the oversized particles. The oversized particles are recycled to the grinder, and the minus 50 mesh particles are pneumatically transferred with nitrogen to the wood flour surge bin as shown in Figure 3-2.

The alternate method for processing wood is partial wood digestion in one of two large autoclaves called pretreaters.

In the pretreater, the wood chips are combined with water and subjected to temperatures of 500^{o}F and pressures of up to 700 psig. The reactor slurry is circulated through an air cooler, by means of a centrifugal pump. The cooled slurry is stored in the pretreated wood slurry tank, and then filtered in the pretreated wood vacuum filter. The mother liquor is pumped to the aqueous waste tank and a filtered cake is produced as shown in Figure 3-3. This technique for wood preparation has only been tested to this point. The rest of this method is described here even though it has not yet been tested. The pretreated wood filter cake is fed to the dryer via a screw conveyor. Once the filter cake is dried the material is sent to be ground into minus 50 mesh particles and transferred to the wood flour surge bin. From the wood flour surge bin, the dry flour can follow two routes. It can be fed directly to the reactor in batches using high-pressure lock hoppers as shown in Figure 3-4, or to the wood flour/oil slurry blender on a continuous basis via the weigh belt feeder as shown in Figures 3-5 and 3-6.

To date, the wood flour/oil slurry blender has served as the only point of entry for biomass into the reaction system. Dry wood flour is fed continuously from the weigh belt feeder to the blender by gravity. From the blender, the flour is mixed with carrier oil — normally anthracene or an anthracene-product oil mixture — by two independently operated helical agitators. The temperature of the slurry is kept between 180 to 200°F with electrical surface heaters. To keep the particles from settling out, the slurry is circulated externally via a Moyno pump. The Moyno pump also delivers slurry to the intake of the high-pressure slurry pumps. The high-pressure slurry pump is a positive displacement type, utilizing two parallel heads operating off a single motor. The stroke of each head can be adjusted independently, which has the same effect as having a full-time spare.

3.1.2 Reaction System

The reaction system consists of both high and low-pressure equipment, as shown in Figure 3-6. The high pressure area includes the slurry feed pumps, preheater, reactor, and reactor bottoms cooler. The low-pressure area includes the bottoms flash tank and blender, and associated Moyno pumps.

From the blender slurry pumps, the slurry, now at system pressure, is combined with carbon monoxide and a sodium carbonate solution. The mixture of wood flour, carrier oil, carbon monoxide, and sodium carbonate solution is pumped through the preheater to the reactor. The preheater is a scraped surface heat exchanger and is part of the reactor system. The reactor is a high-pressure stirred vessel that follows the preheater. The reaction offgases are vented through the top of the reactor under controlled pressure, while the liquid stream is let down to the reactor bottoms cooler.

The reactor bottoms cooler is an air-cooled exchanger with variable louvers. After the slurry is cooled, it is depressurized, by means of a single let-down valve, to near atmospheric pressure and is pumped into the insulated flash tank. There, the dissolved gases and liquid stream are separated.

The liquid stream is pumped out of the flash tank by a Moyno pump. Because of the positive displacement nature of the Moyno pump, a recirculating line to the flash tank is provided as a pressure safeguard. The liquid level is controlled by a level controller.

Because of continual sealing problems with the main reactor gasket and the agitator seal, the reactor is not being used. The preheater is currently serving as both preheater and reactor.

To date the liquid stream is recycled to the blender to be slurried with wood. However, the liquid stream can be directed to three alternate locations — the centrifuge, sample line, or storage tank.

3.1.3 Product Handling

As originally planned, the liquid stream from the bottoms flash tank is pumped to the product centrifuge, as shown in Figure 3-7. The centrifuge provides separation of three phases — oil, water, and solids. The aqueous phase and the solids phase are collected in separate waste disposal drums, while the oil is routed to the product oil surge pot. From the surge pot, the oil is pumped by Moyno pump through a set of cartridge filters back to the blender. An oil slip stream is provided to remove samples and to maintain system material balance.

Unfortunately, the densities of the three phases were too close, and the centrifuge was never able to separate them. Therefore, the centrifuge was bypassed. Instead, the total liquid stream is being recycled from the bottoms flash tank directly to the blender. Eventually, it is sent to a storage tank.

3.1.4 Overhead Vent System

The reaction system is vented at two locations. The first vent is a high-pressure gas, or offgas, which would normally be vented from the reactor to control pressure. Prior to letdown, the offgas exchanges heat with the incoming carbon monoxide. Following letdown, the offgas is cooled in a water-cooled heat exchanger. Leaving the offgas cooler, the condensate, mainly water, is separated from the gas in a knockout drum. A flow measurement and online analyses for CO, CO_2, and H_2 are made. Then, the gas is flared.

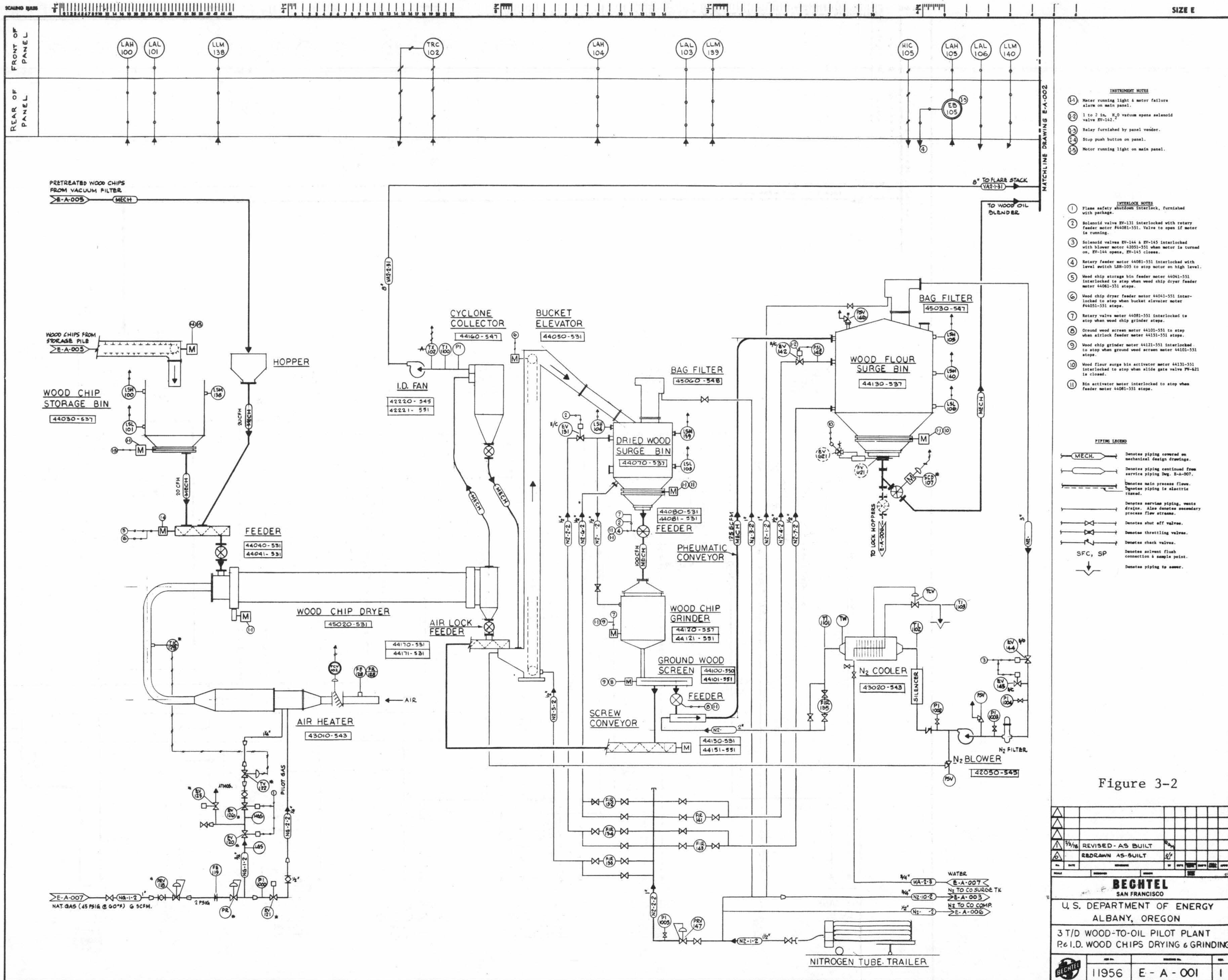
The second vent is a low-pressure gas leaving from the reactor bottoms flash tank. Except for the heat exchange with the CO feed, it travels a parallel path to that of the high-pressure gas. It is cooled and the resulting condensate is separated from the gas. A flow measurement and gas analyses are made, and the gas is flared.

The condensate from both the offgas and the low-pressure gas coolers is collected, weighed, analyzed, and then disposed of offsite.

3.1.5 Support Equipment

The support equipment at the plant includes the CO compressors, catalyst mix tank, and the carrier oil hold tank, as shown in Figures 3-4 and 3-5.

CO Compressors. Carbon monoxide arrives on site in tube trailers holding 100,000 to 120,000 SCF at a nominal 1,800 psig. The pressure is reduced to 120 to 150 psig and is delivered to the intake of one of two parallel CO compressors. The compressors are two-stage diaphragm types, each providing 5 to 10 SCFM, depending on system pressure. Flow control is maintained by recycling excess compressor discharge gas back to the compressor intake. The metered gas is fed to either the inlet of the preheater or to the reactor via the CO interchanger.



FRONT OF PANEL
REAR OF PANEL
MATCHLINE DRAWING E-A-002
PRETREATED WOOD CHIPS FROM VACUUM FILTER
E-A-005
MECH
WOOD CHIPS FROM STORAGE PILE
HOPPER
WOOD CHIP STORAGE BIN
44030-537
FEEDER
44040-531
44041-531
WOOD CHIP DRYER
45020-531
AIR HEATER
43010-543
AIR
I.D. FAN
42220-545
42221-551
CYCLONE COLLECTOR
44160-547
BUCKET ELEVATOR
44050-531
AIR LOCK FEEDER
44170-531
44171-531
BAG FILTER
45060-548
DRIED WOOD SURGE BIN
44070-531
44080-531
44081-531
FEEDER
PNEUMATIC CONVEYOR
WOOD CHIP GRINDER
44120-557
44121-551
GROUND WOOD SCREEN
44100-550
44101-551
FEEDER
SCREW CONVEYOR
44150-531
44151-551
BAG FILTER
45030-547
WOOD FLOUR SURGE BIN
44130-537
TO LOCK HOPPERS
8" TO FLARE STACK
TO WOOD OIL BLENDER
N2 COOLER
43020-543
SILENCER
N2 FILTER
N2 BLOWER
42050-543
NITROGEN TUBE TRAILER
E-A-007
NAT. GAS (45 PSIG @ 60°F) 6 SCFM.
PILOT GAS
WATER
E-A-007
N2 TO CO SURGE TK
E-A-003
N2 TO CO COMP.
E-A-006
INSTRUMENT NOTES
INTERLOCK NOTES
PIPING LEGEND
SIZE E
REVISED - AS BUILT
REDRAWN AS-BUILT
BECHTEL
SAN FRANCISCO
U. S. DEPARTMENT OF ENERGY
ALBANY, OREGON
3 T/D WOOD-TO-OIL PILOT PLANT
P&I.D. WOOD CHIPS DRYING & GRINDING
11956
E-A-001
1

Figure 3-2

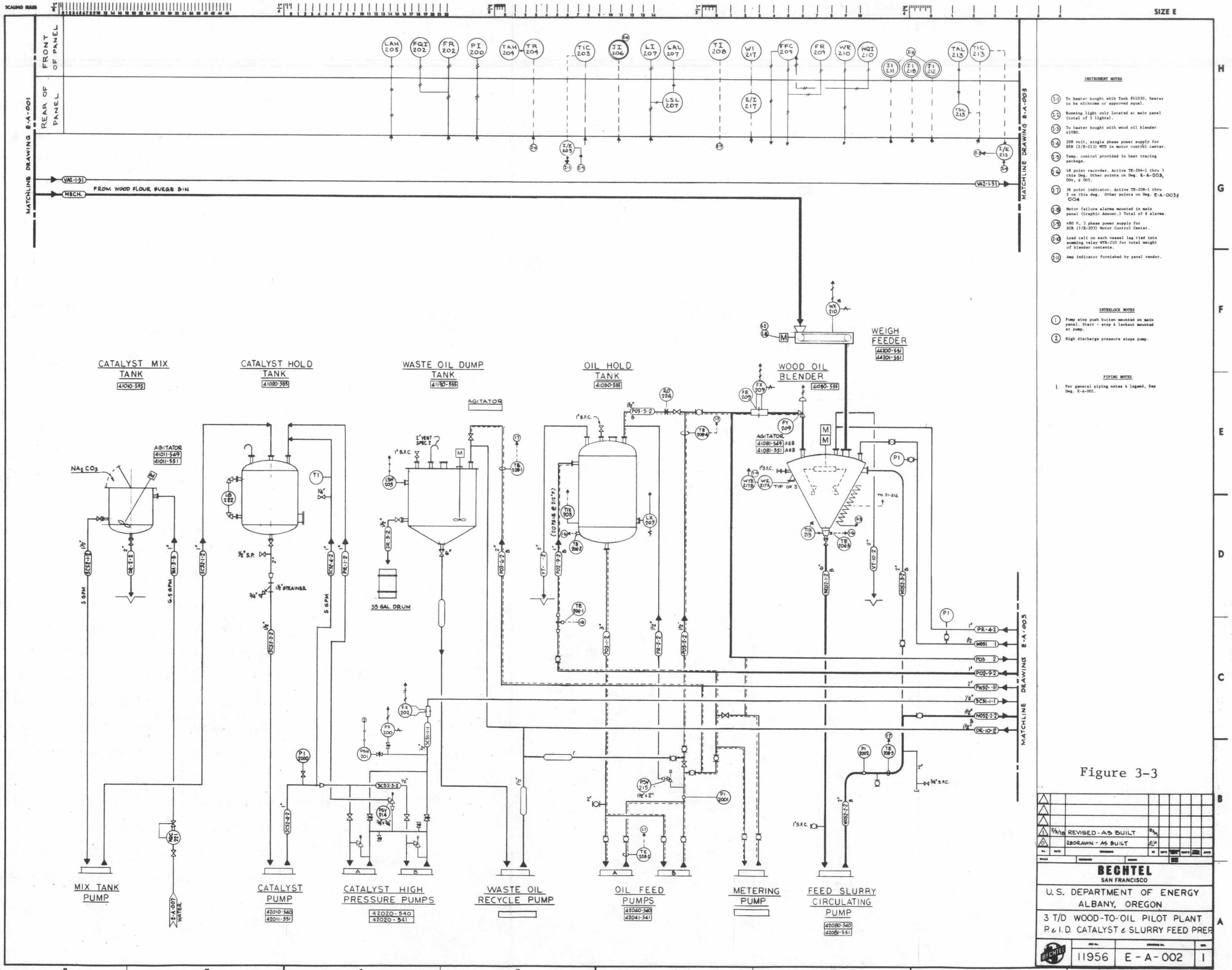
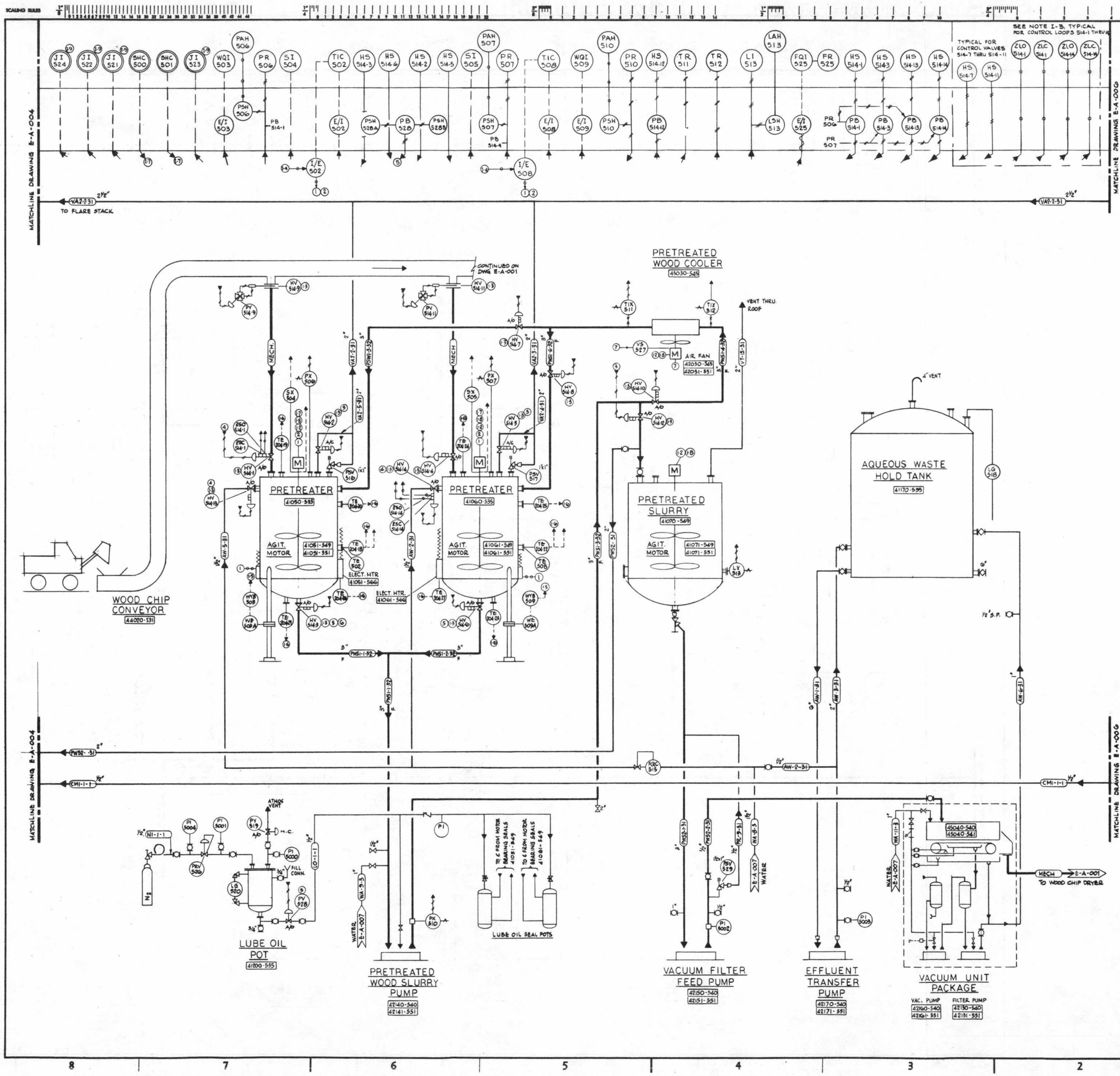

FRONT OF PANEL
REAR OF PANEL
MATCHLINE DRAWING E-A-001
MATCHLINE DRAWING E-A-003
FROM WOOD FLOUR SURGE BIN
CATALYST MIX TANK
41010-595
CATALYST HOLD TANK
41020-595
WASTE OIL DUMP TANK
41130-595
AGITATOR
OIL HOLD TANK
41030-595
WEIGH FEEDER
44200-551
44201-551
WOOD OIL BLENDER
41080-535
55 GAL DRUM
MIX TANK PUMP
CATALYST PUMP
42010-540
42011-551
CATALYST HIGH PRESSURE PUMPS
42020-540
42020-541
WASTE OIL RECYCLE PUMP
OIL FEED PUMPS
42040-540
42041-541
METERING PUMP
FEED SLURRY CIRCULATING PUMP
42080-540
42081-551
INSTRUMENT NOTES
(I-1) To heater bought with Tank #41030, heater to be nichrome or approved equal.
(I-2) Running light only located at main panel (total of 5 lights).
(I-3) To heater bought with wood oil blender 41080.
(I-4) 208 volt, single phase power supply for SCR (I/E-213) MTD in motor control center.
(I-5) Temp. control provided in heat tracing package.
(I-6) 48 point recorder. Active TE-204-1 thru 3 this Dwg. Other points on Dwg. E-A-003, 004, & 005.
(I-7) 36 point indicator. Active TE-208-1 thru 5 on this dwg. Other points on Dwg. E-A-003 & 004
(I-8) Motor failure alarms mounted in main panel (Graphic Annunc.) Total of 6 alarms.
(I-9) 480 V, 3 phase power supply for SCR (I/E-203) Motor Control Center.
(I-10) Load cell on each vessel leg tied into summing relay WYB-210 for total weight of blender contents.
(I-11) Amp indicator furnished by panel vendor.
INTERLOCK NOTES
(1) Pump stop push button mounted on main panel. Start - stop & lockout mounted at pump.
(2) High discharge pressure stops pump.
PIPING NOTES
1. For general piping notes & legend, See Dwg. E-A-001.
REVISED - AS BUILT
REDRAWN - AS BUILT
BECHTEL
SAN FRANCISCO
U.S. DEPARTMENT OF ENERGY
ALBANY, OREGON
3 T/D WOOD-TO-OIL PILOT PLANT
P & I.D. CATALYST & SLURRY FEED PREP
11956
E-A-002
1
SIZE E

Figure 3-3



INSTRUMENT NOTES

(I-1) Control to be furnished with package system inclosed by dashed.

(I-2) Running light only. Located at main panel.

(I-3) "Valve Open" limit switch (ZSO) makes contact at end of stem travel at open position. "Valve Closed" limit switch (ZSC) makes contact at end of stem travel at closed position. Position lights (ZSO & ZSC) on panel indicate valve position.

(I-4) 480 volt, 3 phase power supply for SCR mounted off of main panel.

(I-5) Load cell on each vessel leg (total of 3 per vessel) tied into summing relay WYB to indicate total weight of vessel & contents.

(I-6) Temp. elements 204/18-27 wired to TR-204 shown on Dwg. E-A-002.

(I-7) Manual speed control for agitators on pretreators #41050 & 41060.

(I-8) Motor failure alarm mounted on main panel (Graphic Annunciator).

(I-9) Amp indicators furnished by panel vendor.

(I-10) Process tap line connecting differential pressure transmitter PDX-525 & PDX-526 with lube oil pot.

(I-11) Transmitter output signal from PDX-519-1.

(I-12) Transmitter output signal from PDX-519-2.

INTERLOCK NOTES

(1) To heaters bought with pretreaters #41050 & 41060. Heater controls interlocked so that only one pretreater can be heated at one time.

(2) Interlock provided so that heater cannot operate unless agitator on the same pretreater is running.

(3) Pressure interlock thru pneumatic relay PB-514-12. Valve will not open until line pressure drops below 100 psig.

(4) Pressure interlock thru pneumatic relay PB, valve will not open until pressure drops below 10 psig.

(5) Valve PV-528 opens when HV-514-2 is closed & HV-514-3 is open or when HV-514-5 is closed and HV-514-6 is open.

(6) When HV-514-3 starts to open "valve closed" DPDT limit switch makes one set of contacts to energize EV-519 & allow signal from PDX-519-1 to reach PDIC-519 which controls seal oil pressure on pump 42140-540 at 10 psi higher than press. on pretreater. This system disconnected 4/77.

(7) Vibration switch stops fan on excessive vibration.

PIPING NOTES

1. For general piping notes & legend, see Dwg. E-A-001.

Figure 3-4

REVISED- AS BUILT
REDRAWN AS-BUILT

BECHTEL
SAN FRANCISCO

U. S. DEPARTMENT OF ENERGY
ALBANY, OREGON

3 T/D WOOD-TO-OIL PILOT PLANT
P & I. D. PRETREATMENT OF WOOD CHIPS

11956 E-A-005 1

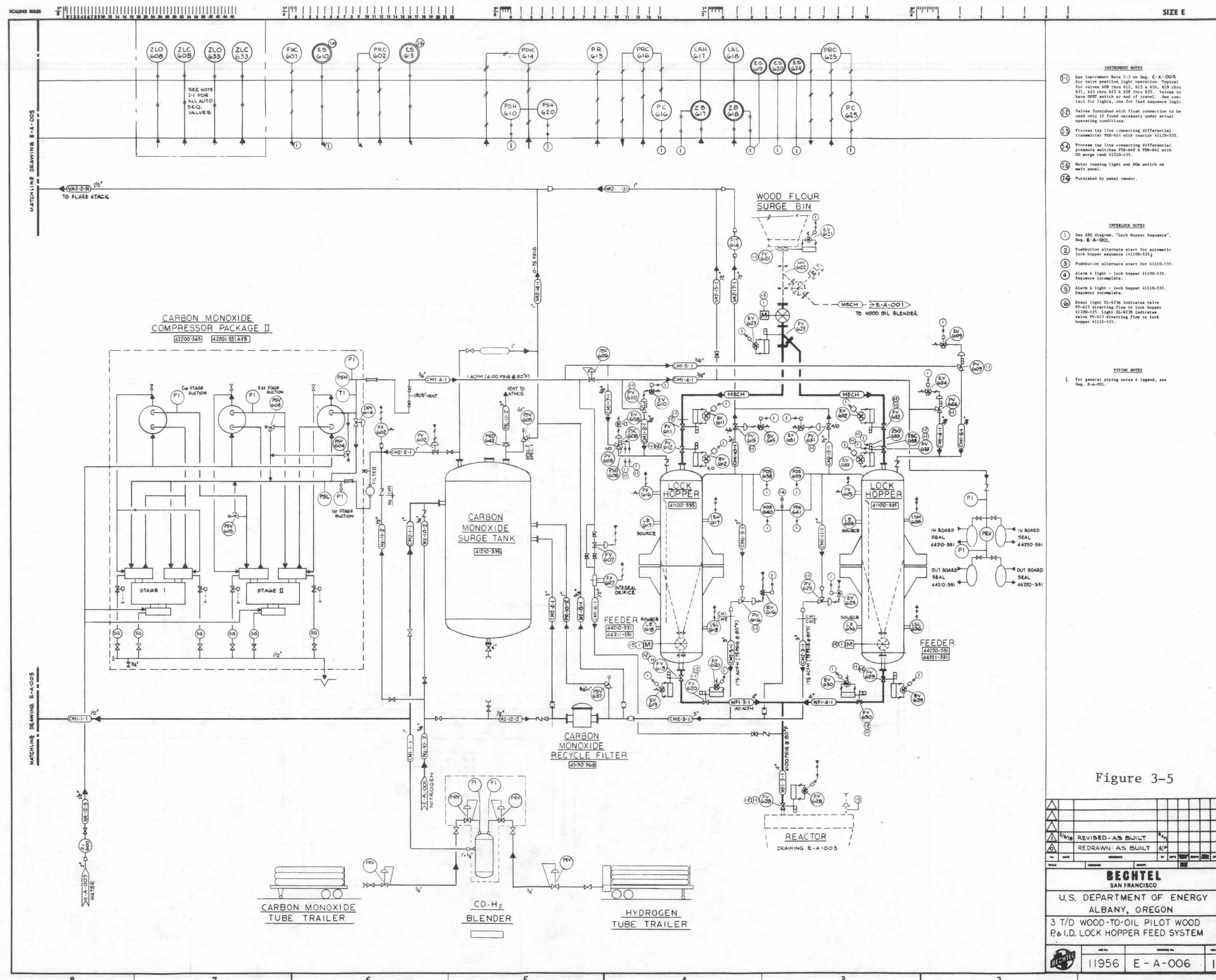

SIZE E
INSTRUMENT NOTES
I-1 See Instrument Note I-3 on Dwg. E-A-005 for valve position light operation. Typical for valves 608 thru 612, 615 & 616, 619 thru 621, 623 thru 625 & 628 thru 633. Valves to have DPDT switch at end of travel. One contact for lights, one for feed sequence logic.
I-2 Valves furnished with flush connection to be used only if found necessary under actual operating conditions.
I-3 Process tap line connecting differential transmitter PDX-614 with reactor 41120-535.
I-4 Process tap line connecting differential pressure switches PDS-640 & PDS-641 with CO surge tank 41210-435.
I-5 Motor running light and HOA switch on main panel.
I-6 Furnished by panel vendor.
INTERLOCK NOTES
1 See SEQ diagram, "Lock Hopper Sequence", Dwg. E-A-001.
2 Pushbutton alternate start for automatic lock hopper sequence (41100-535)
3 Pushbutton alternate start for 41110-535.
4 Alarm & light - lock hopper 41100-535. Sequence incomplete.
5 Alarm & light - lock hopper 41110-535. Sequency incomplete.
6 Event light ZL-623A indicates valve FV-623 diverting flow to lock hopper 41100-535. Light ZL-623B indicates valve FV-623 diverting flow to lock hopper 41110-535.
PIPING NOTES
1. For general piping notes & legend, see Dwg. E-A-001.
MATCHLINE DRAWING E-A-005
TO FLARE STACK
WOOD FLOUR SURGE BIN
TO WOOD OIL BLENDER
CARBON MONOXIDE COMPRESSOR PACKAGE II
42200-545
42201-551 A&B
STAGE I
STAGE II
CARBON MONOXIDE SURGE TANK
41210-535
LOCK HOPPER
41100-535
LOCK HOPPER
41100-535
FEEDER
44210-551
44211-551
FEEDER
44220-551
44221-551
IN BOARD SEAL
OUT BOARD SEAL
CARBON MONOXIDE RECYCLE FILTER
REACTOR
DRAWING E-A-003
CARBON MONOXIDE TUBE TRAILER
CO-H2 BLENDER
HYDROGEN TUBE TRAILER
NITROGEN
WATER
REVISED- AS BUILT
REDRAWN- AS BUILT
BECHTEL
SAN FRANCISCO
U.S. DEPARTMENT OF ENERGY
ALBANY, OREGON
3 T/D WOOD-TO-OIL PILOT WOOD
P.& I.D. LOCK HOPPER FEED SYSTEM
11956
E-A-006
1

Figure 3-5

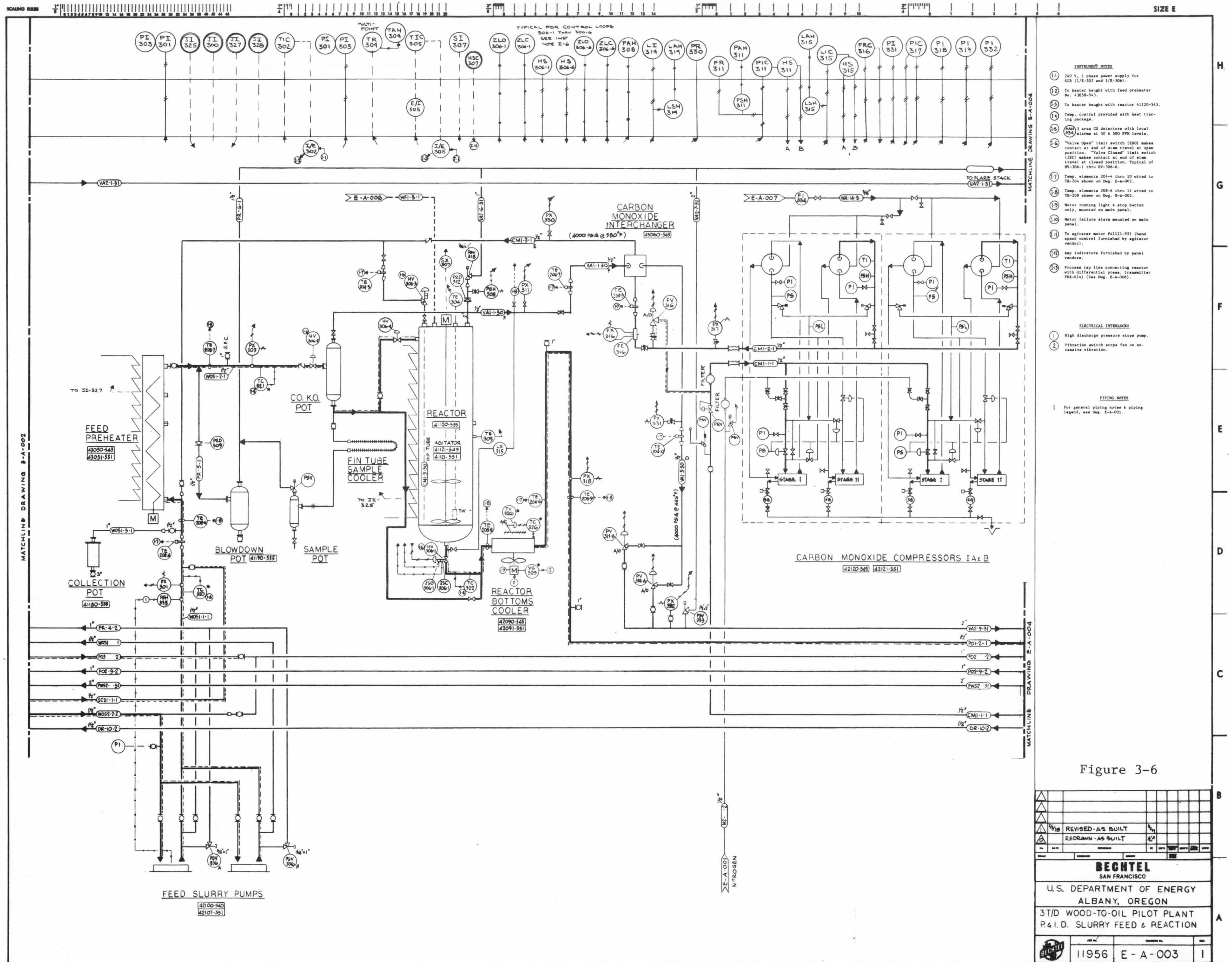

FEED PREHEATER
CO. KO. POT
FIN TUBE SAMPLE COOLER
REACTOR
CARBON MONOXIDE INTERCHANGER
BLOWDOWN POT
SAMPLE POT
COLLECTION POT
REACTOR BOTTOMS COOLER
CARBON MONOXIDE COMPRESSORS IA & B
FEED SLURRY PUMPS
MATCHLINE DRAWING E-A-002
MATCHLINE DRAWING E-A-004
NITROGEN
TO FLARE STACK
INSTRUMENT NOTES
ELECTRICAL INTERLOCKS
PIPING NOTES
REVISED-AS BUILT
REDRAWN-AS BUILT
BECHTEL
SAN FRANCISCO
U.S. DEPARTMENT OF ENERGY
ALBANY, OREGON
3T/D WOOD-TO-OIL PILOT PLANT
P&I.D. SLURRY FEED & REACTION
11956
E-A-003
SIZE E

Figure 3-6

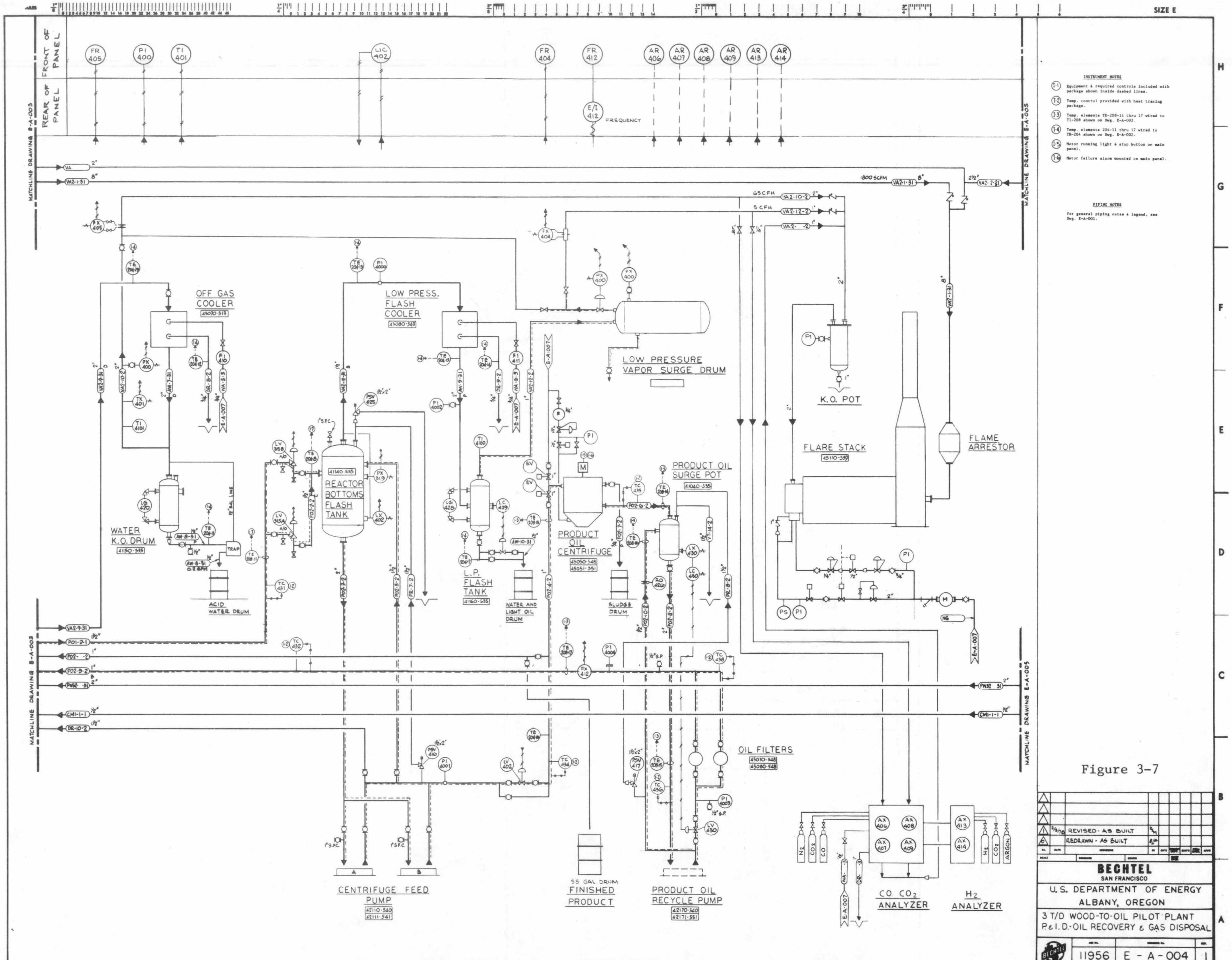

FRONT OF PANEL
REAR OF PANEL
MATCHLINE DRAWING E-A-003
MATCHLINE DRAWING E-A-005
OFF GAS COOLER
LOW PRESS. FLASH COOLER
LOW PRESSURE VAPOR SURGE DRUM
K.O. POT
FLARE STACK
FLAME ARRESTOR
WATER K.O. DRUM
REACTOR BOTTOMS FLASH TANK
L.P. FLASH TANK
PRODUCT OIL CENTRIFUGE
PRODUCT OIL SURGE POT
ACID WATER DRUM
WATER AND LIGHT OIL DRUM
SLUDGE DRUM
OIL FILTERS
CENTRIFUGE FEED PUMP
55 GAL DRUM FINISHED PRODUCT
PRODUCT OIL RECYCLE PUMP
CO CO2 ANALYZER
H2 ANALYZER
FREQUENCY
INSTRUMENT NOTES
PIPING NOTES
REVISED - AS BUILT
REDRAWN - AS BUILT
BECHTEL
SAN FRANCISCO
U.S. DEPARTMENT OF ENERGY
ALBANY, OREGON
3 T/D WOOD-TO-OIL PILOT PLANT
P&I.D.-OIL RECOVERY & GAS DISPOSAL
11956
E - A - 004
1
SIZE E

Figure 3-7

If lock hoppers were used, a third, larger compressor would be put into service. To conserve carbon monoxide, the bulk of the gas for lock hopper operation would be vented into the CO surge tank. The compressor would recycle the carbon monoxide from the surge tank and use fresh CO only as makeup.

Catalyst Mixing. Catalyst solution is prepared in 50 gallon batches in the catalyst mix tank. Sodium carbonate is mixed with hot water to a concentration of 5 to 20 percent by weight, depending on the test in progress. The mixed solution is transferred to the catalyst hold tank where it is continuously circulated and heated to prevent precipitation of the sodium carbonate. The amount of solution required in the process is metered using high-pressure, positive displacement pumps.

Carrier Oil Makeup. Carrier oil, normally anthracene, is stored on site in drums and in the oil hold tank. The oil hold tank is electrically heated to maintain an internal temperature of 200°F. Material in the tank is kept in constant circulation with Moyno pumps. The carrier oil, upon leaving the tank, is filtered and either routed directly to the blender or metered into the blender via a small positive displacement pump.

3.1.6 Utilities

The utilities at the plant include instrument air, nitrogen, electricity, process water, and waste and effluent disposal.

Instrument Air. Plant and instrument air is supplied by one of two parallel reciprocating air compressors. Plant air is available at 100 psig, while instrument air is reduced to 25 psig. In addition, instrument air is dried to -40°F dew point in activated alumina bed dryers.

Nitrogen. Nitrogen is stored on site in a tube trailer containing 45,000 SCF at 2,200 psig. It is used on a continuous basis to maintain a dry, nonflammable atmosphere in the dry wood chip and flour bins. Nitrogen can also be supplied to the intake of the CO compressors to purge the process equipment or maintain pressure during startup, shutdown, or online maintenance activities.

Electricity. All motors, heaters, and line tracing are operated electrically. Voltages of 480, 240, or 120 are available.

Process Water. City water, available on site at a pressure of 60 psig, serves as both cooling water and process water. Cooling water is on a once-through basis. The major uses are for the CO compressors and instrument air compressors. Other uses include the overhead coolers, catalyst solution, mix tank, and pretreaters, in addition to general sanitation.

Waste and Effluent Disposal. Process wastes, both hydrocarbon and aqueous, are removed from the site in drums for disposal elsewhere. Aqueous effluent from cooling water and system spills or washdowns are passed through an API separator prior to leaving the site.

3.2 PLANT COMMISSIONING

The initial schedule for commissioning the plant called for process runs to begin 4 months from January 1977, the date Bechtel took over. However, it took over six months to achieve operation of the complete system and to obtain initial process data. The commissioning period, although longer than planned, produced valuable information that can be used in selecting material and in establishing the operating conditions for the design of a full-scale plant.

Before process testing began, the entire facility was checked out, and all equipment was proof-tested. The major process items requiring proof-testing are listed below:

- 7 pressure vessels
- 15 pumps

- 6 heat exchangers
- 6 wood handling units
- 40 electric motors
- 60 control loops

3.2.1 Summary of Commissioning Procedure

One of the important steps in plant commissioning is equipment testing and evaluation. Equipment operating data were compared with performance specifications supplied by the plant designer and by the equipment manufacturer. Whenever equipment failed to meet specification, a decision was made — after retesting — to modify the equipment or change the process characteristics.

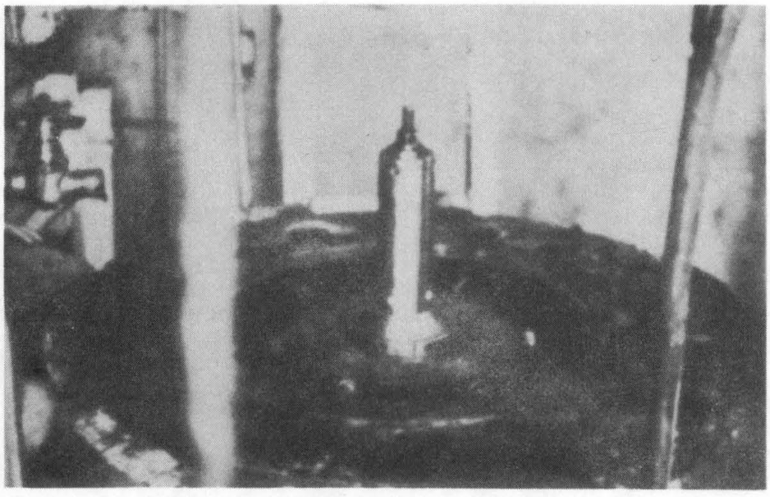
A variety of tests were performed to cover all types of plant equipment. These tests included hydrostatic testing of vessels and piping, flow testing of liquids and solids, etc. A profile was prepared that contained operating history and modifications performed. This is included in the appendix.

After each unit was checked, the entire system was tested. First a reagent was run through, beginning with anthracene. Then nitrogen was added for pressure testing. Carbon monoxide was substituted for nitrogen and run through the system with anthracene. Then water was added to the reagents. Finally, wood was introduced after system stability was established.

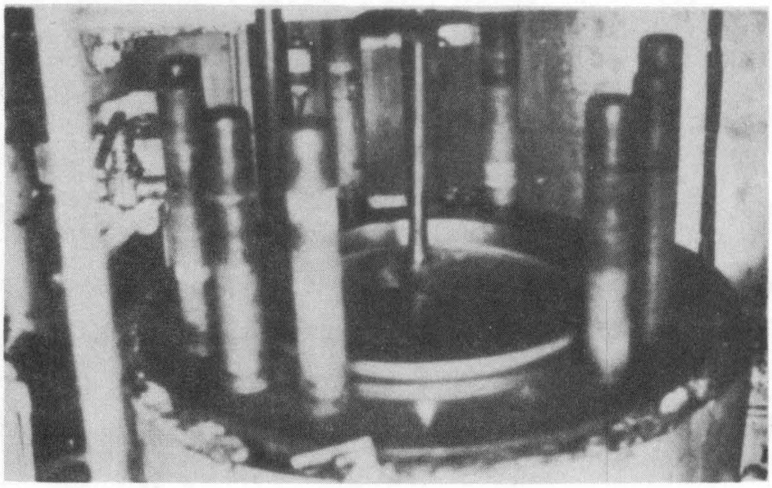
3.2.2 Major Findings During Commissioning

During the commissioning of the plant, a number of difficulties were encountered with the process equipment. This is not unusual in the development of a new process. For example, many modifications had to be made to pump and agitator shaft seals on high-pressure equipment. In addition, problems showed up with the gas compressors, wood handling equipment, and the preheater scraper. To illustrate the magnitude of some of the problems,

Figure 3-8 shows the modifications required on the head to shell closure of the stirred tank reactor.



BEFORE MODIFICATION

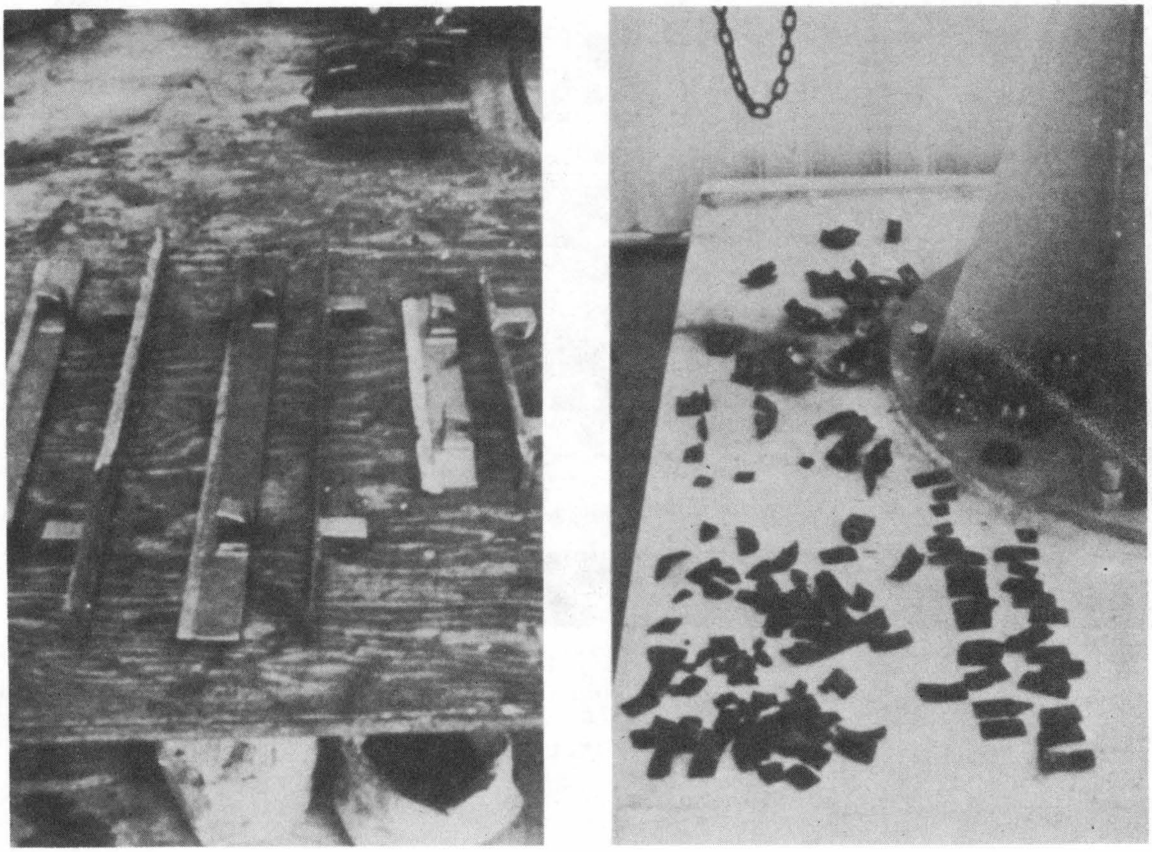


DURING MODIFICATION

Figure 3-8. Reactor Head Seal

This vessel is approximately 24 inches in diameter and designed for pressures of up to 4000 psig. Modifications included complete removal of the original seal mechanism, replacement of the vessel lining, and remachining for a new seal ring. All of the work was done in place, including the machining of the reactor head, which weighs over a ton and is located 45 feet above the ground.

The initial operation of the preheater uncovered difficulties with internal coking and eventual damage to the scraper blades. Figure 3-9 illustrates the condition of some of the 50 scraper blades that are used in this heat **exchanger before and after operation.**



(BEFORE) (AFTER)

Figure 3-9. Preheater Scraper Blades

Degradation of polymeric materials caused numerous problems in the plant. The product oil, or the anthracene vehicle oil, which was used for startup, rapidly attacked gaskets, seal parts, and O-rings, as illustrated in Figure 3-10. Replacement was required in almost every seal and pressure boundary part in the plant. In-depth discussion of the modifications made to the system appears in Section 5.

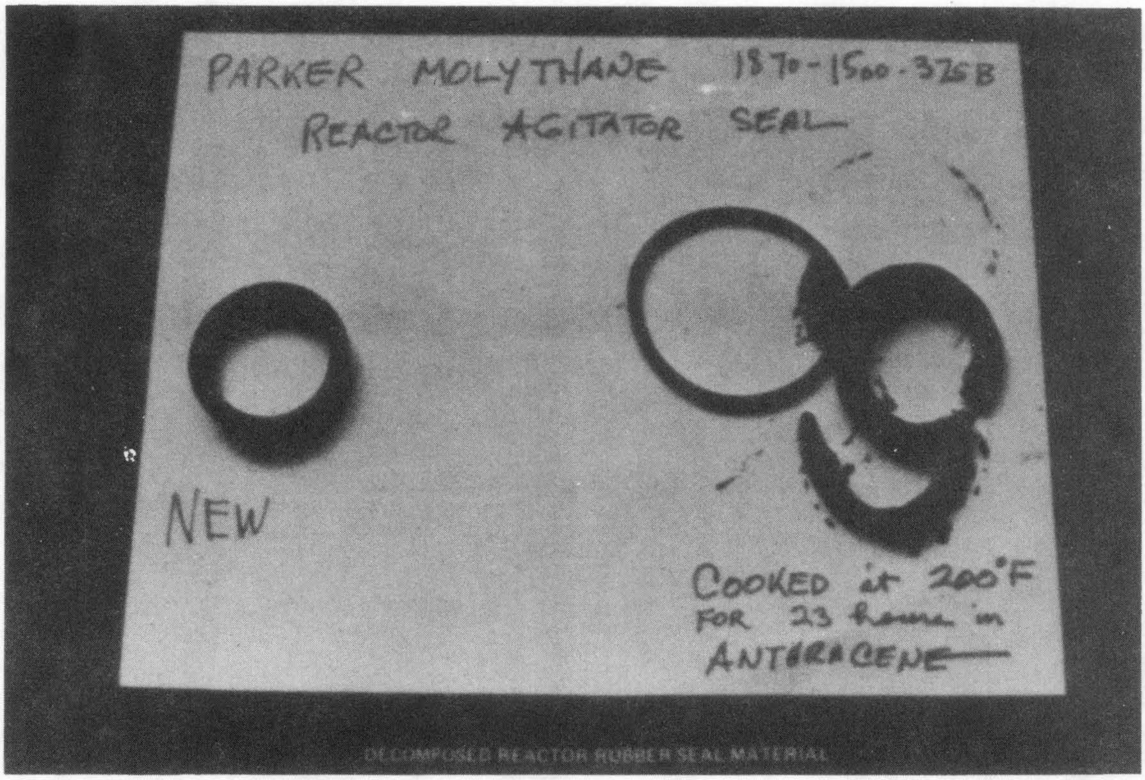


Figure 3-10. Decomposed Reactor Rubber Seal Material

Other findings during commissioning include the following.

The stirred tank reactor (CSTR) was unable to be sealed at the agitator shaft, therefore, it was necessary to bypass it and to introduce all reactants ahead of the preheater. This resulted in a shorter residence time than originally planned. When the shaft seal problems are solved, it is intended to reintroduce the CSTR into the system.

It was found that the centrifuge was unable to separate the solids and water from the oil. This was primarily due to high viscosity.

Significant modifications of the instrument and control systems in the plant were also required. In some cases, the instrumentation selected did not provide measurement over the entire operating range; in other cases, instrumentation was improperly installed. In some areas, there was no instrumentation, causing unsafe conditions, for example, the lack of temperature measurement on the preheater. Since then, modifications, additions, and rearrangements of existing instrumentation have broadened capability, increased safety, and improved control.

3.2.3 Nonprocess Commissioning

Plant commissioning also covered work done in fully equipping the site for both process and maintenance operations. These activities included procurement of office furniture and fixtures, as well as leasing such equipment as a photocopier, telecopier, typewriters, and the computer terminal. Services were also secured for the supply of uniforms and for waste removal.

The machine shop, the instrument shop, and a small analytical laboratory have been outfitted. A large front-end loader for handling wood chips has been purchased; a wood chip metal shed has been built under subcontract; and the property has been landscaped. The low-voltage capability of the plant has been extended by the installation of a 45 kVa transformer and a panel board with 480/220/110 voltage stepdown capabilities. Additional heat tracing has been installed in required locations.

Other extensive modifications were made in the plant to assure safety and remove construction deficiencies. These are discussed in the process and safety addition sections.

Plans are currently being made to provide a larger analytical laboratory. In summary, the site is continually being upgraded.

3.3 PROCESS MODIFICATIONS

A large number of process modifications were required since the system began operation. Numerous mechanical problems were circumvented to improve on-stream time; other modifications provided either improved control of the system or extended system capabilities.

The elimination of the stirred autoclave reactor from the high-pressure reaction system was the first and most significant modification. It was prompted by continuing sealing problems at the high pressures and temperature required to operate the reactor system. The reactor was disconnected only after several weeks of trying to operate the process with the reactor in the system, and achieving a few hours of run time. In this case, the material leaving the preheater was sent directly to the reactor bottoms cooler via a reactor bypass line.

Within a short time after adding the bypass line, it became evident that the centrifuge was unable to separate the solids and water from the oil. As a result, piping was added to the system to recycle the entire liquid stream from the reactor bottoms flash tank to the blender.

Two problems worth noting involved the carbon monoxide feed and the low-pressure vent. As installed, the CO feed to the reaction system was unstable. To solve this problem, a line was provided that would recycle the excess gas to the compressor intake. A control valve was installed in this line.

With the reactor bypassed, all offgas was forced through the bottoms flash tank. This created control problems in the low-pressure vent. Because all the gas was forced through the bottoms flash tank as opposed to being split into two streams, an erratic pulsing flow was created. To solve this, a surge tank was added to lessen the pulsation, and the back-pressure regulator was replaced with a pressure control valve that operated off the pressure flow transmitter.

During cold weather, additional problems were encountered. The overhead vapor, which normally condensed only water and some light oils, began condensing an abundance of waxy material and plugged the entire overhead system. In addition, the catalyst solution began precipitating sodium carbonate, which plugged the lines. To minimize these problems, additional heat tracing and insulation were installed.

Recent process changes have been made to extend the system's capabilities. The high-pressure catalyst pumps, as installed, provided too much capacity for normal operation. To provide a reduced catalyst flow, the spare high-pressure pumps were modified by installing a smaller pump head and a lower speed motor. Flow rates of 0.3 to 20 gph are now possible.

The last few bypass tests required the addition of anthracene on a continuous basis in order to maintain a fixed concentration of reaction product oil in the carrier oil. To do this, a positive displacement metering pump was installed off the oil hold tank.

Recently, provision was made for temporary storage of reaction product oil. Heaters and mixers were added to the waste oil hold tank along with the piping required to pump the oil in and out of the system. With this storage system, sufficient reaction product oil can be stored during maintenance shutdowns to provide an initial charge of carrier oil for ensuing runs.

3.4 MECHANICAL PROBLEMS

From the start of commissioning, the Albany wood-to-oil facility has encountered a variety of mechanical problems. These problems are the result of improper materials selection, equipment design, or faulty quality control. In addition, much of the equipment was inappropriately sized for smooth system operation. These problems were compounded by the plot plan which provides inadequate access to the equipment for maintenance.

The feed preparation section of the plant has had few mechanical problems, with the exception of the wood grinder and the wood flour weigh belt feeder. It was discovered that the grinder had only one-fourth the capacity specified in the design. As a result, the star feeder valve controlling the grinder feed had to be modified to reduce the feed rate or the grinder would have clogged. Originally, the wood flour weigh belt feeder was equipped with a high temperature, heavy-duty belt, resulting in poor sensitivity. A new lightweight belt was installed and the weighing problem was solved.

During plant operation, two problems persisted within the feed preparation area. During periods of inclement weather, the rain and drips from the floor above accumulated on the wood chip table feeder. When the wood chips were fed to the dryer, excess water entered. In some cases, the wood chips would not dry. The undried chips became wet flour and plugged the flour feed lines, the screen, and the cyclone vent lines. To minimize this problem, rain guards were installed.

Whether the flour is wet or dry, bridging of the flour in the feed line to the weigh belt feeder can cause flow stoppages. Pneumatic vibrators have been installed to minimize this problem.

Most of the mechanical difficulties were in the reactor section. The majority, and certainly the most severe problems, were associated with the high-pressure equipment. The first observed mechanical problem was the choice of elastomeric materials for gaskets, seals, O-rings, and even extending to the stators on the Moyno pumps that are used in several locations throughout the plant. As a result of inadequate specification of the carrier oil, Buna-N rubber was chosen as the standard sealing material. Unfortunately, Buna-N is incompatible with aromatic compounds, and anthracene coal tar is highly aromatic in nature. As failures occurred, all seals, gaskets, etc. have been replaced with Viton, Teflon, or other more resistant substances.

Sealing the high-pressure equipment, mainly the reactor and preheater, has created the most severe mechanical difficulties. The reactor head gasket seal was the first to show problems. The main head gasket was sealed with a stainless steel "B" ring. Internal pressure holds the outermost surfaces of the ring against the inside surface of the head and body. This type of seal is used throughout the petroleum industry with good success, but is designed for systems where pressure and temperature are maintained for months, and in some cases, years. It was not designed for a pilot plant where pressures and temperatures are constantly fluctuating. When the reactor was cooled and depressurized, the inner ring relaxed to the point where it broke the sealing surface. Once broken, it could not be resealed. To alleviate this problem, the reactor was machined in place and a new seal installed. The resulting seal has proved satisfactory. Figure 3-10 illustrates the reactor seal repairs.

A more persistent problem existed in the agitator seals of both the preheater and reactor. Both units came with Parker B-type polypak seals. This seal is essentially a high-pressure lip seal, normally used for reciprocating service rather than rotating service. The seal material was Molythane. As with Buna-N, the Molythane proved chemically incompatible with the anthracene. Rapid deterioration of both seals took place under operating conditions, although the reactor agitator seal located in the gas zone showed earliest signs of failure. Replacement of the Molythane seals with a chemically resistant material did not provide a solution.

At this point, discussions with seal manufacturers were initiated. The purpose was to obtain recommendations and subsequent proposals for replacing the reactor agitator seal with a mechanical seal or possibly an enclosed shaft with a magnetic drive. Although the 4000 psig pressure was beyond the state of the art, proposals were received from Crane, Anchor, and Autoclave Engineers. These are being evaluated.

In the interim, the reactor agitator seal has been replaced with a locally fabricated stuffing box. After several trials with various packings, including asbestos and graphite ribbon in various combinations, it was found that braided graphite packing gave the best results. Costs showed only minimal controlled leakage. In-service testing was done on the reactor in March 1978.

The preheater seal is located in the liquid phase at the bottom of the vertically mounted scraped surface exchanger. The highly viscous nature of the slurry entering the preheater makes it possible to operate with slight seal leakage. As with the reactor agitator, a variety of seal materials have been tested. It was found, however, that the higher lubricity inherent in the original Molythane seal offset its chemical incompatibility. Where the mechanical failure of the various fluorinated elastomeric material tested was occurring within 40 to 60 hours run time, the Molythane seals have been found to withstand chemical failure for up to 150 hours. The lack of shaft support was contributing to the failure, especially of the fluorinated seals.

The original seal cavity had only two bronze bushings to provide radial support. As the bushings began to wear, more and more mechanical stress was put on the seals. To alleviate this problem, a new seal cavity was machined that would provide space for two journal bearings. In addition, the stub shaft which passes through the seal cavity has been plated with hard chrome and polished to provide a hard, smooth surface to minimize mechanical wear. The preheater has also been subjected to periodic scraper damage.

During startup of the system, slurry flow stoppages were fairly common. During these periods, temperatures of over 1000^{o}F were experienced. During one of the cooling cycles where the inside fluid was still hot and the shell was cooling off, the shell shrunk against the agitator shaft, causing the shaft to bow. The increased pressure of the blades against the shell, in turn, caused the bolts that hold the blades to the shaft to shear, allowing the blades to fall to the bottom of the exchanger. The loss of the scraper blades eventually causes overheating and internal coking, along with failure of the electrical heaters. During the ensuing shutdown the coke was removed, the blades were replaced, the shaft was shortened, and the seal was repaired.

In addition, several thermocouples and high-temperature protection devices were installed along the shell of the preheater to allow quicker detection of abnormal conditions. Although there have been no temperature excursions since that time, increased pressure occasionally causes shearing of the bolts that hold the blades to the shaft. Periodic examination of the shaft has prevented any further significant damage in this area.

The CO compressors were the other major source of mechanical difficulties. These are two small diaphragm-type compressors that were supplied by Aminco.

During commissioning, repeated diaphragm failures hindered long-term operation of the plant. Initial on-site examination of the compressors and diaphragms was made by Aminco personnel. They recommended the addition of filters to the suction lines to prevent contaminants from reaching the diaphragms and causing punctures. This was done, but it did not solve the problem. A closer examination of the heads and oil plates showed that an error had been made in the original construction and that the angle of the head curvature was too steep. This resulted in stress cracking of the diaphragms. The old heads were returned to Aminco for reworking. In addition to correcting the curvature, the heads were grooved to allow trapped gas to escape, further reducing the stress on the diaphragms.

The new heads are more sensitive to proper diaphragm alignment but appear to have solved the problem of diaphragm failures. Diaphragm life has been extended from between 20 and 40 hours to 1000 hours.

Despite finding solutions to many mechanical problems, continuing maintenance remains an important factor in day-to-day operations. At present, scheduled shutdowns are planned once a week for repair of the preheater seal and repacking of the high-pressure pumps.

3.5 SAFETY CHANGES AND ADDITIONS

Shortly after occupancy, an internal safety audit was made to determine the adequacy of compliance with OSHA and Bechtel safety and fire protection standards. Equipment modifications and additions were made to improve employee safety as a result of this audit. Intensive training and safety sessions were frequently held as part of the process program initiation and equipment operating procedures.

Additions to the plant that were not covered by the audit included a sprinkler system to cover critical areas; fire extinguishing equipment; life support equipment; gas masks and gas detection devices; nonskid surfaces on platforms, stairways, and ladders; safety signs; and other personnel safety provisions.

Major safety deficiencies detailed in the safety audit concerned modifications to the following:

- Blender recirculation system
- Preheater discharge pump
- Vent line to flare
- CO compressors purge and isolation system
- Reactor bottom flash tank safety valve
- Oil hold tank safety valve
- Operating area floor drainage system
- Utility hoists

- Equipment identification
- Product oil and low-pressure flash tank vents
- Bucket elevator switch
- Grinder
- Blender and hot oil tank piping
- CO and nitrogen lines
- Safety valve vent lines

These items have been completed except for the CO and nitrogen lines.

The total cost for correcting plant safety deficiencies is estimated at $16,500. Total accumulated manhours from January 1, 1977 to February 28, 1978 are 37,751. Total lost time due to injuries is one manday. Additions to the plant to assure worker safety and plant security have been extensive as indicated by the low lost-time record. The success of any safety program weighs heavily on continued employee awareness through a good educational program.

Section 4

PROCESS OPERATING RESULTS

During the contract period significant information on process operating variables, as well as specific equipment performance, was obtained. Due to equipment limitations posed by required modifications, not all of the desired operating variables levels for the process were achieved. Within the capabilities of the PDU, however, much information was obtained that could be used for process evaluation, scale-up to large sized equipment and preliminary evaluation. In addition, these preliminary results have provided a basis for recommendations concerning continued testing.

4.1 TEST OBJECTIVES

The major objective of the past year's work was to develop and confirm the liquefaction data developed at PERC. Since the Albany PDU is essentially an enlargement of the bench-scale facility at PERC, the initial series of tests were done in order to duplicate as closely as possible the original test conditions. In these tests the important parameters that were monitored were rate of biomass conversion, oil yield, heat effects, and product quality.

The tests examined two major areas — reaction characteristics, and equipment performance. To do this, the effects of system temperature, pressure, carbon monoxide concentration, residence time, and catalyst utilization were studied. Again, it must be noted that some of these variable ranges were governed by the capabilities of the Albany process equipment and did not necessarily represent the most desirable range. In the future it is hoped that the necessary plant improvements can be made so that the full range of process variables can be studied that are of technical and economic importance.

In addition to the reaction characteristics, a number of important process problems were resolved. Among the most important are:

- Feed mechanism
- Oil recycle
- Slurry handling
- Product separation and characterization
- Environmental considerations

Much of the information gathered in this category was of great importance in the development of the conceptual design discussed later in this report.

4.2 TEST SCHEDULE AND CONDITIONS

Table 4-1 illustrates the overall schedule operations and observations taken during the testing program. The first seven runs were essentially for equipment shakedown and were necessary to establish the hydraulic and thermal performance of the plant. Run #8, which was conducted in July, was the first run where the slurry recycle method of operation was used and where the first measurable conversion of wood was observed. It is important to note that slurry recycle allowed continuous operation without separating water, catalyst, and sludge from the recycle stream. To achieve a base line, run #9 was conducted to check the plant mass balance with zero wood feed as well as to determine the stability of the anthracene cycle. There was no observable degradation of the anthracene. Runs #10 through 17 were essentially process development runs where the major variable was residence time. In run #18, the amount of anthracene added to the recycle stream was continously monitored in an attempt to control rising product viscosity. However, while it was possible to maintain product oil concentrations at a stable value, serious increases in viscosity were still noted. In runs #19 through 23, variations in temperature and pressure were examined.

Operating data and results for runs #8 through #23 are listed in greater detail in the attached appendix.

Table 4-1

TEST CONDITIONS - BYPASS TESTS

Run #	Date	Duration Hours	Preheater Outlet Temp. ^{o}F	Pressure Psig	Feed In % Wood Wt %	CO Feed pph	Water pph	Na_2CO_3 pph	Wood pph	Slurry Flow gph	Residence Time Minutes	Wood Conversion Per Pass %
8	7/27-7/29	39	635	2,000	12	9.5	27.7	-	48	50	20	50
9	8/1 - 8/4	33	-	2,500	0	18.9	13.4	-	-	50	20.5	-
10	8/8 - 8/11	36	658	2,523	7	9.5	13.4	-	40	50	16.5	60
11	8/17-8/17	0	-	3,500	-	2.36	13.4	-	35	50	16.5	-
12	10/26-10/28	55.5	591	2,530	8	31.2	11.7	-	40	40	25.5	80
13	11/4-11/5	39	608	2,500	9	12.8	7.1	-	40	80	13	25
14	11/16-11/18	38	584	2,499	10	35	7.8	0.37	38	60	17	80
15	11/18-11/20	30	602	2,521	7	42.1	13.4	0.49	40	60	17	80
16	11/28-12/5	71	593	2,309	10	11.8	15.1	0.24	40.8	80	13	60
17	12/11-12/12	43	589	2,500	12	18.4	15.1	0.39	39.6	43	24	80
18	12/13-12/22	90	595	2,499	10	19.9	15.1	0.2	39	60	17	85
19	1/3/78-1/7	83	625	2,500	18.5	36.4	15.1	-	60	60	17.1	70
20	1/7-1/9	48	649	1,501	38.4	55.8	15.1	-	50	60	17.1	45
21	1/10-1/16	82	592	1,500	13.2	22.9	15.1	0.24	55	60	17.1	60
22	1/16-1/16	5.5	602	1,500	24.2	23.2	15.1	0.36	50	60	17.1	47
23	1/16-1/19	46.5	587	2,765	17.8	30.4	15.1	0.17	49	60	17	50

4.3 PROCESS RESULTS

Bypass Tests 1 through 7 were used for operational shakedown of the equipment. Wood flour was not introduced until Bypass Test 6. Nevertheless, substantial information was gathered during these preliminary tests. Initial tests were made to establish continuous flow through the bypass loop and observe any limitations in the equipment. During Tests 1 and 2, it was observed that the maximum heat duty of the preheater was 188,000 BTU/Hr. The observed maximum temperature of 543°F at 105 GPH slurry flow was reduced even further with the introduction of water and nitrogen in the last part of Test 1, and again in Test 3. During Test 3, the importance of having a steady gas flow was demonstrated. The heat capacity of the gas was magnified greatly by the vaporization of water into the gas stream. Small fluctuations in gas flow, therefore, have a large effect on preheater exit temperature.

Bypass Test 4 produced some of the most significant and startling results during the early runs. It had always been assumed, and indeed was expounded widely in literature, that water would remain as a separate phase and therefore exert its own vapor pressure at reaction temperatures. In Bypass Test 4, the nitrogen was stopped once flow in the system had been established and the offgas vent line blocked. The system was then allowed to come to pressure equilibrium at a set temperature. The following table summarizes the results.

Table 4-2

PARTIAL PRESSURE OF WATER
AT REACTION CONDITIONS

Temp. (°F.)	Observed System Pressure (psig)	Vapor Pressure of Water (psig)
625	560	1850
634	580	1950
650	670	2175

Since the gas space available could not possibly hold the amount of water being fed, the only conclusion is that at reactor conditions, water dissolves in the oil and exerts a nonideal partial pressure.

Bypass Tests 6 through 8 were the first runs to use carbon monoxide and wood flour. As a result of these runs and the operational difficulties that resulted, several changes were made to the equipment. These are discussed in detail under Process Modifications, but one observation is worth repeating here. Under high pressure, carbon monoxide, due to its high solubility, will form an emulsion or foam. Without special equipment, the foam produced is difficult to disengage. At low pressures, substantial CO remains dissolved in the oil, but no problems with foaming have been observed.

It was considered that degradation of the anthracene carrier oil could be attributed to the changes observed in the oil when flour was introduced into the system. To test this hypothesis, Bypass Test 9 subjected anthracene to full test conditions for about 36 hours. No significant changes were observed in either boiling point range of viscosity.

Bypass Tests 10 through 18 were conducted to establish the effect that residence time had on the conversion of wood flour to oil. Conversion is defined as loss of biomass in one pass through the reaction section. The results of this study confirm that a strong relationship exists between residence time and conversion. Figure 4-1 depicts this relationship with a plot of residence time versus average conversion. It appears that a minimum residence time of 16 to 18 minutes is required to achieve a good conversion, but that additional residence offers only slight improvement. In any event, the overall conversion rates were substantially higher than anticipated.

Early work done on the PERC process, as well as reports written since, suggest that conversions of less than 20 percent should be expected.

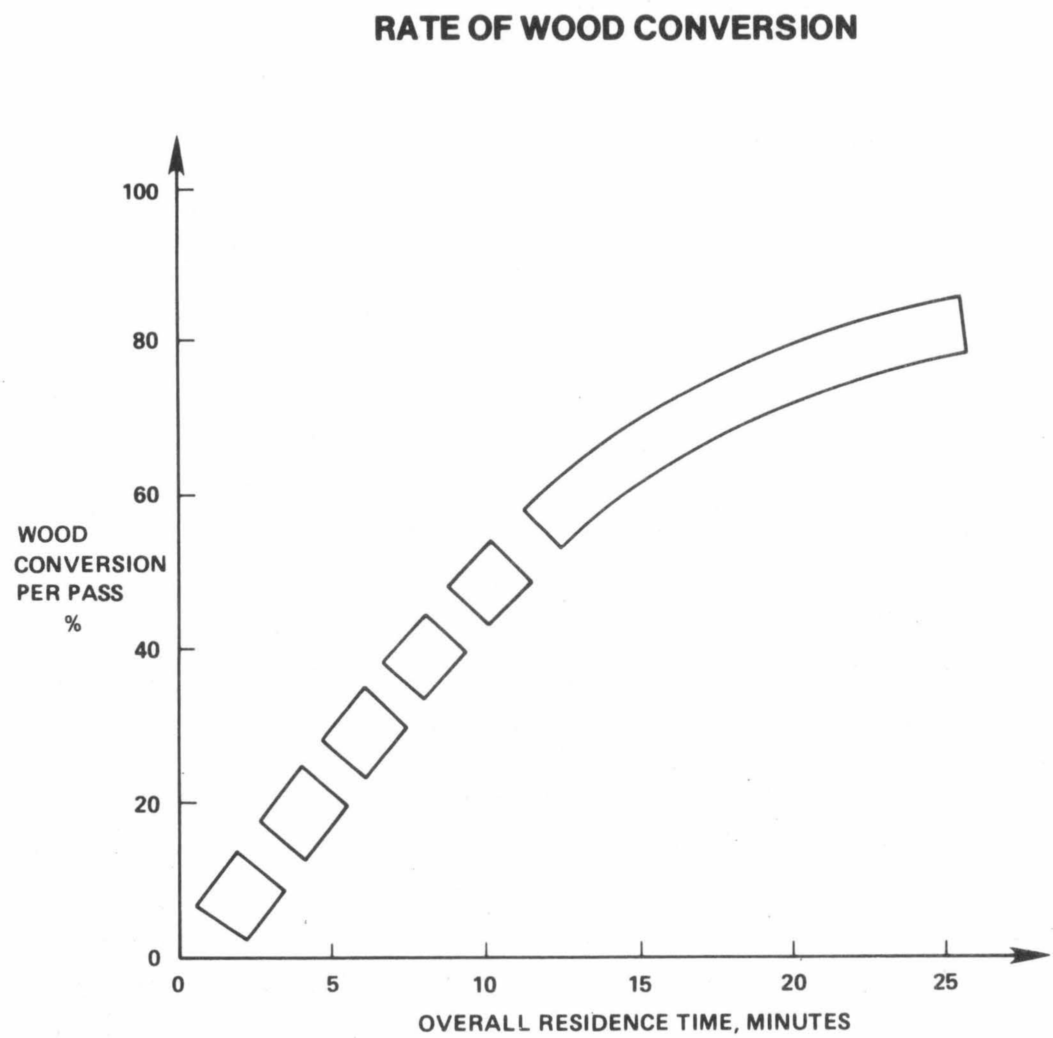


Figure 4-1. Rate of Wood Conversion

Bypass Tests 10 through 18 demonstrated that 70 to 85 percent conversions can be assumed as a minimum for future designs.

Work on the effect of temperature and pressure have only just begun. Although inconclusive, it now appears that for preheater conditions greater than 550°F and 800 psig CO partial pressure, there is little change in the observed preheater operating results.

Interpretation of the results of the later tests, Bypass Tests 19 through 23, were complicated by the formation of polymers during all or part of each run. An effort was made to reduce the effects of polymerization by diluting the process oil stream with anthracene. It was initially thought that anthracene would donate hydrogens to seal off the end groups of the fragmented product oil molecule. However, it was concluded that the polymerization was not prevented and only changed to some degree with respect to severity and speed. By the time Bypass Test 23 was begun, the major objective was to attempt to produce a stable product. This was not achieved in this series of tests.

4.4 PRODUCT CHARACTERISTICS

Product characterization has not been completed at this time. A continuing effort is being expended at Battelle Pacific Northwest Laboratories in Richland, Washington to identify and categorize the product oil. The problem is complicated by the fact that the true reaction product cannot be isolated from the carrier oil by physical means. Because neither the anthracene nor the product oil are pure components, they boil over a range of temperatures. The ranges for the two materials overlap in the 600 to 800°F range (see Figure 4-2), precluding separation by simple distillation.

The reaction system product oil, as removed from the system, is a black tar-like substance. At room temperatures it pours much like cold honey. At 200 °F it becomes quite fluid and easy to handle (see plot of viscosity vs temperature in Figure 4-3). The oil as removed from the system will nominally have about 2.8 percent solids and less than 1 percent water. The

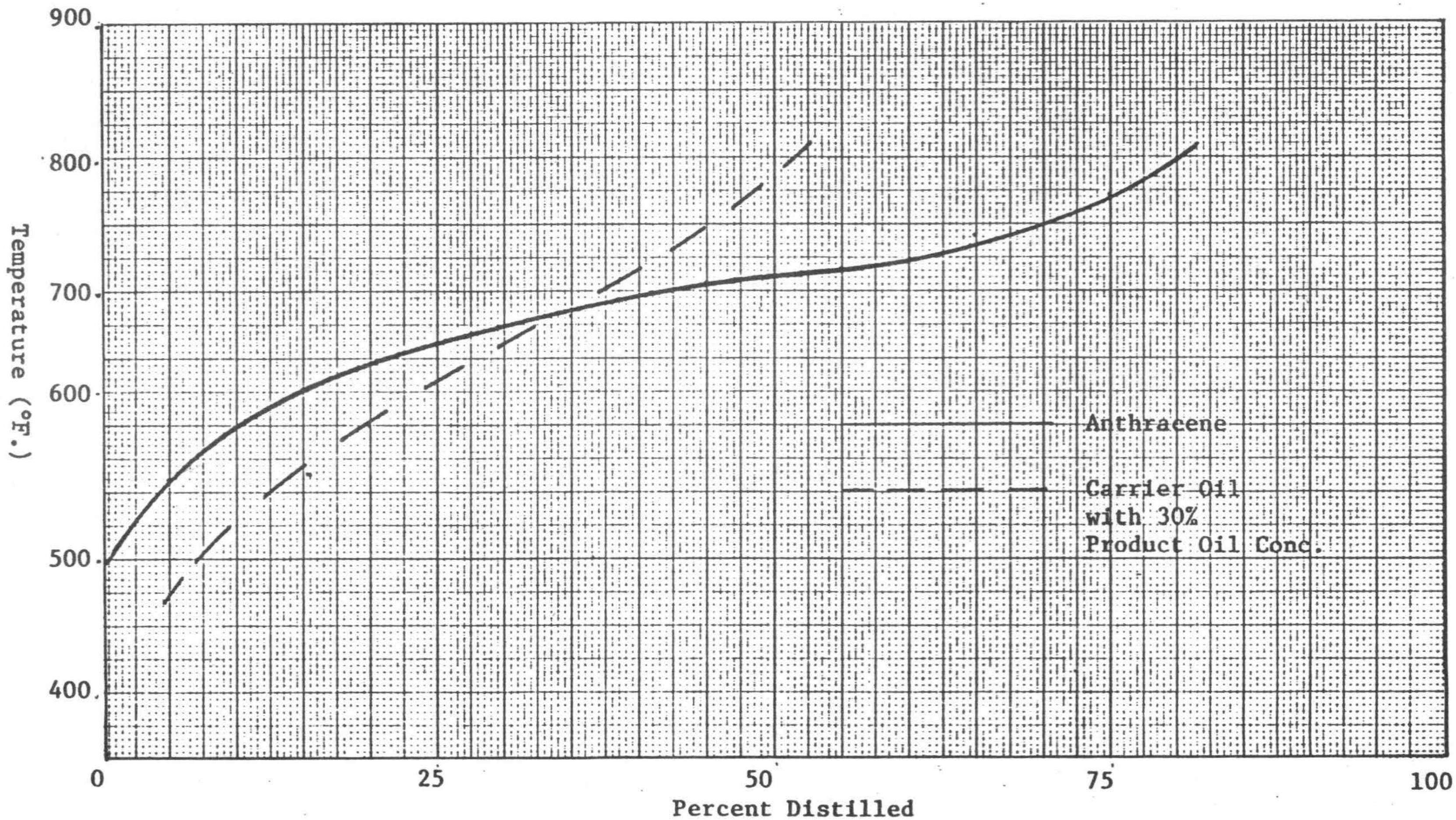


Figure 4-2. Typical Boiling Point Curves

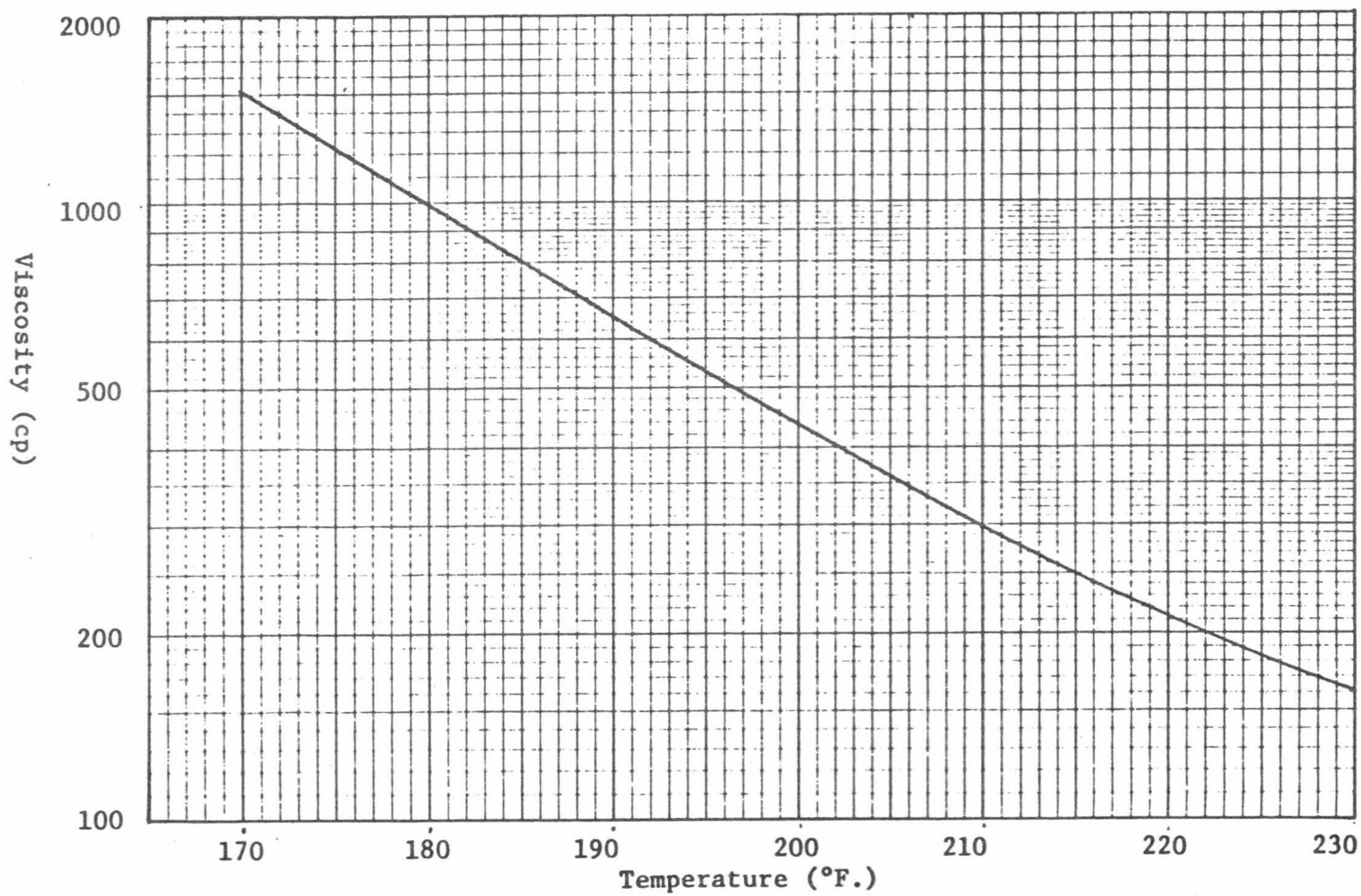


Figure 4-3. Viscosity vs. Temperature

solids can vary in consistency. Some unreacted wood flour can be detected through observation under a microscope, but the bulk of the material is in the form of small black granules resembling coal dust or lamp black. The oil is heavier than water, having a density of about 1.1 at ambient temperatures (see Figure 4-4). Reaction system product oil exerts a very low vapor pressure. At room temperature, it has an estimated vapor pressure of 0.25 psig (see Figure 4-5).

The chemical nature of the oil is not known at this time, although elemental analyses have been made (see Table 4-3). The reaction product oil shows a sharp decrease in the percent of oxygen over dried wood flour. In addition, the heat content has been roughly doubled on a per pound basis.

Table 4-3

ANALYTICAL RESULTS ON
REACTION SYSTEM PRODUCT

	Wood Flour	Anthracene Oil	Average Product
% Product	—	—	53
% Water	1.9	—	<
% C	48.31	89.21	77.2
% H	6.10	5.48	6.5
% N	.13	0.10	.4
% O	40.9	3.03	8.4
Miscellaneous (Inorganics)	2.66	2.18	7.5
Heat Content (BTU/#)	8,186	16,590	15,179

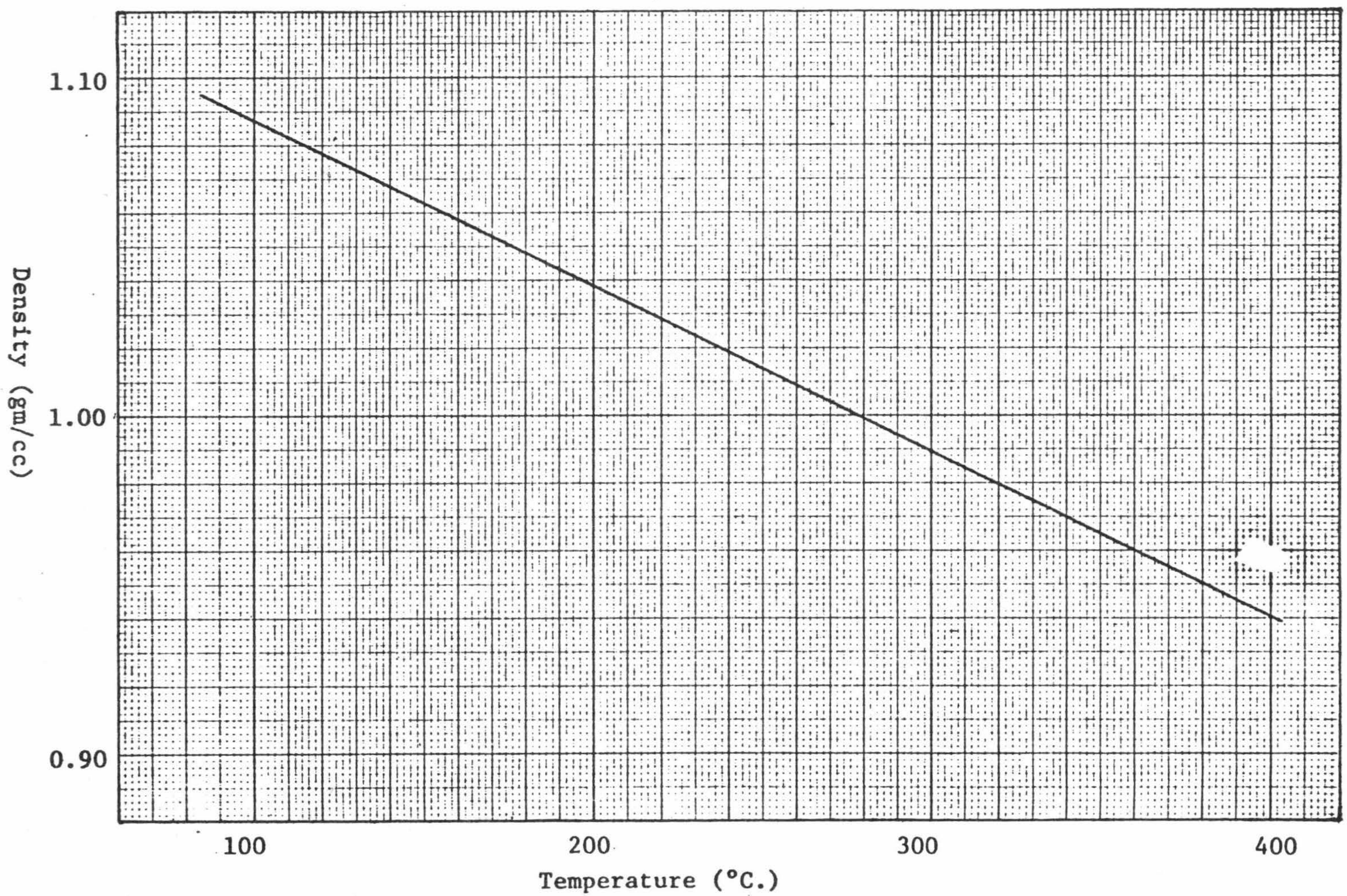


Figure 4-4. Density vs. Temperature — Carrier Oil with 50% Product Oil Concentration

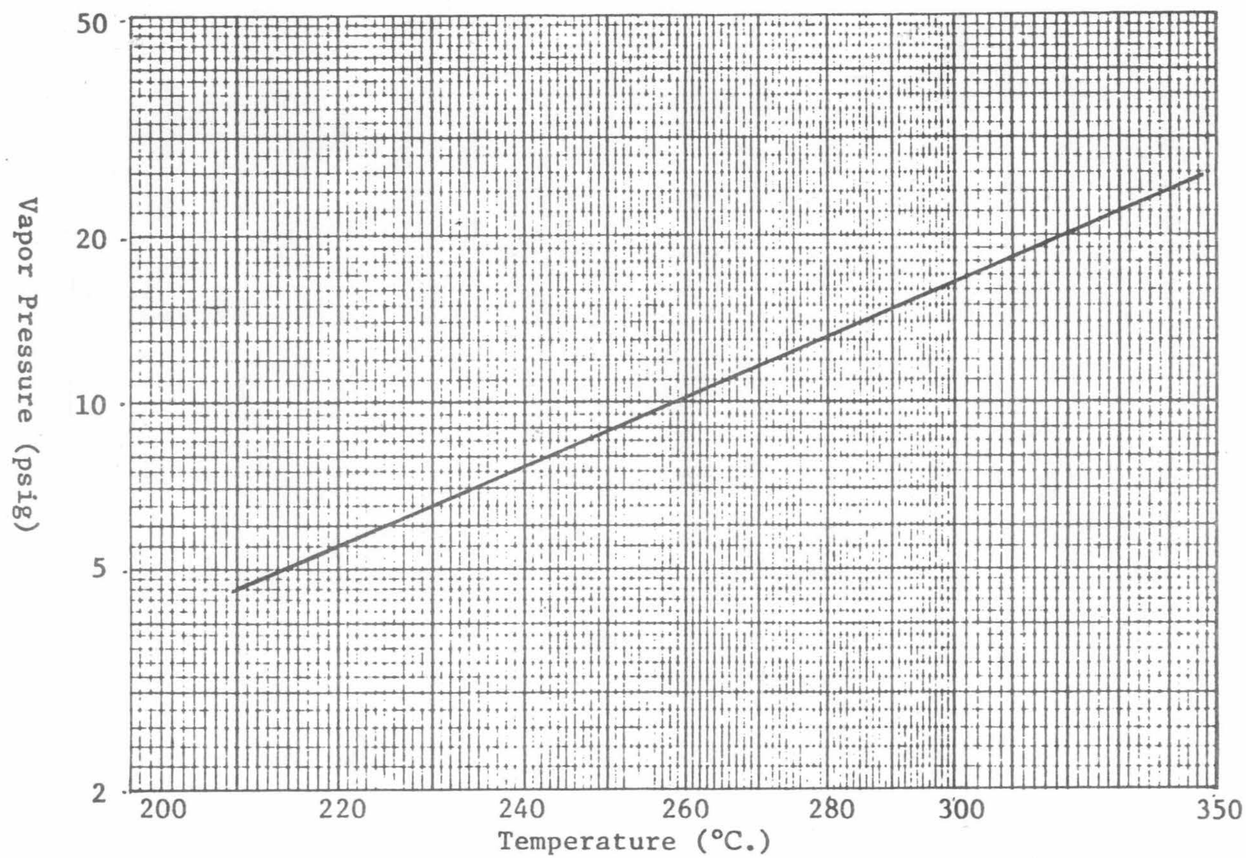


Figure 4-5. Vapor Pressure vs. Temperature — Carrier Oil with 50% Product Oil Concentration

If the reaction product oil begins to polymerize, three effects are noticed in the product characteristics. The first effect is the visual change in appearance of the oil. Unpolymerized oil, as discussed, is tar-like in appearance, and as such, the surface of the material is somewhat rough (like the skin of an orange, only less so). When the material begins to change, the surface becomes quite shiny and smooth. This is accompanied by an increase in tackiness. Normal oil behaves like a heavy cream. If you touch it and pull you finger away, some will stick to your finger.

As it begins to polymerize, the oil becomes much stickier, behaving more like taffy. The third and most important change, readily detected, is the increase in viscosity. The higher the degree of polymerization, the higher the viscosity. Viscosities in the system can increase from a few hundred centipoise to several thousand in a few hours as shown in Figure 4-6.

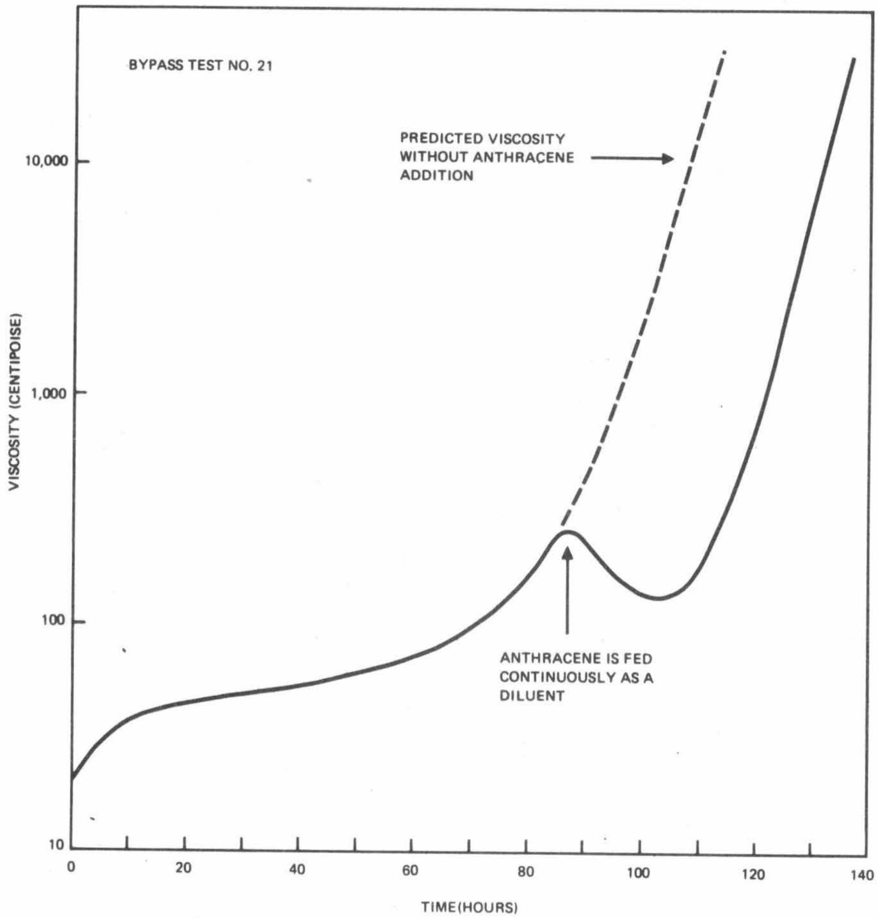


Figure 4-6. Predicted Viscosity

Section 5

FUTURE MODIFICATIONS

5.1 PROCESS ADDITIONS

5.1.1 Introduction

The heart of the Albany wood liquefaction pilot facility consists of a reaction system that includes a scraped surface heat exchanger and a stirred tank reactor. Numerous problems have been encountered with both units during the one-year operation of the pilot facility, especially with sealing. For this reason, scale-up of this type of system to a commercial size is highly questionable.

For future Albany modifications, an alternate reaction system is recommended. It operates as follows. The preheating takes place in a helical coil using hot flue gas as the heating medium. The reaction continues in a hold tank or standpipe, which essentially provides the residence time and mixing necessary for the reaction to go to near completion. This recommendation is based largely on the satisfactory experience gained in the coal liquefaction field with a nearly identical system under similar process conditions.

Figure 5-1 shows a preliminary design modification of the Albany facility. The design is essentially a scaled-down version of the conceptual design of a commercial unit, as discussed in Section 6. There is enough detail in the design to suggest the actual layout of the unit and to provide the basis for a budgetary estimate.

5.1.2 Summary

The cost and availability of the critical equipment have been determined. Installation of the new equipment at Albany appears possible without long-term interruption of the ongoing tests. A budgetary estimate of $1.1 MM has been obtained, with materials accounting for $0.6 MM.

5.1.3 Discussion

For a helical coil preheater as high a slurry flow as possible is desirable to enhance heat transfer and to prevent coking. The maximum flow rate is determined mainly by pressure drop considerations.

Preliminary rheological studies have indicated that at 200 gph and 30 percent solids the pressure drop through the helical coil may be as high as 2,200 psi. This will depend strongly on the carrier-oil quality, which is as yet undefined.

To minimize coking problems, the gas burner for the preheater is located outside the helical coil and the inlet temperature is reduced by air blending. The tube wall temperature does not exceed 800°F. The particulars of the helical coil design are given in Table 5-1.

Table 5-1

HELICAL COIL

Materials Description

1. 3/4" Schedule 160 Incoloy 800 pipe
2. Pipe length — 380 feet
3. Coil diameter — 3 feet
4. Clearance between turns — 2 inches
5. Coil — Housed in annulus (hollow cone in center)
6. Heat flux — 7,800 Btu/hr, ft^2 maximum
7. Slurry exit temperature — 650°F

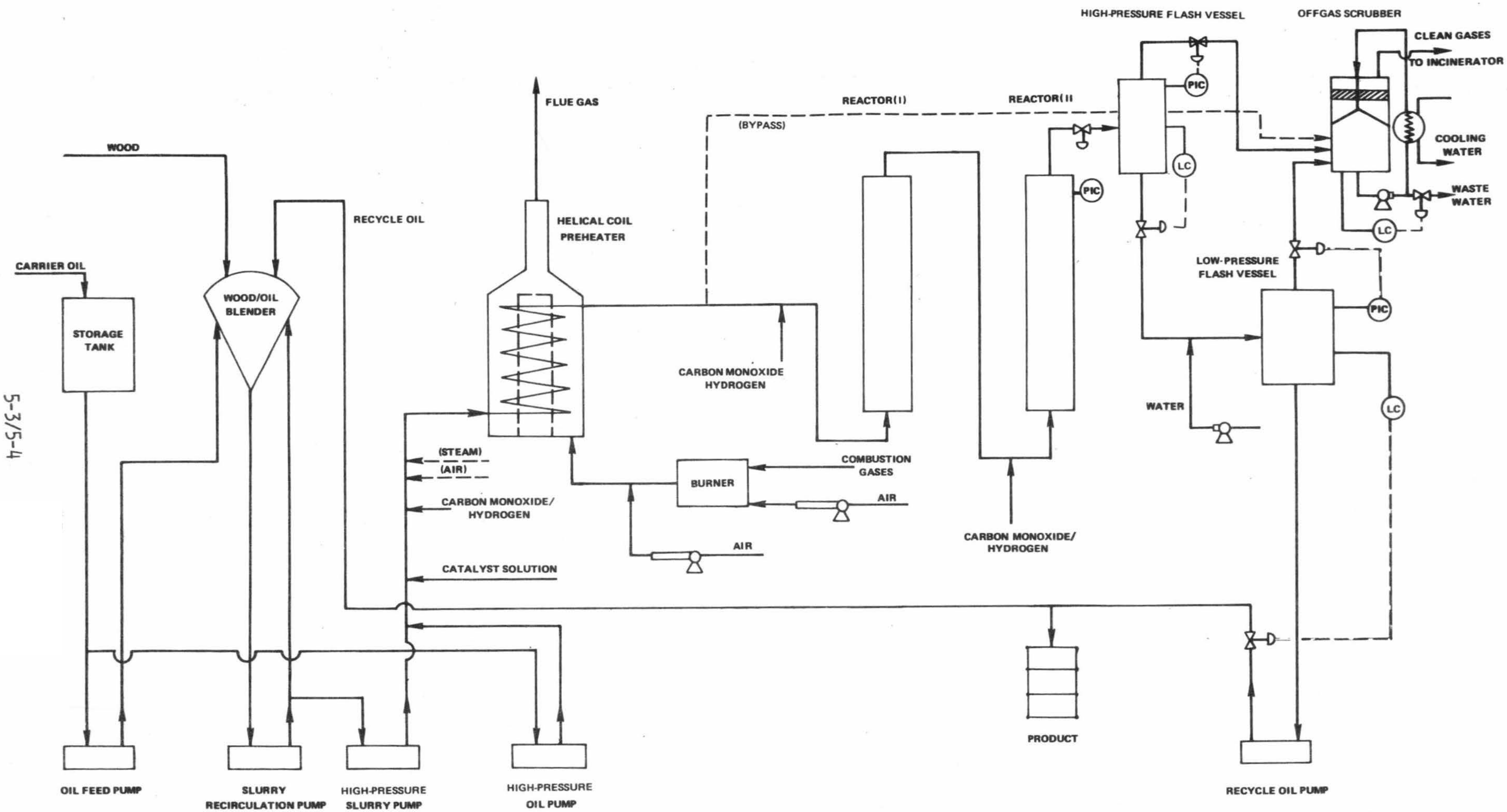


Figure 5-1. Biomass Liquefaction Pilot Plant

Two standpipes in series will serve as the reaction vessels and provide the necessary reaction time. Approximately 1 hour of residence time will be provided at a flow rate of 200 gph. One standpipe could be bypassed in order to cut the residence time in half, without changing the fluid dynamics in the helical coil. A high length/diameter ratio has been selected to provide good mass transfer. The reactor standpipes are made from 8 in. nominal schedule 160 SS (316L) piping. Each one is 40 feet long and can handle pressure to 3,000 psi and temperatures to 650°F.

The offgas system includes two flash vessels and a spray tower. The two flash vessels, in series, flash down the product slurry. First, water is injected upstream of the second flash tank to provide cooling. Then, gases and steam are sent through a spray column, which serves to remove condensibles and heat.

In addition to the reaction system, additional equipment is required. The main items are:

- 400-gallon capacity blender
- Slurry feed pump
- Two slurry recirculation pumps
- Product incinerator
- Steam boiler for decoking

5.2 SUPPORT FACILITIES

An expanded analytical laboratory is proposed for the Albany facility. The necessity for effluent processing of plant samples has become apparent due to the complexity of the biomass liquefaction process. Presently, analytical support is provided by both the U.S. Bureau of Mines in Albany, Oregon and the Battelle Pacific Northwest Laboratories in Richland, Washington. This arrangement, however, is not adequate for the hour-to-hour analysis required for proper PDU operation. The design for the proposed analytical laboratory is shown in Figure 5-2.

While there is space for special tests, the layout is arranged to facilitate the flow of work for hydrocarbon gas analyses, which will make up the majority of samples. Modern automated instruments will be used for many of the routine analyses. In this way, a large number of tests can be accommodated efficiently in a relatively small floor area. The resulting layout is compact, but not crowded.

Provisions have also been made to process the samples that will be handled by conventional wet methods. These include preparations for the automated instruments, routine control tests, and such nonprocess tests as wastewater, solid waste, and offgas monitoring for environmental considerations.

Estimates for the cost to install and fully equip the laboratory were obtained from constructors and vendors of equipment and supplies. Bids were submitted, both written and oral, and represent as definitive an estimate as possible within the schedule limitations. The total costs are estimated at $155,900. A breakdown of the cost is shown in Table 5-3.

The proposed laboratory capabilities are as follows:

- Elemental analyzer
- Vacuum distillation
- Gas and liquid chromatography
- Infrared and UV spectrophotometers
- Atomic absorption spectrometer
- Differential thermal analyzer

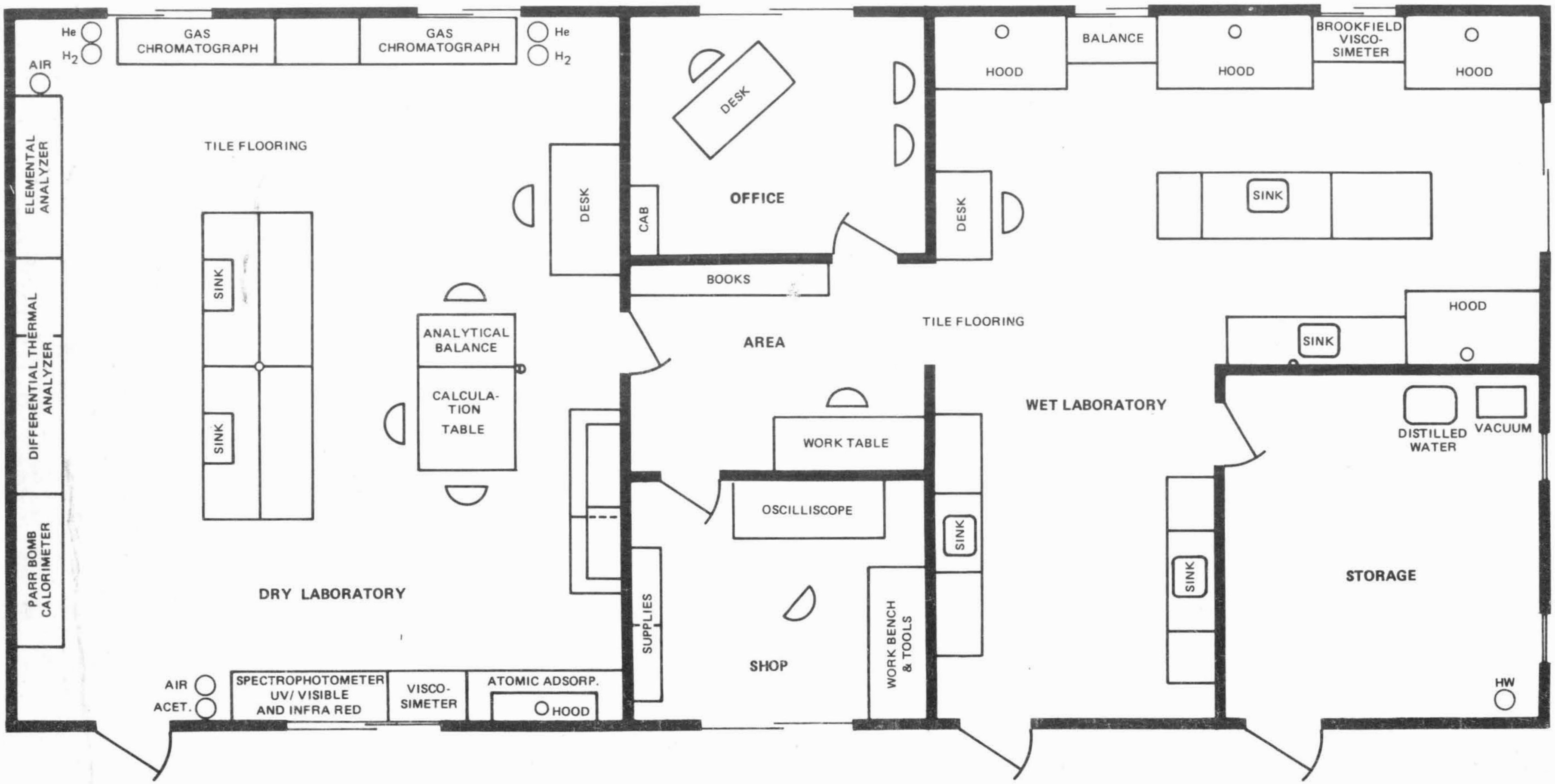


Figure 5-2. Proposed Analytical Laboratory

Although developmental work is continuing, the proposed analytical laboratory will help make the processing of plant samples more efficient.

5.3 AREAS NEEDING FURTHER STUDY

In the continuation of this work a number of activities are recommended.

5.3.1 More Effective Catalyst Use

Examinations of recent data indicate that much of the wood-to-oil conversion noted in the Albany runs is due to simple thermal breakdown instead of the catalytic reaction proposed by PERC. The thermal breakdown causes large numbers of free radicals to form which can recombine into large molecules. This reaction may be responsible for the rapid viscosity buildup that has been noted. It is felt that more effective catalyst contact with the wood may be desirable. Figure 5-3 illustrates what happens to wood, oil, and catalyst in the current system. As shown, the catalyst is fed after the wood/oil slurry is prepared. This allows both the wood particles and the catalyst droplets to be surrounded by oil, thus, preventing intimate contact. An improved method for catalyst use would involve treatment of the wood with sodium carbonate solution prior to drying and grinding, thus facilitating impregnation of the wood with catalyst. This is shown schematically in Figure 5-3. This catalyst treatment has been developed and will be implemented soon.

5.3.2 Use of Syngas

The conceptual design for a full-size plant, as discussed in Section 6 of this report, uses on-site produced syngas as a reactant instead of pure CO. It is felt that the syngas, containing hydrogen as well as CO, may help to provide a product which is lower in oxygen content and in viscosity. The facility for syngas blending has been ordered and will be put into service during March.

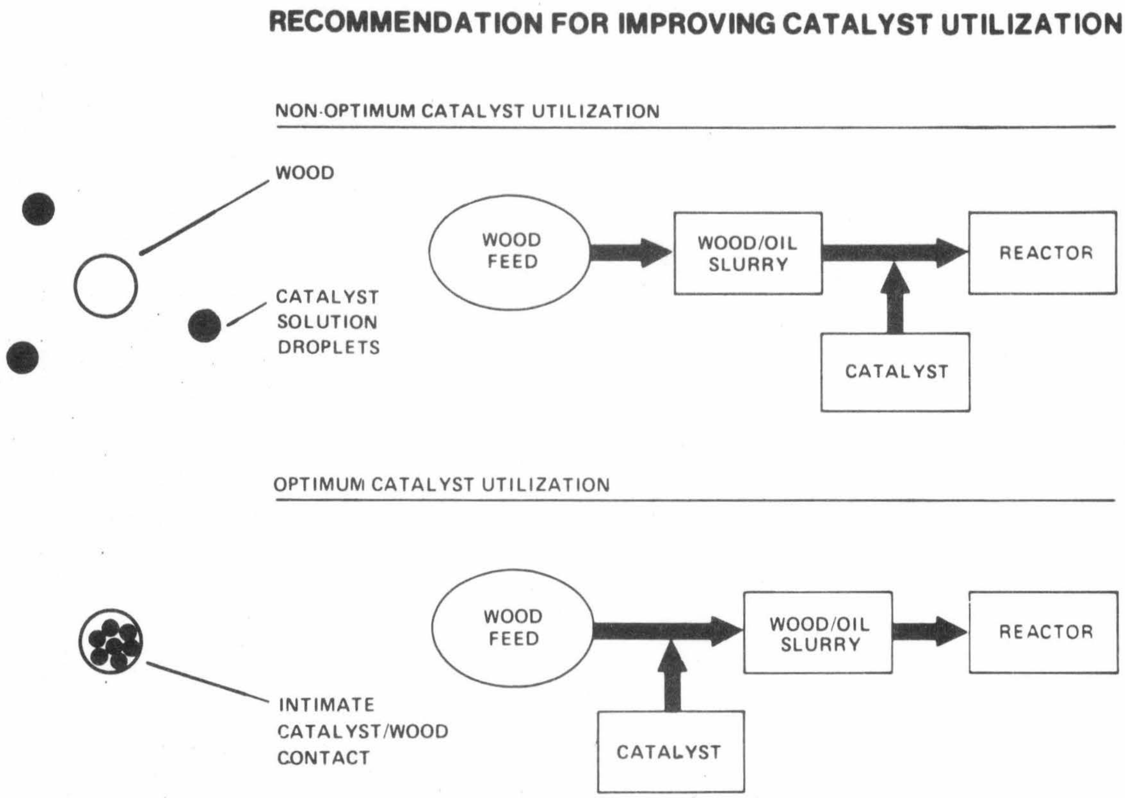


Figure 5-3. Recommendation for Improving Catalyst Utilization

5.3.3 Use of Alternate Vehicle Oil

It has already been demonstrated that the biomass oil cannot be separated from the anthracene due to the similarity in physical properties. As a result, lighter solvents have been tested. Based on these tests, it appears that the use of a lighter solvent, followed by flash distillation for separation, may be possible. If so, future experiments may be possible using external chemical manipulation on the vehicle such as catalytic hydrogenation, etc.

5.3.4 Other Activities

The following provides a brief description of other future activities.

Continuation of PERC Variables. With longer residence time and syngas feeding, a study can be made of the full range of process variables including higher capacities and higher operating temperatures.

Alternate Biomass Feeds. Some preliminary studies on the preparation of alternate biomass for system feeding have already been undertaken. During the next six months the use of rye grass straw will be investigated.

Effluent Characterization. To date, the small amounts of gaseous and aqueous effluents have made plant effluent characterization difficult. A complete characterization of these streams will be vital for further process and economic studies.

Continued Material Studies. The Albany facility makes extensive use of high cost alloys in process vessels, piping, and mechanical equipment. Through a modest program in materials evaluation, the cost of a commercial plant may be reduced.

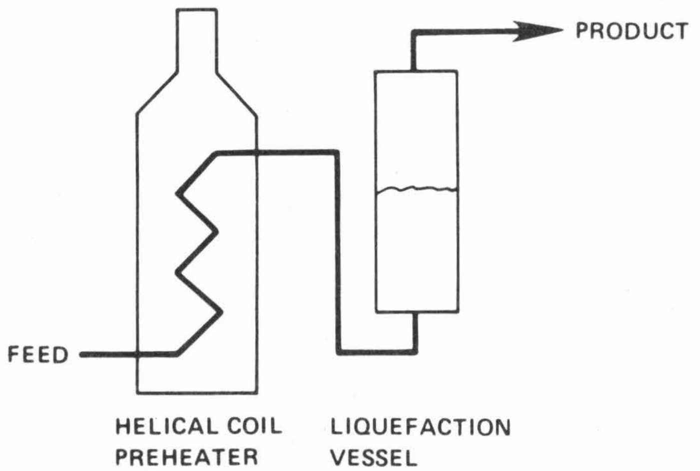
Product Oil Characteristics. The goal for a product from biomass liquefaction is a clean burning liquid fuel. To accomplish this, additional studies will be required on the methods to separate unreacted solids, water, and dissolved inorganics. Additional facilities, particularly in the area of analytical support, will be required at the site.

In addition to these activities, a number of long-term activities are recommended. Some of these will involve modifications or additions to the Albany site; others might be done at outside facilities. These include:

- Installation of an alternate reactor system
- Study of product separation techniques
- Study of syngas and hydrogen effects
- Upgrading of product
- Use of lower cost materials
- Studies on effluent treatability
- Expansion of program support

The preliminary planning for some of these activities has already started. Increased on-site analytical support, a more intensive off-site basic research program, and the procurement and installation of a simple, more reliable reactor system should be included soon. A typical improvement is shown in Figure 5-4.

RECOMMENDED IMPROVEMENTS IN REACTOR DESIGN



ADVANTAGES

- NO HIGH PRESSURE MOVING SEALS
- IMPROVED MIXING
- MINIMUM COITING
- DEMONSTRATED IN COAL LIQUEFACTION PROCESS DEVELOPMENT UNITS

Figure 5-4. Recommended Improvements in Reactor Design

Section 6

COMMERCIAL PROCESS DESIGN AND ECONOMICS

6.1 INTRODUCTION

Operation of a 3 TPD biomass liquefaction pilot plant at Albany, Oregon by Bechtel has shown that wood can be liquified to a synthetic oil at high pressures and moderate temperatures. Some of the results from Albany have been incorporated in the following discussion of commercial design concepts. On the basis of these design concepts, a preliminary economic assessment of the process has been made.

An earlier economic feasibility study of a conceptual biomass liquefaction plant was done by Dravo, where it was concluded that "the wood-to-oil process approached economic feasibility." The status of this concept changed with the advent of new pilot plant data and experience, and process developments from government supported research and development programs. The need to update the economic feasibility of a commercial plant is apparent, based on Albany experience and the present day energy picture.

The basis for evaluation of a commercial biomass liquefaction plant is the basic PERC process scheme. The conceptual commercial plant evaluated in this study is based on Bechtel's process development experience and on studies performed by independent firms. In this feasibility study, the break-even price of synthetic oil represents the competitive potential of the conceptual commercial plant.

Figure 6-1 shows a simplified flow schematic of the commercial plant concept. As shown, the plant is divided into three major sections: reaction, gasification, and product separation.

6.1.1 Reactor Section

Wood chips are first dried, ground, and then slurried with recycled oil. Next, the wood/oil slurry is preheated to a moderately high temperature and pressure in the presence of a sodium carbonate catalyst solution, carbon monoxide, and hydrogen. The reaction mixture is then held in a reactor for a period of time to allow for wood conversion to oil. The gases are separated from the oil, recycled, and combusted to provide process heat for the preheater. Some of the catalyst is recovered and recycled from the product oil. The oil is recycled to be slurried with ground wood and the rest is sent to the Product Separation Section.

6.1.2 Production Separation Section

The resulting oil from the reactor section contains unreacted wood, catalyst, and insoluble solids that need to be removed. The oil is diluted with a solvent and sent to a filter drum for solids removal. The recovered solids are sent to the gasification section for recycle and disposal. Water is added to the oil to remove the water-soluble catalyst. Oil and water are separated through a phase separation. The catalyst-bearing water is sent to the gasification section for catalyst recovery. Solvent is stripped from the oil stream by a distillation column. The solvent is recycled for oil dilution and the product oil is transported to its final commercial use.

6.1.3 Gasification Section

Wood is partially oxidized to form carbon monoxide and hydrogen (syngas) used in the liquefaction process. The syngas reactor is also used to regenerate and concentrate the catalyst for recycle. The gas stream produced in the reactor is stripped of all carbon dioxide by an absorption

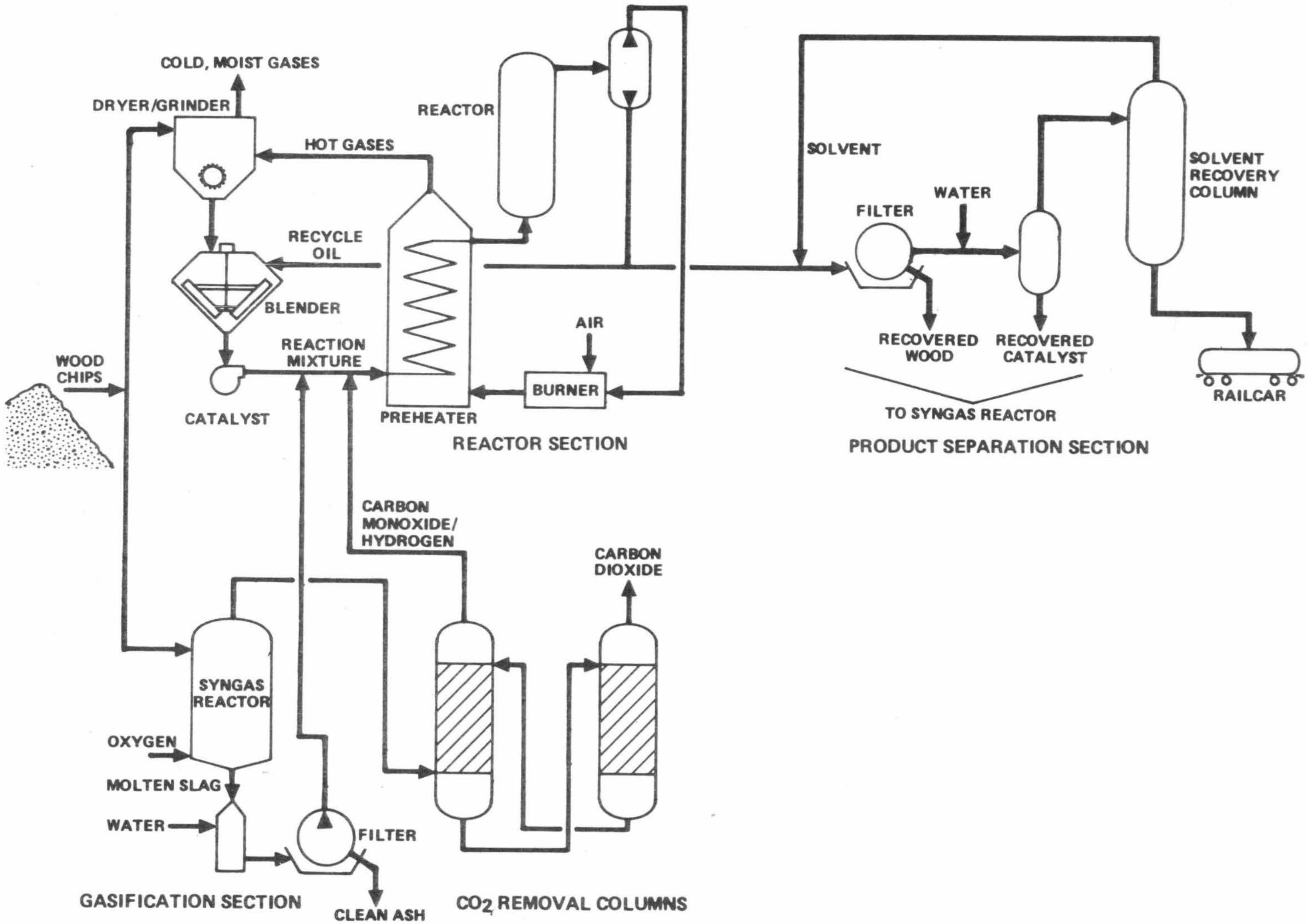


Figure 6-1. Commercial Biomass Liquefaction Pilot Schematic

and a desorption column. The purified carbon monoxide and hydrogen gas stream is compressed and sent to the Reactor Section.

6.2 PROCESS DESIGN BASIS

The original PERC process, as well as the modified version used in this study, are shown in Figure 6-2. Both processes have similar process steps as described in Section 6.1.1. However, there are two major differences. The first major difference is the method of oil recycle. Bechtel's Albany experience has shown that a homogeneous product stream can be expected from the reactor. The phase separation used in the original PERC process assumes easy impurity separation. Therefore, the impurities remain in the product oil. The second major difference is in the catalyst recovery and recycle sections. In the modified PERC process, water is added to the product oil in order to wash out the catalyst salt. The salt solution is then processed for recovery in the syngas reactor. Whereas, in the original PERC process, a phase separation using water is recycled directly to the reactor.

The mass flow rates for a 1000 T/D (short tons) conceptual design are shown in Figure 6-3. In this design, an 80 percent conversion per pass in the reactor was assumed. Experience from Battelle and Albany has shown that a 20 minute residence time at 650°F would be sufficient to achieve this.

The following liquefaction stoichiometry is assumed:

Wood + Carbon Monoxide → Synthetic Oil + Carbon Dioxide

$$C_6H_{9.1}O_{4.12} + 2.625CO \rightarrow C_6H_{9.1}O_{1.495} + 2.625\ CO_2$$

It is assumed that the only reaction which occurs is a reduction of the wood by CO. Other reactions such as dehydration (during heatup and cooldown) and polymerization or condensation reactions are ignored for the sake of this design. It is also assumed that as much H_2 is consumed as is generated in the water-gas shift reaction, causing no net change in hydrogen content. It is realized that this stoichiometry is highly simplified but the available data do not justify introduction of anything more complicated.

The PERC process is intended to produce a product with 20 percent by weight oxygen content. The oxygen content shown here is somewhat higher than observed by PERC workers, and at Battelle and Albany.

Wood is used for conversion to oil, as a CO source, and for steam generation. The design basis for CO production is Union Carbide's Purox process. The Purox process is based upon the partial oxidation of organic material, such as wood, to produce a medium Btu fuel gas composed of CO, H_2, CO_2, and H_2O.

The reaction scheme for the Purox syngas (or synthesis gas) is taken as:

$$Wood + O_2 \rightarrow CO + CO_2 + H_2 + H_2O^*$$

Catalyst recovery is a unique feature of this process. The catalyst-bearing water from oil washing is sent to the syngas furnace where the catalyst is regenerated and discharged as a molten slag with other inorganics from the wood. The catalyst is recovered from the discharged slag by redissolving the soluble portion with water.

The design basis for oil separation from unreacted wood involves product oil dilution with a low boiling solvent such as xylene for viscosity reduction. The diluted oil/wood/solvent mixture is filtered to remove unreacted wood and other solids. Previous developments in removing unreacted coal from liquified-coal product indicates that a precoated vacuum drum filter should be successful for removing unreacted wood particles.

6.3 1000** TPD BIOMASS LIQUEFACTION PLANT PROCESS DESCRIPTION

The 1000 TPD wood-to-oil conceptual plant schematic shown in Figure 6-4 is divided into six sections for ease of discussion. The sections are wood preparation, syngas production, reactor, production separation, catalyst

* Union Carbide Purox ® Process
**As received (50% H_2O content)

recovery, and wastewater treatment. Figures 6-5 through 6-12 are included to illustrate the details of these sections.

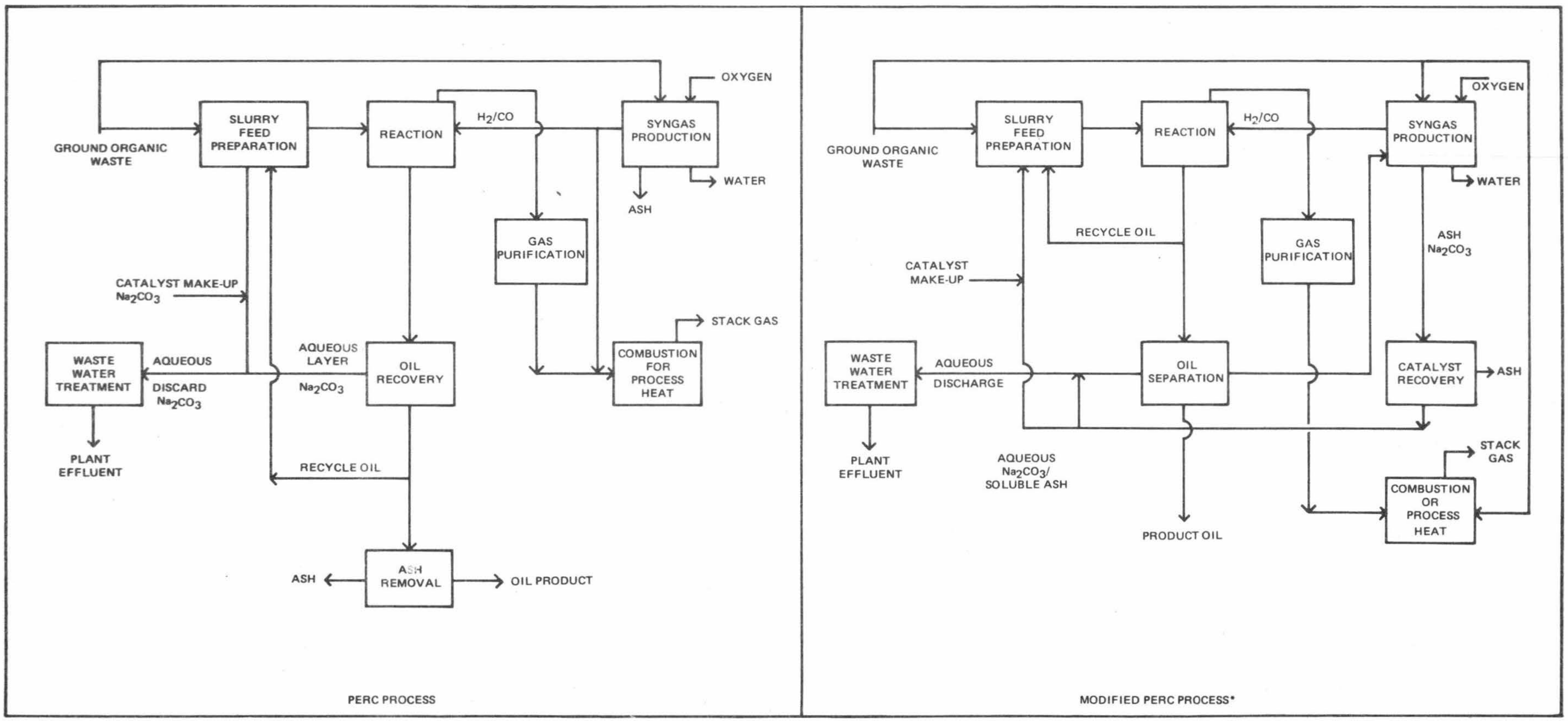
6.3.1 Wood Preparation

This section deals with wood and slurry preparation, as shown in Figure 6-5. Approximately one-half of the total wood fed to the plant is consumed to form oil; the remainder is used to produce carbon monoxide, hydrogen, and process heat. The total wood consumption is assumed to be 1000 TPD for a commercial sized plant. A 100-day supply of wood chips (2" nominal) is specified so as to compensate for severe winter months where transportation may be difficult.

A belt conveyer system beneath the wood pile is used to transport wood to a distribution tower at the rate of 1000 TPD. From this tower wood is distributed to three sections of the plant. Approximately one half of the wood is sent to the Syngas Production Section. A small fraction of wood is sent to a wood-fired boiler for steam generation, and the remaining fraction is sent to the Wood Preparation Section for drying, grinding, and oil slurrying.

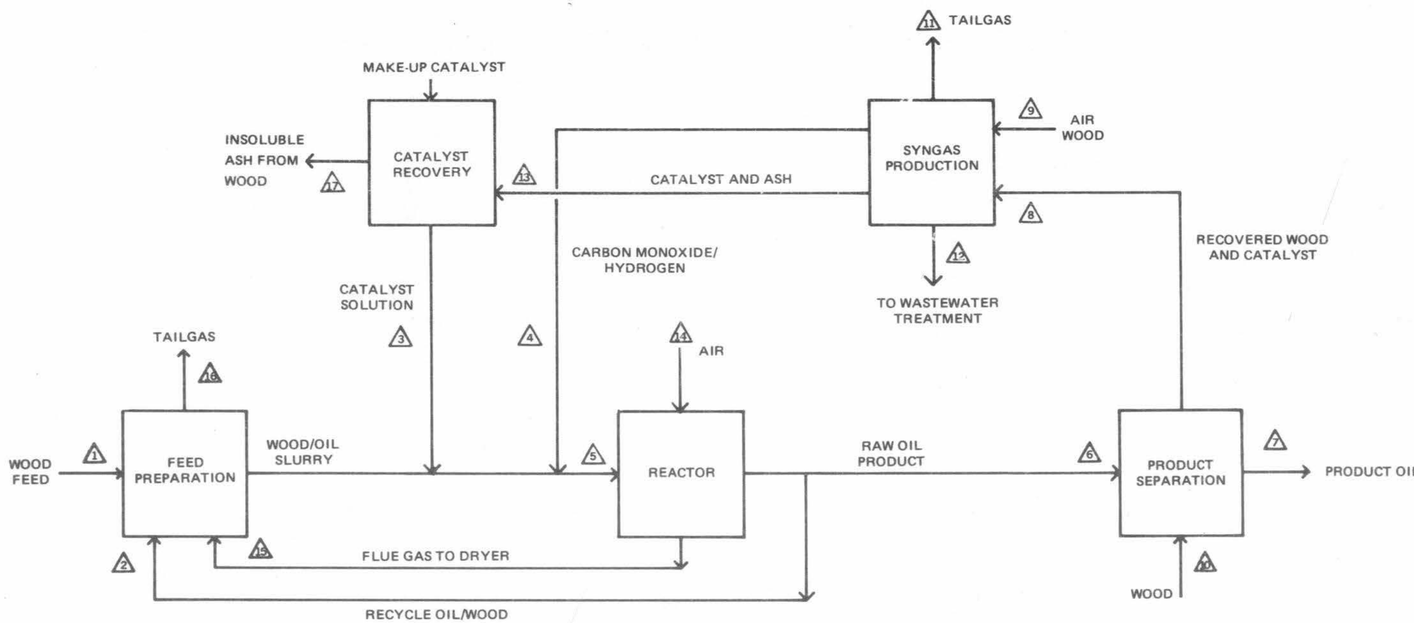
The wood sent to the Wood Preparation Section is conveyed to a wood feed bin where it is conveyed into a dual dryer/grinder system. Flue gas from the Reactor Section is diluted with air to 900^{o}F and is used as the drying gas. The wood is ground and then dried to a 10 percent moisture content. The ground wood is pneumatically conveyed through an air classifier sized for -50 mesh particle size. The ground wood is separated from the gas stream by a cyclone followed by a bag filter. The resulting 200^{o}F tail gas is partially recycled back to the Reactor Section as dilution gas. The remaining tail gas is vented to the atmosphere.

Ground wood collected from the cyclone and bag filter is metered by a star valve, to a continuous weighing mechanism (or scale), to a feed bin, through a star valve, and into a wood/oil blender. Here, the ground wood is slurried with hot recycled oil from the Reactor Section. A wood concentration in the



*BECHTEL RESEARCH AND ENGINEERING

Figure 6-2. Biomass Liquefaction Schematic Flow Plan



PROCESS KEY (TPD)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17*
WOOD (DRY)	250	48			298	12		12	224	26							ASH* ESTIMATED AT 0.1 TPD
OIL (23% O_2)		665			665	170	170										
CATALYST (Na_2CO_3)		15	3.6		18.6	3.6		3.6					3.6				
WATER	250		14		14			26	224	26	16	236	14		94	346	
NITROGEN									530		530			1292	1292	1292	
OXYGEN									151					369	270	270	
CARBON DIOXIDE				1.4	1.4						162				263	263	
CARBON MONOXIDE				166	166												
HYDROGEN				9.1	9.1												

Figure 6-3. Block Flow Diagram — Entire Plant

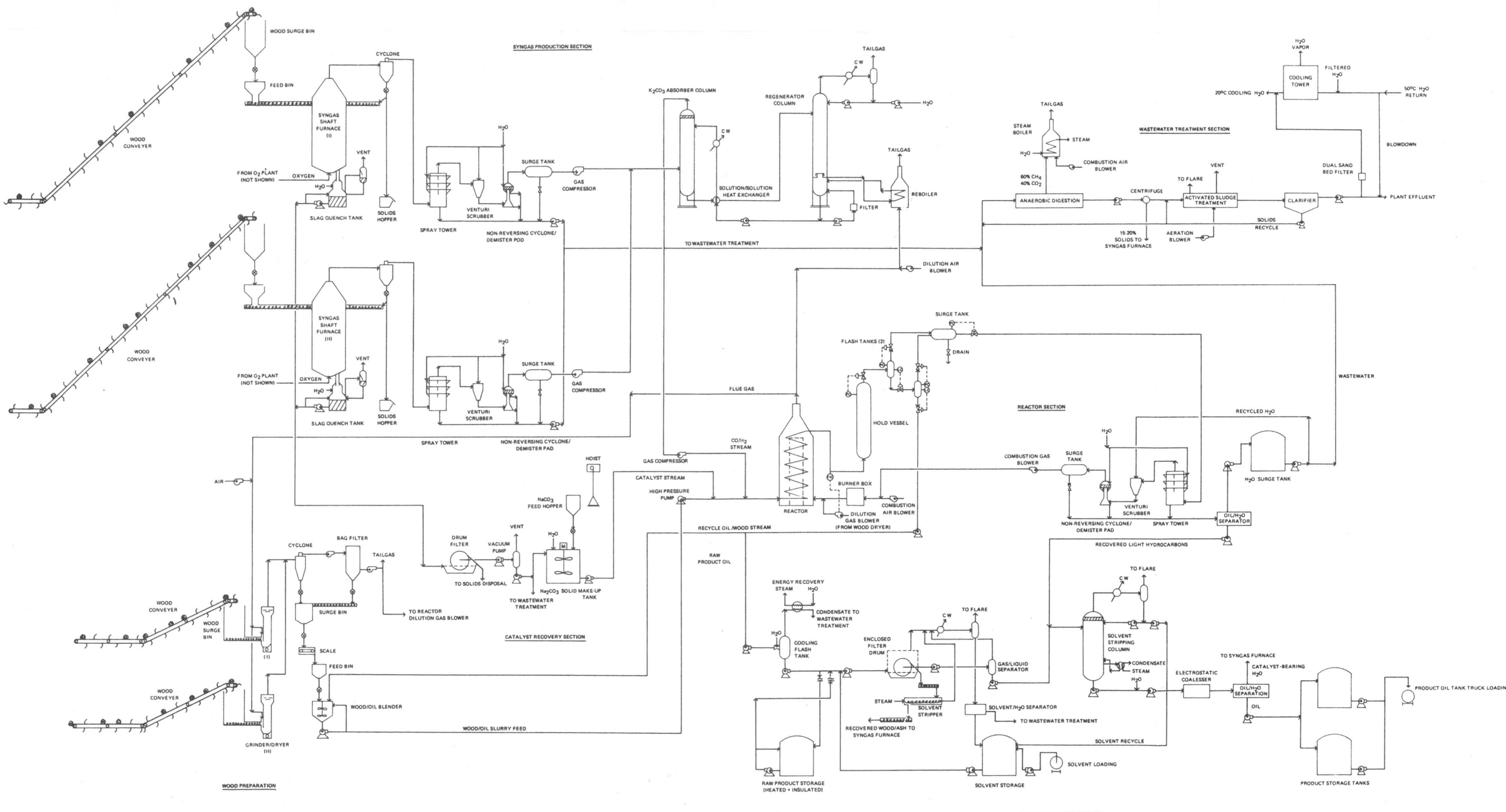


Figure 6-4. Commercial Biomass Liquefaction Plant Schematic

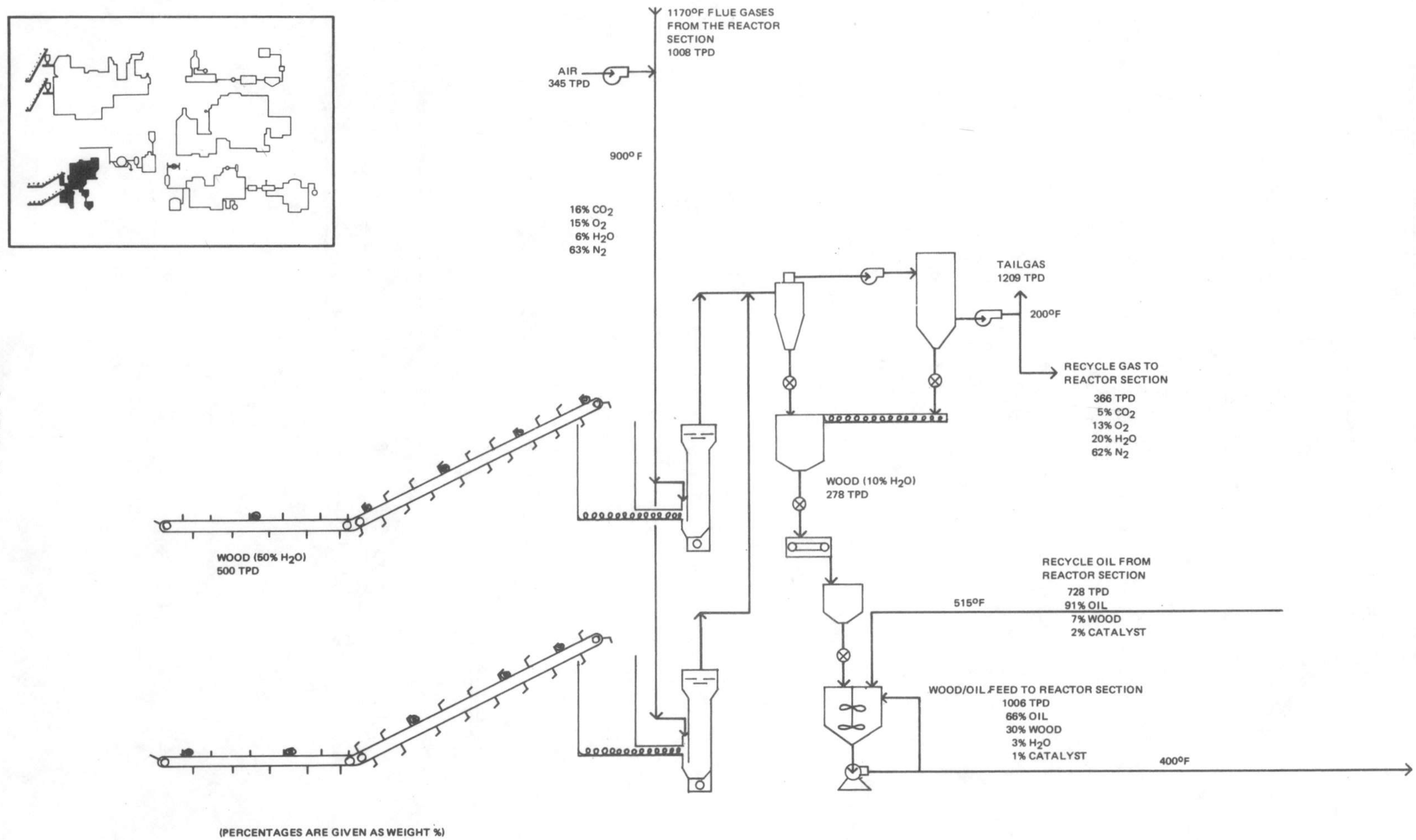


Figure 6-5. Wood Preparation

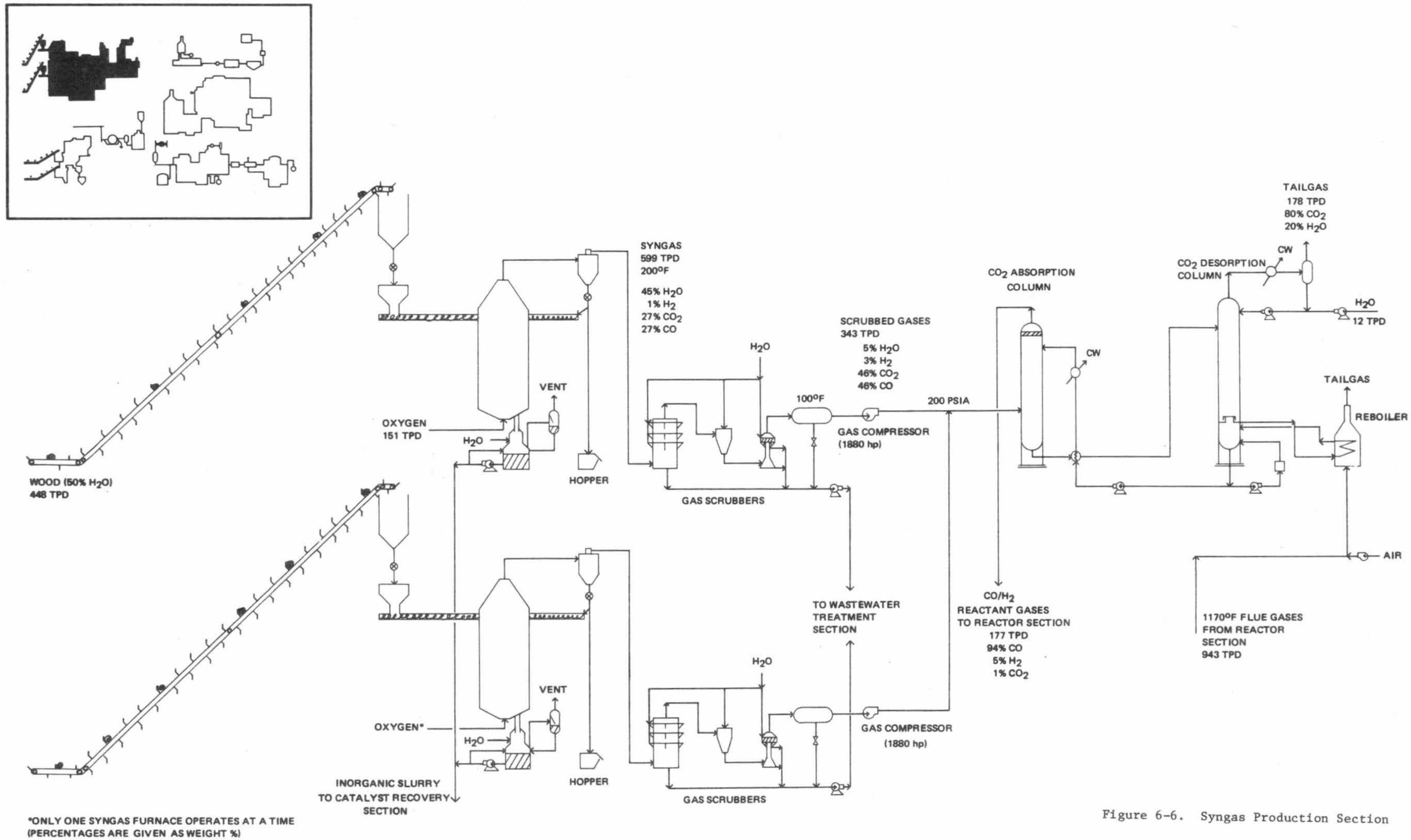


Figure 6-6. Syngas Production Section

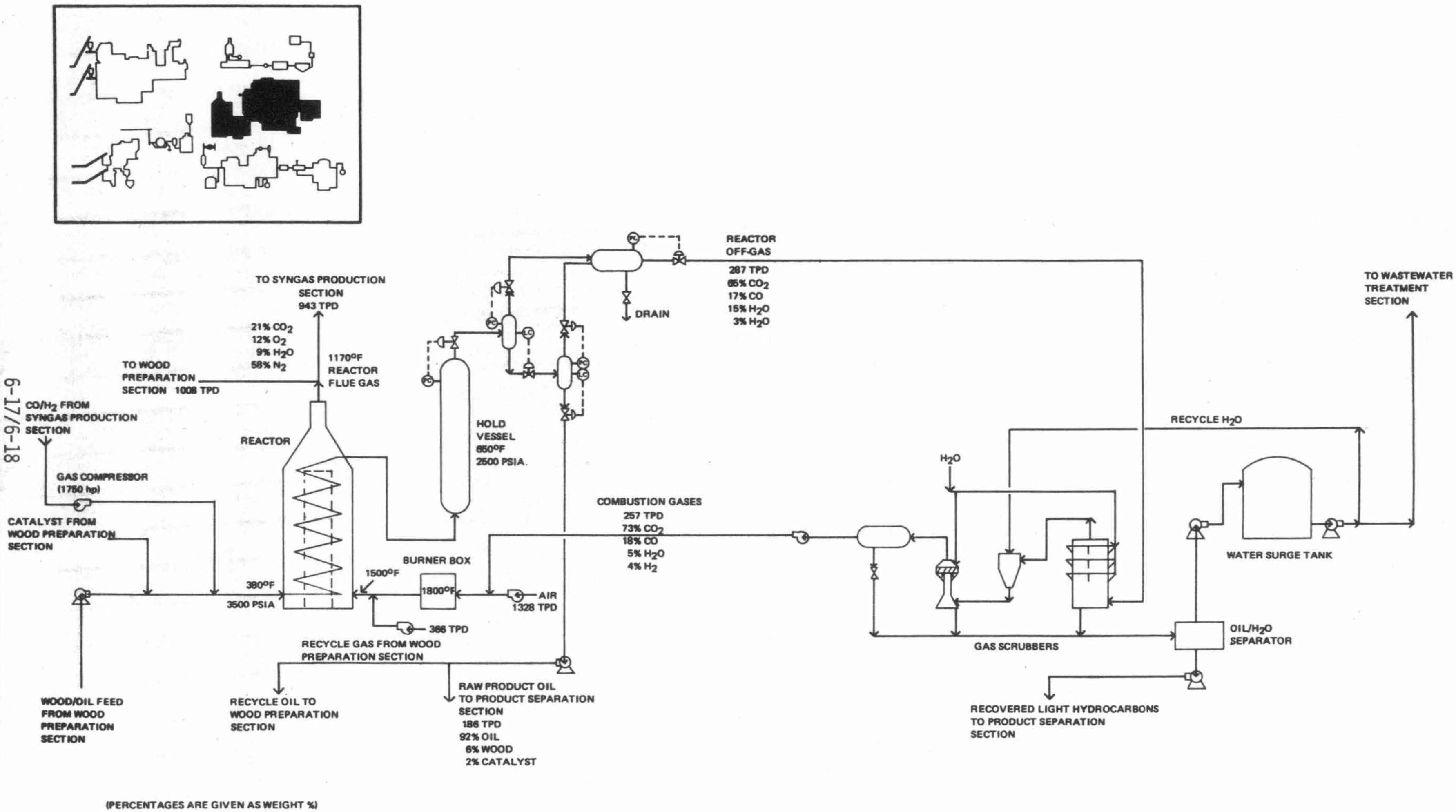
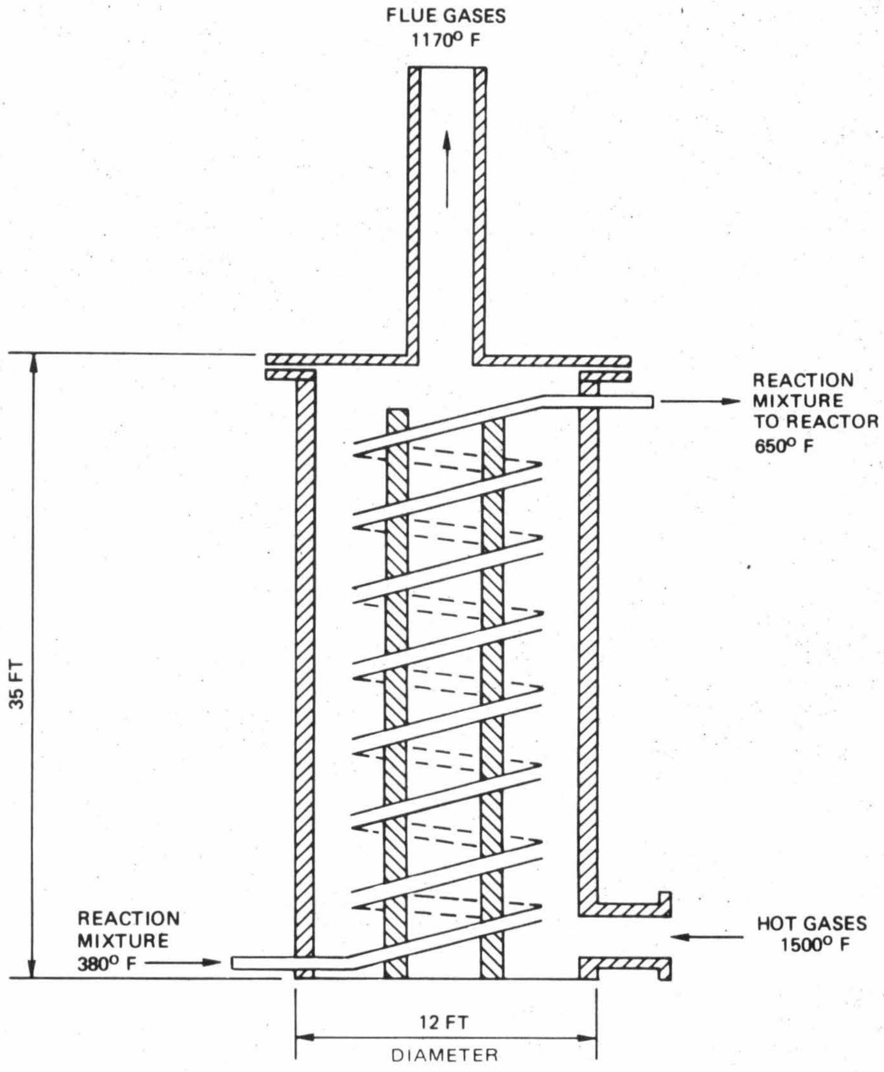


Figure 6-7. Reactor Section



CHARACTERISTICS

- REMOVABLE HELICAL COIL
- COIL DIAMETER: 10 FT
- PIPE MATERIAL: INCOLOY 800
- PIPE DIMENSION: 3" NOMINAL, SCHEDULE 160
  LENGHT: 2217 FT
- 2½" CLEARANCE BETWEEN TURNS
- REFRACTORY WALLS – STEEL SHELL
- 4" CLEARANCE BETWEEN REFRACTORY WALLS AND PIPES
- HOLLOW CONE IN CENTER TO PROVIDE ANNULUS. MADE OF STEEL SHELL AND REFRACTORY.

Figure 6-8. Preheater for 500 TPD Biomass Liquefaction Plant

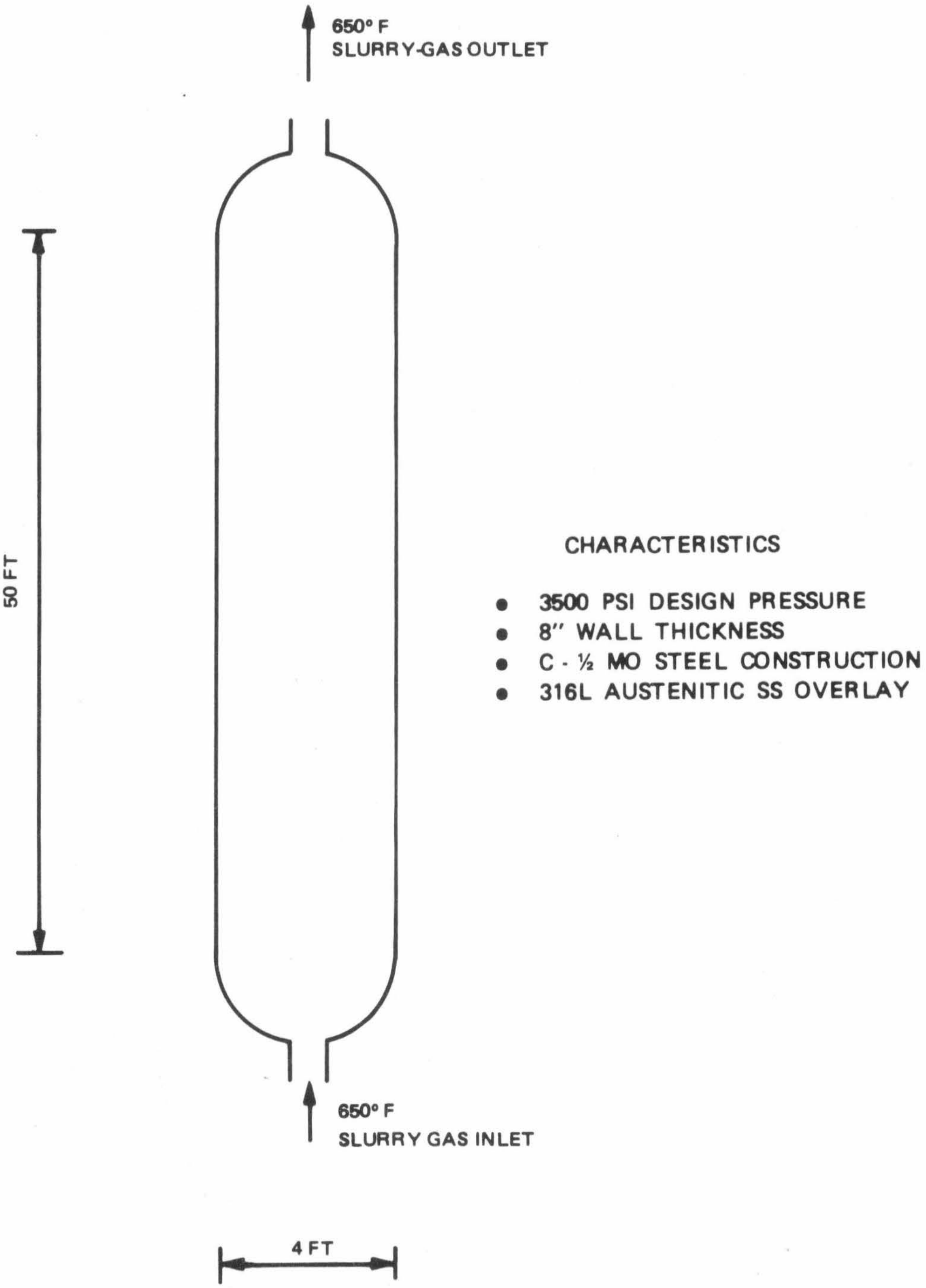
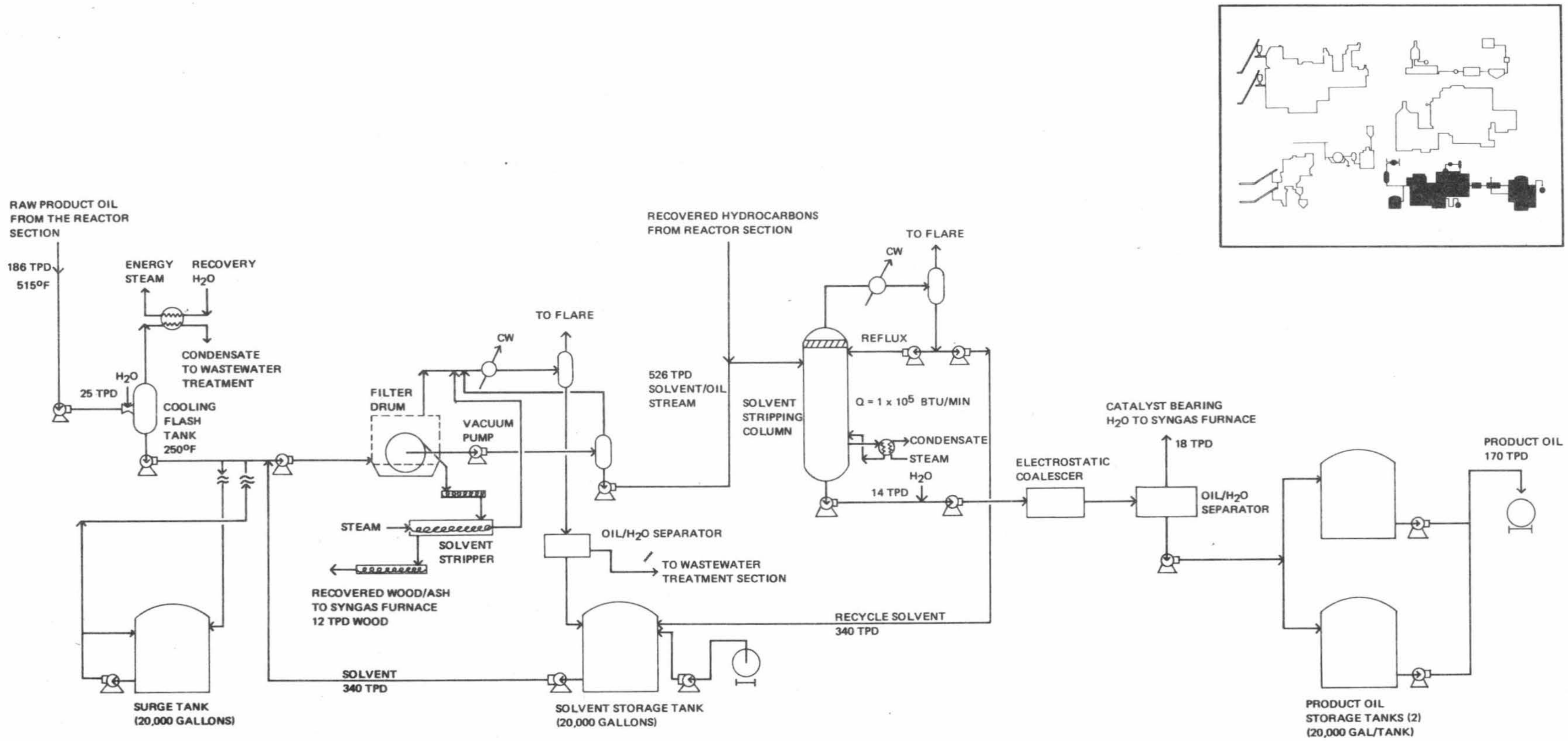


Figure 6-9. Reactor



(PERCENTAGES ARE GIVEN AS WEIGHT %)

Figure 6-10. Product Separation Section

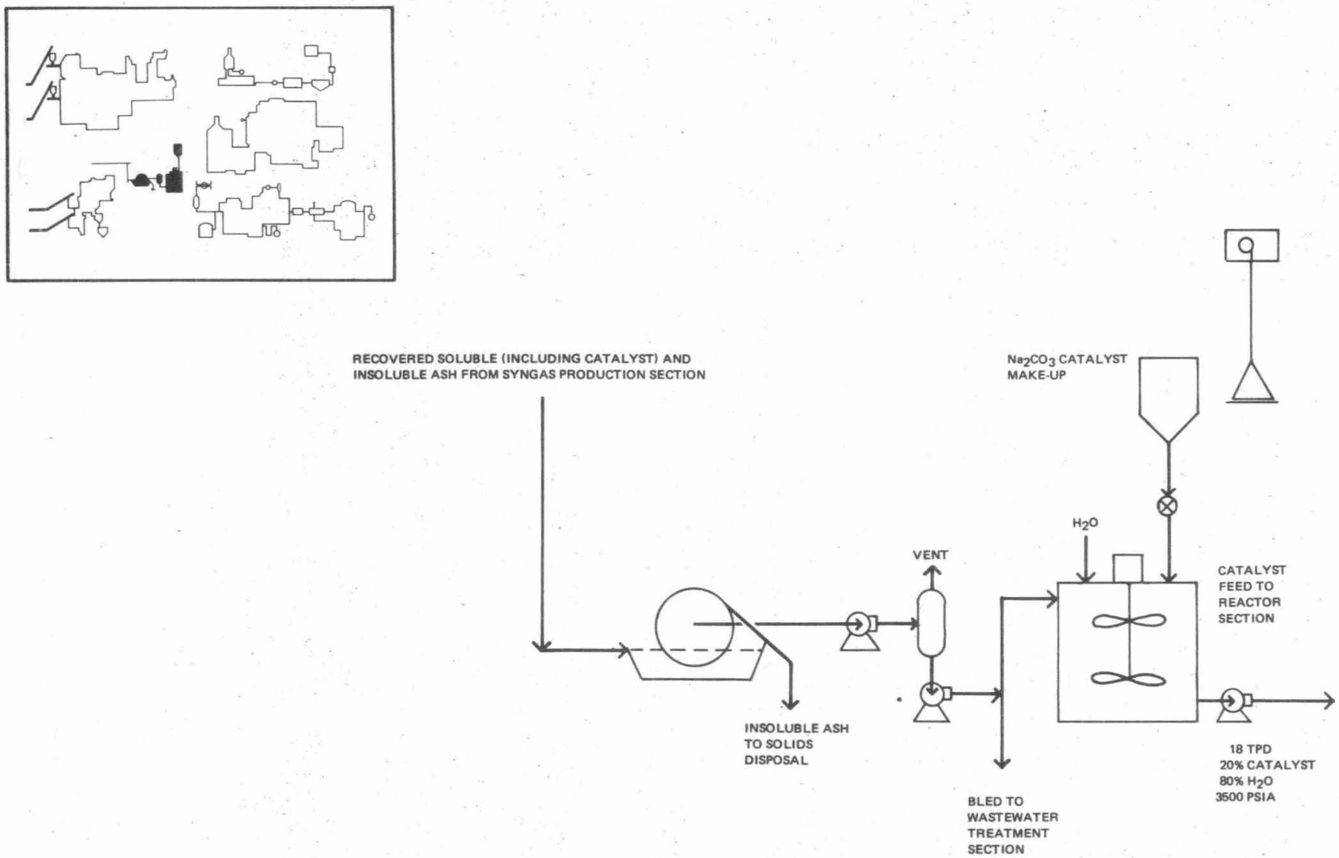


Figure 6-11. Catalyst Recovery Section

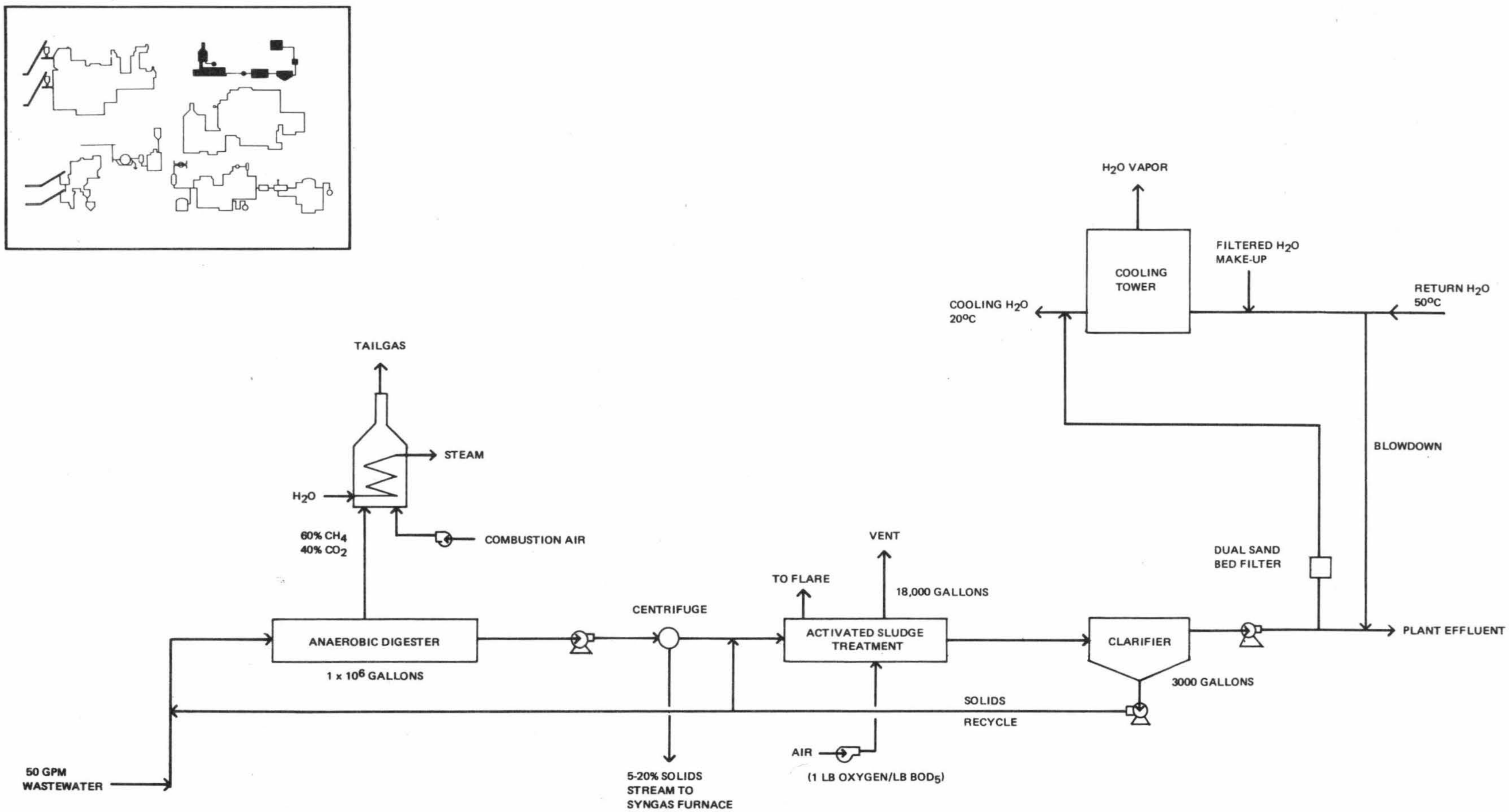


Figure 6-12. Wastewater Treatment Section

slurry of 30 percent has been chosen, since Albany experience indicates that 30 percent is the maximum wood concentration that will ensure slurry flowability. This slurry is sent to the Reactor Section for oil conversion. Table 6-1 lists the equipment for wood preparation.

Table 6-1

WOOD PREPARATION SECTION

Equipment Description

1. Conveyor - wood pile to distribution tower 48" x 500'
2. Front end loaders (2) - mobil equipment
3. Distribution tower hopper system
4. Conveyers (2) - tower to syngas bins 36" x 300'
5. Conveyers (2) - tower to grinder/dryer 36" x 200'
6. Conveyer - tower to wood-fired boiler 24" x 200'
7. Dryer/grinder package - feed bin, dryer/grinder, classifier, cyclone, bag filter, blowers (2), and surge bin
8. Wood scale - 300 TPD
9. Wood/oil blender with agitator - 10,000 gal
10. Wood/oil blender slurry feed pumps and drives (2) - 200 gpm, 200 hp
11. Oil/wood recycle positive displacement pump and drive (2) - 150 gpm, 100 hp

6.3.2 Syngas Production Section

The purpose of this section is to provide a source of purified carbon monoxide and hydrogen reactants for the Reactor Section, as shown in Figure 6-6. Wood is used as the source material for CO and H_2 production.

Wood is conveyed by belt to a surge bin which feeds into a hopper and then into the top of the syngas shaft furnace. The syngas furnace was developed and demonstrated by Union Carbide. It is presently being marketed as the Purox® process. The Purox process is basically a partial oxidation reaction by which organic material can be gasified to form CO, H_2, CO_2, and H_2O. Pure oxygen supplied by an on-site oxygen plant is introduced into the bottom of the furnace where a partial oxidation reaction occurs at 3000°F. The small amount of ash in the wood will leave with other added inorganics (i.e., Na_2CO_3) as molten slag in a catalyst waste stream from the Products Separation Section. The catalyst-bearing molten slag is water quenched and sent to the Catalyst Recovery Section.

The syngas from the shaft furnace passes through a cyclone to remove entrained solids for recycle and/or disposal. The syngas is sent through a series of three water scrubbers to reduce gas temperature to 100°F, thereby condensing light hydrocarbons and decreasing the water content of the gases. The scrubbers also remove any particulate matter from the syngas. Syngas initially enters a spray tower where the gases are quenched with water. The cooled gases exit through the top of the spray tower into a venturi scrubber where any remaining particulates are removed. The water droplets are coalesced and separated from the syngas by a nonreversing cyclone. The syngas passes upwards from the cyclone into a flooded mesh demister pad; then it passes through a large surge tank where any entrained water droplets are separated. The surge tank also serves to dampen any pressure fluctuations due to process upsets.

The scrubbed syngas is compressed from atmosphere pressure to 200 psia via two centrifugal compressors (1880 hp). The compressed syngas is sent to a potassium carbonate-CO_2 absorber column.* The CO_2-free gas stream is then sent to the Reactor Section. The resulting potassium bicarbonate solution is reduced in pressure and reheated to release CO_2 in a packed stripping column. CO_2 and H_2O vapor are vented to the atmosphere. The regenerated potassium carbonate solution is recycled to the absorber column. Table 6-2 lists the equipment for syngas production.

*See Appendix.

Table 6-2

SYNGAS PRODUCTION SECTION

Equipment Description

1. Wood surge bins (2) - 10' dia x 50' x 3/8"
2. Star valves (2)
3. Feed hoppers (2) with screw conveyers
4. Shaft furnaces (2) - 16' dia x 50'
5. Slag quench tank (2) - 8' dia x 12' x 3/8"
6. Slag quench tank centrifugal pumps (2) - 20 gpm
7. Cyclones (2) with star valve-screw conveyers (2)
8. Solids hopper (2)
9. Spray towers (2) - 6' dia x 30' x 3/8"
10. Venturi scrubbers (2)
11. Cyclone/demister pads (2)
12. Surge tanks (2) - 12' dia x 25' x 3/8"
13. Compressors (4) - 1740 BHP
14. Absorber column - 6' dia x 100' x 5/8"; packing - 72' high, 2" saddles
15. Regenerator column - 8' dia x 100' x 3/8"; packing - 69' high, 2" saddles
16. Pumps (3) - 500 gpm, 50 gpm, and 10 gpm
17. Heat exchangers (3) - 2,000 ft^2 (2), 1,000 ft^2
18. Separator tank - 3' dia x 6'
19. Reboiler heater - 2MM Btu/hr

6.3.3 Reactor Section

This section will cover the Reactor Section process description and reactor design details. The basis for the reactor design is especially important because it determines the design of the other process sections.

Reaction Process. As shown in Figure 6-7, the 400°F wood/oil slurry feed from the Wood Preparation Section is pumped to 3500 psia via a water-cooled diaphragm pump. Catalyst solution at 3500 psia is combined with the wood/oil slurry. CO/H_2 gas mixture from the Syngas Section is compressed to 4000 psia and introduced into the wood/oil catalyst slurry. The reactant mixture is charged to the reactor which essentially consists of two parts. The first part of the reactor consists of a single vertical helical coil preheater in a cylindrical brick-lined furnace, 12' dia x 35' high. The second part consists of a large vertically oriented pressure vessel, 4' I.D. x 50'. Reactor equipment specifications are discussed later in this section.

The reaction mixture enters the heater portion of the reactor and is heated to 650°F. The heated mixture is sent to a hold vessel for reaction at 650°F and 2500 psia for 20 minutes. The reacted mixture is reduced in pressure via two flash tanks in series. This means of pressure reduction will minimize the tendency of the oil to foam. Gases from the flash tanks are sent through a surge tank and to a series of three water scrubbers similar to those discussed in the Syngas Production Section. The scrubbed gases are combusted with air at 1800°F with recycled gases from the Wood Preparation Section. The 1500°F gases are sent to the reactor heater coil furnace and exit at 1170°F. The furnace exit flue gas is divided into two streams. One stream is sent to the Wood Preparation Section for wood drying. The other stream is sent to the Syngas Production Section to supply process heat to the K_2CO_3 regenerator column reboiler. After the reaction mixture is flashed down, the oil stream from the second flash tank is split into a recycle oil stream and a raw product oil stream. The recycle oil stream is sent to the Wood Preparation Section for slurrying with wood. The raw product oil stream is sent to the Product Separation Section.

PERC and Albany data seem to indicate that a plug flow reactor may be advantageous with respect to reaction kinetics. In addition, experience at

Albany has shown that operating equipment with moving parts, under the temperatures and pressures required, is expensive and unreliable.

Reactor Design. For the conceptual design, a plug flow reactor has been considered. The significant aspects of the design are pressure drop, heat transfer, coking, and erosion.

Pressure Drop. The viscosity of the fluid, under dynamic conditions, largely determines the pressure drop through the plug flow reactor. There is still considerable uncertainty with respect to the viscosity of the wood slurry under dynamic conditions. The viscosity depends strongly on temperature, wood concentration, oil quality, and slurry shear rate. Preliminary rheological studies are now underway to evaluate the latter phenomenon.

The presence of gases (CO, CO_2, H_2, H_2O) further determines the pressure drop through the plug flow reactor. The volumetric flow of the gases may be as high as 50 percent of the total volumetric flow. This causes an acceleration of the liquid flow but it also reduces the viscosity of the liquid. The net effect on pressure drop is not quite clear. Gases may also cause unstable flow conditions such as slugging stratification.

Heat Transfer. High inside heat transfer coefficients are desirable in order to minimize pipe length and in order to lower the inside wall temperature. Heat transfer can be improved by increasing turbulence (higher velocities). The velocity is limited, however, by pressure drop and erosion considerations.

Coking. The metal wall temperature should be low enough to prevent coking at the wall. Specific coking studies have not been conducted but experience at Albany and in coal liquefaction seems to indicate that coking at the wall appears to be minimal below 900°F.

The coking danger is further determined by the flow characteristics inside the pipe. The coking danger is minimized by having a stable, turbulent flow. Unstable flow, such as slugging flow, could cause conditions under which the inside pipe wall would not be adequately wetted and overheating would result. Laminar flow conditions provide a strong resistance to heat transfer and a subsequent high inside wall temperature. Turbulence should, therefore, be increased as much as possible. This can be accomplished by increasing the fluid velocity. The velocity limit would be determined by pressure drop and erosion problems.

Erosion. Considering the nature of the fluid, potential erosion problems should be considered. In view of the expected high viscosity of the liquid slurry, high velocities will be required to obtain turbulent flow. This velocity is limited by pressure drop and erosion considerations. In coal liquefaction, the slurry velocity is limited to 20 fps because of potential erosion. In wood liquefaction, erosion problems should not be as severe because of the less abrasive nature of the wood slurry.

Additional Considerations. In view of the fact that a three-phase (liquid-solid gas) system exists inside the reactor, vibrational problems caused by slugging should be considered. Because flow distribution is believed to be difficult, single reactor train units are considered desirable.

Corrosion may be a problem, considering the presence of organic acids and hydrogen at high temperatures and pressures. Stainless steel (316) or Inconel (800) have generally been used in coal liquefaction under similar conditions. Alternate alloys are being studied.

Sufficient residence time needs to be provided at high temperature and pressure to allow the reaction to go to near completion. Plug flow is desirable for kinetics purposes. Mechanical stirring is undesirable because of reliability problems. A simple standpipe or hold vessel has been considered with a sufficient rise velocity to prevent solids settling.

Helical Coil Preheater Design. A helical coil preheater design was selected since it allows a "smooth" three-phase flow upwards, thereby minimizing mechanical problems caused by uneven flow. A helical coil also permits use of long lengths of pipe in a rather compact arrangement, thereby minimizing the number of parallel reactor trains required (only one train for a 1000 TPD wood-to-oil plant).

Heat input for the coil is supplied by hot gases from an external combustion chamber. To further minimize coking, only convective heat transfer to the coil is used.

Concurrent flue gas and slurry flow is used to lower the metal wall temperature and to increase the initial rate of slurry heating. The helical coil is housed in a vertical annulus, designed to provide a reasonable flue gas velocity. A standpipe is used to provide sufficient residence time under reaction conditions.

Incolloy 800 is the current construction material for the helical coil.

A single 3" diameter pipe was selected for the coil as a compromise between promotion of turbulence, reduction in pressure drop (for given mass flow), and enhancement of heat transfer. This was considered well within the state of the art of helical coil design.

Table 6-3 and Figures 6-8 and 6-9 give additional details of the reactor system equipment.

Table 6-3

REACTOR SECTION

Equipment Description

1. Compressor and motor - 1800 hp
2. Preheater - helical coil heater unit
3. Reactor - 4' dia x 50' x 2 3/4" 316 ss internal cladding
4. Burner box - 11' dia x 25'
5. Flash tank - 6' dia x 18' x 1 1/2" 316 ss internal cladding
6. Flash tank - 6' dia x 18' x 3/8" 316 ss internal cladding
7. Surge tank - 6' dia x 18' x 3/8" 316 ss internal cladding
8. Surge tank - 6' dia x 18' x 3/8" carbon steel
9. Air blower (2) 25,000 scfm, 10,000 scfm
10. Oil/water separator - 1,000 gal
11. Spray tower - 6' dia x 30' x 3/8"
12. Venturi scrubber
13. Cyclone/demister pad
14. Water storage tank - 20,000 gal FRP
15. Water pump - 100 gpm
16. Diaphragm wood/oil pumps (2) - 200 gpm, 600 hp

6.3.4 Product Separation Section

This section is concerned with the removal of unreacted wood, sodium carbonate catalyst, and miscellaneous insoluble solids from the product oil stream as shown in Figure 6-10. Table 6-4 is the equipment list for the Product Separation area.

From the Reaction Section, impure product oil is sent to a water-fed venturi nozzle leading into a flash tank. The water cools the product oil from 515°F to 250°F and forms low pressure steam which is recovered. The cooled oil is diluted with two parts xylene solvent. The diluted oil

Table 6-4

PRODUCT SEPARATION SECTION

Equipment Description

1. Oil pumps (2) - 50 gpm
2. Oil cooler flash tank - 6' dia x 12' x 3/8"
3. Waste heat boiler - 4,000 lb/hr steam
4. Oil surge tank - 20,000 gallon (heated and insulated)
5. Solvent pump - 150 gpm
6. Oil pumps (2) - 100 gpm
7. Vacuum drum filter - 100 ft^2
8. Exchanger - 100 ft^2
9. Vent drums (3) - 3' dia x 6'
10. Stripper conveyer
11. Separator - 500 gallon
12. Stripping column - 8' dia x 85' x 1/2"
13. Solvent storage tank - 20,000 gallon
14. Reboiler
15. Pumps - 100 gpm (2), 50 gpm (4), 10 gpm (2)
16. Exchanger 1,000 ft^2
17. Electrostatic coalescer
18. Separator - 1,000 gallon
19. Oil storage tanks (6) - 20,000 gallon/tank

is fed to an enclosed diatomaceous earth precoated vacuum filter drum where unreacted wood, some diatomaceous earth, and inert solids are removed. The filtered solids are steam stripped of hydrocarbons in a countercurrent steam-heated screw conveyer. The dried solids are conveyed to the syngas furnace for disposal. The steam/solvent stream is condensed, separated, and the solvent is recycled. The condensate water is sent to wastewater treatment.

The wood-free oil/solvent stream is sent to a stripping column where the solvent is removed, condensed, and recycled. Steam is supplied to the stripping column from a wood-fired steam boiler. The solvent-free oil is cooled in a flash tank by the addition of water and brought up to 5 to 10 percent water concentration for catalyst removal. The oil/water stream passes through an electrostatic coalescer to promote an oil/water phase separation. The catalyst bearing water stream is sent to the Syngas Section for processing. The product oil stream is sent to storage. Eventually, it is loaded into railcars or tank trucks.

6.3.5 Catalyst Recovery Section

An aqueous inorganic slurry containing ash and soluble inorganics from the Syngas Production Section is processed in this section for alkali catalyst recovery as shown in Figure 6-11. Table 6-5 is the equipment list for the Catalyst Recovery Section.

Table 6-5

CATALYST RECOVERY SECTION

Equipment Description

1. Vacuum filter drum - 100 ft^2
2. Vent drum - 3' dia x 6'
3. Pump - 50 gpm
4. Tank and agitator - 20,000 gallon FRP
5. Trash hopper
6. Star valve
7. Hoist - 1 ton
8. Positive displacement pumps (2) - 3,500 psia, 10 gpm

The inorganic slurry contains both soluble and insoluble materials from wood ash, diatomaceous earth, and Na_2CO_3 catalyst. The insoluble solids are removed by a vacuum filter drum and are used as clean solids for landfill. The filtrate is divided into a bleed stream and catalyst recycle stream. The purpose of the bleed is to avoid the accumulation of soluble inorganics from the wood ash. The bleed stream is sent to the Wastewater Treatment Section. The catalyst stream is sent to the catalyst makeup tank. Anhydrous Na_2CO_3 catalyst and water may be added if needed. A high-pressure pump transports the feed catalyst stream to the Reactor Section.

6.3.6 Wastewater Treatment Section

All high organic content wastewater streams are sent to an anaerobic digester as shown in Figure 6-12. Methane gas is a by-product which is combusted for steam generation. The steam can be used to maintain temperatures of the wastewater treatment equipment during winter months. The resulting stream is sent to a centrifuge where the solids are removed and concentrated to a 15 to 20 percent solids stream. The solids stream is sent to the syngas furnace for disposal. The liquor is sent to an activated sludge treatment tank where air is used as the aeration media. The design basis is 1 lb oxygen input for every 1 lb BOD_s in the vessel. The treated water is sent to a clarifier where the remaining solids are settled and recycled back to the digester and activated sludge treatment. The purified water from the clarifier is divided into a recycle and plant effluent stream. The recycled water stream is sent through a dual sand bed filter media, pH adjusted, and used as makeup for the plant cooling tower. Table 6-6 is the equipment list for the Wastewater Treatment Section.

6.4 PLANT LAYOUT

In order to further acquaint the reader with the organization of a commercial plant, Figure 6-13 shows a preliminary layout for a 1000 TPD (wet) capacity plant.

Table 6-6

WASTEWATER TREATMENT SECTION

Equipment Description

1. Digester - 1,000,000 gallon
2. Solids centrifuge
3. Activated sludge treatment - 18,000 gallon
4. Clarifier - 3,000 gallon
5. Sand bed filter
6. Cooling tower
7. Pumps (3) - 50 gpm

Miscellaneous Items

1. Oxygen plant - 150 TPD
2. Wood fueled boiler - 100,000 lb/hr steam

6.5 ECONOMIC ANALYSIS

6.5.1 Capital Costs

Capital and operating costs have been developed on liquefaction plants at 1000 TPD and 5000 TPD. These plants have an oil production capacity of 800 bbl/day and 4000 bbl/day, respectively. The estimates are based on the conceptual design just described and engineering information prepared for the study. Estimating methods consistent with the conceptual nature of the design information were used and included informal vendor contact as well as extrapolation from Bechtel historical information.

The construction cost estimate is composed of field costs and engineering services. The largest category, field costs, includes the direct cost of permanent plant equipment and the indirect cost of temporary construction materials, supervision, etc. The estimate anticipates an engineer-constructor direct-hire operation employing field construction labor.

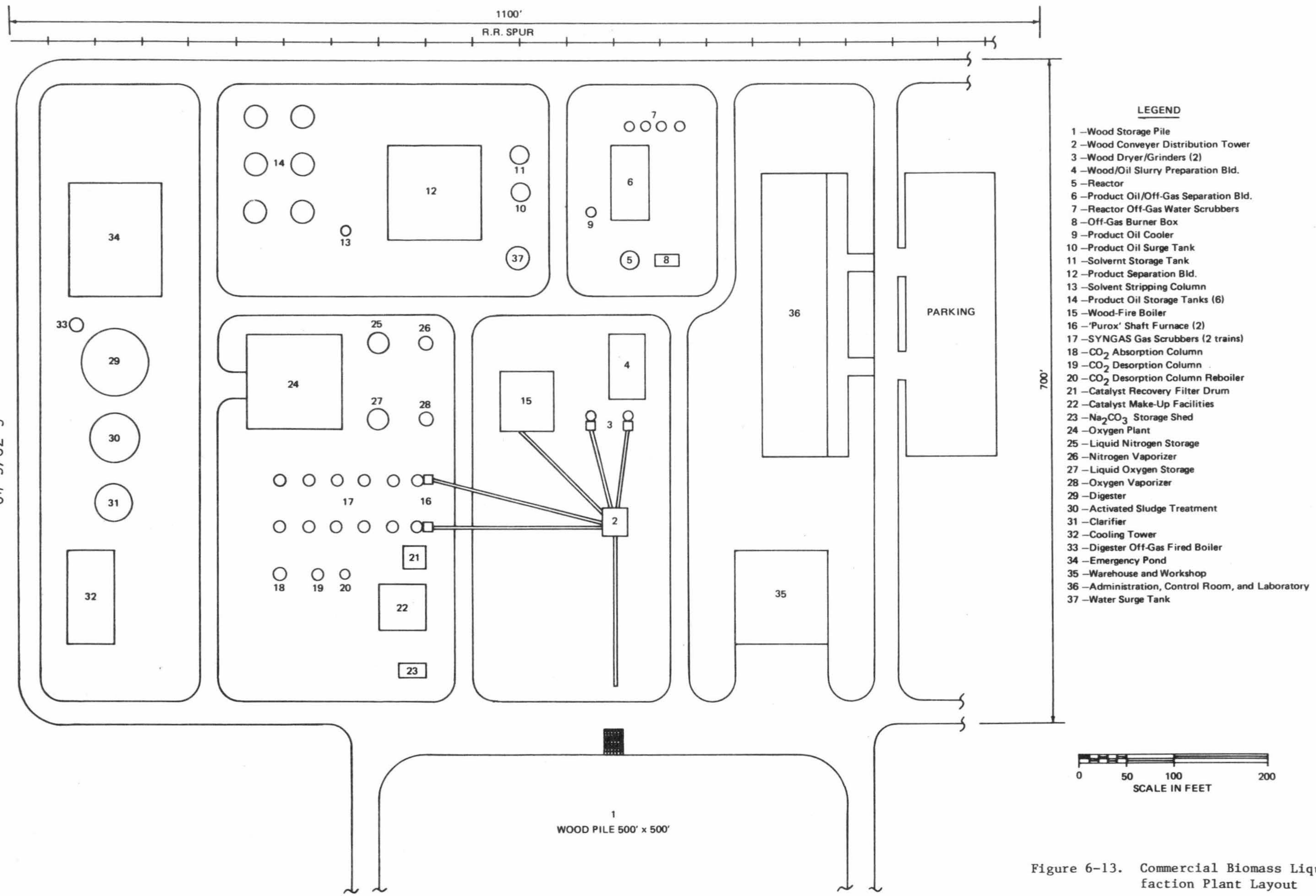


Figure 6-13. Commercial Biomass Liquefaction Plant Layout

Pricing Levels. The estimate is at first quarter 1978 price and wage levels. No allowance has been made for future escalation.

Field Construction Costs. The direct field construction costs of permanent plant equipment, materials, subcontracts, and construction labor have been included in the estimate.

Equipment. Equipment was estimated using Bechtel experience with similar equipment and data derived from recent purchase orders and vendor contacts.

Material. Quantity evaluations were made for identifiable materials and priced using current unit prices from Bechtel sources. Other materials that would be delineated on the final engineering drawings have been evaluated by experience and as a percentage of the installed cost of the identified materials.

Subcontracts. Subcontracts for equipment and materials commonly installed by subcontractors were estimated and priced in accordance with Bechtel experience from current sources.

Construction Labor. The direct construction labor costs for the installation of the plant equipment and material were estimated using recent productivity and a wage range based on labor contracts and fringe benefits for the western United States. This wage rate of $15.00 per hour is based on a craft mix appropriate to the type of construction together with a 5 percent allowance for casual overtime and 1 percent for craft-furnished supervision. Sufficient manual labor to complete the project is assumed to be available in the project vicinity.

Indirect Field Costs. The indirect field costs are those items of construction cost that cannot be ascribed to direct portions of the facility and thus are accounted separately. They were estimated by modifying the experience on similar plants and resulted in an assessment of 80 percent of direct labor costs.

The items covered by indirect field costs are as follows:

- Temporary Construction Facilities. Temporary buildings, working areas, roads, parking areas, utility system, and general purpose scaffolding

- Miscellaneous Construction Services. General job cleanup, maintenance of construction equipment and tools, material handling, and surveying

- Construction Equipment and Supplies. Construction equipment, small tools, consumable supplies, and purchased utilities

- Field Office. Field labor of craft supervision, engineering, procurement, scheduling, personnel administration, warehousing, first aid, and the costs of operating the field office

- Preliminary Check-Out and Acceptance Testing. Testing of materials and equipment to ensure that components and systems are operable

- Project Insurance. Public liability, property damage, and builder's risk insurances

Engineering Services. The engineering services include engineering costs, other home office costs, and fee. Engineering includes preliminary engineering, optimization studies, specifications, detail engineering, vendor-drawing review, site investigation, and support to vendors. Other home office costs include procurement, estimating and scheduling services, quality assurance, acceptance testing, and construction and project management. Fee is included as a function of the total project cost.

The sum of these three categories falls into historically consistent percentages in the range of 10 to 20 percent depending on the complexity of the project. For this study a figure of 12 percent of field construction costs has been used as typical for a plant that, while new in concept, does not depart radically from basic engineering principles.

Allowance for Uncertainty. While it is typical to include an allowance for uncertainty in an analysis of this sort, one is not included here. This is due to the preliminary nature of the process development, which is currently aimed at substantial reductions in plant complexity and cost.

Design Assumptions. The major assumptions for which design data was not available when the estimate was prepared include site specific items which affect civil/structural costs and piping, instrumentation and electrical layout.

Qualifications. The major qualifications in the estimate are wood chip delivery and unloading by others, movement of the product oil beyond the plant limits by others, and major utilities, such as power, which are available at the plant fence line from others.

Exclusions. Process royalties and licenses, plant startup, and any special construction such as widening and strengthening existing roads are excluded from the project scope and are not, therefore, included in the estimate.

The preceding discussion of pricing levels, field construction costs, engineering services, allowance for uncertainty, qualifications and exclusions form the basis of the estimates contained in Table 6-7. Table 6-7 contains the capital cost estimate summary for plants of 1,000 TPD and 5,000 TPD capacity.

6.5.2 Annual Operating and Maintenance Cost

The materials, supplies, and labor for plant operation and maintenance were estimated to reflect first quarter 1978 price and wage levels. They have been included in the estimate on the basis of the following discussion.

Supplies. The annual costs for supplies consumed in the operation of the plant are included as a percentage of operating labor and total maintenance costs. The percentages were developed from published Energy Research and Development Agency (ERDA) material.

Table 6-7

CAPITAL COST ESTIMATE SUMMARY

Capital Costs	Cost $1,000's	
	1000 TPD Plant	5000 TPD Plant
Mechanical	11,600	34,500
Civil and Structural	5,300	15,800
Process Piping and Instruments	7,800	23,200
Electrical	3,900	11,600
Site and Yard	1,000	3,000
Direct Field Cost	29,600	88,100
Indirect Field Cost	7,200	25,300
Total Field Cost	36,800	113,400
Engineering Services	4,400	13,600
Total Construction Cost	41,200	127,000
Land	450	900
Fund, During Construction	7,700	19,800
Other Owner Costs	2,500	6,300
Total Installed Cost	51,850	154,000

Utilities. Power for the plant was estimated from the required electrical load of $.03 per kilowatt hour. Other utilities are included at a nominal cost.

Operating Personnel. Operating personnel costs were estimated based on three shifts and 330 days per year. Operating personnel account for 36 of the total work force of 86 persons.

Maintenance Labor and Materials. The costs of plant maintenance were estimated for the given labor force of 29 persons, and for material costs as a percentage of labor.

Supervision. Supervision labor costs were estimated from the given number of nonmanual personnel.

Administration and Overhead. Administration and overhead costs of rent, office supplies, public relations expenses, travel, and training were estimated as a percentage of labor.

Local Taxes and Insurance. Property and other recurring taxes and insurance were estimated as a percentage of total construction cost. This is a typical rate for the type of plant under construction, and is recommended by published ERDA guidelines.

Operating Cost Tables. Tables 6-7 and 6-8 show the resulting annual operating and maintenance costs for plants of 1,000 TPD and 5,000 TPD capacity.

Table 6-8

ANNUAL COST ESTIMATE SUMMARY

Operating Costs*	$1,000's	
	1,000 TPD Plant	5,000 TPD Plant
Operating Labor	730	1,460
Maintenance Labor and Materials	1,120	2,240
Supervision	420	600
Administration and Overhead	550	790
Supplies	670	1,350
Utilities	1,060	3,180
Local Taxes and Insurance	1,750	5,380
Wood ($20/ton)	3,300	16,500
Total Operating Cost	9,600	31,500
Fixed Cost @ 10%/Year	5,180	15,400
Total Annual Cost	14,780	46,900

*Basis: 330 operating days per year.

6.6 PRODUCT COST

Using the previously developed information on capital and operating costs, it is possible to predict the resulting cost of product. This is shown in Figure 6-14, where the break-even cost of oil in \$/bbl is related to plant capacity and cost of wood. The capacity and wood costs are on a moisture-free basis, as compared to the as-received basis used in sizing the conceptual plant. As such, the plant at 1,000 TPD as-received capacity is represented as 500 TPD on Figure 6-14.

As can be seen, the effect of plant size is strong. This indicates that only large plants are likely to be economically attractive.

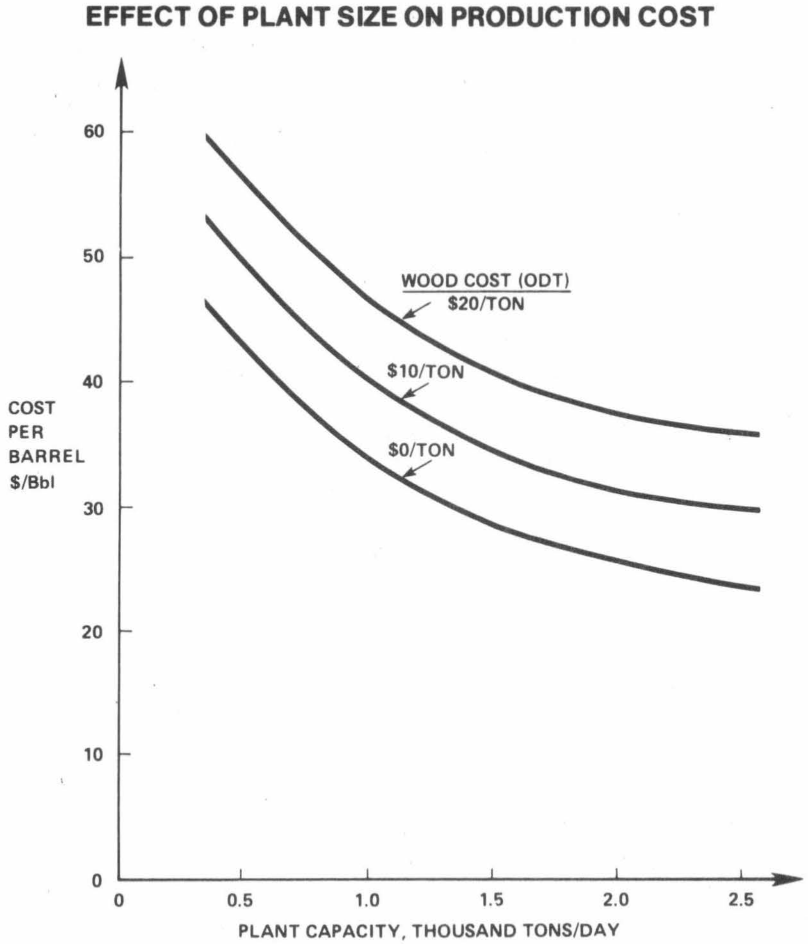


Figure 6-14. Effect of Plant Size on Production Cost

APPENDIX

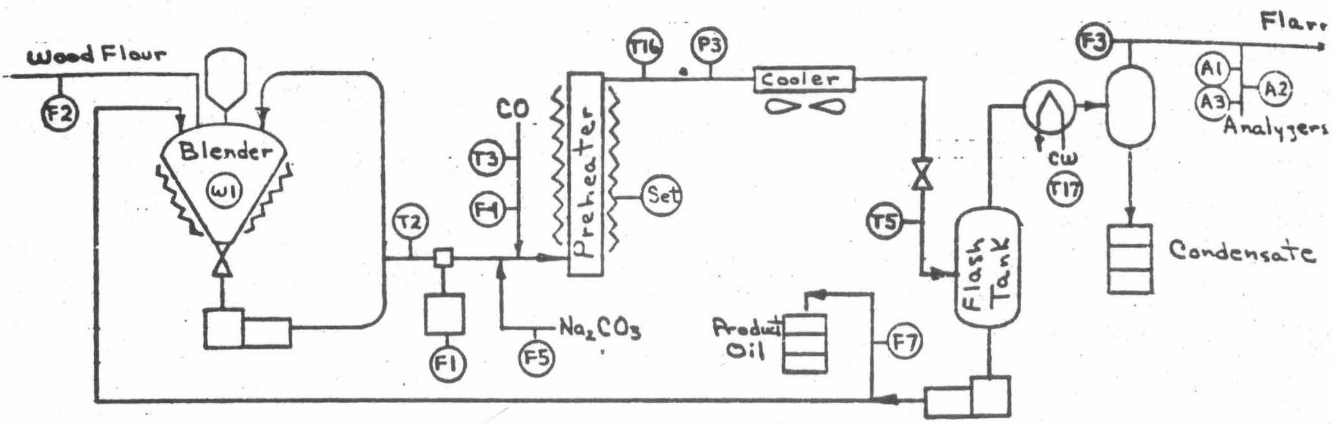
TEST RESULTS – BYPASS TESTS #8-23

Run No.: 8

Date: 7/27/77 to 7/29/77, **Total Time On stream:** 39 Hours

Objective: Operate Bypass System with Improved Flow Control. Block in feed slurry knock out pot to eliminate oil carryover to overheat lines and flare.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	50	gph.
Catalyst Flow Rate:	3.3	gph.
Wood Flour Feed Rate:	48	lbs./hr.
Wt. % Flour in Feed Slurry:	(11-14)	%
CO Feed Rate:	0-4	scfm.
Residence Time:	20	min.
Pressure:	2000	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	650	620	635	615
Conversion wt. %:	80	49	47	77

Cause of Shutdown: Scheduled

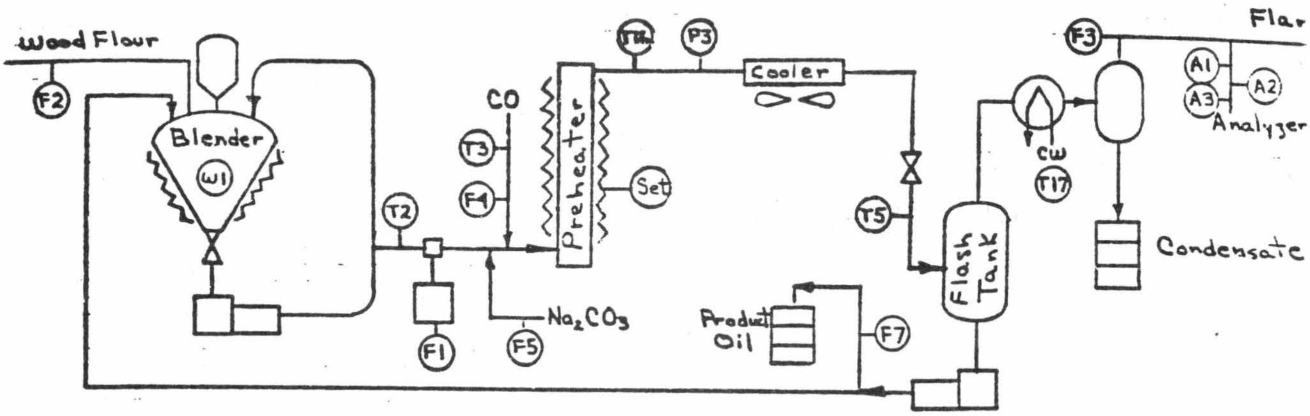
Observations: Operation in the bypass mode with wood flour feed was successfully carried out on a continuous basis. Problems with oil carryover was greatly aleviated.

Run No.: 9

Date: 8/1/77 to 8/4/77, **Total Time On stream:** 33 Hours

Objective: Determine baseline data for bypass system with CO, anthracene and catalyst. No wood.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	50	gph.
Catalyst Flow Rate:	1.6	gph.
Wood Flour Feed Rate:	None	lbs./hr.
Wt. % Flour in Feed Slurry:	None	%
CO Feed Rate:	4	scfm.
Residence Time:	20.5	min.
Pressure:	2500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:

Conversion wt. %:

Cause of Shutdown: Scheduled for Rx Maintenance.

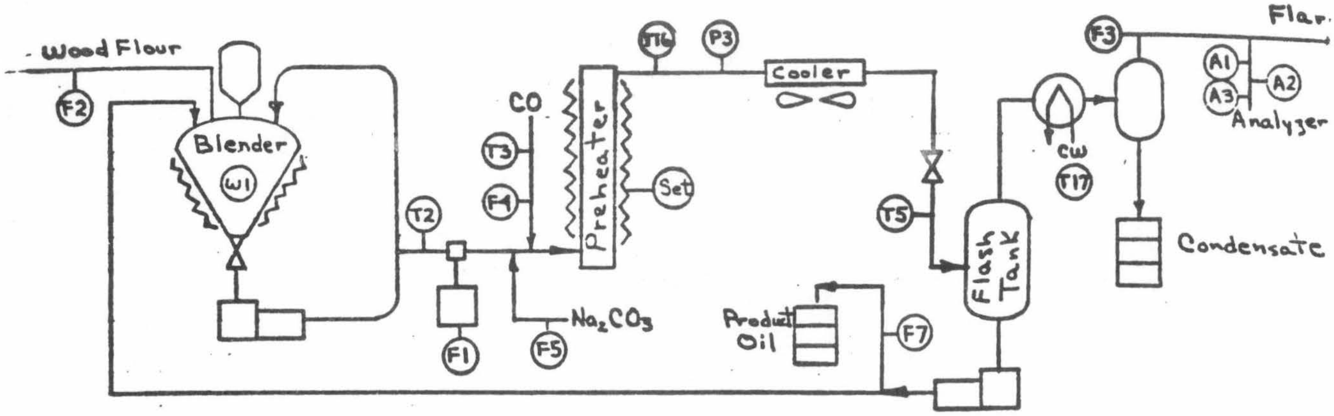
Observations: The anthracene appeared to show no significant change in viscosity or boiling point curve when ran without wood.

Run No.: 10

Date: 8/8/77 to 8/11/77, **Total Time On stream:** 36 Hours

Objective: Test increased wood flour concentration on bypass system oil production.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	50	gph.
Catalyst Flow Rate:	1.6	gph.
Wood Flour Feed Rate:	30/45	lbs./hr.
Wt. % Flour in Feed Slurry:	(6-9)	%
CO Feed Rate:	5 & 2	scfm.
Residence Time:	16.5	min.
Pressure:	3000 & 4000	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	710/705	540/670	700/740	600/710
Conversion wt. %:	91/69	23/70	82/58	72/50

Cause of Shutdown: Scheduled for Rx Maintenance.

Observations: Operation of the system at two different total pressures was successful, with reasonably good control of CO partial pressure.

BYPASS TEST #10

STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

Key	**Description**	
T-2	**Feed Slurry Pump Discharge**	**(°F.)**
T-3	**CO from Interchanger**	**(°F.)**
T-5	**Level Valve #315 Outlet**	**(°F.)**
T-16	**Preheater Outlet**	**(°F.)**
Set	**TIC-302 Setting**	**(% of scale)**
T-17	**L.P. Cooler C.W.**	**(°F.)**
P-3	**System Pressure**	
F-1	**Feed Slurry Pump Stroke**	**(mm)**
F-2	**Wood Flour Feed**	**(lb./hr.)**
F-3	**L.P. Flash Gas Flow**	**(scfm)**
F-4	**CO Feed**	**(scfm)**
F-5	**Catalyst Pump Stroke**	**(mm)**
W-1	**Wood Oil Blend Weight**	**(gross lb.)**
A-1	**H_2 in Off Gas**	**(%)**
A-2	**CO in L.P. Vent**	**(%)**
A-3	**CO_2 in L.P. Vent**	**(%)**

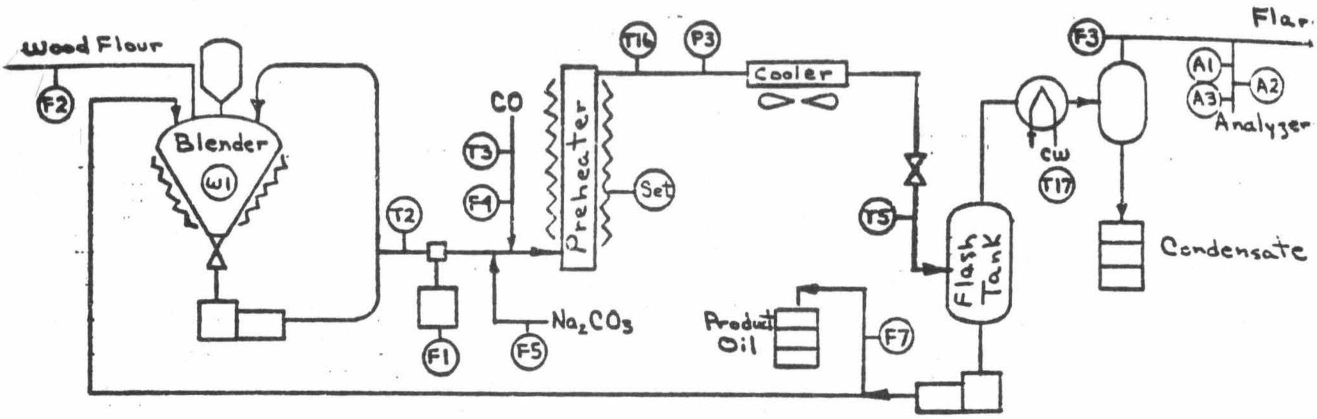
VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	147.306	6.476	1.079	174.000	136.000	38.000
T3	91.639	9.514	1.586	135.000	75.000	60.000
T5	152.528	12.284	2.047	184.000	120.000	64.000
T16	657.611	52.922	8.820	745.000	560.000	185.000
SET	55.139	16.283	2.714	71.000	.000	71.000
T17	136.361	8.996	1.499	171.000	119.000	52.000
P3	3523.611	502.918	83.820	4000.000	3000.000	1000.000
F1	45.000	.000	.000	45.000	45.000	.000
F2	25.306	2.965	.494	32.000	14.000	18.000
F3	.431	.352	.587E-01	1.000	.000	1.000
F4	2.086	2.431	.405	6.200	.000	6.200
F5	1.556	.267	.444E-01	1.600	.000	1.600
W1	1264.028	70.961	11.827	1420.000	1150.000	270.000
A1	.000	.000	.000	.000	.000	.000
A2	.000	.000	.000	.000	.000	.000
A3	.000	.000	.000	.000	.000	.000
F7	.000	.000	.000	.000	.000	.000

Run No.: 11

Date: 8/17 to ----, **Total Time On stream:** (None)

Objective: Test effect of product oil on rate on conversion use of 20% slurry.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	50	gph.
Catalyst Flow Rate:	1.6	gph.
Wood Flour Feed Rate:	35	lbs./hr.
Wt. % Flour in Feed Slurry:	---	%
CO Feed Rate:	5	scfm.
Residence Time:	16.5	min.
Pressure:	3500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.: (No results)

Conversion wt. %:

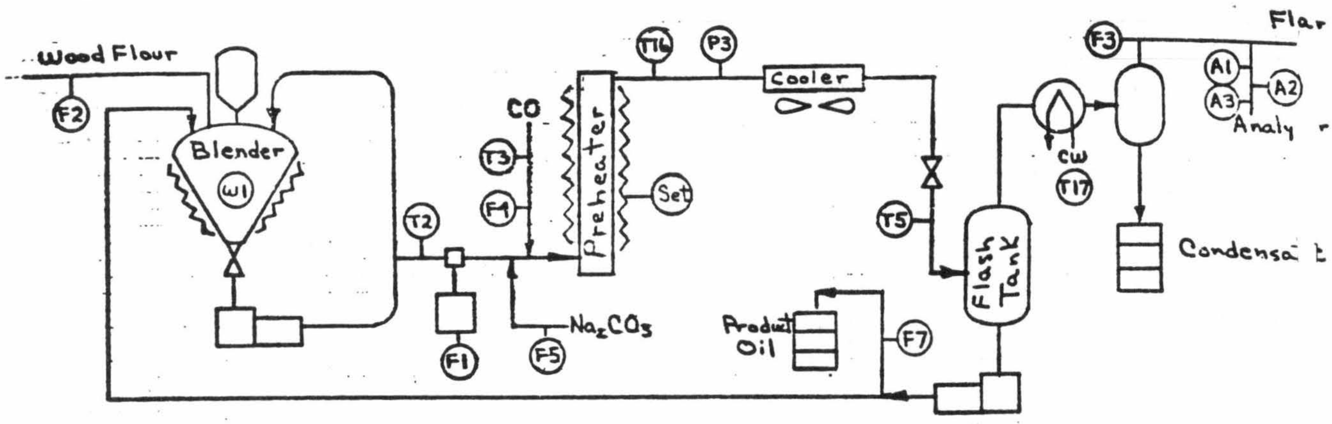
Cause of Shutdown: (Run aborted due to plugging and to preheater seal and
Observations: blade failure.)

Run No.: 12

Date: 10/26/77 to 10/28/77, **Total Time On stream:** 55.5 Hours

Objective: Establish steady state equilibrium in the system.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	40	gph.
Catalyst Flow Rate:	1.4	gph.
Wood Flour Feed Rate:	30-45	lbs./hr.
Wt. % Flour in Feed Slurry:	(6-11)	%
CO Feed Rate:	6.6	scfm.
Residence Time:	25.5	min.
Pressure:	2500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	575	575	533	620	534
Conversion wt. %:	76	76	87	71	83

Cause of Shutdown: Precautionary check of preheater.

Observations: Conversion of biomass did not appear to decrease after 55.5 hours of recycle operation and an estimated 14 passes through the system of the bulk of the material. The longer residence time of 25 minutes resulted in somewhat higher gas yield.

BYPASS TEST #12

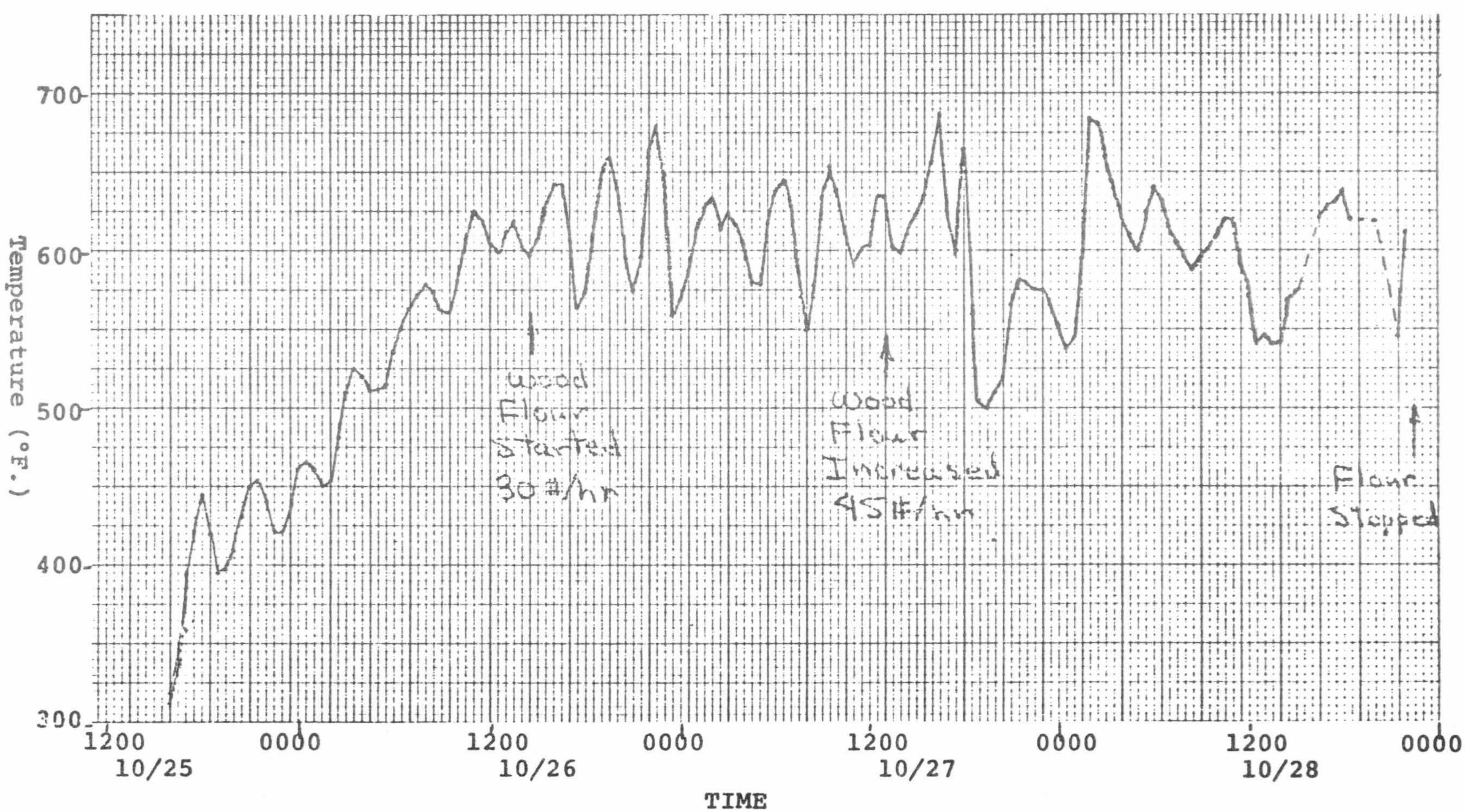
STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

Key	Description	
T-2	Feed Slurry Pump Discharge	(°F.)
T-3	CO from Interchanger	(°F.)
T-5	Level Valve #315 Outlet	(°F.)
T-16	Preheater Outlet	(°F.)
Set	TIC-302 Setting	(% of scale)
T-17	L.P. Cooler C.W.	(°F.)
P-3	System Pressure	
F-1	Feed Slurry Pump Stroke	(mm)
F-2	Wood Flour Feed	(lb./hr.)
F-3	L.P. Flash Gas Flow	(scfm)
F-4	CO Feed	(scfm)
F-5	Catalyst Pump Stroke	(mm)
W-1	Wood Oil Blend Weight	(gross lb.)
A-1	H_2 in Off Gas	(%)
A-2	CO in L.P. Vent	(%)
A-3	CO_2 in L.P. Vent	(%)

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	166.824	4.237	.593	175.000	156.000	19.000
T3	56.451	3.916	.548	64.000	49.000	15.000
T5	195.609	~~23.010~~	3.222	270.000	159.000	111.000
T16	591.216	41.566	5.821	670.000	441.000	229.000
SET	44.471	6.540	.916	60.000	32.000	28.000
T17	84.373	13.266	1.858	125.000	64.000	61.000
P3	2530.392	41.326	5.787	2600.000	2500.000	100.000
F1	36.902	.700	.980E-01	37.000	32.000	5.000
F2	36.765	11.740	1.644	45.000	.000	45.000
F3	4.376	2.812	.394	10.000	.000	10.000
F4	4.896	1.007	.141	6.200	.000	6.200
F5	4.922	.717	.100	6.000	.000	6.000
W1	1131.176	57.685	8.078	1250.000	1000.000	250.000
A1	13.723	8.823	1.236	29.000	.000	29.000
A2	49.730	31.775	4.449	100.000	.000	100.000
A3	41.265	24.114	3.377	83.000	.000	83.000
F7	.000	.000	.000	.000	.000	.000

FIGURE 1

BYPASS TEST 12
Preheater Exit Temperatures



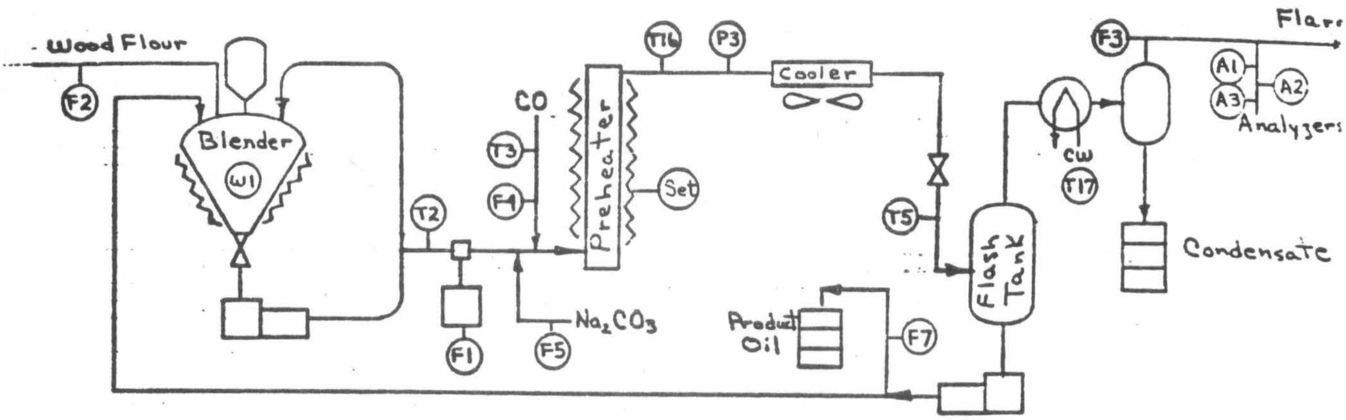
A-9

Run No.: 13

Date: 11/4/77 to 11/5/77, **Total Time On stream:** 39 Hours

Objective: Establish steady state equilibrium in the system.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	80	gph.
Catalyst Flow Rate:	0.85	gph.
Wood Flour Feed Rate:	40-45	lbs./hr.
Wt. % Flour in Feed Slurry:	(4-14%)	%
CO Feed Rate:	2.7	scfm.
Residence Time:	13	min.
Pressure:	2500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	620	588
Conversion wt. %:	37	4

Cause of Shutdown: Preheater agitator seal failure.

Observations: The first good material balance was made. While the total conversions appeared low, oil yield from the wood was high (approximately 52%). CO consumption was low and product oil viscosity was high, compared to previous runs. Exothermicity was noted during the run.

BYPASS TEST #13

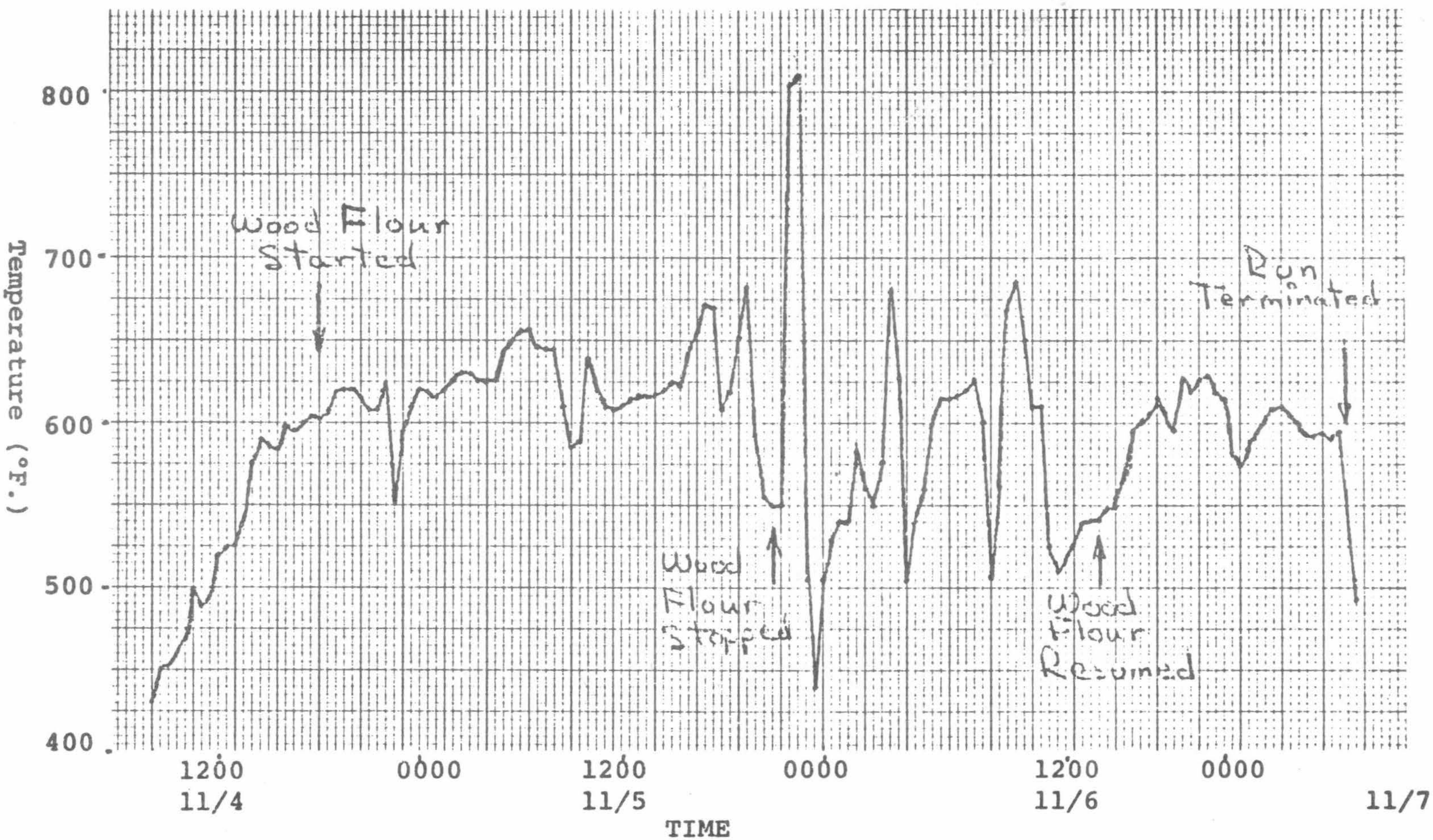
STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

Key	Description	
T-2	Feed Slurry Pump Discharge	(°F.)
T-3	CO from Interchanger	(°F.)
T-5	Level Valve #315 Outlet	(°F.)
T-16	Preheater Outlet	(°F.)
Set	TIC-302 Setting	(% of scale)
T-17	L.P. Cooler C.W.	(°F.)
P-3	System Pressure	
F-1	Feed Slurry Pump Stroke	(mm)
F-2	Wood Flour Feed	(lb./hr.)
F-3	L.P. Flash Gas Flow	(scfm)
F-4	CO Feed	(scfm)
F-5	Catalyst Pump Stroke	(mm)
W-1	Wood Oil Blend Weight	(gross lb.)
A-1	H_2 in Off Gas	(%)
A-2	CO in L.P. Vent	(%)
A-3	CO_2 in L.P. Vent	(%)

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	143.771	12.362	2.090	181.000	132.000	49.000
T3	57.086	2.077	.351	60.000	54.000	6.000
T5	193.429	20.499	3.465	245.000	142.000	103.000
T16	608.286	31.067	5.251	665.000	530.000	135.000
SET	72.343	15.967	2.699	96.000	30.000	66.000
T17	75.600	5.867	.992	85.000	63.000	22.000
P3	2500.000	.000	.000	2500.000	2500.000	.000
F1	74.000	.000	.000	74.000	74.000	.000
F2	42.000	2.485	.420	45.000	40.000	5.000
F3	4.036	1.143	.193	6.500	1.000	5.500
F4	3.037	.649	.110	4.100	2.000	2.100
F5	4.000	2.029	.343	5.000	.000	5.000
W1	1144.714	90.342	15.271	1325.000	1020.000	305.000
A1	8.243	9.658	1.633	19.500	.000	19.500
A2	76.209	16.923	2.861	100.000	.810	99.190
A3	44.086	9.475	1.602	60.000	17.000	43.000
F7	10.129	25.767	4.355	90.000	.000	90.000

FIGURE 3

BYPASS TEST 13
Preheater Exit Temperature



A-12

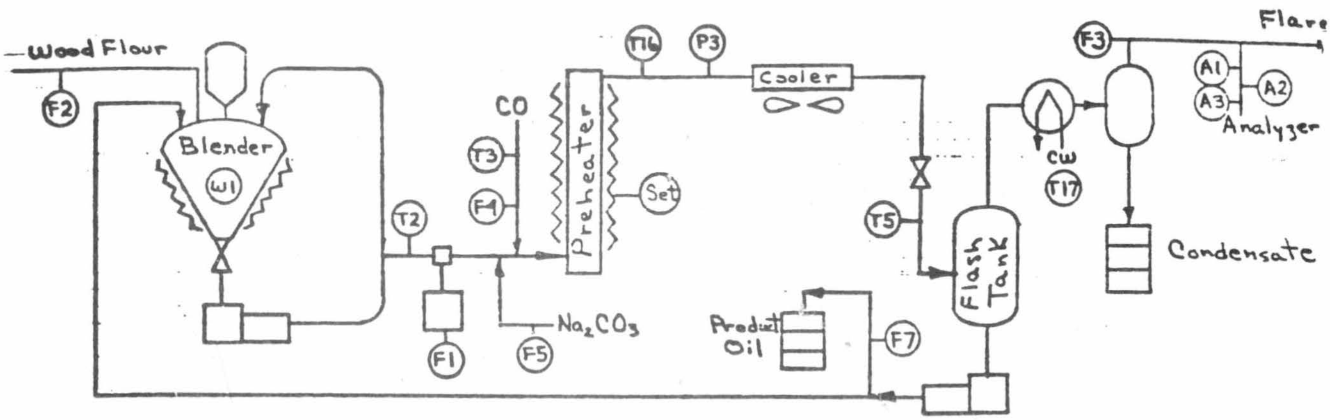
- 11 -

Run No.: 14

Date: 11/16/77 to 11/18/77, **Total Time On stream:** 38 Hours

Objective: Establish steady state equilibrium. Obtain conversions consistent with design conceptual.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	60	gph.
Catalyst Flow Rate:	0.93	gph.
Wood Flour Feed Rate:	38	lbs./hr.
Wt. % Flour in Feed Slurry:	5-10	%
CO Feed Rate:	7.4	scfm.
Residence Time:	17	min.
Pressure:	2500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	700	807	485
Conversion wt. %:	87	86	79

Cause of Shutdown: Preheater agitator seal failure.

Observations: The 17 minute residence time appears to give high conversions and CO consumption typical of longer residence times, as well as the high oil yield achieved with shorter residence times. As in Run No. 13, higher product oil viscosity is evident. Exothermic behavior was again noted at the end of the run.

BYPASS TEST #14

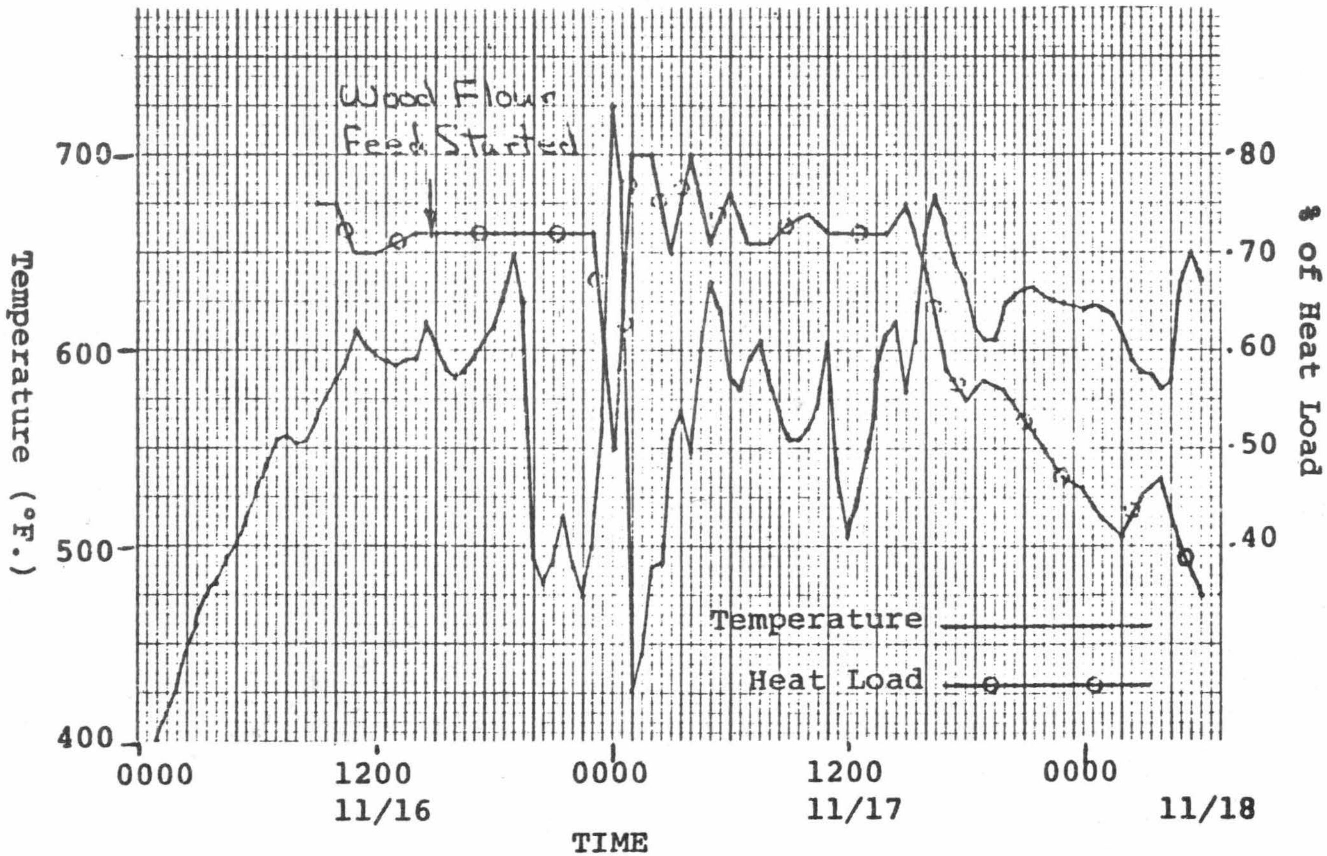
STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

Key	**Description**	
T-2	Feed Slurry Pump Discharge	(°F.)
T-3	CO from Interchanger	(°F.)
T-5	Level Valve #315 Outlet	(°F.)
T-16	Preheater Outlet	(°F.)
Set	TIC-302 Setting	(% of scale)
T-17	L.P. Cooler C.W.	(°F.)
P-3	System Pressure	
F-1	Feed Slurry Pump Stroke	(mm)
F-2	Wood Flour Feed	(lb./hr.)
F-3	L.P. Flash Gas Flow	(scfm)
F-4	CO Feed	(scfm)
F-5	Catalyst Pump Stroke	(mm)
W-1	Wood Oil Blend Weight	(gross lb.)
A-1	H_2 in Off Gas	(%)
A-2	CO in L.P. Vent	(%)
A-3	CO_2 in L.P. Vent	(%)

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	152.872	12.254	1.962	172.000	129.000	43.000
T3	48.821	5.031	.806	66.000	44.000	22.000
T5	226.744	42.946	6.877	318.000	155.000	163.000
T16	584.513	56.234	9.005	700.000	426.000	274.000
SET	63.487	13.143	2.105	80.000	35.000	45.000
T17	74.718	13.532	2.167	99.000	48.000	51.000
P3	2498.718	8.006	1.282	2500.000	2450.000	50.000
F1	60.026	11.331	1.814	100.000	55.000	45.000
F2	31.846	10.371	1.661	40.000	17.000	23.000
F3	7.936	1.593	.255	10.000	3.600	6.400
F4	4.313	.940	.150	6.200	3.000	3.200
F5	4.308	1.454	.233	5.000	.000	5.000
W1	1202.051	54.504	8.729	1340.000	1050.000	290.000
A1	7.923	7.333	1.174	20.000	.000	20.000
A2	75.256	15.993	2.561	96.000	21.000	75.000
A3	36.154	17.356	2.779	60.000	8.000	52.000
F7	11.500	28.987	4.642	103.000	.000	103.000

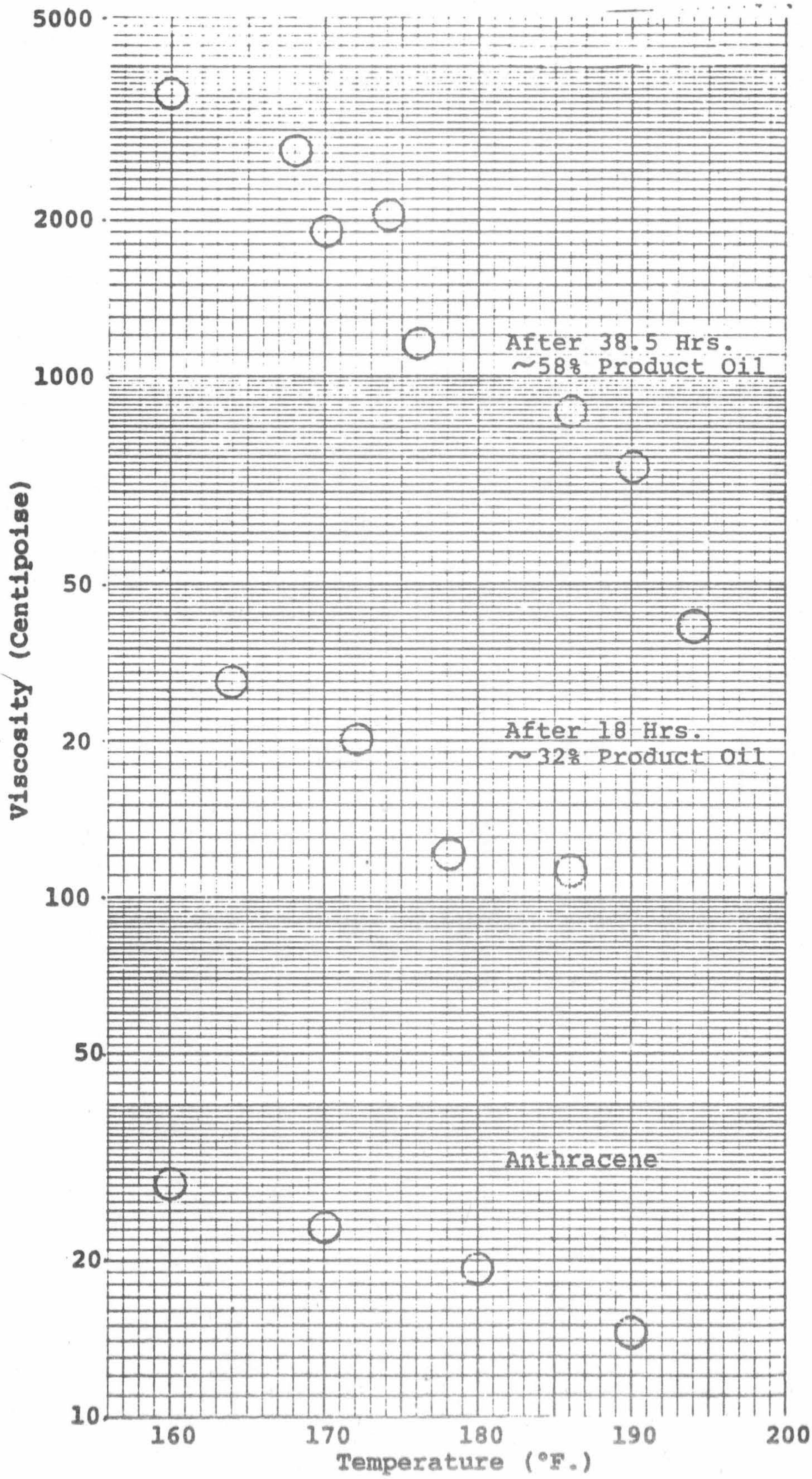
FIGURE 5

BYPASS TEST 14
Preheater Exit Temperatures



– BYPASS TEST #14

VISCOSITY VS. TEMPERATURE

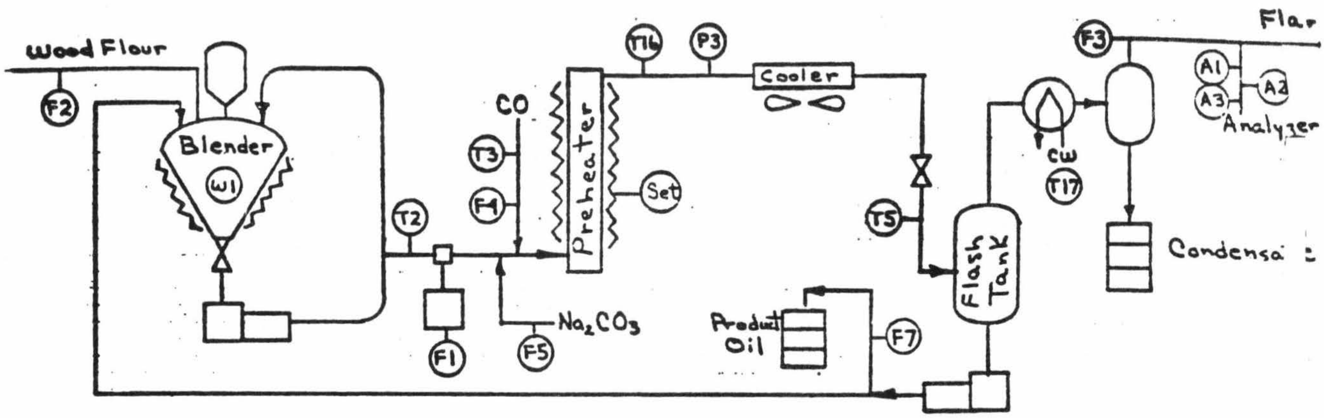


Run No.: 15

Date: 11/18/77 to 11/21/77, **Total Time On stream:** 30 Hours

Objective: Continuation Run #14 conditions to generate more log and analytic data.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	60	gph.
Catalyst Flow Rate:	1.6	gph.
Wood Flour Feed Rate:	40	lbs./hr.
Wt. % Flour in Feed Slurry:	(5-10)	% est.
CO Feed Rate:	8.9	scfm.
Residence Time:	17	min.
Pressure:	2500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:

(Not yet completed.)

Conversion wt. %:

Cause of Shutdown: Pressure agitator seal failure.

Observations: The results and conclusions for Run #14 were further substantiated in Run #15.

BYPASS TEST #15

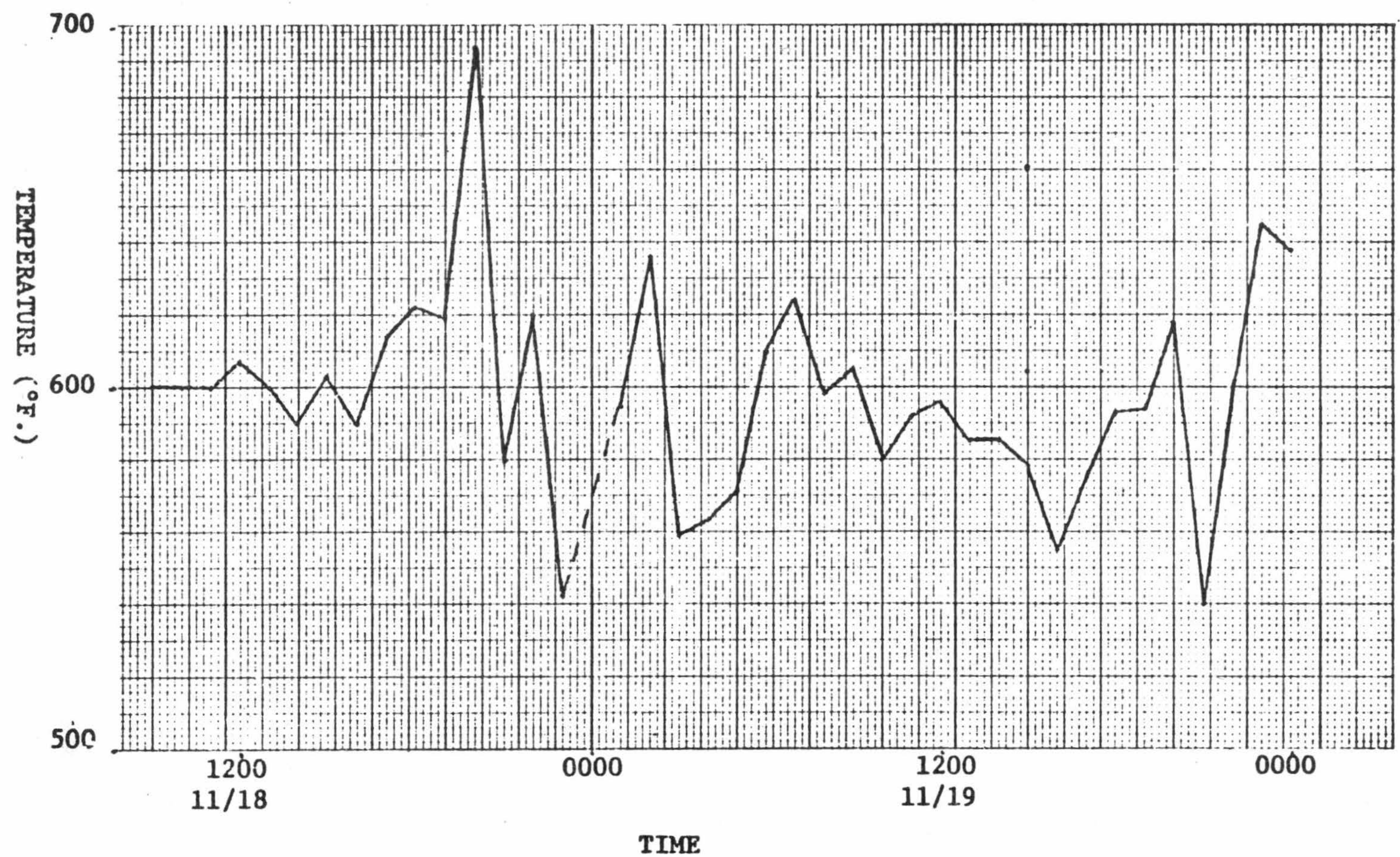
STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

Key	Description	
T-2	Feed Slurry Pump Discharge	(°F.)
T-3	CO from Interchanger	(°F.)
T-5	Level Valve #315 Outlet	(°F.)
T-16	Preheater Outlet	(°F.)
Set	TIC-302 Setting	(% of scale)
T-17	L.P. Cooler C.W.	(°F.)
P-3	System Pressure	
F-1	Feed Slurry Pump Stroke	(mm)
F-2	Wood Flour Feed	(lb./hr.)
F-3	L.P. Flash Gas Flow	(scfm)
F-4	CO Feed	(scfm)
F-5	Catalyst Pump Stroke	(mm)
W-1	Wood Oil Blend Weight	(gross lb.)
A-1	H_2 in Off Gas	(%)
A-2	CO in L.P. Vent	(%)
A-3	CO_2 in L.P. Vent	(%)

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	163.321	5.722	1.081	172.000	145.000	27.000
T3	40.571	3.522	.666	45.000	32.000	13.000
T5	241.929	27.406	5.179	312.000	181.000	131.000
T16	601.893	31.025	5.863	694.000	540.000	154.000
SET	71.179	10.216	1.931	85.000	44.000	41.000
T17	90.643	32.960	6.229	133.000	44.000	89.000
P3	2521.429	41.786	7.897	2600.000	2500.000	100.000
F1	55.000	.000	.000	55.000	55.000	.000
F2	40.000	.000	.000	40.000	40.000	.000
F3	6.182	1.494	.282	9.000	2.000	7.000
F4	4.475	.276	.521E-01	5.000	3.800	1.200
F5	4.107	1.950	.369	5.000	.000	5.000
W1	1207.321	31.812	6.012	1275.000	1150.000	125.000
A1	10.686	8.820	1.667	19.000	.000	19.000
A2	77.679	15.482	2.926	96.000	42.000	54.000
A3	31.964	15.894	3.004	78.000	5.000	73.000
F7	1.857	9.827	1.857	52.000	.000	52.000

Figure 1

BYPASS TEST 15
PREHEATER EXIT TEMPERATURE

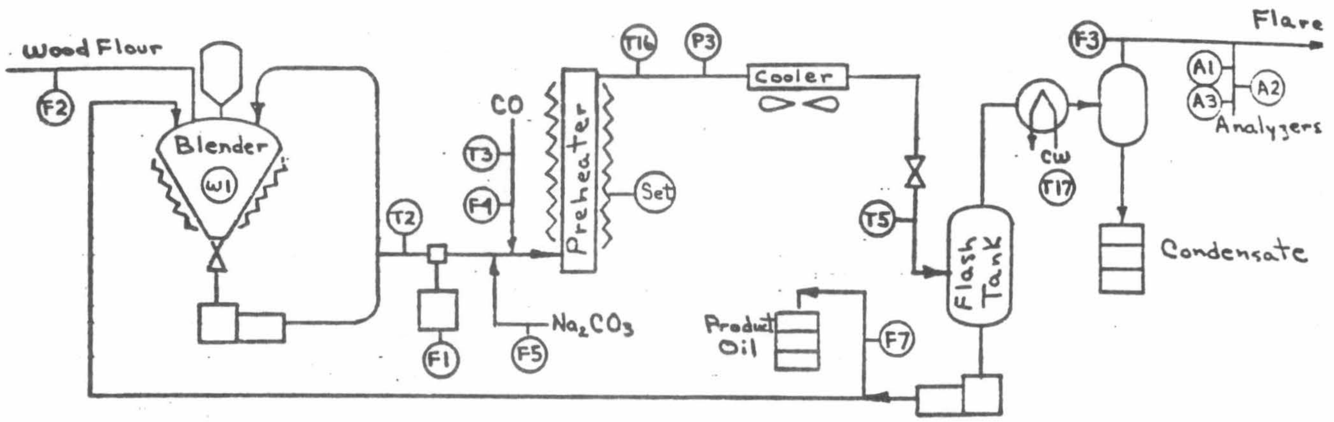


Run No.: 16

Date: 11/28 to 12/5, **Total Time On stream:** 71 Hours

Objective: Obtain extended run at residence time and conversions suspected consistent with conceptual design. Substantiate data from Run #13 (short residence time).

Flowsheet:



Operating Conditions:

Oil Flow Rate:	80	gph.
Catalyst Flow Rate:	1.8	gph.
Wood Flour Feed Rate:	40.8	lbs./hr.
Wt. % Flour in Feed Slurry:	(10-16)	%
CO Feed Rate:	2.5	scfm.
Residence Time:	13	min.
Pressure:	2500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	605	606	594	587	617	598
Conversion wt. %:	72	38	12	56	52	19

Cause of Shutdown: System plugged.

Observations: Run No. 16 results appear to support the data and conclusions for Run No. 13. A relatively long run time (71 hours) and large amount of data were collected. The system eventually plugged up due to what appears to be polymerization of the material.

BYPASS TEST #16

STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

Key	**Description**	
T-2	**Feed Slurry Pump Discharge**	**(°F.)**
T-3	**CO from Interchanger**	**(°F.)**
T-5	**Level Valve #315 Outlet**	**(°F.)**
T-16	**Preheater Outlet**	**(°F.)**
Set	**TIC-302 Setting**	**(% of scale)**
T-17	**L.P. Cooler C.W.**	**(°F.)**
P-3	**System Pressure**	
F-1	**Feed Slurry Pump Stroke**	**(mm)**
F-2	**Wood Flour Feed**	**(lb./hr.)**
F-3	**L.P. Flash Gas Flow**	**(scfm)**
F-4	**CO Feed**	**(scfm)**
F-5	**Catalyst Pump Stroke**	**(mm)**
W-1	**Wood Oil Blend Weight**	**(gross lb.)**
A-1	**H_2 in Off Gas**	**(%)**
A-2	**CO in L.P. Vent**	**(%)**
A-3	**CO_2 in L.P. Vent**	**(%)**

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	169.566	11.160	1.280	185.000	144.000	41.000
T3	57.882	3.124	.359	65.000	50.000	15.000
T5	242.237	24.106	2.765	314.000	207.000	107.000
T16	592.908	21.484	2.464	699.000	513.000	186.000
SET	94.079	13.383	1.535	100.000	.000	100.000
T17	99.500	37.461	4.297	185.000	50.000	135.000
P3	2309.211	260.347	29.864	2600.000	2000.000	600.000
F1	65.237	24.069	2.761	74.000	.000	74.000
F2	40.155	.299	.343E-01	40.800	40.000	.800
F3	3.649	3.518	.404	22.100	.000	22.100
F4	4.403	1.075	.123	6.800	.000	6.800
F5	312.532	795.690	91.272	2700.000	.000	2700.000
W1	1089.414	278.237	31.916	1340.000	82.500	1257.500
A1	1.855	9.663	1.108	84.000	.000	84.000
A2	47.204	27.708	3.178	100.000	.000	100.000
A3	36.592	23.787	2.729	89.000	.000	89.000
F7	5.145	20.834	2.390	113.000	.000	113.000

Figure 2

BYPASS TEST 16
PREHEATER EXIT TEMPERATURE

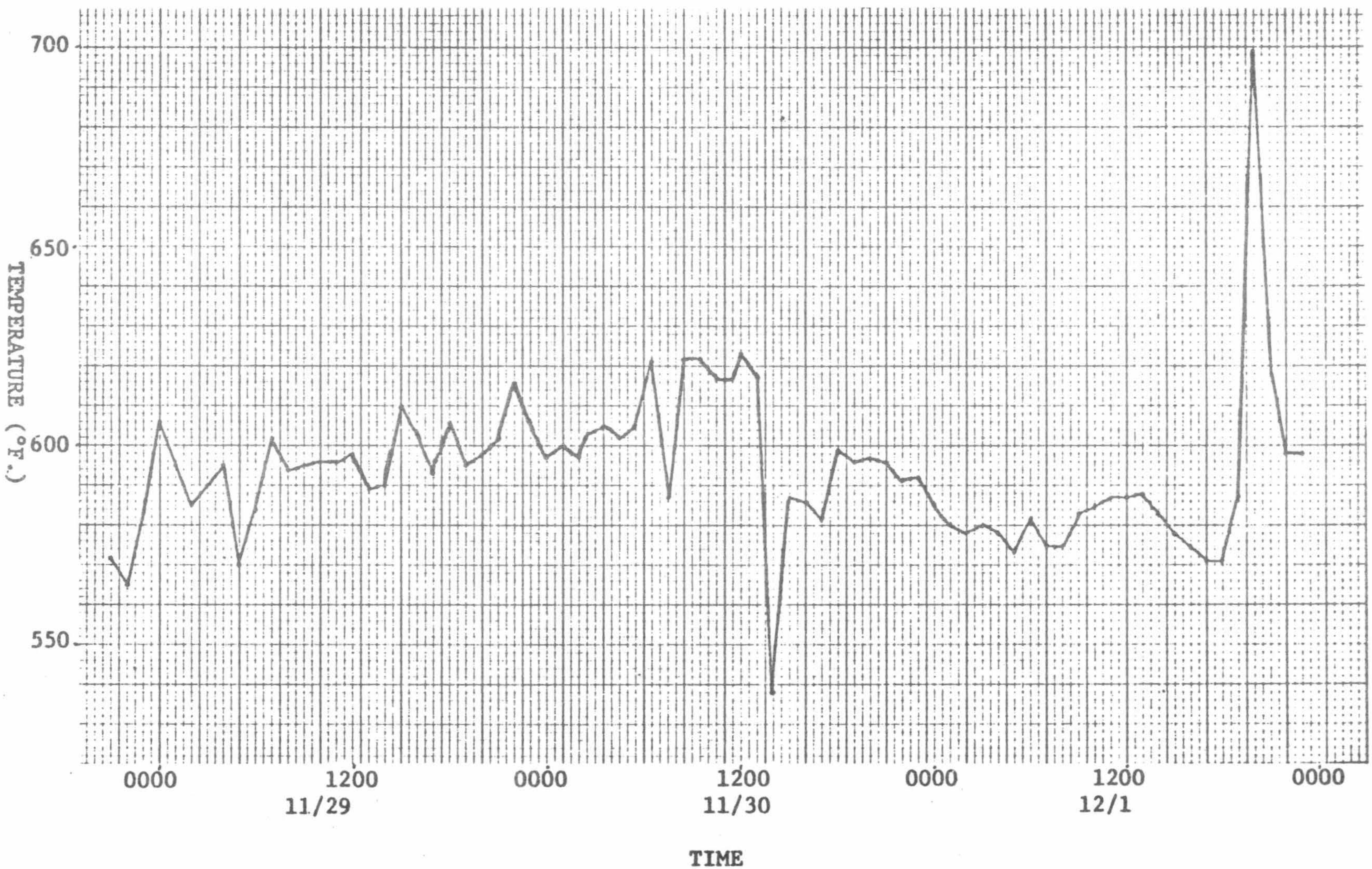
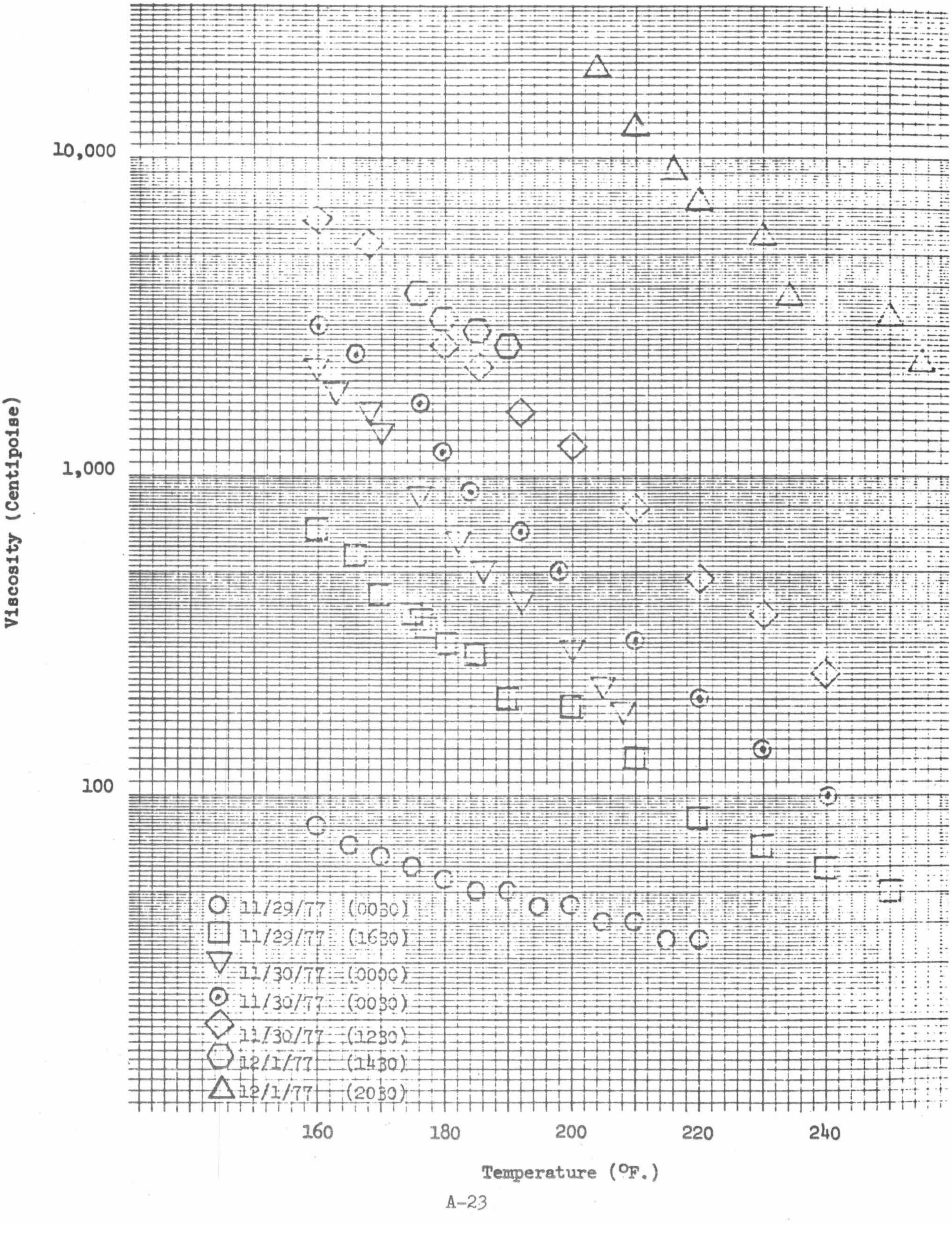


Figure 3

BYPASS TEST #16

VISCOSITY VS. TEMPERATURE

(Product Samples)

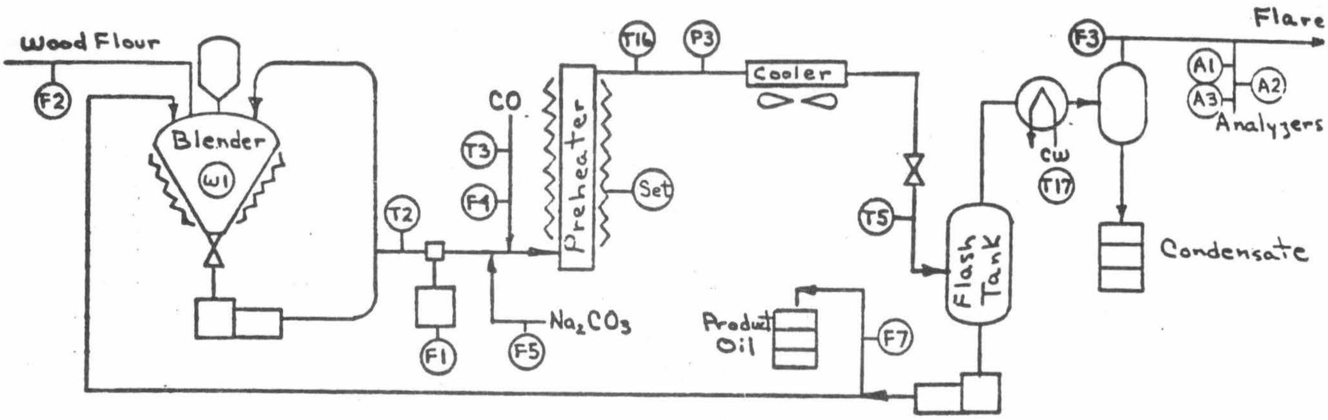


Run No.: 17

Date: 12/11/77 to 12/12/77, **Total Time On stream:** 43 hrs

Objective: Substantiate data from Bypass Test 12 with increased residence times

Flowsheet:



Operating Conditions:

Oil Flow Rate:	43	gph.
Catalyst Flow Rate:	1.8	gph.
Wood Flour Feed Rate:	39.6	lbs./hr.
Wt. % Flour in Feed Slurry:	10.1	%
CO Feed Rate:	3.9	scfm.
Residence Time:	23.4	min.
Pressure:	2500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	580	540	630	600	605
Conversion wt. %:	73.4	67.7	96.4	96.5	96.6
CO pressure at exit, psig:	1320	600	1730	1860	1270

Cause of Shutdown: Unable to maintain steady flow at design condition

Observations:

The combination of higher conversions and lower oil yields per pound of wood flour confirms data in Bypass Test 12.

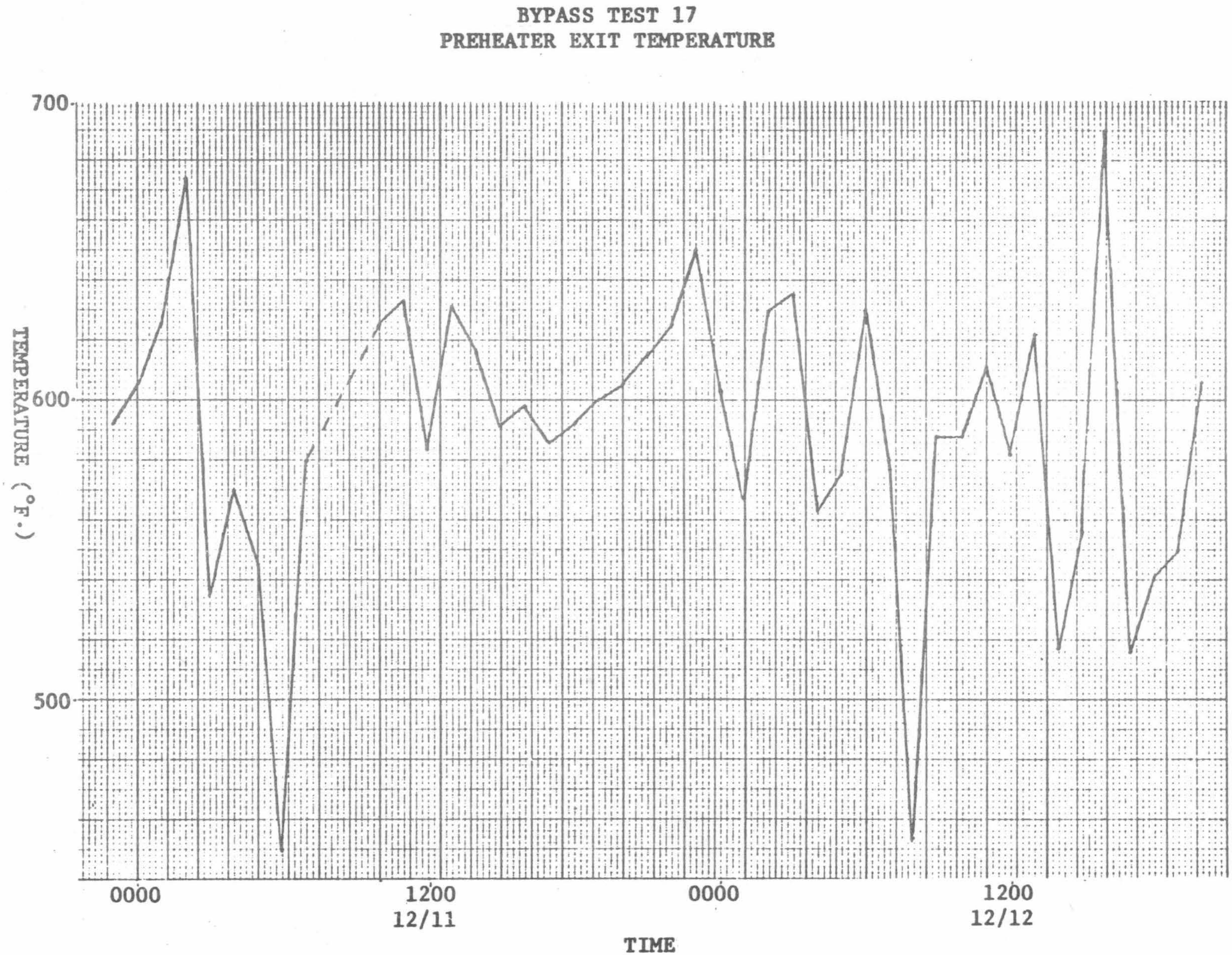
BYPASS TEST #17

STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

T-2	**Feed Slurry Pump Discharge**	**(°F.)**
T-3	CO from Interchanger	**(°F.)**
T-5	Level Valve #315 Outlet	**(°F.)**
T-16	Preheater Outlet	**(°F.)**
Set	TIC-302 Setting	**(% of scale)**
P-3	System Pressure	**(psig)**
F-1	Feed Slurry Pump Stroke	**(mm)**
F-2	Wood Flour Feed	**(lb./hr.)**
F-3	L.P. Flash Gas Flow	**(scfm)**
F-4	CO Feed	**(scfm)**
F-5	Catalyst Pump Stroke	**(mm)**
W-1	Wood Oil Blend Weight	**(gross lb.)**
A-2	CO in L.P. Vent	**(%)**
A-3	CO_2 in L.P. Vent	**(%)**

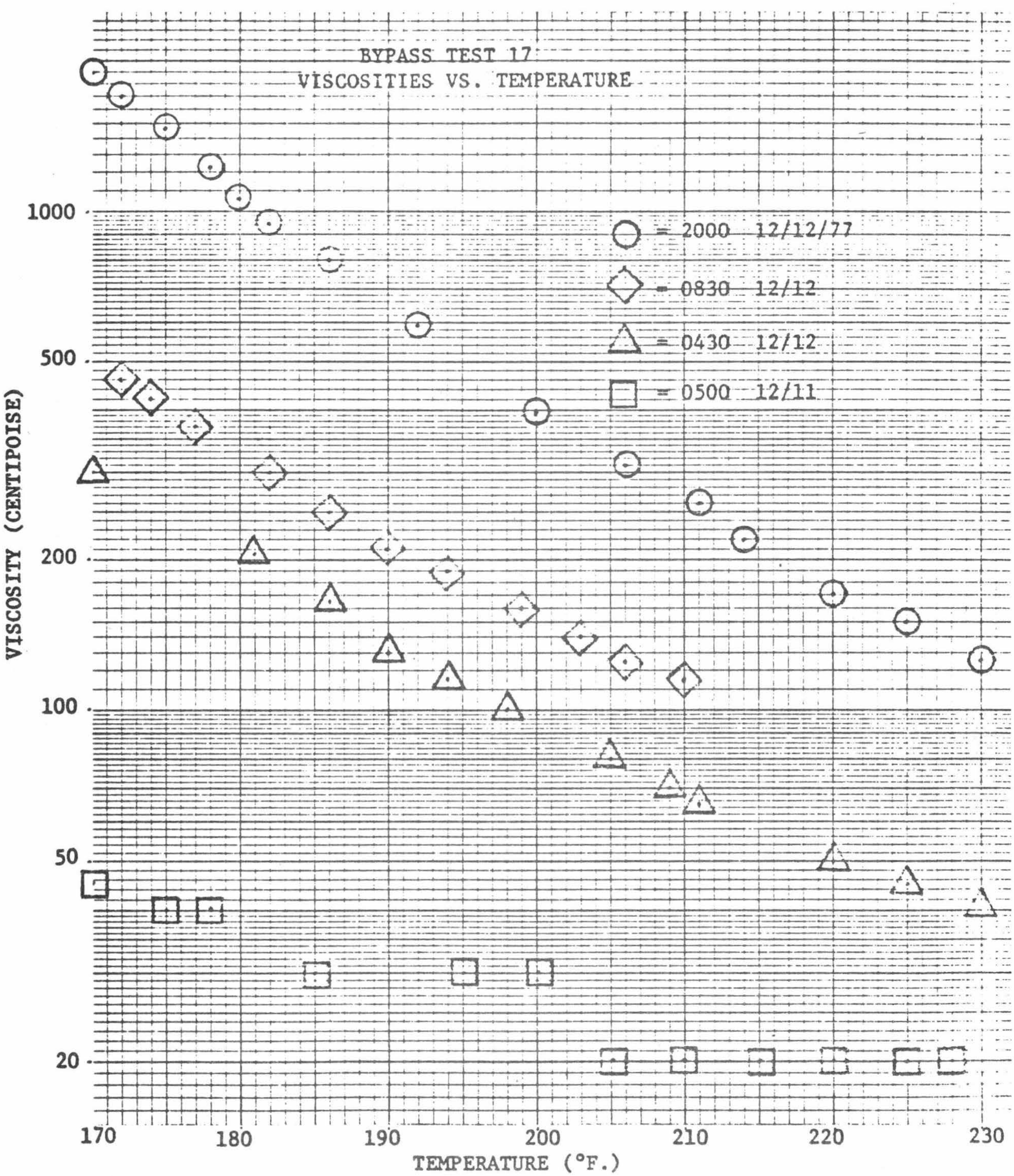
VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	151.500	8.234	1.241	165.000	132.000	33.000
T3	55.591	1.386	.209	60.000	54.000	6.000
T5	213.795	24.919	3.757	289.000	163.000	126.000
T16	589.273	47.790	7.205	690.000	450.000	240.000
SET	64.227	13.823	2.084	100.000	20.000	80.000
P3	2500.000	.000	.000	2500.000	2500.000	.000
F1	45.341	10.115	1.525	75.000	37.000	38.000
F2	38.955	6.077	.916	40.000	.000	40.000
F3	3.798	2.185	.329	8.600	.000	8.600
F4	5.101	1.641	.247	7.300	.000	7.300
F5	15.000	.000	.000	15.000	15.000	.000
W1	1164.432	62.424	9.411	1340.000	1025.000	315.000
A2	40.636	22.232	3.352	74.000	4.000	70.000
A3	36.443	17.815	2.686	67.000	6.000	61.000

Figure 4


BYPASS TEST 17
PREHEATER EXIT TEMPERATURE
700
600
500
TEMPERATURE (°F.)
0000
1200
12/11
0000
1200
12/12
TIME

A-26

Figure 6

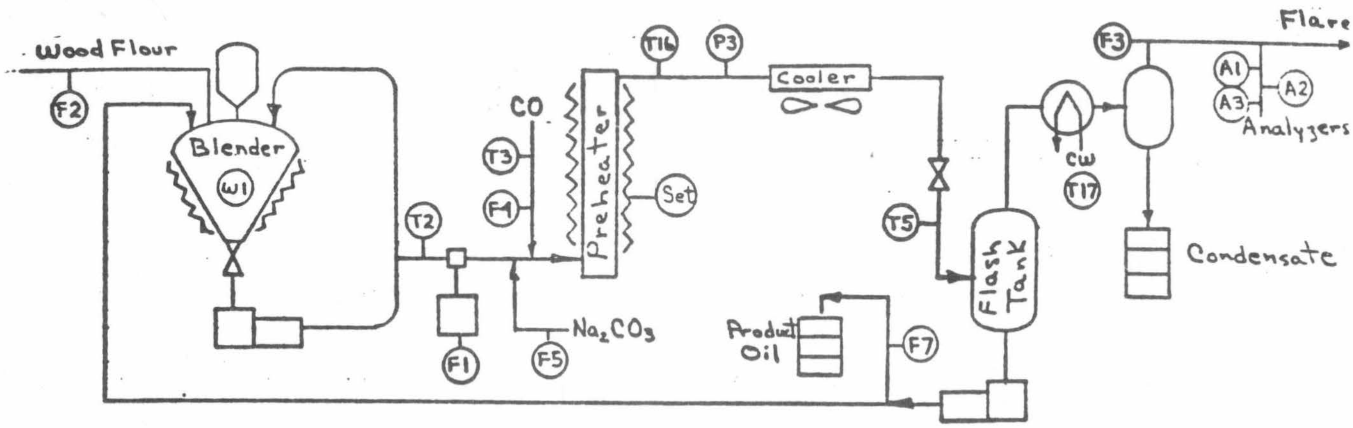

BYPASS TEST 17
VISCOSITIES VS. TEMPERATURE
= 2000 12/12/77
= 0830 12/12
= 0430 12/12
= 0500 12/11
VISCOSITY (CENTIPOISE)
1000
500
200
100
50
20
170
180
190
200
210
220
230
TEMPERATURE (°F.)

Run No.: 18

Date: 12/13/77 to 12/22/77, **Total Time On stream:** 90 hrs

Objective: Establish an extended run at steady state conditions.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	60	gph.
Catalyst Flow Rate:	1.8	gph.
Wood Flour Feed Rate:	39	lbs./hr.
Wt. % Flour in Feed Slurry:	9.7	%
CO Feed Rate:	4.2	scfm.
Residence Time:	17.1	min.
Pressure:	2500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	565	602	550	605	605	625
Conversion wt. %:	17.1	61.8	83.4	96.1	90.9	38.0
CO pressure at exit, psig:	950	575	1135	1830	1500	925

Cause of Shutdown: Scheduled

Observations: Product ~~stability was~~ remained stable for approximately 60 hours before the carrier oil began to polymerize. Coinciding with the increase in viscosity at the end of the run was an ~~observed~~ increasing exotherm in the preheater.

BYPASS TEST #18

STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

T-2	Feed Slurry Pump Discharge	**(°F.)**
T-3	CO from Interchanger	**(°F.)**
T-5	Level Valve #315 Outlet	**(°F.)**
T-16	Preheater Outlet	**(°F.)**
Set	TIC-302 Setting	**(% of scale)**
P-3	System Pressure	**(psig)**
F-1	Feed Slurry Pump Stroke	**(mm)**
F-2	Wood Flour Feed	**(lb./hr.)**
F-3	L.P. Flash Gas Flow	**(scfm)**
F-4	CO Feed	**(scfm)**
F-5	Catalyst Pump Stroke	**(mm)**
W-1	Wood Oil Blend Weight	**(gross lb.)**
A-2	CO in L.P. Vent	**(%)**
A-3	CO_2 in L.P. Vent	**(%)**

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	148.840	7.556	.840	175.000	129.000	46.000
T3	57.370	5.207	.579	65.000	50.000	15.000
T5	234.000	34.935	3.882	288.000	176.000	112.000
T16	595.272	31.798	3.533	665.000	500.000	165.000
SET	77.901	11.353	1.261	98.000	60.000	38.000
P3	2499.012	5.832	.648	2500.000	2450.000	50.000
F1	55.481	1.174	.130	60.000	55.000	5.000
F2	36.327	9.602	1.067	44.000	.000	44.000
F3	4.938	2.119	.235	10.400	.000	10.400
F4	5.795	1.141	.127	8.300	2.500	5.800
F5	15.000	.000	.000	15.000	15.000	.000
W1	1172.099	94.917	10.546	1350.000	990.000	360.000
A2	46.049	15.482	1.720	71.000	11.000	60.000
A3	46.457	8.649	.961	67.000	28.000	39.000

Figure 8

BYPASS TEST 18
PREHEATER EXIT TEMPERATURE

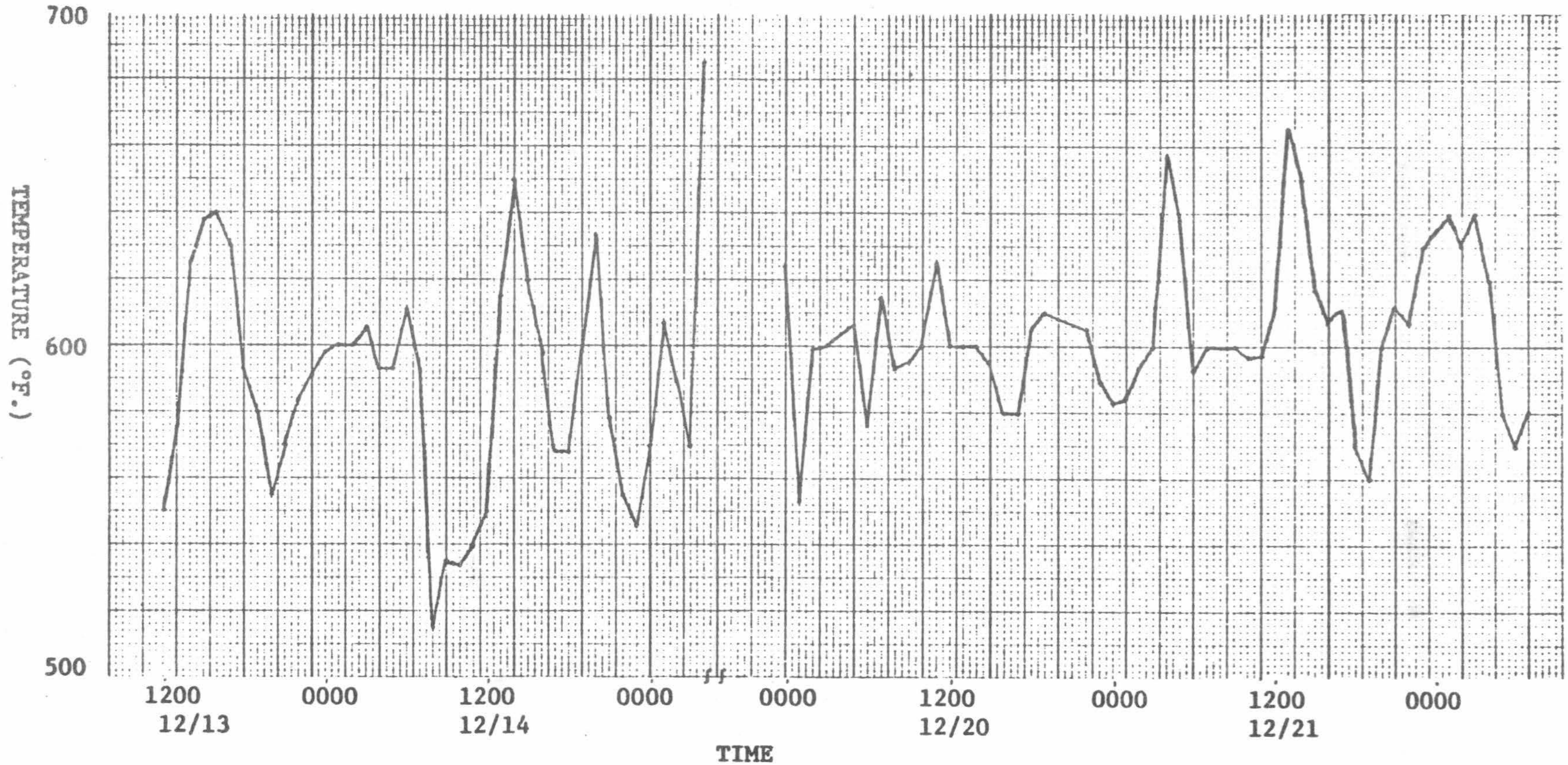
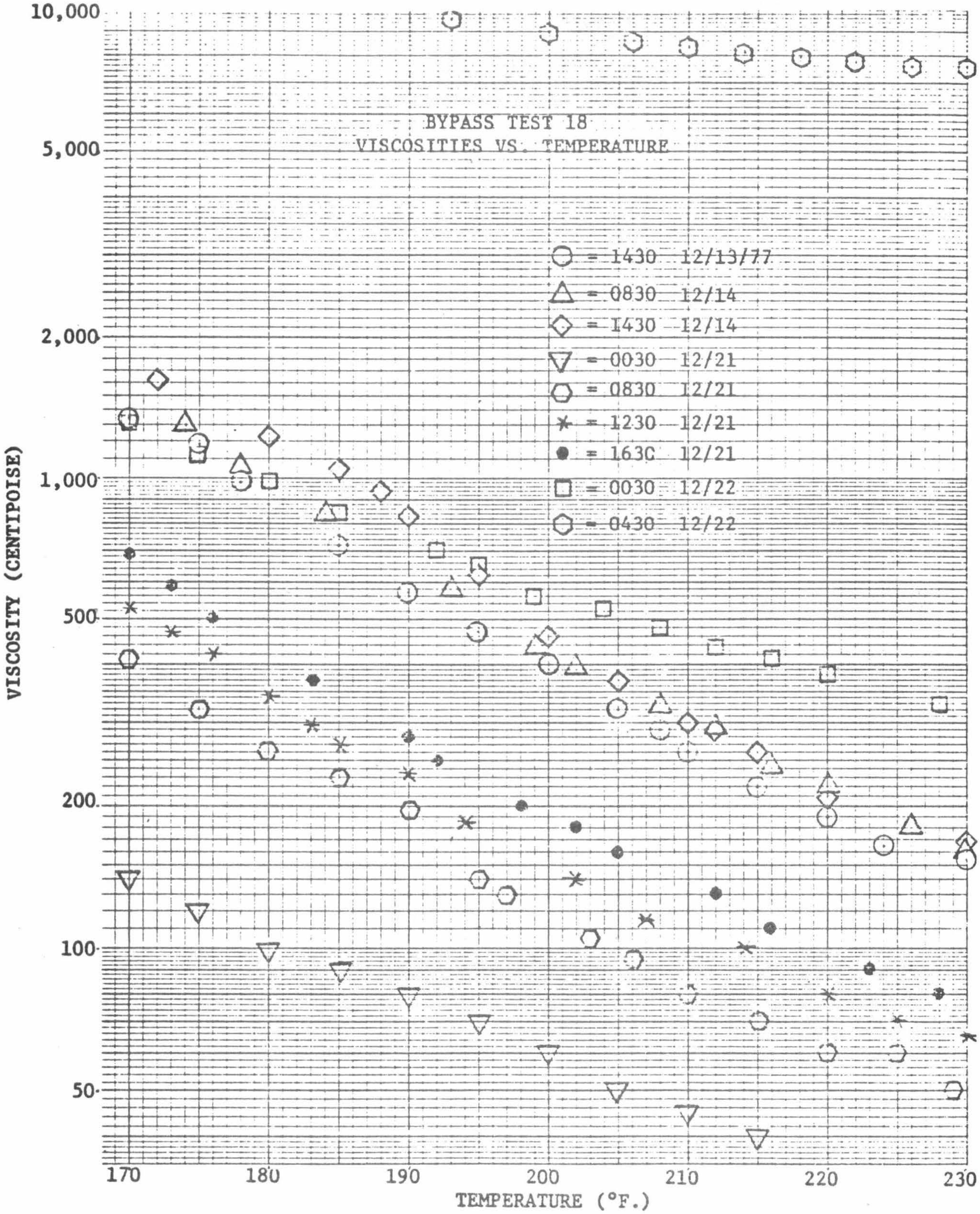


Figure 9

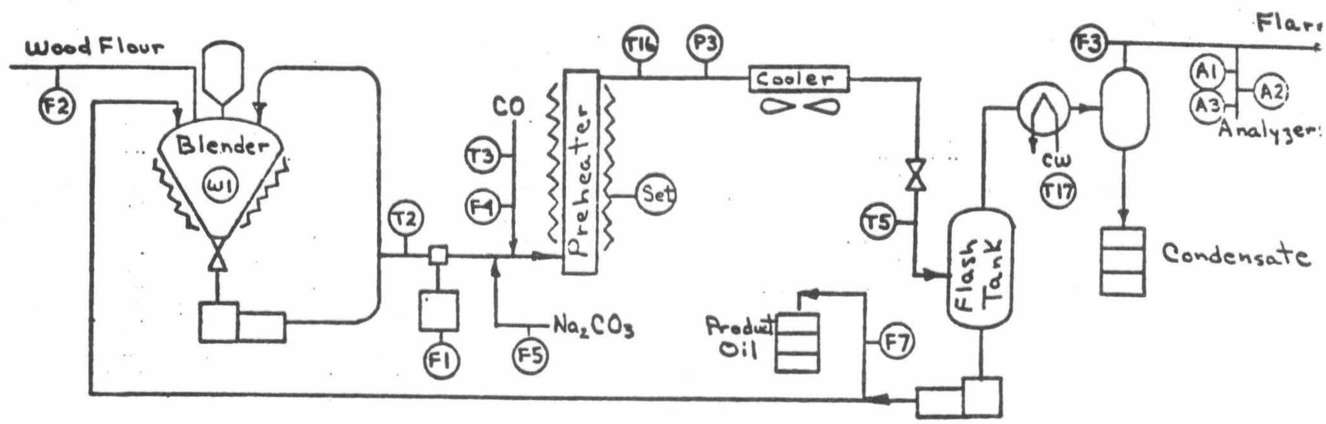

BYPASS TEST 18
VISCOSITIES VS. TEMPERATURE
○ = 1430 12/13/77
△ = 0830 12/14
◇ = 1430 12/14
▽ = 0030 12/21
⬡ = 0830 12/21
✶ = 1230 12/21
● = 1630 12/21
□ = 0030 12/22
⬡ = 0430 12/22
VISCOSITY (CENTIPOISE)
10,000
5,000
2,000
1,000
500
200
100
50
TEMPERATURE (°F.)
170
180
190
200
210
220
230

Run No.: 19

Date: 1/3/78 to 1/7/78, **Total Time On stream:** 83 hrs

Objective: Test effet of higher temperatures at normal operating pressures.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	60	gph.
Catalyst Flow Rate:	1.8	gph.
Wood Flour Feed Rate:	70/50	lbs./hr.
Wt. % Flour in Feed Slurry:	18.5	%
CO Feed Rate:	7.7	scfm.
Residence Time:	17.1	min.
Pressure:	2500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	700	680	660	565	680	630	610
Conversion wt. %:	91.4	97.4	71.6	32.2	96.1	58.2	49.8
CO pressure at exit:	420	750	1615	750	1150	660	66

Cause of Shutdown: Scheduled

Observations: Conversions per pass were the highest seen to date in the first half of the run. The carrier oil began to polymerize half way through the test and conversions dropped off substantially.

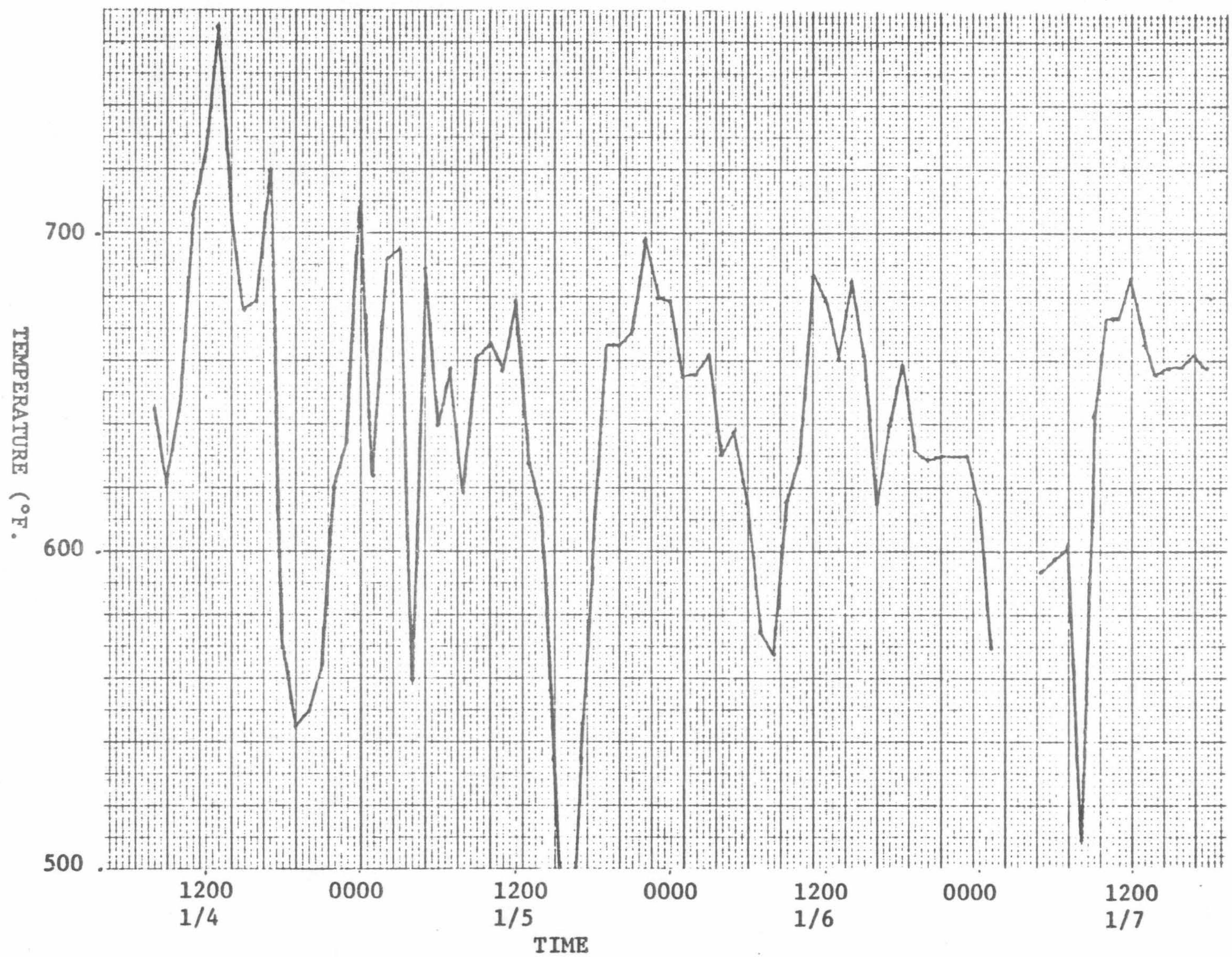
BYPASS TEST #19

STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

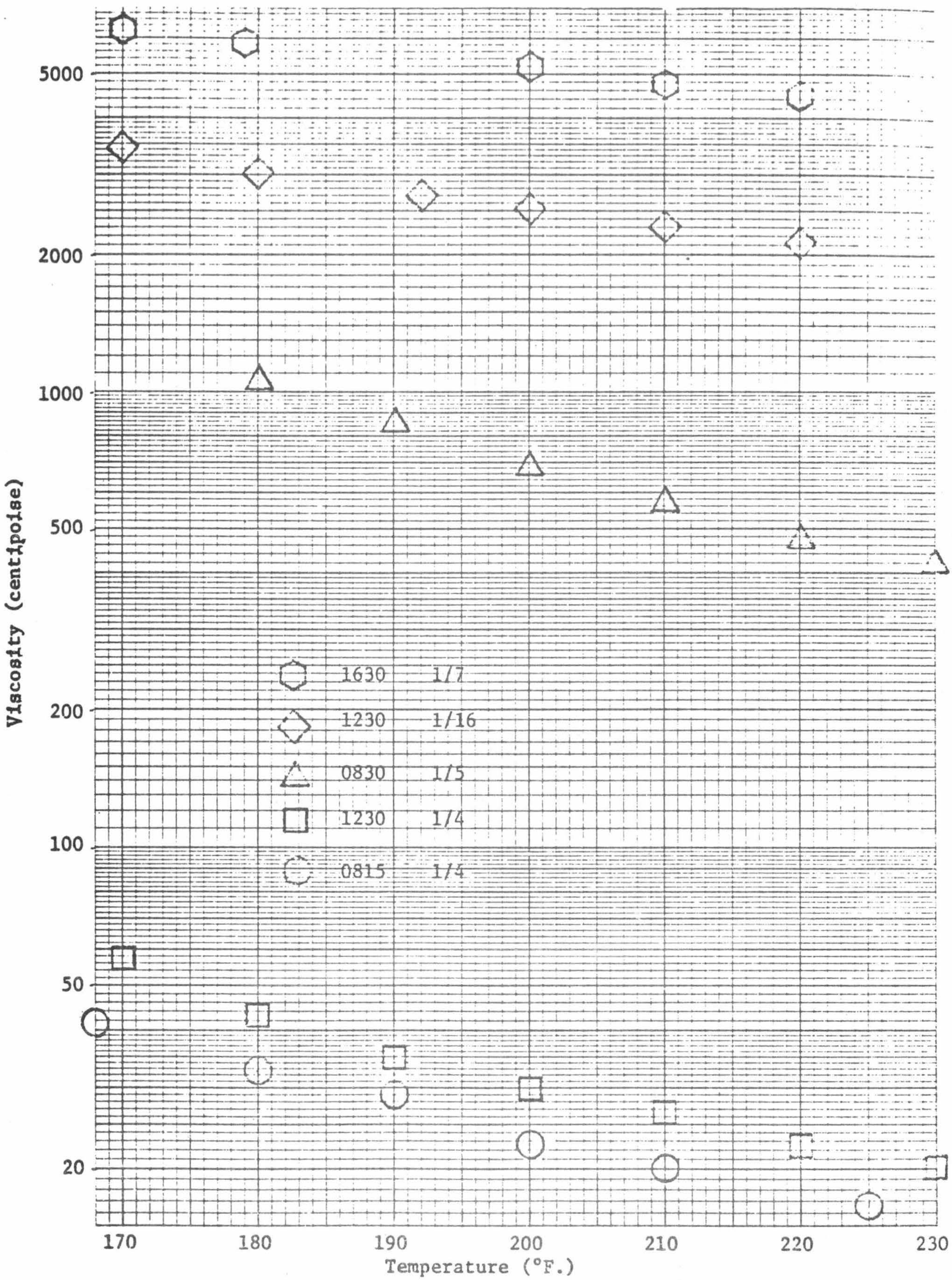
T-2	Feed Slurry Pump Discharge	**(°F.)**
T-3	CO from Interchanger	**(°F.)**
T-5	Level Valve #315 Outlet	**(°F.)**
T-16	Preheater Outlet	**(°F.)**
Set	TIC-302 Setting	**(% of scale)**
P-3	System Pressure	**(psig)**
F-1	Feed Slurry Pump Stroke	**(mm)**
F-2	Wood Flour Feed	**(lb./hr.)**
F-3	L.P. Flash Gas Flow	**(scfm)**
F-4	CO Feed	**(scfm)**
F-5	Catalyst Pump Stroke	**(mm)**
W-1	Wood Oil Blend Weight	**(gross lb.)**
A-2	CO in L.P. Vent	**(%)**
A-3	CO_2 in L.P. Vent	**(%)**

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	141.861	11.009	1.239	165.000	121.000	44.000
T3	52.911	2.260	.254	55.000	49.000	6.000
T5	247.494	39.496	4.444	331.000	150.000	181.000
T16	625.101	54.596	6.143	715.000	460.000	255.000
SET	85.544	14.823	1.668	100.000	.000	100.000
T17	69.203	11.363	1.278	101.000	50.000	51.000
P3	2499.620	3.375	.380	2500.000	2470.000	30.000
F1	55.759	4.606	.518	85.000	45.000	40.000
F2	52.184	11.212	1.261	70.000	.000	70.000
F3	4.458	4.987	.561	30.000	.000	30.000
F4	8.786	1.120	.126	10.000	5.000	5.000
F5	30.000	.000	.000	30.000	30.000	.000
W1	1144.304	103.592	11.655	1300.000	790.000	510.000
A2	42.228	20.245	2.278	90.500	14.000	76.500
A3	51.582	15.384	1.731	87.000	3.000	84.000

BYPASS TEST 19
PREHEATER EXIT TEMPERATURE



BYPASS TEST 19
VISCOSITY VS. TEMPERATURE

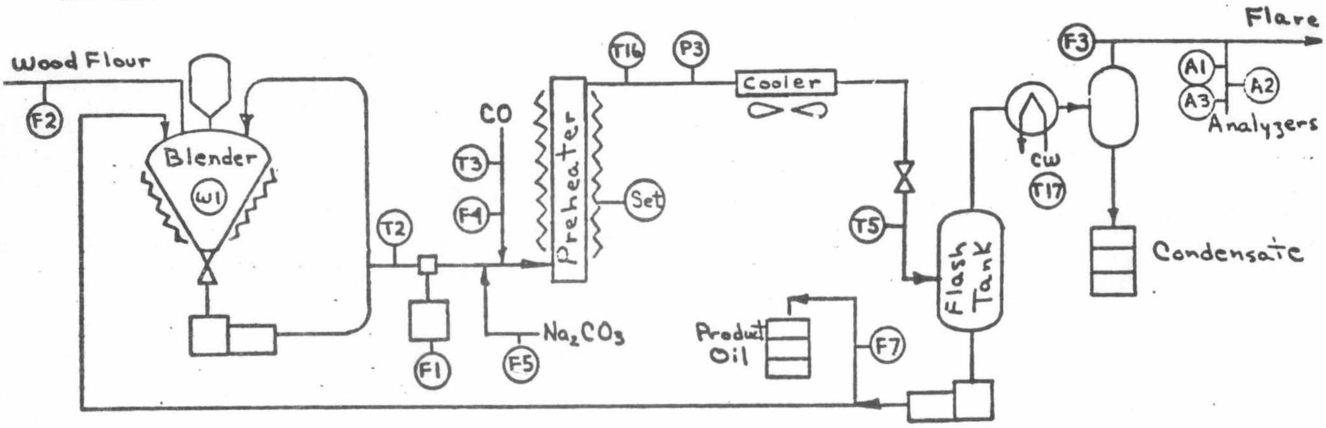


Run No.: 20

Date: 1/7/78 to 1/9/78, **Total Time On stream:** 48 hrs

Objective: Test the effect of higher temperature at reduced ~~[illegible]~~ system pressure.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	60	gph.
Catalyst Flow Rate:	1.8	gph.
Wood Flour Feed Rate:	50	lbs./hr.
Wt. % Flour in Feed Slurry:	38.4	%
CO Feed Rate:	11.8	scfm.
Residence Time:	17.1	min.
Pressure:	1500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	655	665	650
Conversion wt. %:	49.3	45.9	36.2
CO pressure at exit:	470	620	380

Cause of Shutdown: Scheduled

Observations: Material was polymerized prior to ~~[illegible]~~ start of run. Viscosities gradually went from bad to worse.

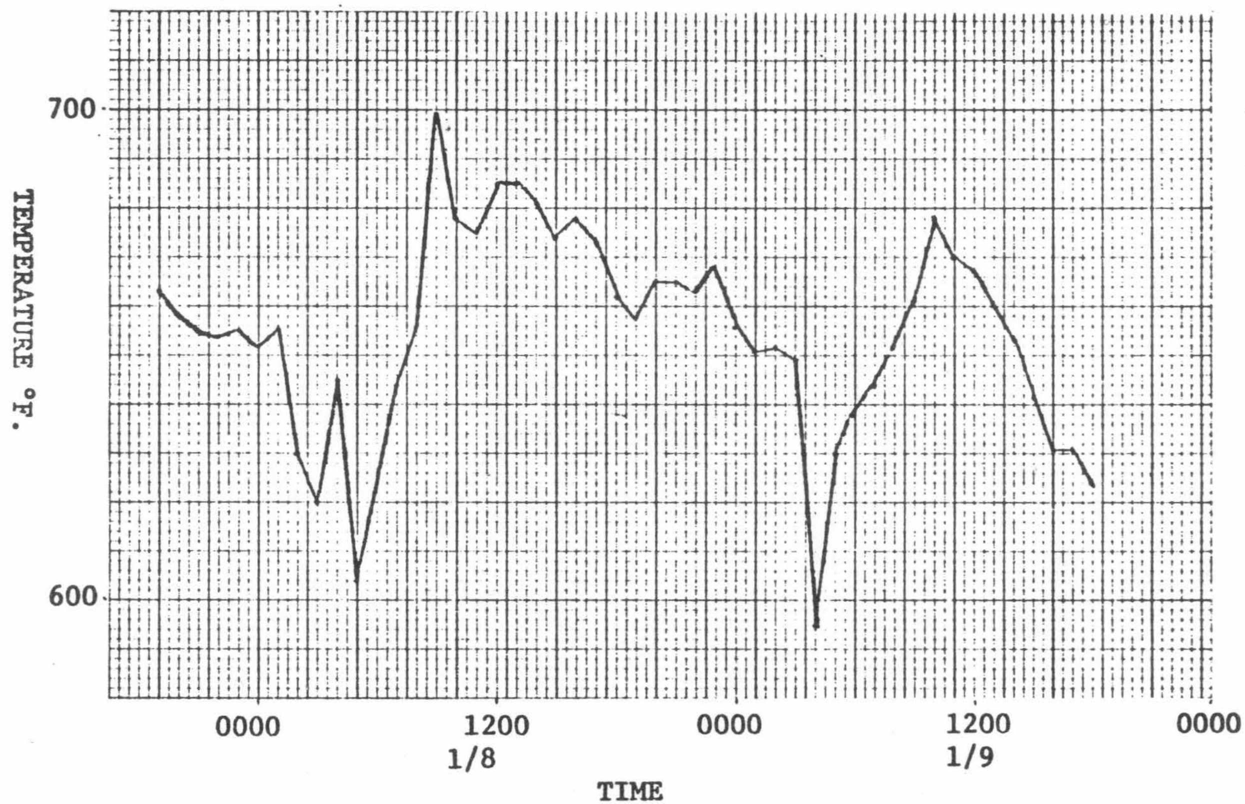
BYPASS TEST #20

STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

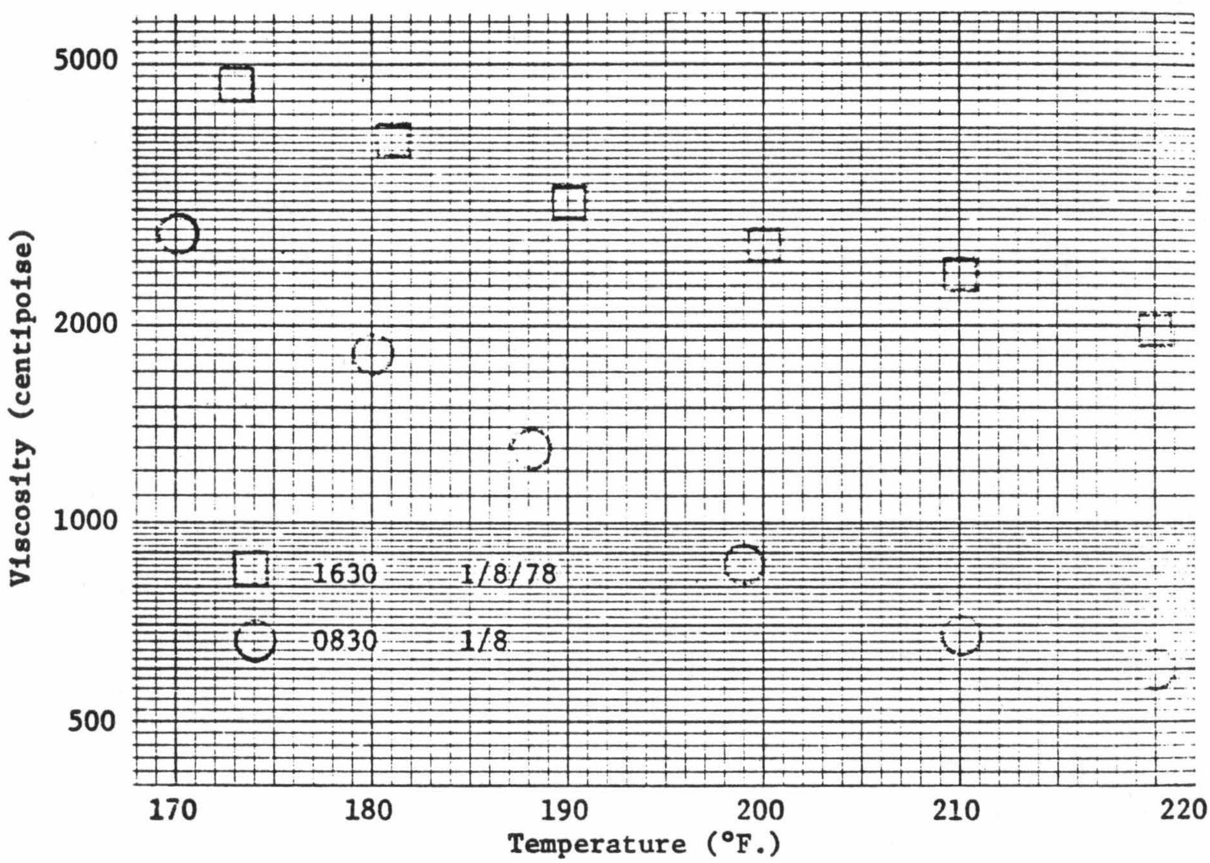
T-2	Feed Slurry Pump Discharge	(°F.)
T-3	CO from Interchanger	(°F.)
T-5	Level Valve #315 Outlet	(°F.)
T-16	Preheater Outlet	(°F.)
Set	TIC-302 Setting	(% of scale)
P-3	System Pressure	(psig)
F-1	Feed Slurry Pump Stroke	(mm)
F-2	Wood Flour Feed	(lb./hr.)
F-3	L.P. Flash Gas Flow	(scfm)
F-4	CO Feed	(scfm)
F-5	Catalyst Pump Stroke	(mm)
W-1	Wood Oil Blend Weight	(gross lb.)
A-2	CO in L.P. Vent	(%)
A-3	CO_2 in L.P. Vent	(%)

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	136.740	8.466	1.197	155.000	125.000	30.000
T3	55.240	1.041	.147	58.000	54.000	4.000
T5	238.600	30.381	4.296	329.000	165.000	164.000
T16	648.840	25.197	3.563	688.000	538.000	150.000
SET	76.020	8.014	1.133	100.000	65.000	35.000
T17	78.620	6.081	.860	108.000	70.000	38.000
P3	1501.400	14.984	2.119	1600.000	1470.000	130.000
F1	55.300	2.121	.300	70.000	55.000	15.000
F2	50.000	.000	.000	50.000	50.000	.000
F3	2.475	.286	.404E-01	3.100	2.000	1.100
F4	8.022	.789	.112	9.400	5.800	3.600
F5	30.000	.000	.000	30.000	30.000	.000
W1	1166.640	62.580	8.850	1300.000	1050.000	250.000
A2	25.700	7.011	.991	45.000	15.000	30.000
A3	52.160	3.772	.533	58.000	39.000	19.000

BYPASS TEST 20
PREHEATER EXIT TEMPERATURE



BYPASS TEST 20
VISCOSITY VS. TEMPERATURE

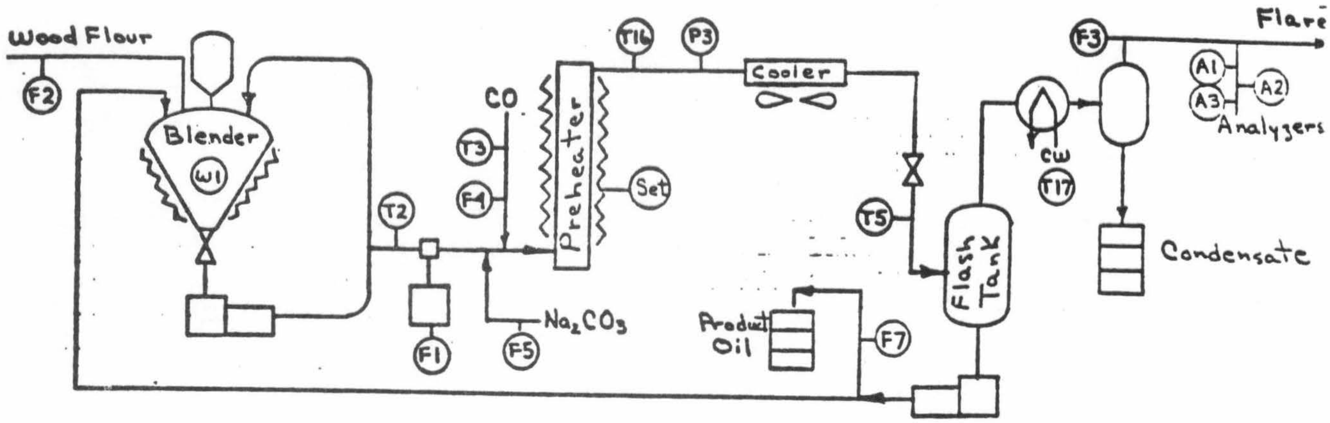


Run No.: 21

Date: 1/10/78 to 1/16/78, **Total Time On stream:** 82 hrs

Objective: Test the combination of ~~standard~~ ~~higher temperature~~, ~~to~~ lower ~~total~~ pressure and moderate CO pressure.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	60	gph.
Catalyst Flow Rate:	1.8	gph.
Wood Flour Feed Rate:	55	lbs./hr.
Wt. % Flour in Feed Slurry:	13.2	%
CO Feed Rate:	4.84	scfm.
Residence Time:	17.1	min.
Pressure:	1500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	540	555	480	610	617	590
Conversion wt. %:	79.9	89.7	18.5	34.6	68.4	58.6
CO pressure at exit, psig:	1245	1200	240	742	490	780

Cause of Shutdown: Scheduled.

Observations: No reduction in conversion was observed ~~until~~ at the lower pressure ~~but~~ until late in the run when polymerization became a ~~major~~ overriding effect

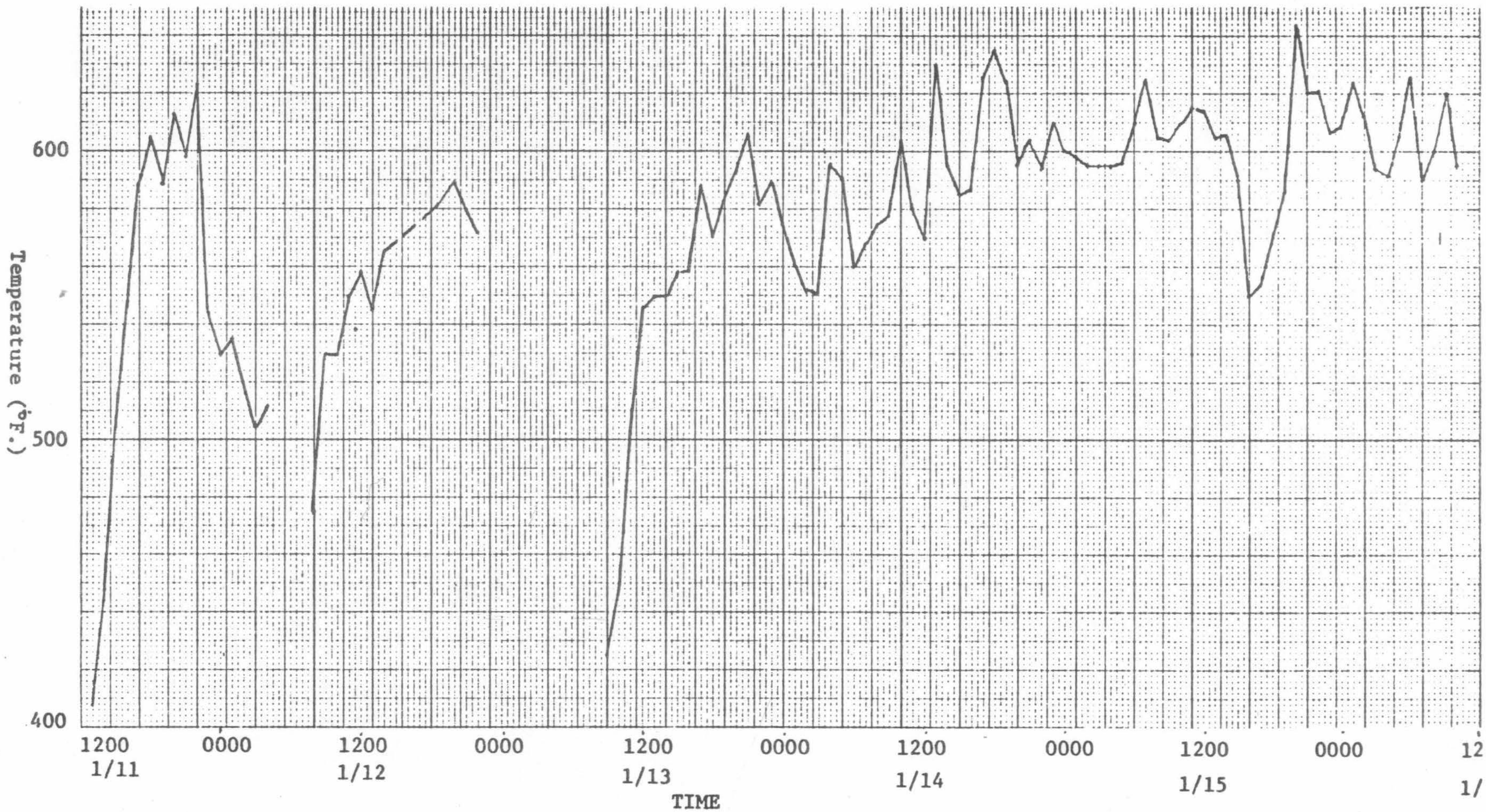
BYPASS TEST #21

STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

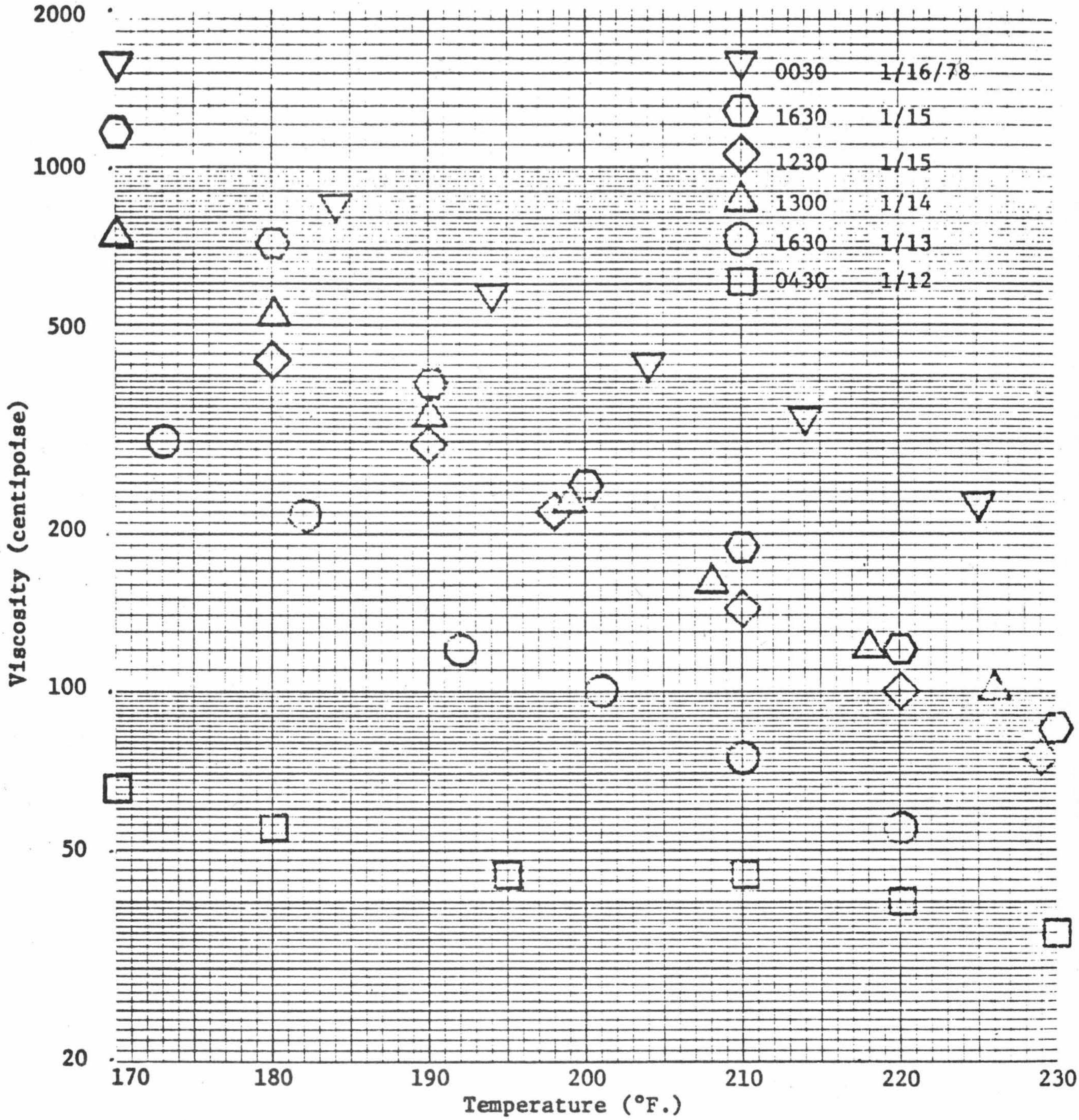
T-2	Feed Slurry Pump Discharge	**(°F.)**
T-3	CO from Interchanger	**(°F.)**
T-5	Level Valve #315 Outlet	**(°F.)**
T-16	Preheater Outlet	**(°F.)**
Set	TIC-302 Setting	**(% of scale)**
P-3	System Pressure	**(psig)**
F-1	Feed Slurry Pump Stroke	**(mm)**
F-2	Wood Flour Feed	**(lb./hr.)**
F-3	L.P. Flash Gas Flow	**(scfm)**
F-4	CO Feed	**(scfm)**
F-5	Catalyst Pump Stroke	**(mm)**
W-1	Wood Oil Blend Weight	**(gross lb.)**
A-2	CO in L.P. Vent	**(%)**
A-3	CO_2 in L.P. Vent	**(%)**

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	137.099	7.130	.846	161.000	130.000	31.000
T3	55.113	2.067	.245	62.000	50.000	12.000
T5	213.620	23.707	2.814	315.000	178.000	137.000
T16	592.127	21.145	2.509	630.000	546.000	84.000
SET	87.986	9.096	1.079	100.000	70.000	30.000
P3	1500.141	2.669	.317	1520.000	1490.000	30.000
F1	55.507	1.881	.223	65.000	55.000	10.000
F2	55.901	10.114	1.200	70.000	42.000	28.000
F3	11.094	6.703	.796	20.000	.000	20.000
F4	6.311	.445	.528E-01	7.700	5.600	2.100
F5	30.000	.000	.000	30.000	30.000	.000
W1	1189.085	60.598	7.191	1320.000	1025.000	295.000
A2	56.693	11.616	1.379	88.000	26.000	62.000
A3	40.521	10.536	1.250	60.000	12.000	48.000

BYPASS TEST 21
PREHEATER EXIT TEMPERATURE



BYPASS TEST 21
VISCOSITY VS. TEMPERATURE

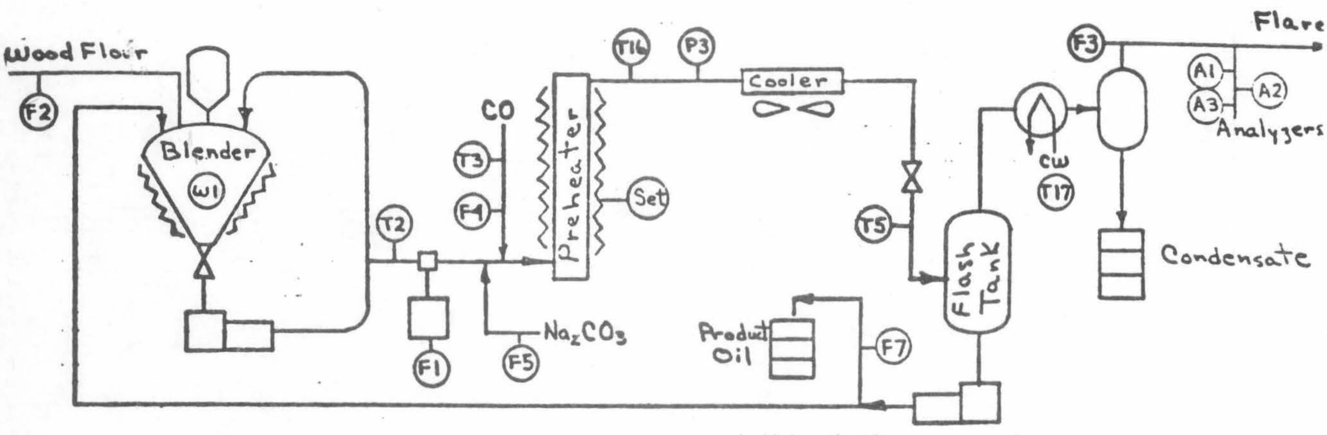


Run No.: 22

Date: 1/16/78 to 1/16/78, **Total Time On stream:** 5.5 hrs

Objective: Test the effect of lower CO pressure at reduced total pressure.

Flowsheet:



Operating Conditions:

Oil Flow Rate:	60	gph.
Catalyst Flow Rate:	1.8	gph.
Wood Flour Feed Rate:	50	lbs./hr.
Wt. % Flour in Feed Slurry:	24.2	%
CO Feed Rate:	4.9	scfm.
Residence Time:	17.1	min.
Pressure:	1500	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	645	585
Conversion wt. %:	7.3	47.0
CO pressure at exit. psig:	588	515

Cause of Shutdown: Excessive thickening of the product oil.

Observations:

The reduced CO pressure appeared to accelerate the increasing viscosity of the carrier oil. The run was terminated prematurely to increase the pressure and reverse this trend.

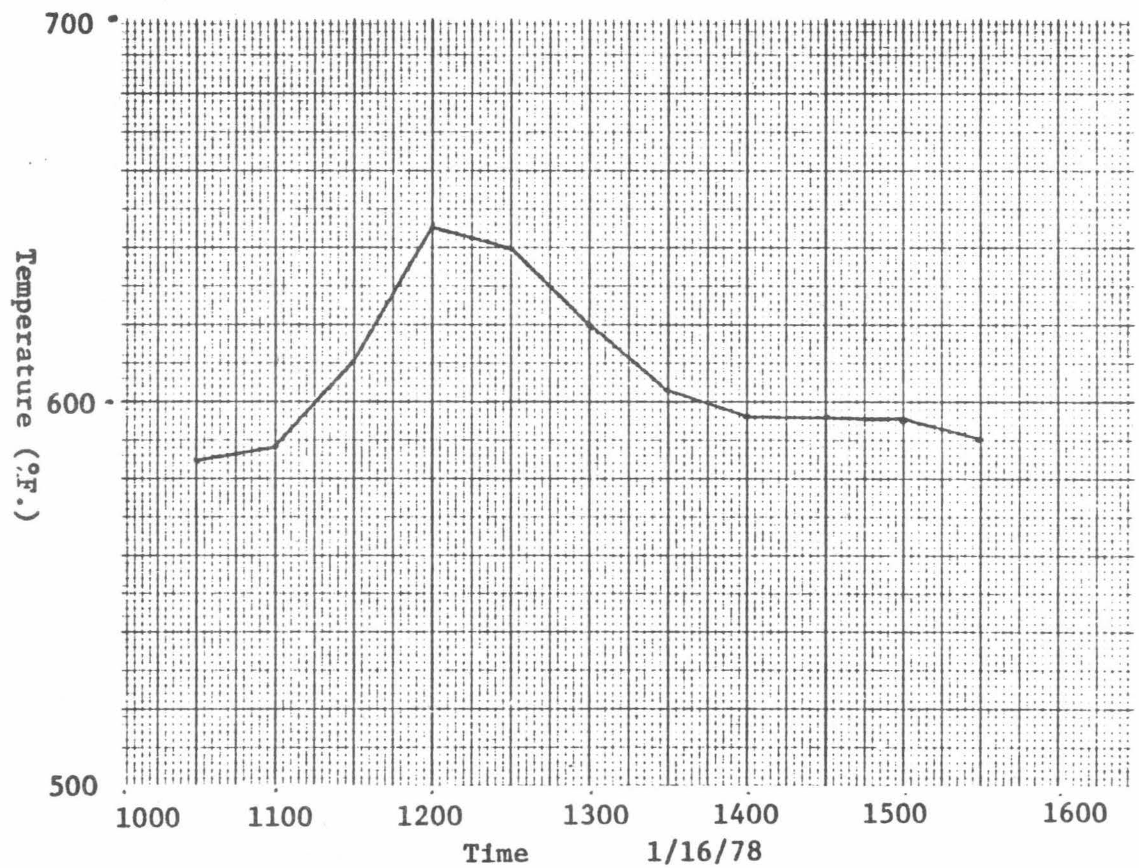
BYPASS TEST #22

STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

T-2	Feed Slurry Pump Discharge	**(°F.)**
T-3	CO from Interchanger	**(°F.)**
T-5	Level Valve #315 Outlet	**(°F.)**
T-16	Preheater Outlet	**(°F.)**
Set	TIC-302 Setting	**(% of scale)**
P-3	System Pressure	**(psig)**
F-1	Feed Slurry Pump Stroke	**(mm)**
F-2	Wood Flour Feed	**(lb./hr.)**
F-3	L.P. Flash Gas Flow	**(scfm)**
F-4	CO Feed	**(scfm)**
F-5	Catalyst Pump Stroke	**(mm)**
W-1	Wood Oil Blend Weight	**(gross lb.)**
A-2	CO in L.P. Vent	**(%)**
A-3	CO_2 in L.P. Vent	**(%)**

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	147.000	6.812	2.781	154.000	135.000	19.000
T3	57.833	2.401	.980	60.000	55.000	5.000
T5	240.333	9.070	3.703	258.000	235.000	23.000
T16	602.500	23.611	9.639	645.000	585.000	60.000
SET	76.000	2.449	1.000	81.000	75.000	6.000
P3	1500.000	.000	.000	1500.000	1500.000	.000
F1	55.000	.000	.000	55.000	55.000	.000
F2	50.000	.000	.000	50.000	50.000	.000
F3	8.617	1.635	.668	10.000	5.400	4.600
F4	5.233	.463	.189	6.000	4.800	1.200
F5	30.000	.000	.000	30.000	30.000	.000
W1	1220.833	29.226	11.932	1250.000	1175.000	75.000
A2	31.417	6.344	2.590	39.000	21.000	18.000
A3	58.667	5.428	2.216	67.000	52.000	15.000

BYPASS TEST 22
PREHEATER EXIT TEMPERATURE

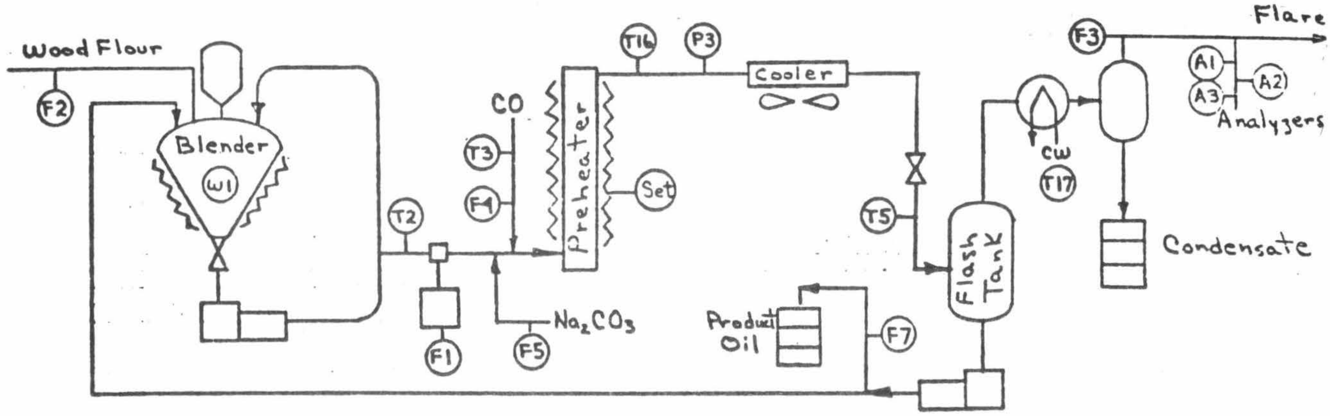


Run No.: 23

Date: 1/16/78 to 1/19/78, **Total Time On stream:** 46.5 hrs

Objective: To see if increasing the CO partial pressure by increasing total pressure and CO flow, would reduce the ~~Polymer make and reduce the~~ viscosity of the patrièr oil

Flowsheet:



Operating Conditions:

Oil Flow Rate:	60	gph.
Catalyst Flow Rate:	1.8	gph.
Wood Flour Feed Rate:	49	lbs./hr.
Wt. % Flour in Feed Slurry:	17.8	%
CO Feed Rate:	6.43	scfm.
Residence Time:	17	min.
Pressure:	2765	psig.

Analytical Results:

Preheater (reactor) outlet temp. °F.:	585	565	581	600	590	565	600
Conversion wt. %:	56.3	37.6	37.8	29.5	60.2	36.6	54.1
CO Pressure at exit, psig:	~~2750~~ 900	~~2750~~ 1510	770	715	610	770	570

Cause of Shutdown: Leak in high pressure valve gasket

Observations:

No lessening in viscosity ~~was~~ resulted. ~~and~~ Polymerized material reduced the conversion of wood flour passing through preheater and ~~flow~~ solids concentration in the system increased accordingly.

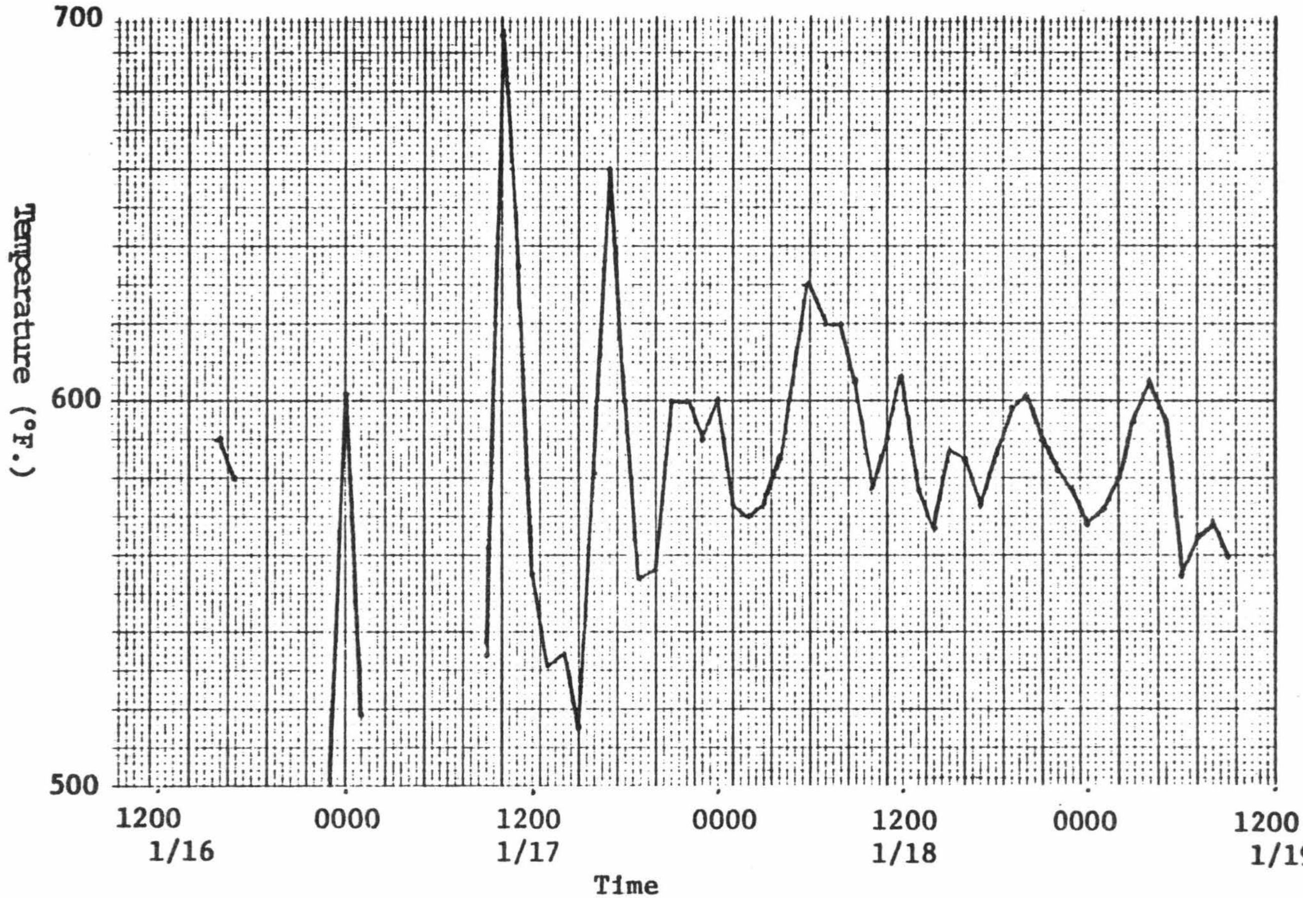
BYPASS TEST #23

STATISTICAL SUMMARY OF OPERATIONAL VARIABLES

T-2	Feed Slurry Pump Discharge	(°F.)
T-3	CO from Interchanger	(°F.)
T-5	Level Valve #315 Outlet	(°F.)
T-16	Preheater Outlet	(°F.)
Set	TIC-302 Setting	(% of scale)
P-3	System Pressure	(psig)
F-1	Feed Slurry Pump Stroke	(mm)
F-2	Wood Flour Feed	(lb./hr.)
F-3	L.P. Flash Gas Flow	(scfm)
F-4	CO Feed	(scfm)
F-5	Catalyst Pump Stroke	(mm)
W-1	Wood Oil Blend Weight	(gross lb.)
A-2	CO in L.P. Vent	(%)
A-3	CO_2 in L.P. Vent	(%)

VARIABLE	MEAN	STD DEV	STD ERR	MAXIMUM	MINIMUM	RANGE
T2	140.333	6.243	1.040	152.000	128.000	24.000
T3	54.472	1.874	.312	58.000	50.000	8.000
T5	213.056	25.377	4.230	269.000	174.000	95.000
T16	587.028	20.232	3.372	655.000	560.000	95.000
SET	84.944	4.922	.820	93.000	75.000	18.000
P3	2765.278	37.454	6.242	2850.000	2700.000	150.000
F1	55.194	1.167	.194	62.000	55.000	7.000
F2	50.000	.000	.000	50.000	50.000	.000
F3	12.222	4.216	.703	20.000	10.000	10.000
F4	7.236	.833	.139	8.200	4.600	3.600
F5	30.000	.000	.000	30.000	30.000	.000
W1	1186.944	60.936	10.156	1300.000	1050.000	250.000
A2	33.986	17.955	2.992	66.000	15.000	51.000
A3	53.903	14.881	2.480	76.000	21.000	55.000

BYPASS TEST 23
PREHEATER EXIT TEMPERATURE



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EQUIPMENT PROFILE

SYSTEM

Wood Chip Loading Conveyor Belt

MANUFACTURER

Transco Northwest

MODE OF OPERATION

A front end loader lifts chips into a small feed hopper. The hopper is mounted above a continuous belt conveyor. The continuous belt conveyor empties into a 3 ton wood chip surge bin (hopper) or dumps directly into one of two vessels called pretreaters via a slide valve.

MANUFACTURER SPECIFICATIONS

Capable of conveying 1900 lbs/hr of wood chips or saw-dust with a density of 15 to 35 lbs/ft^3.

PERFORMANCE DATA

The conveyor has filled the 3 ton surge bin in 30 minutes. That corresponds to 12,000 lbs/hr or about 6 times rated capacity. Average chip bulk density was 14.9 lbs/ft^3. The Westinghouse mac motor is 3 Hp, 3 phase, 451 volts and draws 28.6 amps start-up when moving a full load of wood chips = 4.8, 5.0 and 5.5 amps.

MECHANICAL HISTORY & MODIFICATIONS

The conveyor has moved 10 tons of wood chips to date with no mechanical problems.

1. A plywood rain cover was installed over the 3 ton surge bin.

2. A chain guard was installed near the feed hopper.

3. A chain guard was on the conveyor in the Rx area also (app. 12 feet of conveyor was unprotected).

CONCLUSIONS & RECOMMENDATIONS

Equipment meets/exceeds design specifications.

SYSTEM

Dryer Feed Table Feeder

MANUFACTURER

FMC Link Belt

MODE OF OPERATION

Wood chips are fed to the dryer screw conveyor from the wood chip surge bin via the table feeder.

MANUFACTURER SPECIFICATIONS

Capacity = 1900 lb/hr of wood chips @ 15 to 35 lb/ft^3 bulk density.

PERFORMANCE DATA

Unit handled maximum flow limited by dryer.

5 HP, 3 phase, 449 volts Westinghouse SBFC Motor drew 9.1 amps at start-up. Peak load = 1.3, 1.3, 1.0 amps while running.

MECHANICAL HISTORY & MODIFICATIONS

The slot in the skirt of the feeder was too close to the feeder discharge. Wood chips were binding up at the discharge to the conveyor. Slot was opened wider.

CONCLUSIONS & RECOMMENDATIONS

The unit capacity exceeds system requirements.

SYSTEM

Dryer Feed Screw Conveyor

MANUFACTURER

Model UJ

MODE OF OPERATION

Wood chips are fed from the table feeder to the dryer airlock feeder via a screw conveyor.

MANUFACTURER SPECIFICATIONS

Capacity = 1900 lb/hr of wood chips @ 15 to 35 lb/ft^3 density.

PERFORMANCE DATA

Motor is 3 phase. Under full load test motor drew:

451 volts
19.5 amps start-up
2.0, 2.0 & 1.7 amps running

MECHANICAL HISTORY & MODIFICATIONS

No difficulties

CONCLUSIONS & RECOMMENDATIONS

The unit capacity exceeds system requirements.

SYSTEM

Dryer Feed Star Feeder

MANUFACTURER

Kice

MODE OF OPERATION

Wood chips are fed to the dryer via the dryer rotary star feeder.

MANUFACTURER SPECIFICATIONS

Model #VJ8X6-F1080 was included in dryer package.

PERFORMANCE DATA

This has a maximum feed rate corresponding to 160 pounds of dry (1 to 4% H_2O) chips/hr.

The system is driven by a 1/2 HP 3-phase motor. Under a full load of wood chips the motor drew:

451 volts
6.0 amps start up
0.8, 0.8, & 0.7 amps running

MECHANICAL HISTORY & MODIFICATIONS

No difficulties, but occasionally plugs due to over feeding.

CONCLUSIONS & RECOMMENDATIONS

The capacity of this unit limits the system throughput to about 3 tons wet wood chips per day (the plant name-plate capacity) or about 60 gph of 30% solids slurry unrecycled feed to the preheater.

Investigate increasing feeder rpm with new pullies or by replacing it with a larger capacity feeder.

SYSTEM

Wood Chips Dryer

MANUFACTURER

Aeroglide

MODE OF OPERATION

Wood chips are dried from 40-50% moisture in to approximately 1-4% moisture out. Hot air cocurrently flows through the dryer. Air is heated by burning natural gas at inlet.

MANUFACTURER SPECIFICATIONS

Model No. RI-3-20NGX

385 lb/hr of wet wood chips (60% maximum moisture). Maximum outlet moisture = 4%.

PERFORMANCE DATA

The capacity of the dryer is limited by the rotary (starr feeder) feed valve to 160 lbs/hr.

Performance data is presented in Section II, Part 3. Under full load, the dryer drum drive drew:

453 volts
35.6 amps startup,
3.5, 3.3 & 3.3 amps running

The dryer package (MCC room) drew 449 volts, 13.3, 14.4 and 13.2 amps running.

CONCLUSIONS & RECOMMENDATIONS

Equipment has not been operated at design flow conditions since feed rotary airlock restricts flow to 160 lb/hr maximum. This is not a drawback to plant operations yet.

SYSTEM

Dryer Discharge Bucket Elevator

MANUFACTURER

Screw Conveyor

MODE OF OPERATION

Wood chips from the dryer discharge are lifted in 10" x 6" buckets for discharge into the dried wood storage bin. The bucket elevator is a centrifugal discharge chain type.

MANUFACTURER SPECIFICATIONS

Bucket elevator capacity is 2400 lb/hr. Single speed motor drive.

PERFORMANCE DATA

Flow capacity checks not made. Buckets appear 1/2 to 3/4 full at maximum dryer flow rate.

The unit is driven by 3 HP, 3-phase, 460 volts reliance motor. Under full load the motor draws:

449 volts
31.5 amps start up
3.5, 2.9, 3.3 amps running

MECHANICAL HISTORY & MODIFICATIONS

No difficulties.

CONCLUSIONS & RECOMMENDATIONS

None. Satisfactory performance.

SYSTEM

1. Dried Wood Surge Bin 2. Bin Activator
3. Bin Activator Motor

MANUFACTURER

1. Maecon, Inc. 2. Vibra-screw 3. Reliance

MODE OF OPERATION

Received dried wood chips from the bucket elevator. Provides surge capacity. The bin is equipped with positive flow dischargers, level indicators, and high level alarm.

MANUFACTURER SPECIFICATIONS

Feed rate: up to 2400 lbs/hr
Feed materials: wood chips and wastes
Maximum feed sizes: 2" x 2" x 1/4"
Material may be wet with surface moisture from outside storage
Bulk densigy: 20 to 27 lbs/ft^3

PERFORMANCE DATA

Wood chips are hydroscopic. The chips absorbed enough moisture during 24 hours of bin storage to become ungrindable.

The bin activator motor is a 1.5 HP, 3-phase motor. Under full load the motor drew 20.1 amps start up and 2.5, 2.5 and 2.8 amps running (at 451 volts).

MECHANICAL HISTORY & MODIFICATIONS

A continuous nitrogen purge was applied to the bin to keep the chips dry on storage.

CONCLUSIONS & RECOMMENDATIONS

None

SYSTEM

Feeder to the grinder.

MANUFACTURER

Pneumatic Systems, Incorporated

MODE OF OPERATION

Dried wood chips are fed to the grinder from the dried wood surge bin via the airlock feeder (variable speed drive).

MANUFACTURER SPECIFICATIONS

300 to 1500 lbs/hr of dried wood chips (variable speed). Feed size 2" x 2" x 1/4" maximum.

PERFORMANCE DATA

Flow rates of greater than 2000 lb/hr were obtained at lowest RPM setting. Reducing the lowest rpm setting to 4.4 rpm (pulley) and decreasing valve pocket volume reduced flow rate to 500 lb/hr which is compatible with the Frinden.

Under full load the feeder motor now draws 27.5 startup amps/phase and 1.9, 2.0, and 2.6 running amps for each phase respectively (at 455 volts).

MECHANICAL HISTORY & MODIFICATIONS

Grinder was overloading. The pulley was changed to a larger size and vanes in the feeder were closed down to reduce flow to the grinder.

CONCLUSIONS & RECOMMENDATIONS

Feeder oversized for the grinder by a factor of 8. This was the smallest feeder that provides shearing action which helps promote solids flow.

SYSTEM

Wood chips grinder/motor

MANUFACTURER

Williams Patent Crusher & Pulverizer/General Electric

MODE OF OPERATION

The dried wood chips are ground to minus 50 mesh and discharged to the wood flour screen. The grinder is also capable of grinding pretreated wood to minus 50 mesh.

MANUFACTURER SPECIFICATIONS

Maximum feed rate is 2400 lbs/hr. Maximum feed size is 2" x 2" x 1/4" wood chips. The resulting product is 500 lb/hr of minus 50 mesh wood flour plus a 1900 lb/hr recycle stream (50 mesh particles).

PERFORMANCE DATA

Maximum flow rate obtainable is 500 lb/hr wood chip feed rate.

One hour of grinding is required to process 3 hours of dryer output. Under full load the 75 HP, 3-phase General Electric motor draws 616 start up amp/phase and 30, 26.8 and 271 running amps in each phase respectively (at 454 volts)

MECHANICAL HISTORY & MODIFICATIONS

A nitrogen line was installed to prevent dust explosions in the grinder.

A coupling guard was manufactured and installed.

CONCLUSIONS & RECOMMENDATIONS

Equipment failed to meet feed flow specifications. However, 500 lb/hr of wood flour production exceeds 150 lb/hr maximum required by blender. Therefore, no difficulties result.

SYSTEM

Wood Flour Metering

MANUFACTURER

Fluidizer, Inc., Minneapolis, Minnessota.
Wallace & Tierhan.

MODE OF OPERATION

Wood flour is removed from the wood flour surge bin and fed to wither the blender weigh belt feeder or to the lock hoppers via rotary airlock feeders (44180 & 44190). Before entering the blender, the wood flour feed (25 to 150 lb/hr) rate is measured on a pneumatic weigh belt feeder (WX-210).

MANUFACTURER SPECIFICATIONS

Airlock feeder to blender (44180) - 25 to 160 lb/hr (varying speed). Airlock feeder to lock hoppers (44190) - 900 lb/hr. Weigh belt feeder (WX-210) - 25 to 150 lb/hr.

PERFORMANCE DATA

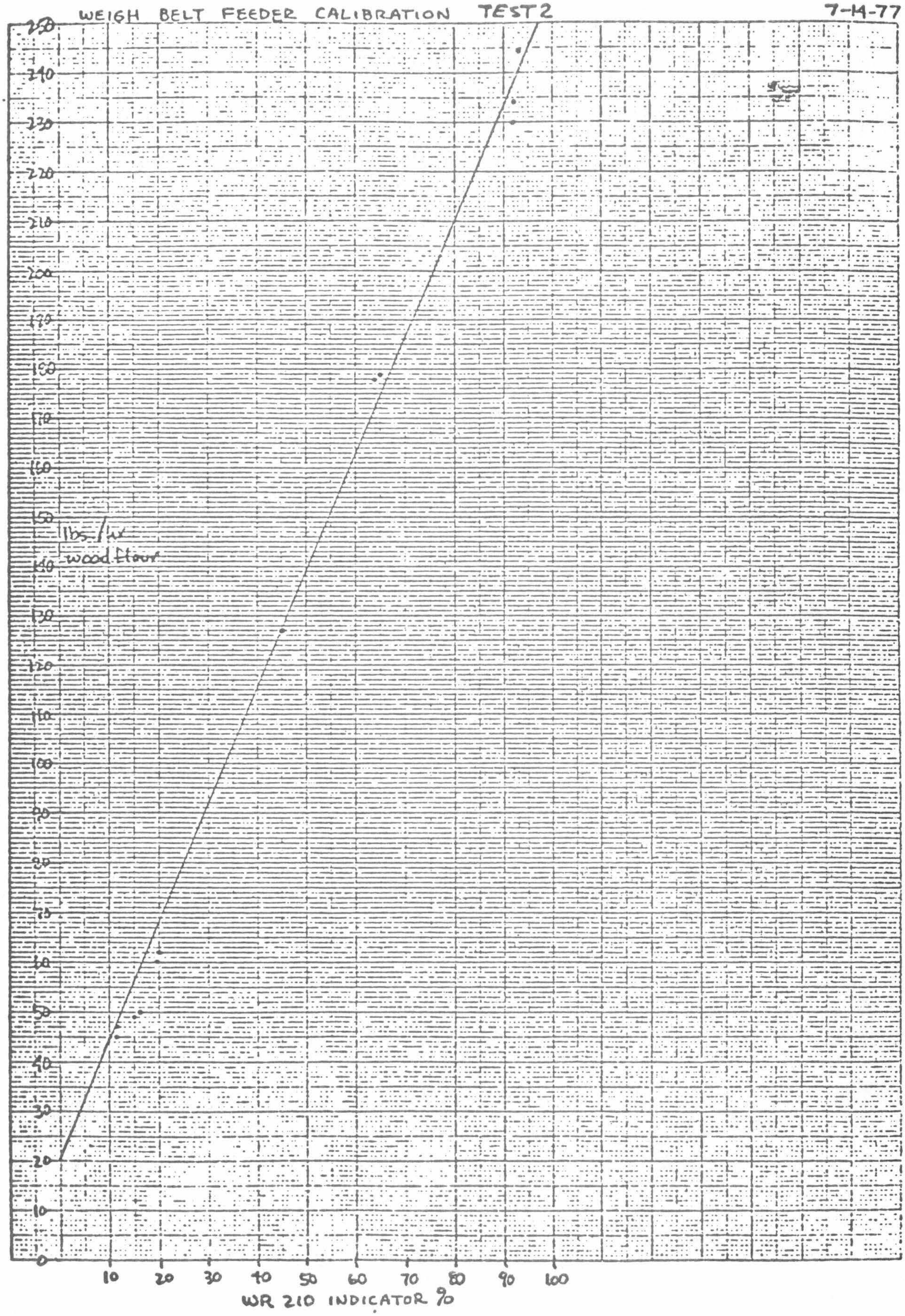
Attached is a flow capacity versus feeder rpm chart for the feeder to the blender. Also attached is a calibration curve for WX-210. A feed rate of 235 lbs/hr (i. e., 157% of rated capacity) has been achieved. This corresponds to about 87 gallons of 30% solids makeup feed to the system.

MECHANICAL HISTORY & MODIFICATIONS

The feeder to the blender initially failed to meet its design capacity, it only flowed 20 lb/hr maximum. Its valve depth was increased by machining the valve body. Initially the weigh belt feeder gave irratic output signals. This was resolved by installing a thinner gauge weigh belt. Pneumatic vibrators were added to the system to promote continuous flow of feed.

CONCLUSIONS & RECOMMENDATIONS

All three pieces of equipment are now operating satisfactorily and meet manufacturer design specifications. However, the pilot plant must feed 160 lbs of dry wood per hour to meet its 3 ton per day name plate capacity.


WEIGH BELT FEEDER CALIBRATION TEST 2
7-14-77
lbs./hr
wood flour
WR 210 INDICATOR %
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250

SYSTEM

Oil Flow, Pumping, Metering and Heating
1. Oil Storage

MANUFACTURER

1. Maecon, Inc., Santa Fe Springs, California (Tank)
2. Chromalox, Inc., (Tank heaters)

MODE OF OPERATION

Anthracene oil is received in 55 gallon drums and fed individually to the oil hold tank, by a Lutz drum pump. Tubular electric heaters are activated by an electronic controller to maintain the desired temperature.

MANUFACTURER SPECIFICATIONS

Vessel Capacity = 750 gallons
Heater Capacity = 5 KW

PERFORMANCE DATA

Vessel capacity verified. A heater amperage draw under maximum load was 5 amps/462 volts, 6 amps/441 volts, and 6 amps/457 volts for each of 3 phases respectively.

MECHANICAL HISTORY & MODIFICATIONS

No modifications. No operational difficulties. Overflow line was extended down to a floor drain.

CONCLUSIONS AND RECOMMENDATIONS

Equipment satisfactory and meets design specifications.

SYSTEM

Oil Flow, Pumping, Metering and Heating
2. Pumping and metering

MANUFACTURER

Robbins & Myers, Inc.

MODE OF OPERATION

Anthracene oil is pumped to the blender via Moyno pumps (oil feed pump A or B) to the wood oil blender. The rate of flow is measured by FX-209 (an integral orifice flow meter).

MANUFACTURER SPECIFICATIONS

20 GPM of heavy oil (SP.GR. = 1.15 @ PT) at 20 PSIG normal discharge pressure.

PERFORMANCE DATA

Maximum amp draw @ 15 PSIG discharge pressure = 2.0 (this was with viton stators).

Flowmeter FX=209 which has a 1/4" integral orifice never operated satisfactorily since pieces of stator rubber plugged it. The orifice has been removed and the plant is now recycling solids in oil back to the blender.

MECHANICAL HISTORY & MODIFICATIONS

Pumps originally supplied with Buna-N stators. Anthracene attacked this material and degraded it to the point where chunks of rubber plugged FX=209.

Orifices were originally installed to provide recirculation, and prevent excessive discharge pressures. Due to frequent pluggage and erattic pump discharge pressures, throttling valves have been installed.

CONCLUSIONS & RECOMMENDATIONS

Viton stators appear to resist anthracene attack. FX-209 must be operated without an orifice if solids will be recycled back to the blender. FX-209 should be replaced with a flow totalizer.

SYSTEM

Blending
1. Blender

MANUFACTURER

Atlantic Research Corporation, Alexandria, Virginia

MODE OF OPERATION

Wood flour is automatically fed into the blender via WX-210, the weigh belt feeder. Anthracene oil or product oil or mixtures of both are fed into the blender via FV-209. The percentage opening of FV-209 is controlled by a ratio flow controller in proportion to the amount of wood flour fed.

MANUFACTURER SPECIFICATIONS

Vessel capacity - 150 gallons. Blender should be capable of mixing 150 lb/hr wood flour in oil up to 30 wt% solids concentration. The blender has independently driven inner and outer agitators each with its independent motor.

PERFORMANCE DATA

The blender has made up to 30 wt% wood flour (minus 50 mesh) slurries in creosote and anthracene oils. Blender agitator amp draw under typical load conditions:

A. Inner Agitator - 453 volts; 38.5 start up amps/ phase; 2.8, 3.7 and 2.8 running amps/phase.

B. Outer Agitator - 453 volts; 42.7 start up amps/ phase; 4.1, 6.1 and 4.6 running amps/phase.

Ratio control not operable. Excess flour jams blender.

MECHANICAL HISTORY & MODIFICATIONS

The 12" knife gate valve at the bottom of the blender leaked and could not be opened or closed unless the bottom flange bolts were loosened. This valve was replaced with a 6" dzurik knife gate valve in the feed slurry pump circulation line.

CONCLUSIONS & RECOMMENDATIONS

Blending operation satisfactory and meets design specifications.

SYSTEM

Blending
2. Blender heating

MANUFACTURER

Chromalox, Inc., Ogden, Utah

MODE OF OPERATION

Anthracene or product oil is fed to the blender at 200 to 230°F. The tubular electric heaters maintain this temperature for the wood/oil slurry.

MANUFACTURER SPECIFICATIONS

Heater duty = 6 KW

PERFORMANCE DATA

Normal operation temperature measurement indicates no change in slurry temperature. Note: Heaters cannot raise temperature of mixture from ambient temperature to 200°F. This is beyond the design specifications. Typical feed temperature is 150°F. Typical exit temperature is usually 170 to 180°F.

MECHANICAL HISTORY & MODIFICATIONS

No changes have been made to the blender heaters.

CONCLUSIONS & RECOMMENDATIONS

None

SYSTEM

Blending
3. Weight Measurement (W1-217)

MANUFACTURER

Torroid Corporation, Huntsville, Alabama

MODE OF OPERATION

The blender rests on three load cells whose output signals are summed to indicate blender inventory. The span is 0 to 1500 lbs.

MANUFACTURER SPECIFICATIONS

PERFORMANCE DATA

The weights indicated correspond within ± 20 pounds of the weights of oil or slurry known to have been fed to the blender. This is the highest accuracy that can be readout on the scale.

MECHANICAL HISTORY & MODIFICATIONS

Initially drifting of zero points occurred. A manufacturers representative resolved the problem by electronic changes.

CONCLUSIONS & RECOMMENDATIONS

Equipment is accurate to ± 20 pounds. The precision is insufficient for material balance purposes but is indicative of level buildup in the blender (inferred by weight).

SYSTEM

Moyno Pumps
1. Slurry recirculation

MANUFACTURER

Robbins & Myers, Incorporated

MODE OF OPERATION

Moves slurry from blender to preheater.

MANUFACTURER SPECIFICATIONS

5 GPM capacity of 30 to 50 wt% wood flour in oil slurry. Normal discharge pressure = 100 psig.

PERFORMANCE DATA

Maximum shutoff head with water = 37 psig (1/21/77). This pressure decreased to 17 psig (7/1/77).

MECHANICAL HISTORY & MODIFICATIONS

Anthracene attacks Buna-N stators leaving pieces of rubber in lines and in the feed slurry pump suction. The Buna-N stators were replaced with a viton stator.

CONCLUSIONS & RECOMMENDATIONS

Viton stators seem satisfactory.

SYSTEM

Moyno Pumps
2. Centrifuge feed

MANUFACTURER

Robbins & Myers, Incorporated

MODE OF OPERATION

Product oil and unreacted solids plus an aqueous phase are pumped from the bottoms flash tank to the centrifuge. Capability exists to pump to the blender if recirculation of slurry is desired. Two pumps installed in parallel (full spare).

MANUFACTURER SPECIFICATIONS

5 GPM capacity of 10% solids in oil slurry. Normal discharge pressure = 20 psig.

PERFORMANCE DATA

Maximum shutoff pressure with recirculation line open = 5 psig.

MECHANICAL HISTORY & MODIFICATIONS

Anthrancene attacks Buna-N stators leaving pieces of rubber in lines and orifices. The Buna-N stetor was replaced with a viton stator.

Recirculation orifice had to be replaced with a throttling valve.

CONCLUSIONS & RECOMMENDATIONS

The new stators seem to be serviceable.

SYSTEM

High Pressure Slurry Pumping

MANUFACTURER

Bran & Lubbe Ltd., England

MODE OF OPERATION

The wood oil slurry (up to 30 or 50% concentration) is pumped up to 4000 psig discharge pressure and fed into the preheater inlet. Capability exists of feeding oil from the oil hold tank to the pump suction. Discharge piping allows recycle or discharge (at low pressure) back to the blender. The pump has two parallel pump heads of equal capacity driven by a common motor.

MANUFACTURER SPECIFICATIONS

200 gal/hr capacity of 30 to 50% wood flour (if pretreated @ 50%). Normal discharge pressure = 4000 psig.

PERFORMANCE DATA

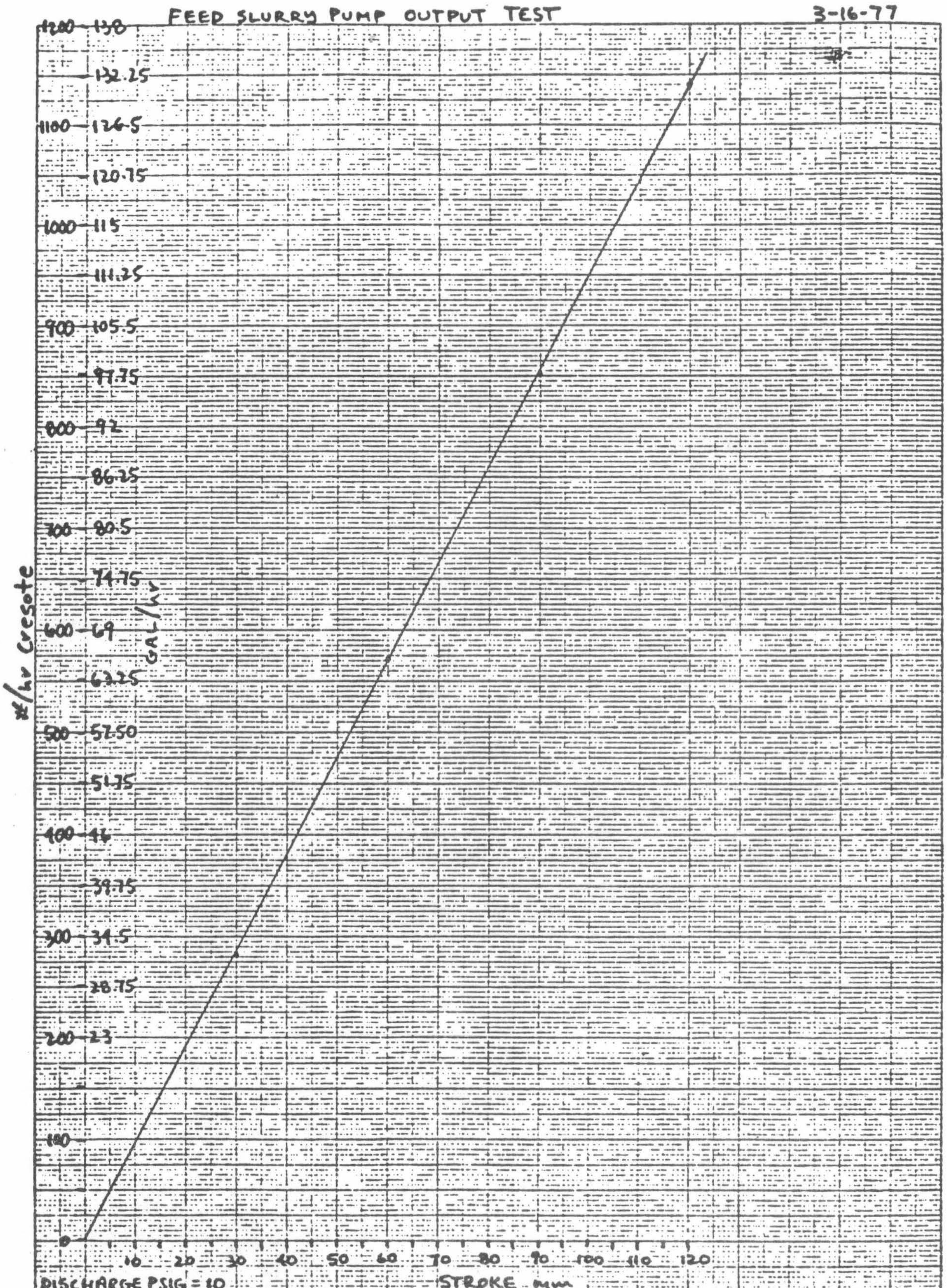
Attached is a calibration curve of flow rate versus pump stroke length. Note: This curve applies to either pump 1/2. The pump stroke and outputs of the 2 heads can be adjusted independently. The minimum pump flow rate occurs for 30% solids conc. slurry because suction piping plugs.

MECHANICAL HISTORY & MODIFICATIONS

Hydrostatic operation initially indicated a leak in right side pump head. Manufacturer replaced defective head. Suction gaskets (compressed asbestos) ruptured several times until replaced by stainless steel gaskets.

CONCLUSIONS & RECOMMENDATIONS

Design conditions met. Each pump 1/2 meets plant flow requirements, therefore the "B" side can be considered a spare even though there is a common motor.



50° F
SP.GR. 50°F = 1.07
RATED 100 GAL/hr. per PUMPHEAD

Bechtel Corporation
Research & Engineering

SYSTEM

Catalyst Feed System
1. Catalyst Mixing and Pumping to Storage

MANUFACTURER

Goulds Pump, Inc.

MODE OF OPERATION

Batches (up to 120 gallons for one day's run) of 20% sodium carbonate in water are mixed and transferred to the catalyst hold tank. Hot water (130^{o}F) is used.

MANUFACTURER SPECIFICATIONS

None Available

PERFORMANCE DATA

20% Na_2CO_3 not exceeded. At maximum load, the 3-phase motor draws 32.4 start-up amps and 2.8, 2.8 and 27 running amps/phase (452 volts).

MECHANICAL HISTORY & MODIFICATIONS

The temperature of the solution must be maintained at greater than 77^{o}F because at this point sodium carbonate will precipitate out and plug catalyst lines.

CONCLUSIONS & RECOMMENDATIONS

System operation satisfactory.

SYSTEM

Catalyst Feed System
2. Catalyst Holding & Low and High Pressure Pumping

MANUFACTURER

Duriron Company (Low Pressure Pump)

Bran & Lubbe, LTD, England (High Pressure Pump)

MODE OF OPERATION

The 20% sodium carbonate solution is pumped up to 4000 psig discharge pressure by a centrifugal (L. P.) and piston pump (H. P.) in series. The catalyst solution is fed to the inlet of the preheater.

MANUFACTURER SPECIFICATIONS

5 gal/min of 20% sodium carbonate aqueous solution.
Normal discharge pressure = 20 psig.

PERFORMANCE DATA

Attached is a pump calibration curve for the high pressure feed pump (A and B).

Under full load the pumps draw:

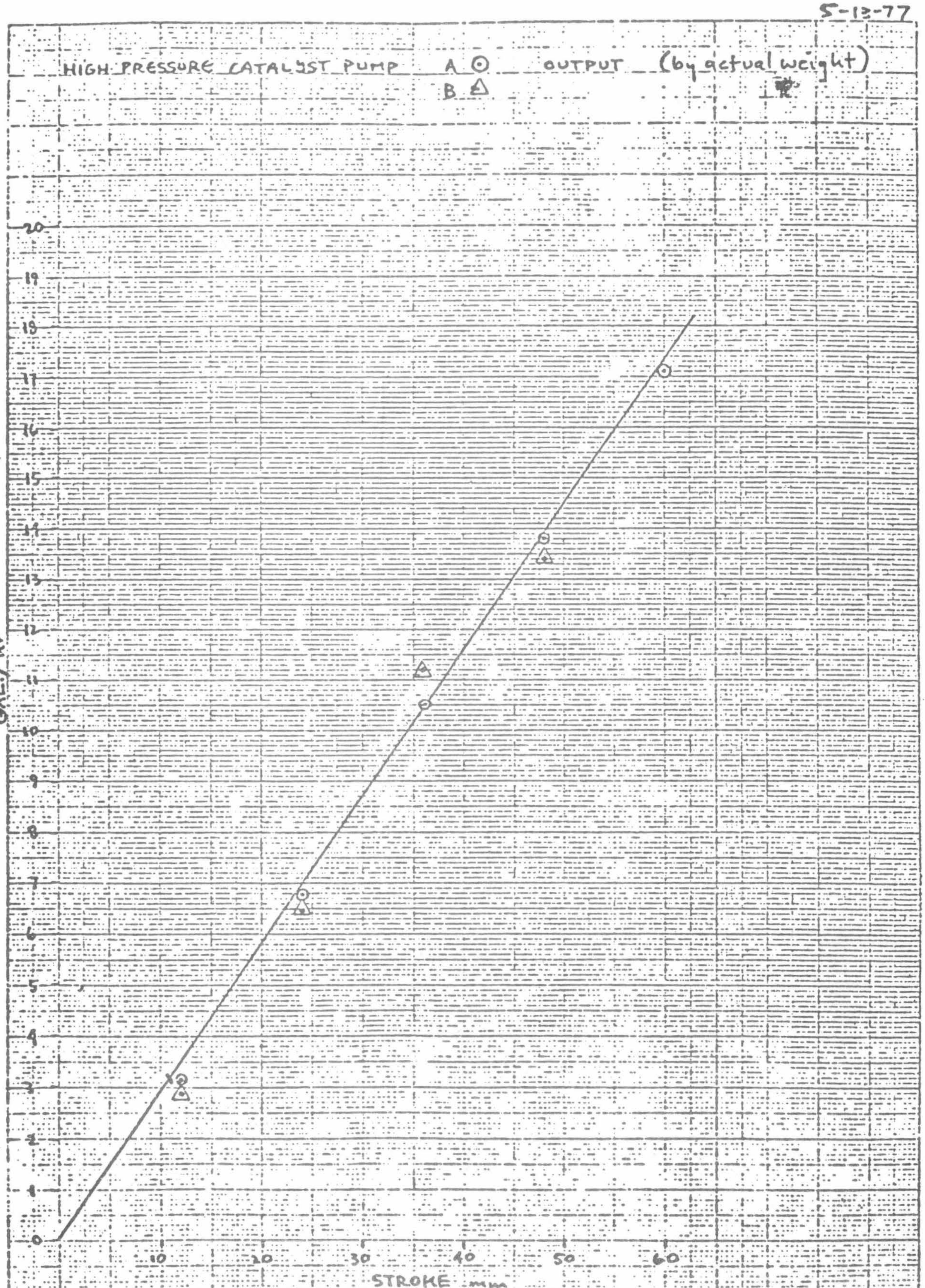
	Volts	Startup Amps/Phase	Running Amps/Phase
Low Pressure	447	12.3	2.0, 1.7, 1.7
High Pressure Pump A	451	27.1	2.1, 2.8, 2.0
High Pressure Pump B	448	35.6	3.0, 2.8, 2.8

MECHANICAL HISTORY & MODIFICATIONS

The L. P. pump recirculation line back to the catalyst hold tank was heat traced and insulated to maintain solution temperature at 100°F. Only difficulties encountered were when solution temperature dropped and discharge line plugged.

CONCLUSIONS & RECOMMENDATIONS

Equipment meets specifications and operation is satisfactory.



Bechtel Corporation
Research & Engineering

SYSTEM

CO Compression
CO Compressor Feed to Reactor (CO Comp. IA & IB)

MANUFACTURER

American Instrument Company, Siver Spring, Maryland

MODE OF OPERATION

The two compressors (A & B) can be run simultaneously to produce up to 10 SCFM of CO. The CO can be charged into the process stream in a pipe just before the preheater or dispensed directly into the reactor.

MANUFACTURER SPECIFICATIONS

Capacity 5 SCFM @ 50 psig suction and 4000 psig downstream.

PERFORMANCE DATA

Both compressors have developed 4000 psig discharge pressures with nitorgen and carbon monoxide. Flow capacity checks have not been verified because of inadequacies in flow measurement instrumentation.

MECHANICAL HISTORY & MODIFICATIONS

Continuous diaphram failures on all heads keep occurring after 18 hours maximum running time. The manufacturer claims average diaphram life is 2000 hours. Oil recirculation lines to compensating pumps have burst. Manufacturer supplied copper tubing where stainless steel was required. Manufacturer service representative visited site and recommended suction filters which were installed but problem persisted. Grooved heads are being shipped to us as possible solution to diaphram problems.

CONCLUSIONS AND RECOMMENDATIONS

Very poor performance to date.

SYSTEM

CO Compression
Compressor Feed to Lock Hoppers

MANUFACTURER

American Instrument Company, Silver Spring, Maryland

MODE OF OPERATION

Carbon monoxide is used to pressurize either of two lock hoppers. Suction is taken from the CO surge tank at 50-75 psig and delivered to the lock hoppers at 4100 psig.

MANUFACTURER SPECIFICATIONS

200 SCFM capacity at 50 psig suction pressure capable of delivering 4400 psig discharge pressure.

PERFORMANCE DATA

Test ran by Aminco representative (10/76) on plant air. Compressor was slow to reach 4000 psig. Fitting on upstream side of discharge flex hose failed. Water flow switches had to be jumpered to operate. Was found installed backwards. Capacity flow checks have not been made since lock hopper system is not operational.

MECHANICAL HISTORY & MODIFICATIONS

Maximum running time has been approximately 20 hours. System not operated in conjunction with lock hoppers but rather to pressurize the reactor when CO Compressors IA or IB have failed. Diaphram failures on 1st and 3rd stage heads have occurred (previous to installing suction filters). The unit has not been tested since the new filters were installed.

CONCLUSIONS & RECOMMENDATIONS

Very poor performance to date.

SYSTEM

CO Compression
Gas Delivery Pressure Filtration

MANUFACTURER

Filterite Corporation, Timonium, Maryland

MODE OF OPERATION

Carbon monoxide from the tube trailers is filtered to remove dirt ant metallic particles from entering compressor suction lines.

MANUFACTURER SPECIFICATIONS

Five-micron size filter. 3000 psig maximum pressure rating.

PERFORMANCE DATA

None

MECHANICAL HISTORY & MODIFICATIONS

Compressor diaphram failures on small CO compressors (A & B) were not caused by dirt or metal particles since filter installation. A filter was installed on the large compressor but not tested to date.

CONCLUSIONS & RECOMMENDATIONS

Equipment operation is satisfactory to date.

SYSTEM

CO Compression
Bypass & Flow Control

MANUFACTURER

Fischer/Porter Company

MODE OF OPERATION

The flow rate of carbon monixide into the reactor is controlled by FIC-316 which operates FY-316 which recycles CO to CO Comp. I A or B suction.

MANUFACTURER SPECIFICATIONS

The range of flow is 0 to 5 SCFM at 4000 psig operating pressures.

PERFORMANCE DATA

The plug in FY-316 appears oversized since a small valve opening releases the total gas flow to the suction decreasing system pressure.

MECHANICAL HISTORY & MODIFICATIONS

Flow control of CO into the reactor has been utilized but gives poor performance due to an oversized valve.

CONCLUSIONS & RECOMMENDATIONS

Install a smaller valve seat to throttle gas flow.

SYSTEM

Gas Pressure and Composition Control (for reactor offgas)

MANUFACTURER

Fischer & Porter Company

MODE OF OPERATION

Total reactor pressure is maintained by PIC-311 which depressurizes reactor gases to flare. Flare back pressure is about 2-10 psig. Reactor offgas composition control will be attempted by regulating CO feed flow rate.

MANUFACTURER SPECIFICATIONS

Maximum operating pressure = 4000 psig.

PERFORMANCE DATA

None

MECHANICAL HISTORY & MODIFICATIONS

No difficulties with pressure control. On several occasions condensed anthracene carried over into system but was removed. Cause not attributable to pressure control equipment

CONCLUSIONS & RECOMMENDATIONS

Equipment satisfactory.

SYSTEM

Preheater

MANUFACTURER

Maecon, Inc., Santa Fe Springs, California

MODE OF OPERATION

Wood slurry catalyst solution at 4000 psig are preheated to the reaction temperature in a scraped surface heat exchanger. Heat is provided electrically by tubular heaters (chromalox). Also, carbon monoxide is in section upstream of the preheater to initiate oil production reactions.

MANUFACTURER SPECIFICATIONS

Flow rate = 500 lb/hr of slurry. Inlet Temperature = 200°F. Outlet temperature = 705°F. Viscosity ≥ 50,000 cp. Rated heater capacity = 50 KW.

PERFORMANCE DATA

Maximum outlet temperature was not obtainable at 105 gph (1008 lb/hr) anthracene flow. Maximum measured heater duty at 100% controller setting = 188,000 btu/hr, (i. e., 55.3 KW).

MECHANICAL HISTORY & MODIFICATIONS

Scraper must operate on lubricative fluid only. Attempts to run water only resulted in loud screeching noises. Skin thermocouples attached at 2nd and 3rd discharge outlets are nonfunctional. Temperature control has not been attempted in automatic mode due to long dead time between TX-302 and the preheater outlet.

CONCLUSIONS & RECOMMENDATIONS

Internal process fluid temperature measurement desirable. First and second nozzle outlets could be converted to thermocouples since their use for process flow is not planned.

SYSTEM

Knockout Pot (Feed Slurry)

MANUFACTURER

Maecon, Incorporated, Santa Fe Springs, California

MODE OF OPERATION

The preheated slurry and gas mixture flows into a 6" x 30" knockout pot where gases are separated and reinjected in the reactor gas sparger. Slurry flows out the pot bottom into the reactor.

MANUFACTURER SPECIFICATIONS

None avaliable.

PERFORMANCE DATA

Level control very difficult with CO but was very easy with N_2.

MECHANICAL HISTORY & MODIFICATIONS

Carryover of oil into overhead system occurred frequently. conversion to pressure control resulted in a more workable bypass system.

CONCLUSIONS & RECOMMENDATIONS

Isolate pot and use only as a wide spot in the process line without function.

SYSTEM

Sample Cooler

MANUFACTURER

Brown Fintube Company, Tulsa, Oklahoma

MODE OF OPERATION

Batch samples of slurry can be drawn off between the preheater and the reactor. Depressurization (4000 → atm) is across a 1/4" orifice downstream of the cooler and cooling (650°F → 150°F) is in a finned tube heat exchanger.

MANUFACTURER SPECIFICATIONS

None

PERFORMANCE DATA

About 1/2 gallon hold up volume exists in the sample line.

System not operated. The hold up (dead time) between samples was sufficient to plug the line each time with "frozen" material.

MECHANICAL HISTORY & MODIFICATIONS

A simple sample pot with valve was substituted.

CONCLUSIONS & RECOMMENDATIONS

Unsatisfactory design. Sample pots with valves are sufficient.

SYSTEM

Reactor
1. Vessel

MANUFACTURER

Maecon, Incorporated, Santa Fe Springs, California

MODE OF OPERATION

Preheated slurry and carbon monoxide are mixed in this continuous stirred tank reactor. Maximum oper. press = 4000 psig and temperature = 705°F. Heating (or rather maintaining) slurry at reaction temperature is done by electric tubular heaters.

MANUFACTURER SPECIFICATIONS

Capacity = 100 gal
Inside Dimensions = 24" x 67"
Agitator rpm = 60 to 180 (variable)
Material = 316 SS (overlay on C.S.)

Reactor Heater

Rating = 25 KW
MFR - Pacific Chromalox

PERFORMANCE DATA

See section on reactor performance.

MECHANICAL HISTORY & MODIFICATIONS

"B" ring head gasket failed. Maecon supervised replacement with spare. Spare failed after failure of agitator seal.

The reactor head gasket was modified to a "graylock joint". The grayloc passed hydrostatic tests and has been maintaining pressure seal effectively to date. Sparge tube specified on drawings was omitted by the manufacturer and was added later on site.

CONCLUSIONS & RECOMMENDATIONS

Vessel pressure integrity is satisfactory to date. Grayloc joint satisfactory. A new double mechanical seal has been ordered for the agitator shaft.

SYSTEM

Reactor
2. Agitator

MANUFACTURER

Maecon Inc., Santa Fe Springs, California
Myers Engineering Co., Los Angeles, California

MODE OF OPERATION

Depending on reactor level (up to 100 gal max), slurry and gas mixtures are blended to insure good gas/solids contact.

MANUFACTURER SPECIFICATIONS	Seal
Design Speed - 60 to 180 rpm	Manufacturer - Parker Packing Co.
Motor Rating - 3 hp	Type - Poly Pac B
Material - 316 SS	Material - Viton or Molythane

PERFORMANCE DATA

Seals passed hydrostatic tests. Tests with anthracene at pressure and temperature have resulted in failures of both molythane and viton.

MECHANICAL HISTORY & MODIFICATIONS

Molythane Seal showed definite signs of chemical attack by anthracene. All viton failures were mechanical in nature. New graphite packing seals were designed and installed but have proved unsatisfactory to date.

CONCLUSIONS & RECOMMENDATIONS

Seal performance is very poor. Alternative seal design is being investigated.

SYSTEM

Reactor
3. Level Measurement

MANUFACTURER

Maecon Inc., Santa Fe Springs, California
Fischer & Porter Co.

MODE OF OPERATION

Slurry level in the reactor is measured by a differential pressure transmitter (LX-315). The range of controllable levels is 0 to 100 gal.

MANUFACTURER SPECIFICATIONS

None.

PERFORMANCE DATA

The reactor has not been operated continuously under level control.

MECHANICAL HISTORY & MODIFICATIONS

Operation checkout with water and anthracene satisfactory. Occasionally LX-315 responses were sluggish. Cause unknown to date. Level sensing transmitter locations were changed to span entire height of the reactor.

CONCLUSIONS & RECOMMENDATIONS

Operation must be verified. Plugging due to solids or heavy tars settling out on level transmitter chemical seal could be a potential problem.

SYSTEM

Reactor
4. Temperature Measurement

MANUFACTURER

Maecon Inc., Santa Fe Springs, California
Wiscomb Weidner, Salt Lake City, Utah

MODE OF OPERATION

Slurry temperatures are measured by two thermowells (TE-305 and TE-304-1 to 12). TE-304 is a submerged multi-point tube with elements spaced 4 inches apart, beginning at the reactor bottom.

MANUFACTURER SPECIFICATIONS

None.

PERFORMANCE DATA

See Reactor Performance section.

MECHANICAL HISTORY & MODIFICATIONS

No operational difficulties to date.

CONCLUSIONS & RECOMMENDATIONS

Satisfactory operation.

SYSTEM

Reactor
5. Gas Feed Sparging

MANUFACTURER

Maecon Inc., Santa Fe Springs, California/Bechtel Corp.

MODE OF OPERATION

Carbon monoxide is injected into the bottom of the slurry through a sparger to promote good gas/solids contact.

MANUFACTURER SPECIFICATIONS

None.

PERFORMANCE DATA

The system has not been operated to date.

MECHANICAL HISTORY & MODIFICATIONS

Not installed by manufacturer oversight. Added later on site during gasket repair.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

CO Interchanger

MANUFACTURER

Brown Fin Tube Co., Tulsa, Oklahoma

MODE OF OPERATION

The carbon monoxide fed to the reactor is preheated to almost reaction temperature by counter-current heat exchange with the reactor off gases. This is done at approximately 4100 psi pressures.

MANUFACTURER SPECIFICATIONS

Feed CO Temp. In	= 80^{o}F	Out = 650^{o}F
Reactor Off Gases In	= 630^{o}F	Out = 500^{o}F
Feed CO Flow	= 4.4 SCFM	
Reactor Gas Flow	= 31 SCFM (max)	
Heat Exchanged	= 4000 Btu/hr	

PERFORMANCE DATA

None.

MECHANICAL HISTORY & MODIFICATIONS

Carryover of anthracene from the feed slurry knock-out pot plugged this heat exchanger twice.

CONCLUSIONS & RECOMMENDATIONS

Continuous carryover of oils and tars could be a problem with plugging and fouling. Not worth having on a small system. Heat economy is small.

SYSTEM

Off-Gas System
1. Reactor Off-Gas Cooler

MANUFACTURER

Brown Fintube Co., Tulsa, Oklahoma

MODE OF OPERATION

Reactor off gases after being depressurized to 10 psig across PY-311 flow through the reactor off-gas cooler. Water and light oils condense out.

MANUFACTURER SPECIFICATIONS

Duty	= 58,600 Btu/hr
Reactor Gas Flow	= 140 lbs/hr (~31 SCFM)
Steam Condensed	= 25 lbs/hr
Cooling Water Temp. In	= 60°F Out = 160°F

PERFORMANCE DATA

None. Total oily water condensed out in one continuous run was 6 gal (50 lbs in 24 hours).

MECHANICAL HISTORY & MODIFICATIONS

No difficulties with heat exchanger.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Off-Gas System
2. Bottoms Flash Gas Cooler

MANUFACTURER

Brown Fintube Co., Tulsa, Oklahoma

MODE OF OPERATION

After the reactor bottoms is depressurized to approximately 10 psig, the two-phase mixture flows into the bottoms flash tank. The bottoms flash gas is cooled in a double pipe (hairpin) exchanger to remove oily water.

MANUFACTURER SPECIFICATIONS

Duty	= 75,400 Btu/hr
Material	= 316 SS
Gas Flow Rate	= 49 lbs/hr
Noncondensibles	= trace
Steam Flow	= 49 lbs/hr

PERFORMANCE DATA

None.

MECHANICAL HISTORY & MODIFICATIONS

No difficulties encountered with exchanger.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Off-Gas System
3. Off-Gas $CO/CO_2/H_2$ Analyzers

MANUFACTURER

Beckman Instrument Co., Seattle, Washington

MODE OF OPERATION

The composition of either the reactor off gas or bottoms flash gas is analyzed by infrared analyzers for CO/CO_2 content. The sample system can be diverted to a gas chromatograph for hydrogen analysis.

MANUFACTURER SPECIFICATIONS

None.

PERFORMANCE DATA

Calibration curves attached.

MECHANICAL HISTORY & MODIFICATIONS

System has been calibrated with standard gases. Indication of CO/CO_2 presence has been recorded.

CONCLUSIONS & RECOMMENDATIONS

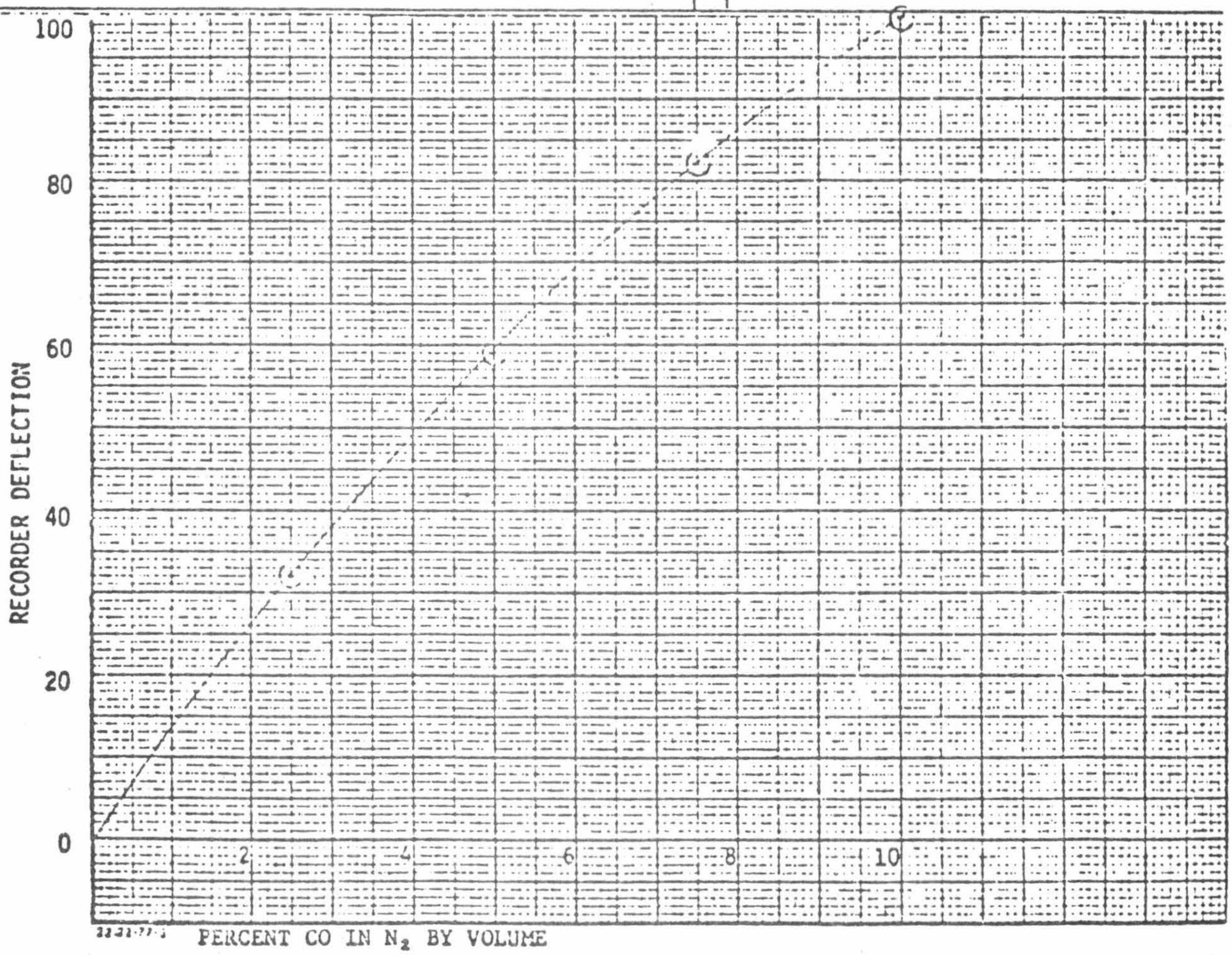
None. The CO and CO_2 analyzers are operating satisfactorily.

Beckman® INSTRUMENTS, INC.
PROCESS INSTRUMENTS DIVISION
FULLERTON CALIFORNIA • 92634

INFRARED ANALYZER CALIBRATION & DATA SHEET

Customer: MAECON INC.	S.O. No.: DC74171
Address: ALBANY, OREGON	P.O. No.: 7565-3
Application: CARBON MONOXIDE	Model No.: 864-13-1-7
Ranges: 1. 2. 3. 0-10%	Serial No.: 101460
1. Uncalibrated Linearizer Range 1 [ ]	
2. Calibrated Linearizer Range 1. [ ] 2. [ ] 3. [ ]	Detector Ser. No.: 0750-E
Refer to switch chart on schematic	Detector Part No.: 633938
3. Gas Free Calibration Assy. [ ]	Tag No.:
Sapphire [ ] Irtran [ ] Other [ ]	Configuration No.: 788913
4. Calibration Curve [ ] Typical Curve [X]	
5. Current Output Board [ ]	Repeatability: (In % of F.S.)
6. Bench Mounting Kit [ ]	Range 1: % Range 3: %
7. Stainless Steel Tubing [ ] Teflon Tubing [ ]	Range 2: % Range 4: %
8. Air Purge Kit [ ]	
9. Explosion Proof Case [ ]	
10. Remote Range Switching [ ]	
AC Power 50 HZ [ ] 60 HZ [ ]	
Source Part No. 630952 [ ] 635898 [ ]	
Window Material:	
Sapphire [X] Irtran [ ] Other [ ]	Engineer: Sheila Sutherland
Calibration Pressure:	
Atmospheric [X] Other [ ]	Date: September 5, 1975
Remarks:	

Interference Gas	Mol %	Resp. Equiv.
1.		
2.		
3.		



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PROCESS INSTRUMENTS DIVISION
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INFRARED ANALYZER CALIBRATION & DATA SHEET

Customer: MAECON INC.
Address: ALBANY, OREGON
Application: CARBON MONOXIDE
Ranges: 1. 0-100% 2. IDLE 3. 0-10%

1. Uncalibrated Linearizer Range 1 [X]
2. Calibrated Linearizer Range 1. [ ] 2. [ ] 3. [ ]
   Refer to switch chart on schematic
3. Gas Free Calibration Assy. [ ]
   Sapphire [ ] Irtran [ ] Other [ ]
4. Calibration Curve [ ] Typical Curve [X]
5. Current Output Board [ ]
6. Bench Mounting Kit [ ]
7. Stainless Steel Tubing [ ] Teflon Tubing [X]
8. Air Purge Kit [ ]
9. Explosion Proof Case [ ]
10. Remote Range Switching [ ]
    AC Power 50 HZ [ ] 60 HZ [X]
    Source Part No. 630952 [X] 635898 [ ]
    Window Material:
    Sapphire [X] Irtran [ ] Other [X] MICA
    Calibration Pressure:
    Atmospheric [X] Other [ ]

Remarks:

S.O. No.: DC74171
P.O. No.: 7565-3
Model No.: 864-13-1-7
Serial No.: 101460

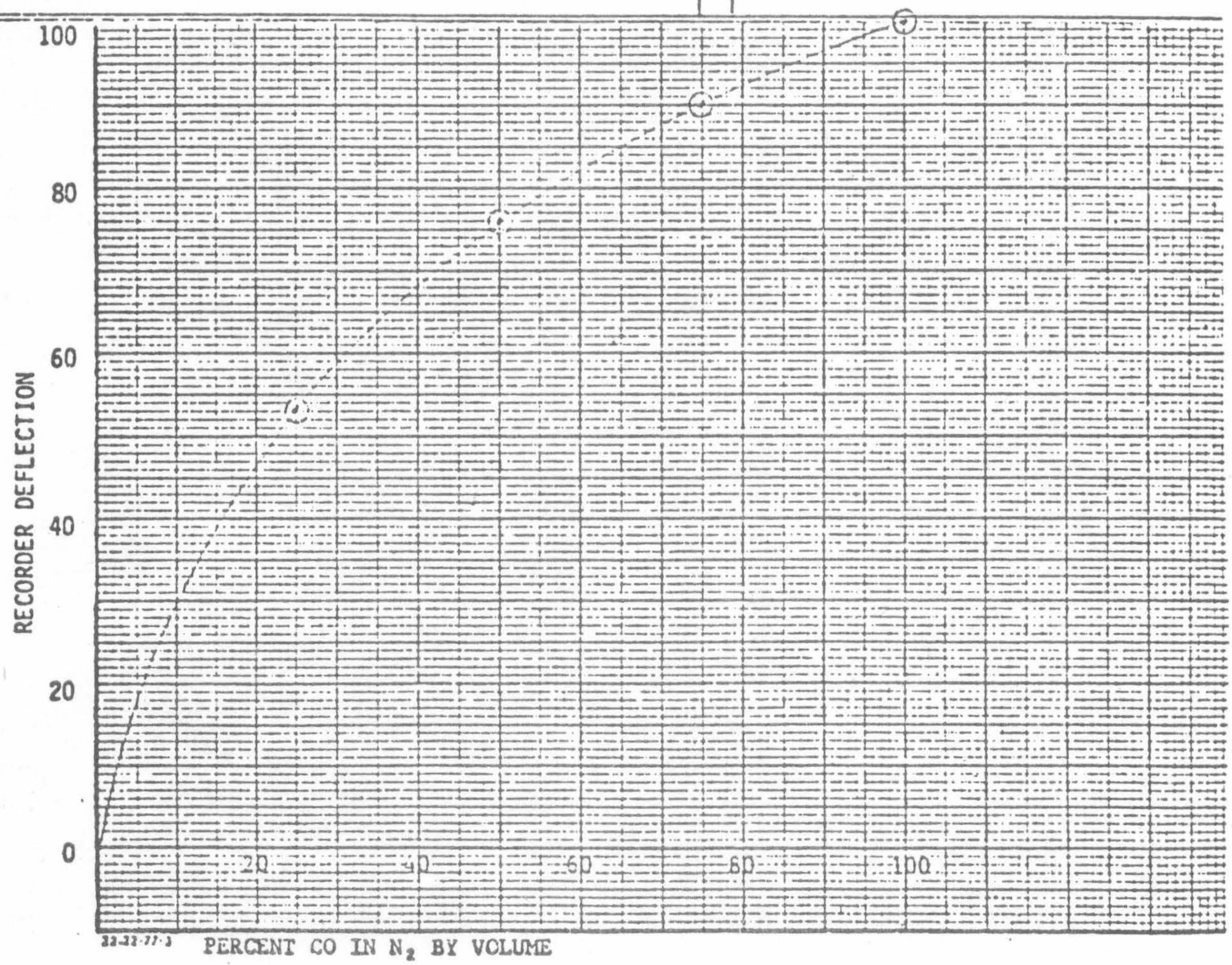
Detector Ser. No.: 0750-E
Detector Part No.: 633938
Tag No.: AX-406
Configuration No.: 788913

Repeatability: (In % of F.S.)
Range 1: ±1% Range 3: ±
Range 2: % Range 4: %

Interference Gas	Mol %	Resp. Equiv.
1. CO_2	10	0
2.		
3.		

Engineer: Suds Sutherland

Date: September 5, 1975



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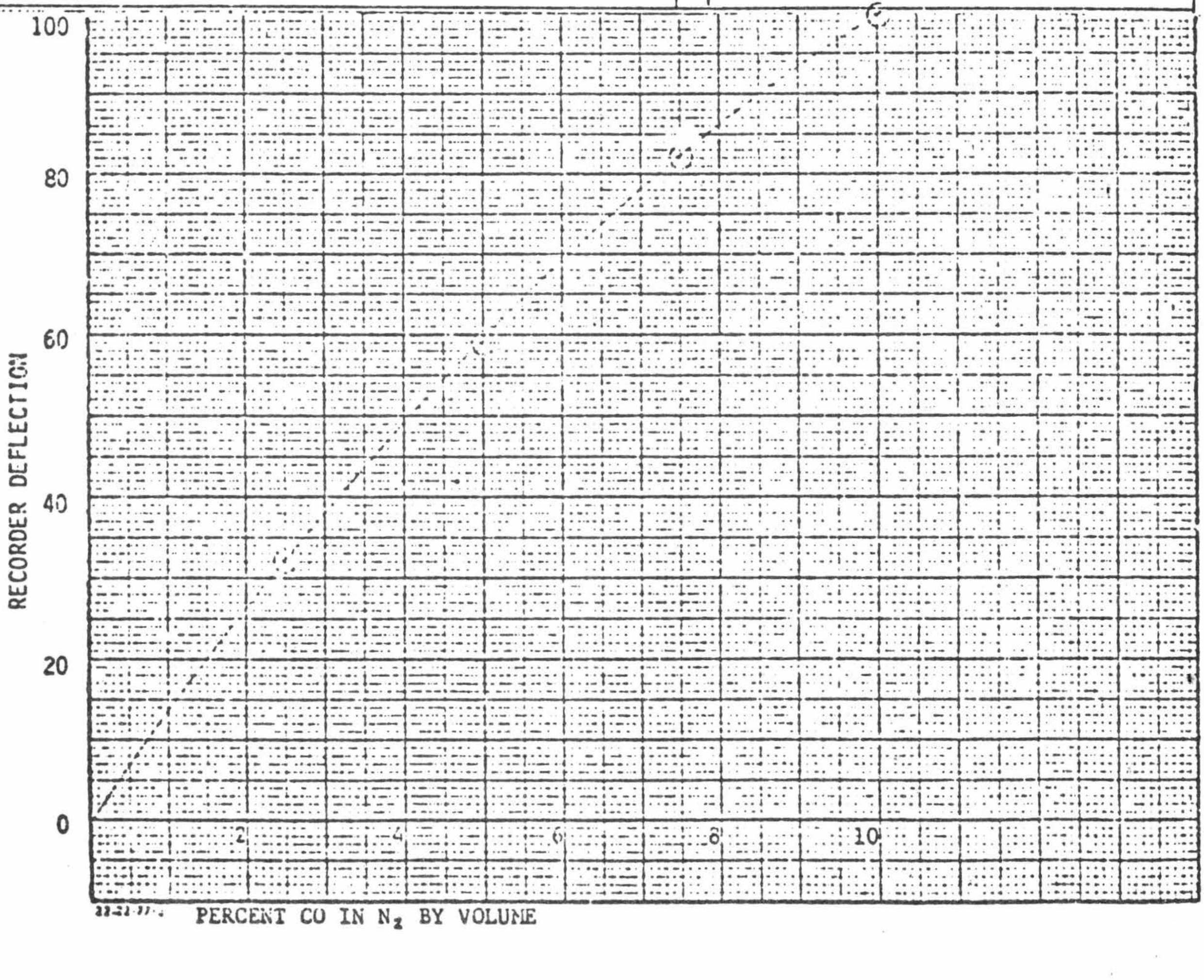
INFRARED ANALYZER CALIBRATION & DATA SHEET

Customer: MAECON INC.	S.O. No.: DC 74171
Address: ALBANY, OREGON	P.O. No.: 7565-3
Application: CARBON MONOXIDE	Model No.: 864-13-1-7
Ranges: 1. 2. 3. 0-10%	Serial No.: 101476
1. Uncalibrated Linearizer Range 1 [ ]	
2. Calibrated Linearizer Range 1. [ ] 2. [ ] 3. [ ]	Detector Ser. No.: 3159-E
Refer to switch chart on schematic	Detector Part No.: 633938
3. Gas Free Calibration Assy. [ ]	Tag No.: AX-408
Sapphire [ ] Irtran [ ] Other [ ]	Configuration No.: 788913
4. Calibration Curve [ ] Typical Curve [X]	
5. Current Output Board [ ]	Repeatability: (In % of F.S.)
6. Bench Mounting Kit [ ]	Range 1: % Range 3: %
7. Stainless Steel Tubing [ ] Teflon Tubing [ ]	Range 2: % Range 4: %
8. Air Purge Kit [ ]	
9. Explosion Proof Case [ ]	Interference Gas / Mol % / Resp. Equiv.
10. Remote Range Switching [ ]	1.
AC Power 50 HZ [ ] 60 HZ [ ]	2.
Source Part No. 630952 [ ] 635898 [ ]	3.
Window Material:	
Sapphire [X] Irtran [ ] Other [ ]	Engineer: [signature]
Calibration Pressure:	
Atmospheric [X] Other [ ]	Date: September 15, 1975
Remarks:	



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INFRARED ANALYZER CALIBRATION & DATA SHEET

Customer: MAECON INC
Address: ALBANY, OREGON
Application: CARBON MONOXIDE
Ranges: 1. 0-100% 2. IDLE 3. 0-10%
1. Uncalibrated Linearizer Range 1 [X]
2. Calibrated Linearizer Range 1. [ ] 2. [ ] 3. [ ]
Refer to switch chart on schematic
3. Gas Free Calibration Assy. [ ]
Sapphire [ ] Irtren [ ] Other [ ]
4. Calibration Curve [ ] Typical Curve [X]
5. Current Output Board [ ]
6. Bench Mounting Kit [ ]
7. Stainless Steel Tubing [ ] Teflon Tubing [X]
8. Air Purge Kit [ ]
9. Explosion Proof Case [ ]
10. Remote Range Switching [ ]
AC Power 50 HZ [ ] 60 HZ [X]
Source Part No. 630952 [X] 635898 [ ]
Window Material:
Sapphire [X] Irtran [ ] Other [X] MICA
Calibration Pressure:
Atmospheric [X] Other [ ]
Remarks: MOTOR SOURCE ASSEMBLY REPLACEMENT: 633773

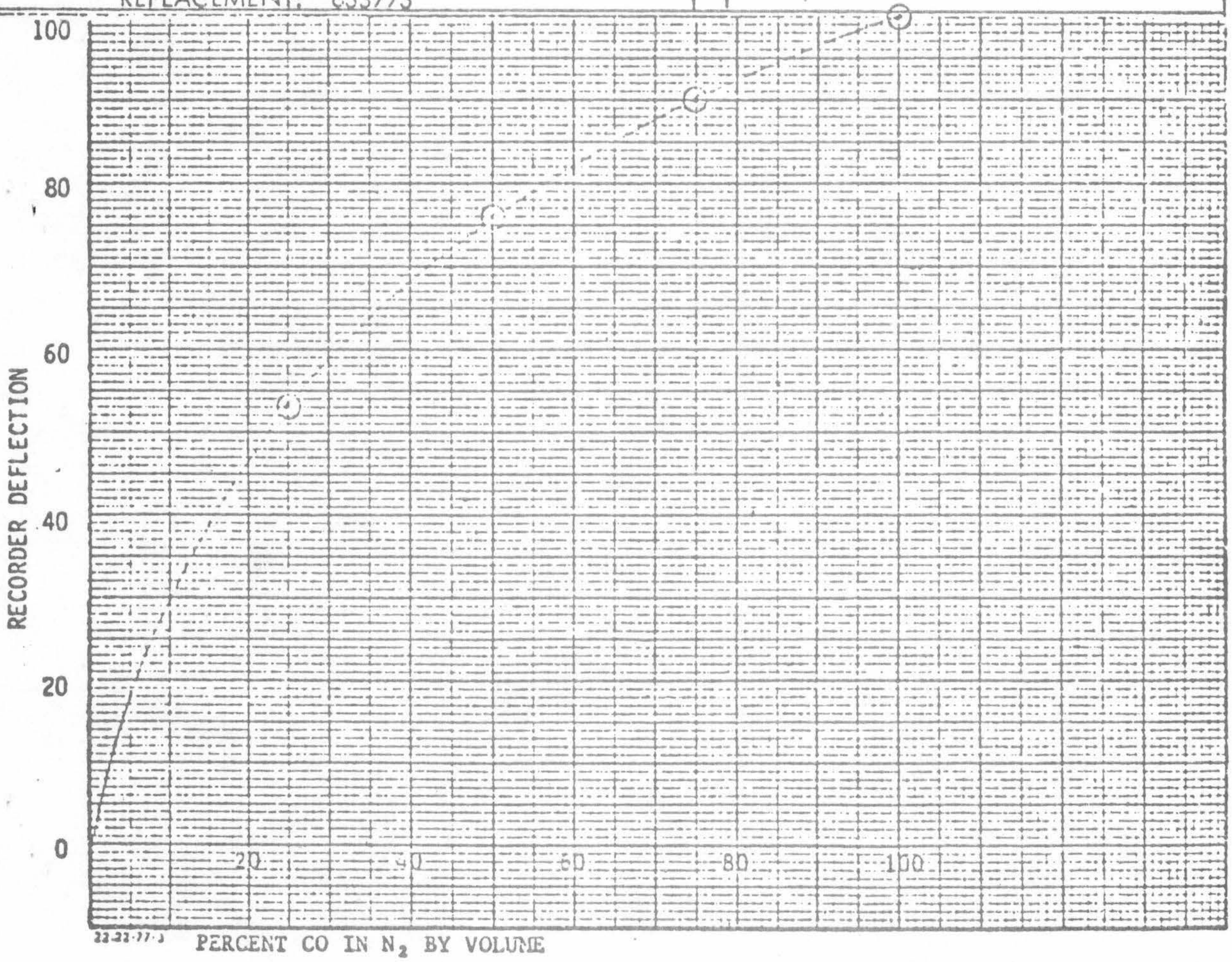
S.O. No.: DC 74171
P.O. No.: 7565-3
Model No.: 864-13-1-7
Serial No.: 101476

Detector Ser. No.: 3159-E
Detector Part No.: 633938
Tag No.: AX-408
Configuration No.: 788913

Repeatability: (In % of F.S.)
Range 1: ±1 % Range 3: ±1 %
Range 2: % Range 4: %

Interference Gas	Mol %	Resp. Equiv.
1. CO_2	10	0
2.		
3.		

Engineer: Suds Sutherland
Date: September 15, 1975



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INFRARED ANALYZER CALIBRATION & DATA SHEET

Customer: MARCON INC.
Address: ALBANY, OREGON
Application: CARBON DIOXIDE
Ranges: 1. 0-100% 2. IDLE 3. IDLE

1. Uncalibrated Linearizer Range 1 [X]
2. Calibrated Linearizer Range 1.[ ] 2.[ ] 3.[ ]
   Refer to switch chart on schematic
3. Gas Free Calibration Assy.[ ]
   Sapphire[ ] Irtran [ ] Other [ ]
4. Calibration Curve [X] Typical Curve [ ]
5. Current Output Board [ ]
6. Bench Mounting Kit [ ]
7. Stainless Steel Tubing [ ] Teflon Tubing [X]
8. Air Purge Kit [ ]
9. Explosion Proof Case [ ]
10. Remote Range Switching [ ]
   AC Power 50 HZ [ ] 60 HZ [X]
   Source Part No. 630952 [X] 635898 [ ]
   Window Material:
   Sapphire [X] Irtran [ ] Other [ ]
   Calibration Pressure:
   Atmospheric [X] Other [ ]

Remarks: MOTOR SOURCE ASSEMBLY
REPLACEMENT: 638450

S.O. No.: DC 74171
P.O. No.: 7565-3
Model No.: 865-26-1-7
Serial No.: 100833

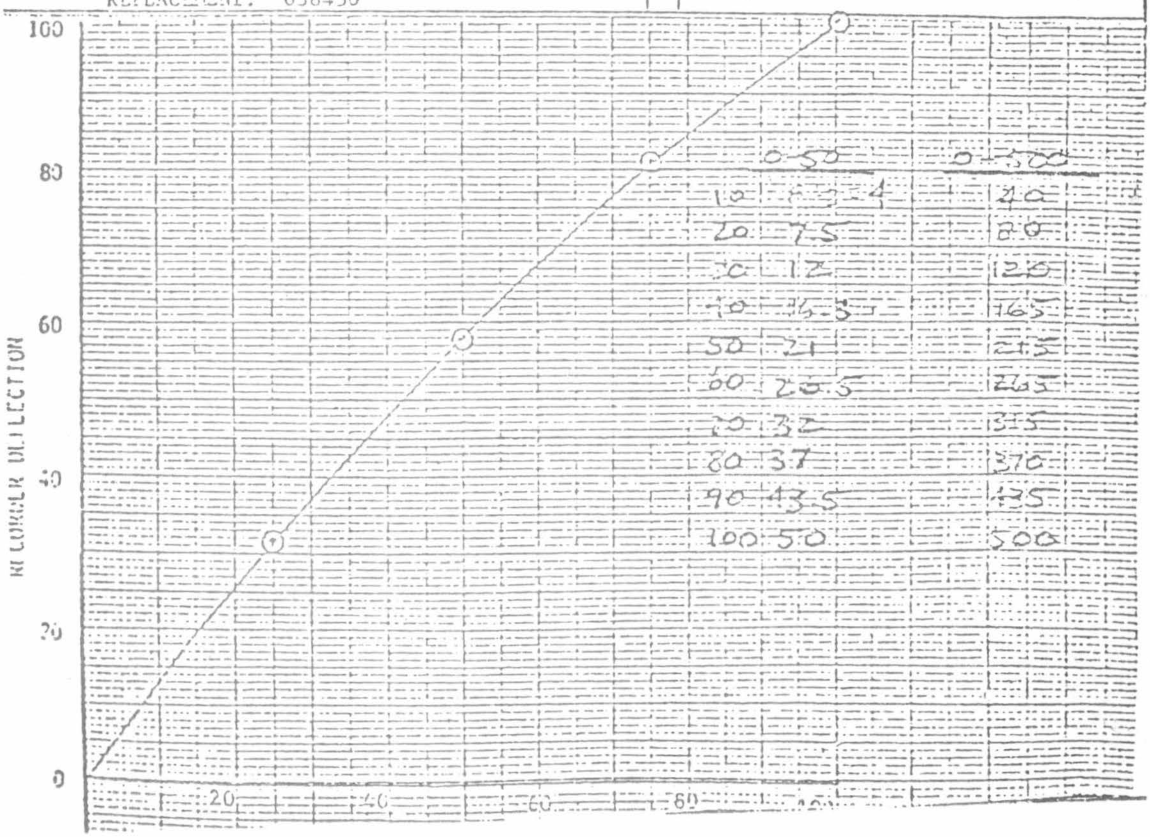
Detector Ser. No.: 2726-E
Detector Part No.: 633943
Tag No.: AX409
Configuration No.: 788926

Repeatability: (In % of F.S.)
Range 1: ±1% Range 3: %
Range 2: % Range 4: %

Interference Gas	Vol %	Resp. Equiv.
1.		
2.		
3.		

Engineer: Suds Sutherland

Date: September 8, 1975



SYSTEM

Knock-Out Drums/Flare Inlet System
1. Reactor Off-Gas Knock-Out Drum

MANUFACTURER

Maecon Inc., Santa Fe Springs, California

MODE OF OPERATION

Condensed oily water from the reactor off-gas cooler is separated from the noncondensible gas stream by the off-gas knock-out pot.

MANUFACTURER SPECIFICATIONS

None.

PERFORMANCE DATA

None. Feed inlet now enters through the gas outlet pipe above the vessel.

MECHANICAL HISTORY & MODIFICATIONS

No difficulties encountered to date. However, piping design is unsatisfactory and will not permit gas/liquid separation.

CONCLUSIONS & RECOMMENDATIONS

Feed inlet piping should be rerouted to enter the vessel 1/3 up from the bottom for proper gas/liquid disengaging.

SYSTEM

Knock-Out Drums/Flare Inlet System
2. Bottoms Flash Gas Knock-Out Drum

MANUFACTURER

Maecon Inc., Santa Fe Springs, California

MODE OF OPERATION

Water condensed in the bottoms flash cooler is accumulated and removed from any noncondensible gases in the bottom flash knock-out drum.

MANUFACTURER SPECIFICATIONS

None.

PERFORMANCE DATA

None.

MECHANICAL HISTORY & MODIFICATIONS

No difficulties encountered to date.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Knock-Out Drums/Flare Inlet System
3. Flare Inlet Header

MANUFACTURER

Maecon Inc., Santa Fe Springs, California

MODE OF OPERATION

Reactor off gas and bottom flash gas noncondensibles are fed into the flare inlet header which combines all plant gas streams before entering the flare. Installed in August to prevent anthracene surge into the flare.

MANUFACTURER SPECIFICATIONS

None.

PERFORMANCE DATA

None.

MECHANICAL HISTORY & MODIFICATIONS

Original installation of inlet header had a low point in the line where water and oils could accumulate and plug the system. The line was rolled to eliminate the low point, and a drain valve was installed to drain any condensate.

CONCLUSIONS & RECOMMENDATIONS

System operation has been satisfactory since modification.

SYSTEM

Reactor Bottoms Cooler

MANUFACTURER

Thermal Finned Processors Inc.

MODE OF OPERATION

The reactor bottoms which should consist of product/ carrier oil and unreacted/partially reacted solids is cooled from 700°F to 400°F in the reactor bottoms cooler.

MANUFACTURER SPECIFICATIONS

Duty	= 116,000 Btu/hr
Oil Flow Rate	= 507 lbs/hr
Tube Design Pressure	= 4400 psig

PERFORMANCE DATA

Operation of cooler without fan and the top louvers closed has cooled reactor bottoms to 200°F. Occasional bumping of fan has been required but never continuous operation. During startup, difficulty was encountered with anthracene plugging cooler tubes and being unable to flow even with reactor pressure at 1200 psig.

MECHANICAL HISTORY & MODIFICATIONS

None.

CONCLUSIONS & RECOMMENDATIONS

The unit appears to be oversized for service.

SYSTEM

Pressure Letdown Valves

MANUFACTURER

Masoneilan Corp., Montebello, California

MODE OF OPERATION

The reactor bottoms is depressurized from 4000 psig to 10 psig across either LV-315 A or B.

MANUFACTURER SPECIFICATION

Maximum oil flow rate = 507 lbs/hr
ΔP across valve = 3950 psi

PERFORMANCE DATA

Satisfactory. At 50 gph oil flow through the system, the valve runs 20% open. The valve is occasionally opened to 80% to unplug the orifice.

MECHANICAL HISTORY & MODIFICATIONS

Valve operation satisfactory until August 19, 1977, when plug broke. Previous to this, pieces of Buna-N rubber had plugged valve. Also, pieces of "rock-like" carbon have stopped flow.

CONCLUSIONS & RECOMMENDATIONS

LY-315 B should be relocated closer to the bottoms flash tank to reduce pipe length of two-phase flow mixture. This will avoid overpressurization potential.

SYSTEM

Bottoms Flash Tank

MANUFACTURER

Maecon Inc., Santa Fe Springs, California

MODE OF OPERATION

The mixture of product oil, solids and flashed gases is separated in the bottoms flash tank. Gases flow to the LP cooler, and oil/solids flow to the centrifuge feed pump suction.

MANUFACTURER SPECIFICATIONS

Capacity = 45 gal
Material = 316 SS

PERFORMANCE DATA

Size is satisfactory.

MECHANICAL HISTORY & MODIFICATIONS

Level transmitter (LX-402) gas line rerouted to the bottoms flash tank off gas line due to plugging with oil at previous location. Amount of off gas flow less than 1 scfm cannot be measured with 13/64-inch orifice, but this is insignificant in the overall material balance.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Centrifuge

MANUFACTURER

Centrico Inc., Belmont, California

MODE OF OPERATION

Product oil, carrier oil, unreacted solids, ash and an aqueous phase are fed to a continuous centrifuge which clarifies the oil and water phases and intermittently blows down the solids.

MANUFACTURER SPECIFICATIONS

Feed Rate = 160 to 600 lbs/hr @ 210^{o}F
Variable Feed Composition
Solids Size = $<$50 mesh
Product Oil Sp. Gr. = 1.15 @ 60^{o}F

PERFORMANCE DATA

On April 27, 1977, manufacturer representative started up centrifuge and separated water and anthracene (no solids separation). Amount of flush water required for each blowdown cycle = 1.74 gal. Unit is flushed every three minutes. One analysis of blowdown sludge was 11% solids, 26% water, and 63% oil.

MECHANICAL HISTORY & MODIFICATIONS

Ring dam setting changed from 95 to 85 mm to clarify aqueous/oil phases. Plugging of bowl with excess solids resulted in violent vibration and loosening of head cover. Solids discharge pipe modified to eliminate splashing of oil during blowdown cycle.

CONCLUSIONS & RECOMMENDATIONS

Amount of oil entrained with blowdown solids appears high. This will adversely affect oil yield material balances. The centrifuge must be fine tuned to achieve a better degree of separation. The Centrico may not be the best unit for this application. Furthermore, a centrifuge may not be required for the process.

SYSTEM

Filters (Product Oil)

MANUFACTURER

AMF Inc.

MODE OF OPERATION

The product oil from the centrifuge flows to a 10 gal product oil surge pot and is pumped back to the blender with occasional bleedoff as the level in the pot increases to product oil drums. On the discharge side of the pump are two cartridge filters to remove any remaining solids.

MANUFACTURER SPECIFICATIONS

Remove 60 micron particles and larger at 2 gpm maximum from heavy oil (@ 200^{o}F).
Maximum ΔP dirty = 50 psi.

PERFORMANCE DATA

No tests since heaters added.

MECHANICAL HISTORY & MODIFICATIONS

Attempts to pump anthracene at ~190^{o}F failed with bags in the filters because of rapid pluggage by anthracene crystals. Strip heaters added to maintain 200-120^{o}F temperature. Filters have been operated without bags, since fine solids removal has not been necessary.

CONCLUSIONS & RECOMMENDATIONS

The value of final solids removal is questionable. These filters are a potential plugging problem in the process.

SYSTEM

Pretreater Vessel & Heatup

MANUFACTURER

Maecon Inc., Santa Fe Springs, California

MODE OF OPERATION

Wood chips are conveyed into either of two pretreaters. Water is metered and the system secured. Heat is applied externally by tubular electric heaters, and the temperature of the mixture is raised to 500°F. Internal steam pressure generated will be 750 psig. At the end of the heatup cycle the mixture is pumped through an air cooler, cooled to 150°F, and dumped into the pretreated wood slurry hold tank.

MANUFACTURER SPECIFICATIONS

Capacity = 375 gal
Vessel Press. Rating = 3000 psig
Agitator Seal Press. Rating = 750 psig
Heater Duty = 1.6 MM Btu/hr

PERFORMANCE DATA

System has been inoperative. Awaiting installation of agitator seal oil recirculation system.

MECHANICAL HISTORY & MODIFICATIONS

Two tests conducted on pretreatment. First test aborted because of fire on vessel head due to leaking agitator seal oil. Second test was terminated early, after a sudden depressurization due to operator error.

CONCLUSIONS & RECOMMENDATIONS

Recirculating seal oil system required to prevent damage to agitator mechanical seals. Installation of 3000 psi seals should be investigated in order to operate pretreaters as batch autoclaves.

SYSTEM

Pretreater Circulation Pumps

MANUFACTURER

Wilson Snyder Co., Garland, Texas

MODE OF OPERATION

Pretreated wood slurry is pumped (starting at 500°F, 750 psig) through an air cooler and back into the pretreater until the mixture temperature is 140°F.

MANUFACTURER SPECIFICATIONS

Capacity = 5 gpm
Maximum Discharge Pressure = 100 psig
Viscosity = 80,000
CP @ min. PT = 140°F
Solids Content = 30 to 50 wt %

PERFORMANCE DATA

None.

MECHANICAL HISTORY & MODIFICATIONS

Pump modified to allow recirculating oil to flow through seal. Motor hp increased from 3 to 5.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Pretreated Wood Slurry Cooler

MANUFACTURER

Thermal Finned Process Inc.

MODE OF OPERATION

See Pretreated Wood Slurry Pump.

MANUFACTURER SPECIFICATIONS

Duty	= 1.6×10^6 Btu/hr
Fluid Flow Rate	= 30,000 lbs/hr
Temperature In	= 500°F to 140°F
Design Tube Pressure	= 1250 psig

PERFORMANCE DATA

None.

MECHANICAL HISTORY & MODIFICATIONS

Plugging occurred during one of the early tests. The plug was easily removed with plant air.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Pretreated Wood Slurry Tank

MANUFACTURER

Maecon Inc., Santa Fe Springs, California

MODE OF OPERATION

Cooled pretreated wood slurry is stored in the pretreated wood slurry hold tank in batches. Slurry is then fed to the vacuum filter.

MANUFACTURER SPECIFICATIONS

Capacity = 544 gal.
Pressure = atm.
Material = CS

PERFORMANCE DATA

None.

MECHANICAL HISTORY & MODIFICATIONS

None.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Pretreated Wood Vacuum Filter

MANUFACTURER

Straight Line Filters Inc., Maryland

MODE OF OPERATION

Pretreated Wood Slurry is vacuum filtered to remove excess water before feeding solids to the wood chip dryer.

MANUFACTURER SPECIFICATIONS

Slurry feed rate = 550 lbs/hr
% solid in slurry out = 15.5 wt %
Operating temperature = 150°F

PERFORMANCE DATA

Never tested.

MECHANICAL HISTORY & MODIFICATIONS

None.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Lock Hopper System Sequencing Studies

MANUFACTURER

Maecon Inc./Wiscomb Weidner Co., Salt Lake City, Utah

MODE OF OPERATION

The feed/pressurization/reactor feed/depressurization cycles of both lock hoppers are automatically controlled by an electronic controller in the main control panel.

MANUFACTURER SPECIFICATIONS

None available. (Refer to Rust Eng. Co. logic diagram.)

PERFORMANCE DATA

None. Sequencing studies completed, and the electrical sequencing system is functioning satisfactorily.

MECHANICAL HISTORY & MODIFICATIONS

Manufacturer representative operated the controller through two complete cycles for each lock hopper. Dummy pressure and level input signals were used. Cycles were run through in automatic and manual modes.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Lock Hopper Solids Feed/Level Control

MANUFACTURER

Fluidizer Inc., Minneapolis, Minnesota (Airlock Feeder)
Kay Ray Inc. (Level Control)

MODE OF OPERATION

Wood flour is removed from the wood flour surge bin and fed into either one of two lock hoppers. Fill time is approximately 10 minutes. The rotary air lock valve is the same as feeds the weight belt feeder.

MANUFACTURER SPECIFICATIONS

Flour feed rate = 900 lbs/hr.

PERFORMANCE DATA

None.

MECHANICAL HISTORY & MODIFICATIONS

Feeder throughput verified to be 900 lbs/hr. Gamma ray level indication system has not been operated.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Lock Hopper Pressurization

MANUFACTURER

American Instrument Co., Silver Spring, Maryland

MODE OF OPERATION

Carbon monoxide is used to pressurize the lock hoppers from atmospheric pressure to 4100 psig. The pressurization time can vary from 30 minutes to one hour depending on overall sequence time. CO is depressurized to 50 psig and stored in a surge tank for recycle and pressurization.

MANUFACTURER SPECIFICATIONS

See CO Compression.

PERFORMANCE DATA

See CO Compression.

MECHANICAL HISTORY & MODIFICATIONS

See CO Compression.

CONCLUSIONS & RECOMMENDATIONS

None.

SYSTEM

Lock Hopper Solids Feed to Reactor

MANUFACTURER

Sprout Waldron Co.

MODE OF OPERATION

Wood flour is metered into the reactor by rotary air-lock feeders inside each lock hopper. Flour is fed at 150 lbs/hr for one hour through each lock hopper.

MANUFACTURER SPECIFICATIONS

Variable feed rate = 25 to 150 lbs/hr.

PERFORMANCE DATA

None.

MECHANICAL HISTORY & MODIFICATIONS

Equipment no operated.

CONCLUSIONS & RECOMMENDATIONS

None.

PLANT MOTOR ELECTRICAL LOAD MEASUREMENTS

Equipment	Volts	Start-up amps	Running amps
pneumatic conveyor	454		6.2, 5.6, 6.0
ground wood screen	451	17.2	2.2, 2.1, 2.6
grinder	454	616	30, 26.8, 27.1
grinder feeder	455	27.5	1.9, 2.0, 2.6
bin activator-dried wood surge bin	451	20.1	2.5, 2.5, 2.8
feed slurry recirucation pump	454	57.1	4.8, 3.9, 4.3
w/o blender agitator A (inner)	453	39.5	2.8, 3.7, 2.8
w/o blender agitator B (outer)	453	42.7	4.1, 6.1, 4.6
- anthracene	60°F for both agitators		
table feeder	449	9.1	1.2, 1,3, 1.0
screw conveyor to dryer inlet	451	19.5	2.0, 2.0, 1.7
feed airlock to dryer inlet	451	6.0	0.8, 0.8, 0.7
dryer I.D. fan	451	90	9.0, 8.9, 8.5
trickle valve	451	6.3	0.9, 0.9, 0.8
dryer drumdrive	453	35.6	3.5, 3.3, 3.3
airlock feeder dyer disharge	453	34.6	31., 3.0, 2.9
screw conveyor-oversize	453	15.6	1.3, 1.6, 1.5
bucket elevator	449	31.5	3.5, 2.9, 3.3

Equipment	Volts	Start-up amps	Running amps
dryer package	449		13.3, 14.4, 13.2
weigh belt feeder	457	3.4	0.8, 0.5, 0.7
instrument aie camp A	453 - not operational		
instrument air camp B	453		18.9, 19.1, 20.5
oil hold tank	circuit		
volts	A 233, B 208, B 241	A 283, B 261, C 272	A 378, B 369, C 372
amps	1 1 a	1 3 3	3 4 4
controller %	25%	50%	75%
volts	A B C 462 441 457		
amps	5 6 6		
controller %	100%		
pneumatic conveyor: airlock feeder 454 volts 10.3 amps startup 1.7, 2.1, 1.7 amps running			
N_2 blower	454	51.6	4.6, 4.7, 4.1
oil feed pump A	447	9.5	1.8, 1.7, 1.7
oil feed pump B	449	8.4	1.9, 1.7, 1.6
Centrifuge feed pump A	449	62.1	5.8, 5.3, 5.5
Centrifuge feed pump B	448	62.9	5.6, 5.4, 5.9
product oil recycle pump	448	63.6	5.4, 5.1, 5.3
low press. catalyst pump	447	12.3	2.0, 1.7, 1.7
catalyst transfer pump	452	32.4	2.8, 2.8, 2.7
feed slurry pump	448	160	20.9, 20.3, 20.9
pretreated wood slurry cooler fan	449	85.6	15.8, 15.0, 15.1
High press. catalyst pump A	451	27.1	2.1, 2.8, 2.0

Equipment	Volts	Start-up amps	Running amps
High press. catalyst pump B	448	35.6	3.0, 2.8, 2.8
pretreated wood slurry hold tank agitator	449	12.7	2.0, 1.9, 1.7
Catalyst mix tank agitator	449	2.3	0.3, 0.6, 0.4
			2.8, 2.8, 2.7
feed slurry pump	448	160	20.9, 20.3, 20.9
bottoms cooler fan	450	13.4	2.2, 2.1, 2.1
pretreated wood slurry cooler fan	449	85.6	15.8, 15.0, 15.1
high press catalyst pumps A	451	27.1	2.1, 2.8, 2.0
high press catalyst pumps B	448	35.6	3.0, 2.8, 2.8
pretreated wood slurry hold tank agitator	449	12.7	2.0, 1.9, 1.7
catalyst mix tank agitator	449	2.3	0.4, 0.6, 0.4
vacuum filter feed pump	452	23.5	2.7, 2.5, 2.4
flare stack	452	12.2	1.3, 1.1, 1.2
CO camp. I-A	450	78.3	9.5, 9.5, 9.7
CO camp I-B	453	79.7	9.4, 8.9, 9.1

Equipment	Volts	Start-up amps	Running amps
effluent transfer pump			
- run dry	450	21	1.7, 1.3, 1.3
vacuum filter package			
running	454		8.1, 8.0, 8.3
vacuum filtrate pump	454	11.4	1.0, 0.8, 1.0
vacuum pump	450	61.5	6.3, 6.6, 6.3
Belt drive	450	6.1	0.8, 0.8, 0.8

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