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EDS COAL LIQUEFACTION PROCESS DEVELOPMENT, PHASE V
EDS Consolidation Program, Flushing and Blowdown System Design
Interim Report

January 1984
Date Submitted

Work Performed Under Contract No. FC05-77ET10069

Exxon Research and Engineering Company
Florham Park, New Jersey

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EDS COAL LIQUEFACTION PROCESS DEVELOPMENT

PHASE V

EDS Consolidation Program
Flushing and Blowdown System Design

Interim Report

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Submitted - January, 1984

PREPARED FOR
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EDS COAL LIQUEFACTION PROCESS DEVELOPMENT - PHASE V
EDS CONSOLIDATION PROGRAM
FLUSHING AND BLOWDOWN SYSTEM DESIGN

Abstract

This is an Interim Report prepared under the U.S. Department of Energy Cooperative Agreement No. DE-FC05-77ET10069 for EDS Coal Liquefaction Process Development - Phase V. Funding for the EDS Project is shared by U.S. Department of Energy, Exxon Company, U.S.A. (a division of Exxon Corporation), Electric Power Research Institute, Japan Coal Liquefaction Development Company, Phillips Coal Company, Anaconda Minerals Company, Ruhrkohle AG, and ENI. The agreement covers the period January 1, 1977 through December 31, 1984. The laboratory process research and development studies were conducted at various Exxon Research and Engineering (ER&E) facilities: Research and Development Division at Baytown, Texas; Products Research Division at Linden, New Jersey; and the Exxon Research and Development Laboratories at Baton Rouge, Louisiana. The engineering research and development studies were performed by the Exxon Engineering Synthetic Fuels Department, Technology Department, and Petroleum Department at Florham Park, New Jersey.

This report documents the results of a study which evaluates the flushing and blowdown requirements for a commercial-scale EDS plant. The work was conducted as part of the EDS Consolidation Program. The design recommendations represent a consolidation of learnings accrued during previous phases of the EDS Project including results obtained from ECLP operations, from the ECLP Test Program, and from past EDS Study Design preparations.

FLUSHING AND BLOWDOWN SYSTEM DESIGN

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EDS CONSOLIDATION PROGRAM

FLUSHING AND BLOWDOWN SYSTEM DESIGN

This report documents the results of a study which evaluates the flushing and blowdown system design requirements for a commercial-scale EDS plant. The work was conducted as part of the EDS Consolidation Program. The design recommendations represent a consolidation of learnings accrued during previous phases of the EDS Project including results obtained from ECLP operations, from the ECLP Test Program, and from past EDS Study Design preparations.

General Description

The flushing and blowdown system of an EDS plant provides the means of removing viscous coal products and slurry streams from plant vessels and lines. In addition, it provides the flushing oil needed during normal operations for purging instruments in slurry service, for flushing slurry pump and slurry agitator seals, and for flushing slurry safety valve inlet lines. It contains a blowdown system for collecting material from washing operations, including the transport of the collected material to slop tankage. The rerun options for depleting the inventory of collected slop are a related aspect of the flushing and blowdown system design although specific equipment for handling slop is not part of the flushing and blowdown system facilities.

This report is broken into seven subsections to describe the items which should be considered when designing a commercial-scale flushing and blowdown system. "Flushing Source Requirements" describes items which should be evaluated when determining the appropriate source and supply conditions of flush oil for various plant users. "Specific Flush Oil User Requirements" discusses specific requirements by equipment user category, e.g., pumps, valves, instrument taps, etc. "Flushing Oil Supply Requirements" highlights the design considerations for the major flushing oil supply headers. "Blowdown Requirements" presents information on the design of the blowdown collection system which includes the blowdown headers and the blowdown collection vessels and transport pumps. "Slop Rerun" discusses the various options available for management of slop inventories including recommendations for preferred rerun procedures. "Miscellaneous Considerations" provides non-specific design consideration items which should be evaluated. And "Commercial Plant Design" presents simplified flow plans with design notes which incorporate the recommendations of the report into an overall guidance procedure for a pioneer plant design.

Summary of Major Recommendations

The major recommendations which result from this study are summarized below. Other items, not summarized, may have equal importance in the design of a commercial-scale flushing and blowdown system. However, the summarized items represent areas where this study has identified different approaches for the design relative to previous methods used for study design descriptions of the flushing and blowdown system requirements.

- Flushing Oil Media

Past study designs have only provided recycle solvent as a plant-wide flushing medium. ECLP experience indicated that a higher temperature, lower volatility medium was preferred for flushing the equipment in the vacuum fractionator area. In addition, a higher boiling point flush oil than recycle solvent was required for flushing pumps in vacuum bottoms service. As a result, it is recommended that a vacuum gas oil flush oil system, maintained at a 550°F supply temperature, be provided for future commercial plant designs.

- Supply System Pressure Levels

At ECLP, thirteen subsystem pressure levels ranging from 85 to 3000 psig were provided to supply flushing oil to various plant users. ECLP operations personnel judged that the complexity of these multi-level systems was undesirable. For future commercial plant designs, it is recommended that two pressure-level supply systems be provided for the recycle solvent flushing medium and one pressure-level supply system be provided for the vacuum gas oil flushing medium. The systems will be maintained at the highest normal operating pressure of any equipment item which uses the system. Although this may require raising the design pressure of a few equipment components in the plant, it eliminates the need for numerous pressure control and safety valves. It also lowers the number of auxiliary flushing oil supply pumps needed as slurry pump auxiliary equipment and eliminates the need for many flush oil accumulators pressurized by recycle gas.

- Flush Oil Donor Hydrogen Level

To minimize the impact on yields or coal throughput, recycle solvent flush oil should preferentially be composed of hydrogenated recycle solvent. A portion of the flush oil is normally used to flush slurry pumps, instrument taps, and safety valves and therefore enters the normal process flow path. In addition, all flush oil used during non-normal operations is collected as slop from the blowdown system and eventually must be rerun. In both instances, high donor hydrogen levels in the flush oil will result in the minimum impact on normal operations. Reduction in the quantity of recycle solvent normally supplied to liquefaction from the solvent fractionators to meet the target solvent-to-coal ratio should be possible by an amount approaching the slop rerun and normal user rates if the flush oil has nearly equivalent donor hydrogen quality.

- Use of Centrifugal Pumps in Slurry Services

Wherever possible, centrifugal pumps instead of positive displacement pumps should be used for slurry services. Centrifugal pumps have lower seal flush oil requirements than reciprocating pumps. Of probable greater importance is the fact that centrifugal pumps do not require slurry safety valves for overpressure protection while positive displacement pumps normally do. Other than for the high pressure liquefaction slurry feed pumps, which must be reciprocating, all other EDS plant slurry pumping services may be adaptable to use of centrifugal pumps. These include the blowdown collection and slop transport pumps as well as the vacuum bottoms pump.

- Slop Rerun

Slop should continuously be rerun during normal plant operations to deplete plant inventories. Slop management will be extremely important for a commercial EDS plant to maintain service factor and coal throughput at acceptable levels. Recycle solvent-type slop should be rerun during normal operations through the slurry drier. Vacuum gas oil-type slop should be rerun during normal operations by feed upstream of the vacuum fractionator preheat furnace. In addition, the product fractionator facilities should be utilized in a blocked operation following minor or major plant turnaround shutdowns to completely deplete both types of slop inventories before maintenance in the product fractionation areas begins.

- Train Integration

To provide flush oil in sufficient quantity to allow acceptable equipment flushing, enormous flow rates are required during worst-case operations. Except in the most unusual circumstances, it is unlikely that the full EDS plant will come down simultaneously. To allow some investment and operating cost savings at acceptable risk, integrating the plant's flushing oil supply system at the supply pump location is recommended.

1. Flushing Source Requirements

Several items should be considered when determining the appropriate source and supply conditions of flush oil for various plant users. In general, the plant-wide supply system which contains recycle solvent will be acceptable. However, in some instances, an alternative supply will better suit the needs of the user. In particular, vacuum gas oil, maintained at an elevated temperature level, is the preferred flushing oil medium for the product fractionation area of the plant.

• Initial Boiling Point

Initial boiling point of the flush supply is of importance when providing flushing fluid for pump sealing. To avoid flashing in the pump stuffingbox, the initial boiling point at the minimum stuffingbox pressure must be at least 100°F above the rated pumpage temperature. The minimum stuffingbox pressure should be assumed to be:

- Reciprocating pumps: Minimum suction pressure (based on NPSH calculation point)
- Centrifugal pumps with balance holes or pumping vanes on the back of the impeller: Suction pressure plus 10% of rated differential pressure
- Other centrifugal pumps: Suction pressure plus 66% of rated differential pressure
- Rotary screw pumps: Suction or discharge pressure, depending on pump design

From the standpoint of initial boiling point limitations, either recycle solvent or vacuum gas oil are acceptable as the source of stuffingbox flush supply oil for typical slurry pumps specified in EDS plant designs.

For flush oil supplied to other process users, the initial boiling point of the flushing fluid must be considered if it will result in vaporization when contact is made with the process fluid. Whether or not this will be of concern will depend on the service and the available vapor release path, and each service should be considered individually.

• Compatibility

Compatibility of flush oil supply with the user's process fluid will not be a problem as long as both source and user fluid are coal-derived. All coal liquids have proven to be compatible with each other. Only during initial startup, before inventories of coal-derived flush supplies have been established, would a potential problem exist. To avoid this potential problem, the fluid brought in for the initial startup inventory should be selected to insure compatibility with all coal-derived liquids and slurries. Creosote oil has proven to be acceptable for pilot plant demonstrations although a petroleum source may be necessary for commercial-scale plants to insure availability in sufficient quantity.

- Solids Content

In general, since flushing fluids are provided to remove solids from process equipment, the flushing supply should be as solids-free as possible. However, from a realistic viewpoint, the ability to completely remove solids from the flushing supply system may be difficult to achieve at all times. Because of this, users of flush oil which have stringent limitations on solids content should identify their requirements and provide design features at the user location which guarantees that the flush fluid has an acceptable solids concentration.

Where recycle solvent represents the flush fluid, solids content should not be a problem. Recycle solvent is derived following distillation of spent solvent at the product fractionation facilities and following processing in the solvent hydrogenation unit which contains a fixed-bed catalyst-filled reactor. This combination of processing should result in a solids-free recycle solvent.

When vacuum gas oil represents the flush fluid, the likelihood of solids contamination increases. Upsets in the product fractionators could result in solids carryover into the vacuum gas oil sidestream. Filters should be provided to eliminate solids which might be contained in the vacuum gas oil flush.

Flushing oil, whether recycle solvent or vacuum gas oil, which is supplied for pump sealing should always be filtered by the pump user for removal of tramp material. A common filtering unit is recommended for each flush system. The unit should consist of twin removable filters, which are monitored and alarmed for high differential pressure. The recommended filtering size is 75 micron (200 mesh). Gelling, or accumulation of gell-like materials in filters, was occasionally experienced at ECLP because of increases in fluid viscosity due to lowered fluid temperatures. Therefore, filters should be insulated or traced to prevent gelling. Note that gelling caused by chemical degradation was also experienced on one occasion at ECLP. Unhydrogenated solvent chemically degraded after being stored in a tank for a number of weeks.

Flush streams serving reciprocating pumps, and the barrier fluid portion of dual mechanical seals in centrifugal and rotary pumps, should be refiltered at each pump. Twin removable filters with a differential pressure indicator and alarm are recommended. Filtration of 10 microns is desirable for such applications; however, filtration of 25 microns may be more practical from an operation standpoint. Therefore, a 10 micron system which is easily adaptable to 25 microns is recommended. These specific requirements when applied to individual pumps should be considered when providing the auxiliary equipment necessary for the slurry pumping service under evaluation.

- Temperature

In general, the maximum supply temperature of the flush oil is not a concern as long as it is less than the process temperature of the flush oil user. One exception is when flush oil is supplied to reciprocating pumps.

cating pumps packed with teflon-based materials. In such cases, the flush supply temperature should not exceed 180°F.

Minimum supply temperature should be considered for all cases individually. The major concerns involve possible solidification of the process fluid at the user location and possible thermal shock to the user equipment. One area of particular concern is the vacuum bottoms piping. ECLP experience has resulted in the recommendation that 550°F flush oil be made available to this area to avoid solidification of the process fluid. This means that vacuum gas oil must be the flushing medium since recycle solvent would result in excessive vaporization at this temperature and the low system pressure.

- Pressure

Flushing oil supply systems which contain recycle solvent will be available within the EDS plant at two pressure levels. The high pressure system will be maintained at a pressure equivalent to the high pressure slurry feed pumps' discharge pressure. The low pressure system will be maintained at the highest process pressure found within the slurry drying and product fractionation areas of the plant. With such a combination of systems, flush oil can be made available to any area of the plant without the need for booster pumps for specific users.

Having only two levels of pressure supply will simplify the distribution of flush oil to the plant users. At ECLP, thirteen subsystem pressure levels ranging from 85 to 3000 psig were provided with each subsystem having its own pressure control valve and safety valve. The complexity of these multi-level pressure subsystems was judged to be undesirable and ECLP operations personnel recommended that commercial designs maintain only two or possibly three pressure level systems.

With only two pressure levels, care must be exercised when evaluating piping supply design systems to insure that process users cannot be overpressured by the flushing oil supply system. This may require raising the design pressure of a few equipment components within the plant.

The above discussion has dealt with the major flush oil supply systems which will contain recycle solvent. Another supply system which contains vacuum gas oil will be required in the EDS plant. The vacuum gas oil flush will be required for pump flushing within the product fractionation area and also for flushing of the vacuum bottoms lines. (ECLP experience indicated that 550°F flush oil be made available for this purpose to avoid solidification of the process fluid; use of recycle solvent at this temperature and at the low pressure levels in this system would result in excessive vaporization). This system will be maintained at one pressure level, equivalent to the maximum supply pressure found at the user locations.

- Donor Hydrogen Level

Donor hydrogen level of the flush oil has no importance in terms of the flush oil's ability to purge lines or serve its basic process purpose of removing or excluding solids from process areas. However, since

all flush oil will either enter the processing flow path (e.g., pump and instrumentation flush) or will be collected as slop for eventual rerun, using flush oil which has a high donor hydrogen level has certain advantages. Of most importance is the effect of slop rerun on unit capacity. If the flush oil (which will represent the largest portion of the slop) has a reasonably high donor hydrogen level, it should be possible to back out recycle solvent and replace it with slop during rerun operations without adversely impacting on throughput or yields. If the flush oil donor hydrogen level was low, rerunning slop by processing through the normal operational flow path would require a greater reduction in coal throughput or a lowering of conversion.

For these reasons, flush oil inventory should be maintained when possible through use of hydrogenated recycle solvent instead of through use of spent solvent. In addition to the benefits of increased donor hydrogen levels, maintaining inventory through use of hydrogenated recycle solvent should also help to guarantee that the flush oil supply is free of solids.

2. Specific Flush Oil User Requirements

The flushing oil users within an EDS plant can be grouped by category with each category having special areas which should be considered when specifying flush oil supply requirements. The major categories include flushing for valves, pumps, instruments, safety valves, solids withdrawal, agitators, and piping/equipment.

• Valves

All slurry block valves will require flushing capability. The most promising valve types, as identified through testing at ECLP⁽¹⁾, are wedge gate valves, through conduit gate valves, and ball valves. Which valve type is selected for any given service will depend on the solids concentration, fouling tendencies, erosion/corrosion/abrasion characteristics, and frequency of operation. Through conduit gate valves will require flushing of the body cavity and seats during each valve operation. Experience will dictate if flushing of the wedge and ball valves will be required during each operation. However, flushing connections should be provided for every slurry block valve type.

Since block valve flushing will not be continuous, consideration of the impact flushing requirements have on normal operations is not necessary. Flushing rates per valve are of importance mainly to determine the piping supply requirements for the lateral from the flush oil distribution header. However, since flush oil will become part of the process fluid, flushing source requirements should be considered as for any user.

Information on flushing rate requirements is limited. At present, design calculations should assume that 9 GPM are required for 2 inch NPS valves and 14 GPM for 6 inch NPS valves. Proration should be utilized to determine flush rates for valves of other sizes. Valves can be equipped for automatic flushing during cycling. However, these systems would be expensive and must be weighed against the credits for controlled flushing in place of operator attention.

• Pumps

Requirements for pump flush supply systems are described in detail as a subsection of the EDS Data Book.⁽¹⁾ Because the presence of solids in a pump stuffingbox can result in rapid failure of a pump sealing system, consideration of flush oil supply requirements is of great importance. Pump flushing must be provided for all slurry pumps and is also recommended for normally clean services which can be subject to solids contamination of the pumpage as a result of process upsets. Examples of these normally clean services are those distillation tower sidestreams which are withdrawn immediately above the normal slurry level.

The flushing source requirements (such as initial boiling point, compatibility, solids concentration, and temperature) previously discussed, must be considered when selecting the pump flushing oil supply source. In addition, the following items should be evaluated. Many of these items will be particular to the pumping service under consideration and will be

the responsibility of the machinery engineer and pump vendor to insure that the pump auxiliaries are capable of meeting these requirements.

The flush supply system must be 100% reliable. When auxiliary flush supply pumps are provided, they should be spared with auto-start (based on low system pressure). When steam turbine drivers are used, the flush system should have sufficient capacitance to maintain flush pressure and flow until the spare pump reaches its normal operating conditions. Note that the need for auxiliary flush supply pumps in a commercial plant design should be limited since main supply headers will be maintained at pressure levels higher than all user requirements.

The source of flush oil should not be dependent on continuous operation of a process or a process pump. Instead, an inventory should be provided in a surge supply vessel which is sufficient to maintain flush pressure and flow during interruptions of the process or pump operation. At ECLP, light vacuum gas oil flush supply was at times interrupted when process upsets at the atmospheric fractionator resulted in temporary loss of feed to the vacuum tower. For a commercial plant design, it is recommended that the main supply headers utilize tankage as the surge supply vessel.

The quantity of pump flushing oil depends on the pump type. In general, flushing rates for centrifugal and rotary screw pumps are small in relation to the pumpage rate. For reciprocating pumps, the flushing rate is a much higher percentage of the pumpage. It is desirable to flush all pump types with a flush oil which would normally represent a portion of the pumpage.

For reciprocating pumps, flush oil should be supplied at 5% of the normal pumpage rate. Within an EDS plant, reciprocating pumps are specified for two types of service. One location is in service as the high pressure slurry feed pumps for the liquefaction unit. Here, the flush oil can be supplied as a slipstream of the normal recycle solvent from the solvent fractionator. It should be noted that a heat exchanger, perhaps as part of the pump auxiliary system, must be provided to cool the flush oil portion of the recycle solvent to 180°F. Higher flush oil supply temperatures would detrimentally effect the teflon-based packing material. When doing process heat calculations around the slurry drier and the liquefaction unit, the loss of heat in this flush oil portion of the recycle solvent should be considered.

The second type of service where reciprocating pumps would possibly be specified would be for movement of the collected blowdown to slop tankage and the movement of slop to the rerun facilities. For this type of service, reciprocating pumps are desirable since they can best handle the likely fluctuations in solids concentrations and fluid properties. However, flush oil requirements at 5% of the pumpage would result in large losses of clear liquids for non-process purposes. With the successful demonstration of centrifugal pumps in slurry service at ECLP, specification of centrifugal pumps, with their attendant lower flush oil requirements, should be considered for future commercial plant designs.

A centrifugal pump used for blowdown or slop service could be designed for high impeller tip speeds. Minimization of tip speed to protect against excessive erosion during the few periods when the blowdown or slop is high in solids concentration would not be necessary. Design calculations for the blowdown service with a centrifugal pump should insure that sufficient discharge pressure can be made available for periods when the pumpage is directed through auxiliary cooling facilities before entering tankage.

Flush oil requirements for centrifugal pumps depend on the seal design and on the rate of pumpage. For services where there is a desire to minimize flushing oil losses, use of a double mechanical seal system with supply of both a recirculating barrier fluid and a flush stream can be utilized. This sealing system, with the barrier fluid recirculation feature, is also used for those services where the seal face temperature must be kept high enough to prevent solidification of pumpage during start-up. Examples of this service-type in an EDS plant are the vacuum bottoms/flux recycle booster pumps.

Other centrifugal pumps, where temperature or loss of flush fluid are not concerns, utilize API style pumps and conventional petroleum refinery practices to estimate flush requirements. Slurry construction style pumps generally require greater flush flow due to their larger shaft diameters. For flushing system design calculations in the absence of detailed information for any given service, the rates shown in Table 1 can be utilized. A 30% contingency margin is recommended for the flush system flow requirements. As Table 1 indicates, even with a 30% contingency allowance, the flushing oil requirements for centrifugal pumps are at most 3.5% of the pumpage (for small 75 GPM pumps) and are more typically less than 1% of the pumpage.

The flushing requirements for rotary screw pumps are dependent on the detailed engineering of the pump design. Items which impact on the flushing rate include the stuffingbox design pressure, the sealing arrangement (packing vs. mechanical seals), operating conditions of the pump if processing wash oil instead of process fluid, and restrictions on flush injection rate losses to the pumpage. Within an EDS plant, the only service which may utilize rotary screw pumps is the vacuum fractionator bottoms. When lacking detailed information on the pump design for this service, an estimate of the flushing oil requirement can be made by assuming 3 GPM must be supplied to each mechanical seal and 0.5 GPM to each stuffingbox. A typical design would have four stuffingboxes and four mechanical seals resulting in a total flush requirement per operating pump of 14 GPM. This would represent approximately 1% of the pumpage for this service.

The flush oil supply source for the vacuum bottoms rotary screw pump will be vacuum gas oil. The vacuum gas oil flush in that portion of the vacuum bottoms which is solidified for downstream processing instead of being recycled to liquefaction is lost as a process fluid. However, since less than 50% of the vacuum bottoms is typically sent to solidification, less than 7 GPM of flush oil is lost. Also, control of the quantity of heavy boiling liquids in the vacuum bottoms pumpage is possible through operational modifications to the vacuum fractionator which decrease the

1000°F- content of the bottoms and increase the vacuum gas oil sidestream rate. Therefore, loss of flush oil through this flow path is controllable and should be of no concern.

As slurry pump design and development efforts continue, there is a possibility that centrifugal pumps will be usable for the vacuum bottoms service. This would modify the flush oil requirements for this service within an EDS plant. Use of centrifugal pumps instead of rotary screw pumps is of more importance in terms of the safety requirements of the system, since centrifugal pump designs do not require safety valves for protection while the rotary screw pumps do.

- Instrument Taps

Instruments in slurry service must have their taps kept clear of solids. All instrument taps should come off the top of lines and vessels or at least be sloped downward toward the process sensing point to minimize the chance of solids accumulating in the tap. Use of this instrument tap orientation avoids the need for flush oil purges for those services which do not contain high melting point materials (e.g., pressure gauges on slurry drier booster pump discharge). Also, instrument applications for three-phase fluids do not require purging since the vapor forms a gas pocket in the instrument tap (e.g., liquefaction reactor pressure gauges). Slurry services which do not contain vapor in the process line and which contain high melting point materials require continuous purge with flush oil (e.g., pressure gauges in fractionator bottoms circuits).

The quantity of flush oil purge required per instrument tap is low. Each purged tap needs approximately 1.1 GPH. At this rate, even an inordinately high number of instrument taps, such as 1000, would only result in a total flush oil requirement of 18 GPM. Therefore, instrument tap flushing requirements will not have a significant impact on overall plant flushing requirements. Of more importance for instrument tap purges will be the orderly design of supply piping with instrumentation and valving to measure and control flows to the necessary levels.

- Safety Valves

Safety valves which protect equipment which contains slurries require flush oil to keep solids away from the valve seat during normal operations. Efforts to identify the design requirements for safety valves in slurry service are ongoing with several options under consideration. Within an EDS plant, services which may require slurry safety valves are found in two locations -- at the discharge of high pressure reciprocating liquefaction slurry feed pumps and at the discharge of the vacuum bottoms pump if a rotary screw design is utilized. Other locations which may require safety valves include the blowdown and slop transport pumps if positive displacement pumps are provided for these services.

The high pressure liquefaction slurry feed pumps will definitely be of reciprocating design and will likely require safety valves for protection. (Safety valves can be eliminated if steam turbine drivers are utilized.) Each pump, individually, will require protection upstream of its discharge block valves. Several options are currently being considered

for design of the safety valve inlet system to insure that an unobstructed path is always available. All options will require flushing oil at a rate being determined as part of another Design Study.

One option would place the safety valve inlet line directly on the discharge piping. The safety valve inlet line would rise vertically and flush oil would be injected near the valve body. A current, possibly conservative, approach for determining the flush oil requirement is to provide sufficient flush to maintain a downward velocity in the inlet line of 3 ft/sec (equivalent to approximately 9 GPM per pump if a 3 inch inlet line is assumed). This velocity may drop to as low as 1 ft/sec as evaluations continue. Concern with this system centers on the possibility that pressure pulsations in the discharge line could result in slurry at times making contact with the safety valve seat.

A second option involves placing the safety valve on the discharge line but located in the vapor space of the pump's pulsation dampener. The vapor space would be maintained at the necessary volume by treat gas injection. Flush oil injection would still be recommended into the pulsation dampener's vapor space to further assist in keeping slurry from the safety valve seat. Determination of flush oil rate would likely also be based on maintaining a 1-3 ft/sec rate of flush oil movement toward the process stream. However, the diameter of the pulsation dampener would likely be greater than for a safety valve inlet line and therefore would result in increased rate requirements.

Other possible options include use of safety valves integral with the pump design which protect each cylinder individually and use of a system similar but separate to the pulsation dampener which is dedicated only to safety valve protection against slurry fouling. Both of these alternatives would also require flushing oil injection.

A portion of the recycle solvent normally sent to the slurry driers can serve as the flush oil for this service. However, since the required supply pressure level must equal the safety valve set pressure, special consideration must be given regarding how this pressure level is achieved. The probable best choice would be to utilize a portion of the recycle solvent available in the high pressure flushing header on a continuous basis. The rate of recycle solvent sent to the slurry driers should be reduced by the quantity of required flush oil and heat balance calculations in the slurry drier and liquefaction areas should account for the resulting loss of process heat.

For a typical commercial plant design, four high pressure slurry feed pumps will be operating per liquefaction line. (This assumes that use of control valves will be acceptable to adequately distribute slurry flow to each furnace pass and that a dedicated pump per furnace pass is not required. Slurry feed manifolding is the subject of another Design Study.) To meet a 1-3 ft/sec velocity criteria and with the assumption that a 3 inch inlet line to a safety valve located directly on the discharge line will be acceptable, 22-66 GPM of flush oil will be required to flush the safety valve for each high pressure slurry feed pump.

ECLP utilized a rotary screw pump for its vacuum bottoms service and rotary screw pumps have been specified in all recent EDS study designs for this service. Because rotary screw pumps operate by positive displacement, safety valves are required to protect discharge equipment unless discharge pressure is limited by another method.

Rotary screw pump discharge pressure can be limited by providing a steam turbine driver for the pump instead of an electric motor. The driver design can then be engineered to limit the energy input of the system and therefore the maximum possible discharge pressure. If a rotary screw design remains a requirement for the vacuum bottoms service, this will likely represent the preferred method for designing the system and will therefore eliminate the need for safety valves.

Safety valves could be used for protection of the rotary screw vacuum bottoms pumps with consideration given to those items previously discussed for the high pressure liquefaction slurry feed pumps. Conversely, steam turbine drivers could be used for the high pressure liquefaction slurry feed pumps if any uncertainty remains regarding the ability to isolate the safety valve seat from slurry contamination. However, maintaining a slurry-free safety valve environment for the vacuum bottoms circuit would present incrementally more severe problems than for the liquefaction feed circuit. The vacuum bottoms are higher in solids concentration, more viscous, more prone to fouling, and at a significantly higher temperature. Safety valve flush oil would have to be supplied at high temperature to prevent solidification of the process fluid and would likely be vacuum gas oil. The vacuum gas oil flush oil would be lost in that portion of the vacuum bottoms which is sent to solidification. In addition, the safety valve discharge line to the vacuum tower flash zone would have to be traced at high temperature to guarantee non-solidification in the discharge line should the safety valve blow.

Although use of steam turbine drivers appears to be the optimum solution if rotary screw pumps are required for the vacuum bottoms service, a better but unproven option would involve the use of centrifugal pumps for this service. ECLP's positive experience with centrifugal pumps in other severe services and continuing slurry pump development activities make such an option look promising for the future. With centrifugal pumps, slurry safety valves would not be required to protect discharge equipment.

The discharge line from safety valves in slurry service will also require flushing oil connections. The connections would be utilized intermittently during normal operations to guarantee a clean discharge line in case the safety valve may have simmered periodically. The connections would also be used following any safety valve release to clear the line of slurry.

- Solids Withdrawal

Flushing oil is required whenever solids are withdrawn from a liquefaction reactor. The flushing oil is used to dilute the withdrawn process stream to assist in its movement through downstream processing equipment. In addition, the flushing oil should be utilized to backflush the solids withdrawal line toward the liquefaction reactors after each

withdrawal operation to purge the line of stagnant slurry. Recycle solvent from the high pressure flushing oil header is utilized for this service. Frequency of operations and withdrawal rates will depend on experience once commercial-scale facilities are operational and will also likely be a function of coal type.

- Agitators

Agitators are used to stir certain slurry-containing vessels within an EDS plant such as the slurry driers and the solids withdrawal collection drum. Flush oil is required for these services to maintain the shaft seal of the agitator free of solids. Flush oil rates will depend on the seal design and clearances for each service but will typically be low.

- Equipment Flushing

Flush oil is required intermittently at various plant locations to purge slurries from equipment which is non-operational either due to maintenance operations or emergency situations. All slurry pumps require connections to the flush oil header to allow removal of slurry contained within the pump's isolation block valves when the pump is brought down for maintenance. Flush oil is also required wherever slurry lines branch to clean non-flowing lines of stagnant slurry. In addition, the plant layout must be evaluated in detail to select locations where flush oil is required to purge equipment and piping during periods of overall unit shutdown.

ECLP experience can be utilized to specify certain locations where flushing oil connections are mandatory. A review of the equipment, piping, and block valve arrangements for any new design should also be conducted to identify additional locations where flushing oil connections would be useful or necessary.

Specific flushing locations provided at ECLP include:

- + Immediately downstream of the high pressure slurry feed pump -- In the event of failure of the pump, flush oil could be injected through the furnace coils to prevent coking and a major shutdown. In a commercial plant, multiple pumps will be provided and complete loss of flow should not be a problem. However, in a commercial design, a heat exchanger which was not provided at ECLP is located between the slurry feed pumps and the furnace. The flush oil connection should prove useful commercially to clean this exchanger upon unit shutdowns. Since the purpose of this connection at ECLP was to prevent coking or plugging in the furnace tubes, a similar philosophy should be utilized commercially for each of the furnace flow paths. Flush oil connections entering downstream of any slurry block or control valve should be provided for each furnace pass.
- + Slurry preheat furnace common outlet -- In the event of furnace coil plugging, the downstream equipment would be flushed and saved from plugging. At ECLP, the connection was never used for its intended purpose since the furnace coil never plugged during normal coal-in operations. It did prove useful, however, for assisting to unplug the reactors of packed, loose solids during non-coal operations. For similar purposes, a connection should also be provided

for commercial plant designs. Also, should the furnace outlet block valve close for emergency purposes (e.g. rupture of a furnace tube), this connection would be useful to remove slurry from the downstream piping during the shutdown.

- + First reactor outlet -- For use to flush downstream equipment should the first reactor plug. Also, for possible use as emergency quench for the exothermic liquefaction reactor. The reactor never did plug during normal coal-in operations at ECLP. ECLP also determined that this connection was redundant since the flush to the solids withdrawal nozzle could be used for the same purpose. Similar reasoning should apply for a commercial plant design with the solids withdrawal flush connections at all reactors being available for emergency flush oil or quench injection as necessary.
- + Last reactor outlet -- For flushing downstream equipment should the reactors plug. At ECLP, this connection was used periodically when the reactors packed with loose solids during non-coal-in operations. The only instance when such a connection would be necessary would be if a plug occurred within the last reactor downstream of the last solids withdrawal point. Otherwise, upstream solids withdrawal flushing connections could be used for this purpose. Such a plug location would appear to have small but finite probability of happening and a similar connection should probably be provided for a commercial plant design.
- + Effluent separator letdown valve outlet -- For flushing downstream equipment should the letdown valve plug or fail closed. At ECLP, this connection was useful for its intended purpose and a similar connection should be supplied for a commercial plant.
- + Atmospheric bottoms pumps' common discharge -- For flushing downstream equipment upon pump failure. At ECLP, this connection was used extensively due to poor initial performance of the pumps and due to later problems when loose tower refractory affected pump operations. Commercially, a similar connection should be supplied at this location.
- + Vacuum tower flash zone -- For flushing the bottom section of the tower should the vacuum fractionator feed furnace plug. This connection was never used at ECLP. The furnace never plugged and other flush oil connections in the vacuum bottoms pump circuit were available to serve the same purpose. In a commercial plant, a flushing connection should be provided immediately downstream of the vacuum fractionator feed furnace outlet block valve. The connection could be utilized to flush all downstream equipment, including the lower section of the vacuum tower, should the furnace plug or should the furnace outlet block valves close due to emergency conditions in the furnace.
- + Vacuum bottoms recycle booster pump suction -- For flushing the bottoms recycle circuit should this mode of operation be terminated while continuing to run the plant. This line was used for its intended purpose at ECLP several times until the vacuum bottoms were fluxed on a continuous basis with solvent fractionator bot-

toms. For a commercial plant design, a flushing connection should be provided at the vacuum bottoms booster pumps' common discharge to allow flushing the downstream lines should the pumps fail. A connection immediately upstream of the pumps would not appear to serve any useful purpose.

The philosophy for supplying flush oil connections is basically fundamental. Wherever slurry is present, a flush oil connection should be provided immediately downstream of any location where a flow blockage can occur. Obvious locations include any pumping service, any isolation block valve, and any control valve. Less obvious locations would be any area where a flow blockage has a high probability of occurring. Such candidate locations would be the feed slurry heat exchanger service and perhaps downstream of the last liquefaction reactor.

Table 2 provides a summary of the potential flush oil user locations within an EDS plant. Where possible, an estimate of the anticipated flush oil flow requirement per user is provided. Design specification information would be required to develop the requirement estimates in greater detail.

3. Flushing Oil Supply Requirements

- Recycle Solvent Supply Headers

Equipment flushing requirements are non-normal with flush oil supplied from the available headers on demand. The method used to insure the availability of flushing oil for the high pressure header is to utilize a flushing oil pump with a capacity equivalent to that rate of recycle solvent plus vacuum gas oil normally sent to liquefaction. With no demand, the pump recycles from its discharge to suction but always maintains the supply header at full pressure. The header pressure is maintained at the maximum required supply pressure which is equivalent to the design discharge pressure of the high pressure slurry feed pumps. For past EDS study designs, the high pressure flushing oil pumps have taken suction from the low pressure flushing oil header. Future designs should take suction directly from flushing oil tankage to eliminate any interaction with the low pressure system.

In past EDS study designs, the low pressure flushing oil system was supplied directly from tankage. However, the supply pump was specified as part of the offsite system for oil movement and storage. Future designs should specify these pumps as part of the onsite design for the flushing and blowdown system since they are such an integral part of the facilities. The pump should recycle in a manner similar to the high pressure flushing oil supply pump with flushing oil available on demand. Recycle solvent should be the flushing medium for the main low pressure header which supplies flush oil to the slurry drier and atmospheric pipestill areas. The supply pressure level should be set equal to the maximum normal pressure level in these systems which is found at the slurry drier booster pump discharge. Maximum supply rate should be based on the normal effluent separator slurry flow rate.

- Recycle Solvent Storage Temperature

Past EDS study designs have stored recycle solvent at a temperature of 160°F. This allowed storage in "cold" tanks (< 200°F) instead of "hot" tanks (> 265°F) where concerns about water vaporization must be considered. However, cooling recycle solvent to 160°F and later heatup requirements when reused resulted in large wastes of energy. In addition, hotter temperatures are desirable from the standpoint of utilizing recycle solvent as flush oil since hotter flush oil lessens the heat integration impacts of normal users (e.g., pump and safety valve flushing), lessens the likelihood for process fluid solidification, and lessens the likelihood that heat input to the blowdown collection drum (which must be maintained at a minimum temperature of 250°F) will be required. Also, the likelihood of having water contamination of the recycle solvent which would vaporize in "hot" tankage should be small. Therefore, it is recommended that recycle solvent in future designs be stored in tankage at 300°F.

- Vacuum Gas Oil Supply Header

Evaluations of plant flushing oil requirements seem to indicate a need for an additional supply system supplemental to the main high and low pressure headers which will contain recycle solvent. Vacuum gas oil at a

temperature of approximately 550°F is the preferred flushing medium for equipment downstream of the atmospheric fractionator. In the atmospheric bottoms and vacuum bottoms circuits, use of high temperature vacuum gas oil avoids potential flashing problems and process fluid solidification which could occur if lower temperature recycle solvent were used.

The vacuum gas oil flushing header should be designed in a manner similar to the high and low pressure recycle solvent flushing oil headers. The supply pump should take suction directly from tankage and should recycle at the design supply flow rate to guarantee availability of flush oil on demand. The system pressure level should be maintained at a level equivalent to the maximum normally attained pressure level in the user circuits. This location would be at the atmospheric bottoms pump discharge or the vacuum bottoms/flux recycle booster pump discharge. Maximum flow rate supply should be set equivalent to the normal flow of atmospheric bottoms.

- Vacuum Gas Oil Tankage

Tankage should be supplied in future EDS designs to store vacuum gas oil which will be utilized as a flushing medium. The maximum allowable tankage storage temperature is 450°F and this storage temperature is recommended for vacuum gas oil. Vacuum gas oil should not degrade too rapidly at this temperature. Since vacuum gas oil used as a flushing medium is required at 550°F, preheaters in the supply distribution network will need to be provided.

4. Blowdown Requirements

The plant's blowdown collection system must be flexible enough to handle a wide range of blowdown conditions. Because of the intermittent nature of its use, it is not possible to operate the system in a well-controlled manner. Wide variations in blowdown rate, composition, temperature, and source can be expected. The collection system should be designed for worst case conditions with consideration given to other situations which will not be as severe.

- Blowdown Headers

At ECLP, two blowdown headers were provided. One header collected blowdowns from high pressure locations while the second header collected blowdowns from the lower pressure areas. Both headers were connected to the blowdown collection drum.

No clear purpose is apparent for providing two headers. The initial design considerations for the ECLP blowdown collection system indicated that two parallel headers should be provided connected by a rupture disk. During normal flushing operations, one header was intended for use with the belief that this would allow adequate control of saltation velocities. Upon an emergency relief of large proportions, overpressure in the header normally used would blow the connecting rupture disk and the combined cross-sectional area of the parallel headers would allow an adequate path for release.

In a commercial plant, provision of parallel headers does not appear to be necessary. Instead, a single header should be sized for the maximum expected release rate from those areas of the plant which use recycle solvent as the flushing medium. In actual fact, depending on the location of the blowdown collection drum in relation to the liquefaction, slurry drying, and product distillation areas, multiple headers may be provided. Each collection header would terminate at the blowdown drum but might originate from different directions.

As indicated by the flushing supply discussion, it is recommended that a vacuum gas oil flushing oil system be provided in a commercial plant to supplement the recycle solvent flushing oil system. The vacuum gas oil would be supplied at a temperature near 550°F and would be used to flush those areas of the plant which contain highly viscous slurries such as those around the vacuum fractionator. It would seem justified to also provide a separate blowdown collection system in this area to allow segregation of the recycle solvent and vacuum gas oil containing blowdowns. Otherwise, slugs of one type or other of the blowdowns could be expected periodically with large compositional ranges which could impact on the design of the blowdown drum and transport system and of the rerun facility.

- Header Design

The blowdown headers should be designed with a continuous slope from the farthest collection point to the blowdown collection drum. At ECLP, a slope of one-quarter inch per 10 foot of length proved to be ac-

ceptable. Location of the blowdown drum at a central location to assist in meeting this restriction should be considered during layout of the detailed plot plan. The collection headers should also be steam traced and insulated.

- Lateral Design

Laterals must enter the top of the main blowdown headers. This prevents slurry traveling down the header from entering an unused lateral. Each lateral should also be flushed to the main blowdown header after its use to remove any slurry. Each lateral is therefore always full of flush oil and assists in keeping slurry from the main blowdown header from backing into the lateral.

Provision should also be made to allow the blinding of each lateral which enters the main header. Should any lateral plug, it would then be possible to isolate it from the overall collection system without the need to completely bring down the unit.

- Erosion

The materials of construction for each lateral must be considered individually. Areas of particular concern will be those which connect high pressure portions of the liquefaction unit to the collection header. High letdown velocities in combination with the high solids concentration will result in high erosion rates which should be evaluated when selecting the piping materials and the piping layout (minimize bends).

- Blowdown Connections

As a general rule, one blowdown connection will be required for each flushing oil supply connection provided for use during non-normal operations. Whereas the flushing oil supply points are provided immediately downstream of any location which could cause an interruption of slurry flow, the blowdown connections should be provided immediately upstream of any location which could cause an interruption of slurry flow.

Following detailed design, the flow plans should be evaluated in detail to identify locations where blowdown collection laterals should be provided. Special collection points from the bottom of each liquefaction reactor should be provided to allow complete drainage of their contents during shutdown periods.

- Low Point Drains

Low points in any piping configuration are unavoidable. In addition, since the blowdown header is elevated and requires that all laterals enter the top, each lateral by definition has a low point.

All low points will require a drain connection. Draining is only required if reasons exist to believe that slurry has not adequately been flushed away or if maintenance in the area is required. It may be desirable to use a slop truck when draining areas of large volume. Since drain valves must be connected to the bottom of piping or equipment, they will be

a difficult service, prone to plugging. ECLP experience has resulted in the recommendation that when conventional valves are used as drain valves, sufficient clearance be provided to allow access for a rod-out tool. At least 10 inches is recommended. In addition, rather than having the drain valve directed downward toward grade or platform where release of hot slurry could splash and injure the operator, tangential orientation of the valve off the pipe bottom is recommended. This also improves the access for use of a rod-out tool should the valve plug.

Drain valves are typically 3/4-inch. Use of one-inch valves, particularly in areas of heavy wall piping, would decrease the likelihood of valve plugging and ease the difficulty of clearing a valve should it plug. However, the safety consequences of potentially large releases from a larger diameter valve should it fail or blow open must be considered versus the value of improved drainage operability.

A potential solution to the problem would be the use of commercial drain valves which utilize a long threaded plug to keep the drainage path clear. However, experience with these valves at ECLP in service at sample collection points was poor. The valves continually stuck and this problem was particularly noticeable in vacuum bottoms service. Improvements in the design of these valves could make them useful for eventual commercial applications.

- Bleeder Valves

Double block valves are required for isolation purposes for equipment in slurry service. The main function of the bleeder valve is to check to see if the outboard valve is holding. The bleeder valve does not necessarily have a drainage function. Therefore, it is not necessary to locate the bleeder valve on the bottom of the process line where the likelihood for plugging is higher. Instead, they should be placed off the top of the process line. For large valves, the bleeder could be placed off the top of the valve body to decrease the distance between the double block valves.

- Blowdown Collection

Releases to the blowdown headers are collected by a blowdown drum. The blowdown drum is provided with an agitator to maintain solids in suspension. The drum also serves to disengage vapors from the collected blowdown and to dampen any temperature fluctuations in the collected fluid.

It is desirable to maintain the collection drum for the recycle solvent blowdown header at a minimum temperature of 250°F. This allows the vaporization of water from the collected blowdown before transport to the slop tankage. To assist in the maintenance of a 250°F minimum temperature, steam coils are provided within the collection drum. Complete vaporization of the water from the drum is desirable but not essential since the effluent is sent to wet slop tankage.

The blowdown collection drum can either be balanced on the flare or be provided with a pressure controller which maintains the drum at a target pressure by bringing in fuel gas on demand or releasing vapor to a

combustor location such as the offsite boilers. Balancing to the flare is the simplest and most problem-free solution. Fluctuations in the released vapor composition, including degree of water saturation, could create problems if the vapors were sent to a combustor. This option should be kept in mind for eventual commercial applications once operating experience on a large scale provides an indication of the degree of waste energy through connection to the flare. Note that if the blowdown collection drum is not balanced to the flare, a safety valve which protects the blowdown system from overpressure should be provided.

At ECLP, the inventory of the blowdown drum was maintained at sufficient volume to limit the temperature rise during blowdown at 20°F per minute. At ECLP, this volume was approximately equivalent to 10 minutes holdup for the maximum expected collection rate. A similar design procedure should be used for a commercial plant once details of the facilities become available. The evaluation should consider a variety of contingencies to determine which combination of blowdown rate, duration, temperature, and composition are limiting.

As further protection against high temperatures, ECLP's blowdown drum was provided with a water quench system. High temperatures in the liquid holdup portion of the drum would actuate the water quench system and spray water into the vapor space of the drum. A similar system is recommended for commercial designs until experience indicates that such a backup is not needed. The water source should be the plant's firewater system to guarantee dependability. Process water supply pumps might be non-operational during the type of severe emergency situation (such as a major power failure) which could result in large blowdown releases that cause the spray system to actuate.

- Blowdown Transfer Pumps

Blowdown transfer pumps are required to move the collected blowdown to slop tankage. As previously discussed, centrifugal pumps require lower rates of pump flush oil relative to reciprocating pumps. Since pump flush oil for this service contributes to the inventory of slop, use of centrifugal pumps is preferred if they can be selected to adequately operate over the range of expected compositions.

The blowdown transfer pumps will be continuously operating, with recycle to the blowdown drum used as necessary to maintain pump flows at acceptable levels. A level control signal from the blowdown drum should be utilized to determine the split of pumpage to tankage or to recycle.

The blowdown transfer pumps should also be supplied with a guaranteed source of power. Power source can either be steam or electricity from sources protected during emergency situations.

- Blowdown Cooling

At ECLP, the blowdown was cooled to a maximum temperature of 180°F before being sent to the slop tankage. Although the steam coil in the blowdown drum was provided to vaporize the majority of water from the collected blowdown, some concerns remained that residual water would vapor-

ize upon entering the slop tank. To avoid this, the ECLP blowdown was cooled to 180°F by routing through a worm cooler. The worm cooler also provided supplemental emergency control of blowdown temperature in addition to that provided by the inventory in the blowdown drum and the water spray quench system. A similar worm cooler system should be provided for initial commercial plants. Should experience indicate that the emergency cooling capacity is not required, later designs can replace the worm cooler with an airfin designed to decrease the blowdown to 180°F.

- Vacuum Gas Oil Blowdown Collection

A separate blowdown collection system should be provided for those areas of the plant which use vacuum gas oil as the flushing medium. Blowdown from these areas of the plant will be more viscous and prone to solidification at low temperatures than those which originate from systems flushed with recycle solvent. Since the vacuum gas oil flushing medium is supplied at 550°F, and since the operating temperature of all plant areas serviced by vacuum gas oil flush will be at temperatures above 550°F, the blowdowns will be above 550°F as they enter the collection drum. Extreme care should be exercised to keep water out of this system to avoid flash vaporization to steam of unacceptable volume.

The blowdown collection drum should be designed for the maximum temperature of source equipment. This will likely be equivalent to the atmospheric or vacuum fractionator design temperatures. An inventory should be maintained in the collection drum, similar to that provided for the recycle solvent blowdown collection drum, to dampen temperature and compositional fluctuations in the collected blowdown. However, this blowdown collection drum should not be supplied with an emergency water quench system. It is essential that this system be kept free of water.

Centrifugal blowdown transfer pumps should also be provided for this system to minimize the loss of pump flushing oil to slop tankage.

The maximum temperature allowed for hot tankage is 450°F. A worm cooler should be provided for this system which is capable of lowering the collected blowdown during the worst contingency operation to 450°F. Since excess cooling capacity will be available during other than worst case emergencies, a temperature control system should be provided which maintains the temperature of any part of the blowdown to as near to a 450°F maximum as possible. This may require a valving arrangement which allows downstream sections of the worm cooler to be automatically bypassed during normal operations. Temperature control by blending completely bypassed material with blowdown which has passed through the entire worm cooler is not acceptable since the temperature of the cooled portion could be much lower than 450°F and could cause solidification to occur. As discussed for the recycle solvent blowdown system, experience following pioneer plant commercial operations may allow use of an airfin instead of a worm cooler for this service for later applications.

- Slop Tankage

Two types of slop tankage for storing blowdowns are required. The first type will store 180°F maximum blowdown from the recycle solvent.

blowdown collection system. The second type will store 450°F maximum blowdown from the vacuum gas oil collection system.

To allow atmospheric storage, the true vapor pressure of blowdowns sent to slop tankage must be less than 13 psia. Since the blowdown collection drums will operate at approximately 10 psig when connected to the flare header, and since the contents will be at equilibrium at the blowdown drum operating temperature, the vapor pressure of the blowdown as it leaves the collection drum will be approximately 10 psig. It is therefore imperative that the blowdown be cooled on the way to slop tankage to reduce its true vapor pressure at the storage temperature to an acceptable level. Calculations should be made during detailed design which flash the expected blowdown drum contents at its controlled minimum temperature (250°F for recycle solvent blowdown and 550°F for vacuum gas oil blowdown). A determination of the vapor pressure of the non-vaporized blowdown when cooled to the slop tankage storage temperature (180°F for recycle solvent blowdown and 450°F for vacuum gas oil blowdown) should then be made. If the 13 psia limit is not achieved, either the collection drum temperature should be raised or the slop tankage storage temperature should be lowered until the limit is reached.

5. Slop Rerun

Several options are available for rerunning slop collected from the blowdown operations of an EDS plant. Slop management will be an important operating consideration and will have to be closely monitored for a commercial plant to avoid periods when coal processing capacity must be limited because of high slop inventories.

• Slop Composition

One of the most important slop compositional parameters will be boiling range. Boiling range will determine which portions of the process equipment become overloaded when slop is rerun through the normal processing flow path. Based on ECLP experience, the flushing oil medium typically represented 95% of the slop volume. It is therefore likely that slop will mainly be composed of either recycle solvent or vacuum gas oil.

Slop temperature is another parameter which could impact on allowable runoff rates. Recycle solvent slop will be stored at 180°F. If this material is rerun as feed to the slurry driers, the heat balance of the unit must be considered when determining what rerun rate is achievable.

At times it may be desirable to utilize only the product fractionation facilities to rerun slop. If this option is used, portions of the fractionators (in particular, the vacuum bottoms area) would be prone to running dry if only small quantities of heavy boiling liquids were present. The ability of the solidification belts to solidify vacuum bottoms derived during slop rerun operations would also have to be evaluated.

• Rerun Options

Because all slop will contain solids, any rerun operation requires the availability of the vacuum fractionator and its solidification equipment. However, several options exist for getting the solids-portion of the slop to the vacuum fractionator.

The preferred rerun route for slop composed mainly of recycle solvent is to feed it to the slurry driers during normal operations. Experience will dictate what quantity of slop can successfully be processed in this manner without adversely effecting coal throughput or yields. Rate will also vary depending on slop composition. As mentioned previously, slop which is composed mainly of hydrogenated recycle solvent of nearly normal donor hydrogen content would have the least impact on normal operations. Recycle solvent from the solvent fractionator could be reduced in these instances while being replaced with slop. Slop composed mainly of vacuum gas oil can also be rerun through the slurry drying facilities. In these instances, the allowable rate will be much lower than for recycle solvent-type slop. Slop rerun bottlenecks for rerun of vacuum gas oil-type slop will likely be found in the vacuum fractionator area.

Another option for slop rerun is to feed it to the product fractionators without previous processing through the slurry drier and liquefaction facilities. Recycle solvent-type slop must first pass through the atmospheric fractionator although vacuum gas oil-type slop should be fed

directly to the vacuum fractionator. This option would seem to be the preferred rerun route for vacuum gas oil-type slop during normal operations. Using this route would be limited only by vacuum gas oil removal capabilities at the vacuum fractionator and would not impact on coal feed or conversion. This route is not desirable during normal operations for recycle solvent-type slop since its 180°F feed temperature would adversely impact on the unit's heat balance and fractionation capability.

Using the product fractionators in a blocked operation is another possibility. Slop make is directionally related to service factor. At low service factor, more slop can be expected since this probably means more startups and shutdowns. Startups and shutdowns with their attendant flushing oil requirements will be the major contributors to slop inventory. Directionally, this means that spare processing capacity is most likely to be available when slop inventory is high immediately following a shutdown.

For example, when an EDS train is brought down for major or minor turnarounds, slop inventory will likely be high. The product fractionators can be kept operational for a few days or until the slop inventory is depleted while maintenance begins in the slurry drier and liquefaction facilities. If this is done, the vacuum feed preheat furnace should be manifolded such that slop is preheated by it before being fed to the atmospheric fractionator. Atmospheric fractionator bottoms during slop rerun would then bypass the furnace and be fed directly to the vacuum fractionator. Such a blocked operation would allow rapid depletion of slop inventories, empty slop tankage in preparation for the anticipated blowdowns from startup operations, and reduce the quantity of slop which would need to be rerun in a more-controlled manner during subsequent normal operations.

Another option, which is not presently recommended for initial commercial plant designs, would be to provide a dedicated slop rerun facility in the plant. The facility would require a furnace for heat input and either flash separation or fractionation equipment to separate the slop into component fractions. A solidification unit would also be needed for removal of heavy boiling liquids and solids. Experience with pioneer EDS plant operations will provide information on whether the expense of a dedicated facility is justified for slop management as a trade-off for lost service factor when normal equipment is utilized for rerun.

- Slop Rerun Priorities

In general, vacuum gas oil-type slop should be run preferentially before recycle solvent-type slop. Vacuum gas oil-type slop will contain heavier boiling range material and will also be stored at a temperature of 450°F. This combination could lead to potential degradation of the material if stored for long periods of time. An operational goal should be to rundown vacuum gas oil-type slop at the earliest opportunities and the maximum possible rates.

6. Miscellaneous Considerations

- Power Supply

Since the flushing and blowdown system must be operable to allow bringing the EDS plant down safely, the flushing supply and blowdown collection pumps should be provided with drivers which have a fully reliable power source. Offsite design considerations should assign equal importance to reliability of the flushing and blowdown system as is assigned, for example, to firewater supply pumps. Use of electric drivers is acceptable if power supply can be guaranteed through use of turbogenerators tied to a reliable steam supply.

- Train Integration

To provide flushing oil in sufficient quantity to allow acceptable equipment flushing, enormous flow rates are required during worst-case operations. Since it's unlikely, except in the most unusual circumstances, that the full EDS plant would come down simultaneously, integrating the flushing supply headers for the two parallel plant trains and the four parallel liquefaction lines would allow some investment and operating cost savings at acceptable risk.

Based on the flushing oil supply requirements as previously described, flush oil supply rates based on the WYOBK Addendum⁽¹⁾ are 2400 GPM of high pressure recycle solvent per liquefaction line, 3400 GPM of low pressure recycle solvent per liquefaction line, and 3800 GPM of low pressure vacuum gas oil per plant train. A reasonable supply arrangement with the integrated supply concept would be to supply 2N/1S pumps at 2400 GPM each for the high pressure recycle solvent headers, 2N/1S pumps at 3400 GPM each for the low pressure recycle solvent headers, and 1N/1S pumps at 3800 GPM each for the low pressure vacuum gas oil headers.

- Flushing Priorities

Upon emergency shutdown, priorities will have to be assigned to which locations get supplied with flush oil. Use of all or many of the provided flush oil connections simultaneously would deplete the flush oil headers of solvent. A reasonable guidance procedure would be to consecutively flush starting at the farthest upstream location and proceeding to the last downstream location until all stagnant lines and equipment have been flushed. Operating guides should be supplied upon completion of the detailed plant design which indicate the priority requirements and which also give an indication as to the length of time required to satisfactorily flush between various points in the plant.

- Flow Indication

To manage the flow and inventory of flush oil, flow measurement devices should be provided which allow adequate monitoring of the system. Without adequate monitoring capability, unacceptably high flushing oil usage could occur which would detrimentally impact on coal-processing capability. As an example, during one week of ECLP operations, 900 barrels of slop were generated which compared to a total solvent production rate of

300 barrels. All this slop must eventually be rerun which could result in a need to reduce coal throughput.

Use of rotameters to measure flows is not recommended. Rotameter reliability and accuracy were not acceptable for ECLP monitoring. Instead, orifice meters should be installed which allow measurement of usage for every major flushing oil lateral. Monitoring of flush oil usage is conceivably of sufficient importance that all flow measurements should be available in the control house on demand. Additionally, a flushing oil software management program which analyzes usage including integration over time would likely be cost-effective.

Flow measurement of all normal recycle solvent flush oil users located upstream of the liquefaction reactors should be available in the control house. The summation of their measurements should be utilized to decrease the amount of recycle solvent sent to the slurry driers to maintain the target solvent-to-coal ratio.

- Restriction Orifices

Selected use of restriction orifices to limit flushing oil supply rates to various locations should be considered. Poor operator attention during flushing operations could at times otherwise result in unacceptably high use of flush oil.

7. Commercial Plant Design

The preceding portion of this memorandum has discussed the various requirements and design considerations for a flushing and blowdown system for an EDS plant. The following section consolidates this information into recommendations for a commercial plant design. For illustrative purposes, the recently completed WYOBR Addendum⁽¹⁾ has been used to provide an indication of approximate processing rates and operating conditions for design.

Since the flushing and blowdown units are a support facility for slurry-containing areas of plant, a detailed design description of its requirements is not possible without information on the detailed design and equipment layout of the major processing sections of slurry drying, liquefaction, and product distillation. This particularly applies regarding identification of the many flushing oil supply user locations and rates and the numerous blowdown collection laterals. However, all major flushing and blowdown equipment items with the basis for their design can be identified. Also, the general processing arrangement can be specified and important items which should be considered once detailed design information becomes available can be highlighted.

Figures 1 through 4 represent schematic flow plans for a commercial flushing and blowdown system. Each figure is supported by design notes which describe items which should be considered during the detailed design phase. Figure 1 depicts the high and low pressure recycle solvent flushing oil supply system. Figure 2 shows the vacuum gas oil flushing oil supply system. Figure 3 represents the recycle solvent blowdown collection system while Figure 4 provides similar information for the vacuum gas oil blowdown collection system.

References

1. "EDS Wyoming Coal Bottoms Recycle Study Design Addendum," Interim Report No. FE-2983-123.

Table 1

Flush Flow Rate Requirement for
Slurry Construction Centrifugal Pumps

<u>Capacity</u> <u>(GPM)</u>	<u>Discharge</u> <u>Flange Size</u> <u>(Inches)</u>	<u>Shaft Sleeve</u> <u>O.D.</u> <u>(Inches)</u>	<u>Flush Flow</u> <u>Rate</u> <u>(GPM)</u>
2400-3000	10	6.25	5-10
800-2400	6	5.5	3-5
300-800	4	3.5	2-3
75-300	1.5-2	2.75	1.5-2

(Estimates are by a leading slurry pump manufacturer).

Notes:

1. Shaft sizes are not expected to significantly exceed 6.25" because of double volute construction in larger pumps.
2. Flush flow rates are based on a floating close clearance throat bushing and a 15-25 psi differential across the throat bushing. Flow rates will also depend on the pump shaft speed, the condition of the throat bushing and the temperature differential between the flush fluid and pumpage (too large a differential requires reduced flow rates to prevent thermal shock of the back wear plate).

TABLE 2

FLUSHING OIL USER REQUIREMENTS

1. High Pressure Recycle Solvent Flush Oil

Normal Requirements	Rate, GPM/Trair	Comments
- High Pressure Slurry Feed Pump Seals	328	Assumes 8 of 12 pumps operating; flush supplied at 5% of pumpage.
- High Pressure Slurry Feed Pump Safety Valves	352	Assumes 8 of 12 pumps operating, 3-inch inlet line, 2 ft/sec flush rate.
- High Pressure Slurry Instruments	4	Assumes 200 instrument taps at 1.1 GPH per tap.
TOTAL	684	Rate of recycle solvent supplied to the slurry driers should be decreased by this amount.
Intermittent Requirements		
- Valves	-	Rate depends on valve size.
- Solids Withdrawal	-	Rate, frequency, and duration are dependent on coal type.
- Equipment Flushing	-	Maximum rate at any user location is 2400 GPM, equivalent to the normal rate of recycle solvent plus VGO supplied per line; a rate of 4800 GPM is available plant-wide at any time.

TABLE 2 (Cont'd)

FLUSHING OIL USER REQUIREMENTS

2. Low Pressure Recycle Solvent Flush Oil

Normal Requirements	Rate, GPM/Train	Comments
- Slurry Booster Pump Seals	156	Assumes 6 of 9 pumps operating (3 slurry driers); 2 stages per pump; flush supplied at 13 GPM/stage.
- Atmospheric Bottoms Pump Seals	13	Assumes 1 of 1 pumps operating; flush supplied at 13 GPM/pump.
- Recycle Solvent Blowdown Collection Transfer Pump Seals	13	Assumes 1 of 2 pumps operating; centrifugal design; flush supplied at 13 GPM/pump.
- Recycle Solvent Slop Transfer Pump Seals	13	Assumes 1 of 2 pumps operating; centrifugal design; flush supplied at 13 GPM/pump.
- Atmospheric Fractionator Sidestream Pump Seals	13	Assumes 1 of 2 pumps operating; flush supplied at 13 GPM/pump.
- Slurry Drier Agitator Seals	10	Assumes 3 operational slurry driers for one train; flush supplied at 10 GPM/agitator.
- Solids Withdrawal Collection Drum Agitator Seals	20	Assumes 2 operational drums per train; flush supplied at 10 GPM/agitator.
- Recycle Solvent Blowdown Collection Drum Agitator Seals	10	Assumes 1 operational drum per train; flush supplied at 10 GPM/agitator.

TABLE 2 (Cont'd)

FLUSHING OIL USER REQUIREMENTS

2. Low Pressure Recycle Solvent Flush Oil (Cont'd)

● Normal Requirements (Cont'd)	<u>Rate, GPM/Train</u>	<u>Comments</u>
- Recycle Solvent Slop Tankage Agitator Seals	10	● Assumes 1 tank per train; flush supplied at 10 GPM/agitator.
- Low Pressure Slurry Instruments	4	● Assumes 200 instrument taps at 1.1 GPH per tap.
- Safety Valve Inlet Lines	-	● Only required if positive displacement pumps are used; have assumed that blowdown and slop transfer pumps use centrifugal designs.
TOTAL	262	● Rate of recycle solvent supplied to the slurry driers should be reduced by 156 GPM--equivalent to the seal flush rate at the booster pumps.
● Intermittent Requirements		
- Valves	-	● Rate depends on valve size.
- Safety Valve Discharge Lines	-	● For periodic flushing of any slurry safety valve; have assumed that only the high pressure slurry feed pumps require any, but blowdown and slop transfer pumps may if of positive displacement design.
- Equipment Flushing	-	● Maximum rate at any user location is 3400 GPM, equivalent to the normal rate of effluent separator slurry per line; a rate of 6800 GPM is available plant-wide at any time.

TABLE 2 (Cont'd)

FLUSHING OIL USER REQUIREMENTS

3. Vacuum Gas Oil Flush Oil (Cont'd)

• Normal Requirements (Cont'd)

- Slurry Instruments

Rate, GPM/Train

4

Comments

• Assumes 200 instrument taps at 1.1 GPH/tap.

- Safety Valve Inlet Lines

-

• None assumed; only required if positive displacement pumps of unlimited power input are used; have assumed steam drivers for vacuum bottoms rotary screw pump and that the blowdown and slop transfer pumps use centrifugal designs.

TOTAL

83.5

• Intermittent Requirements

- Valves

-

• Rate depends on valve size.

- Safety Valve Discharge Lines

-

• None assumed but see comment directly above.

- Equipment Flushing

-

• Maximum rate at any user location is 3800 GPM, equivalent to the normal rate of atmospheric bottoms per train; this also represents the plant-wide rate available at any time.

FIGURE 1
RECYCLE SOLVENT FLUSHING OIL SUPPLY

DATE	SHEET	OF	REVISION NO.
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NOTES: RECYCLE SOLVENT FLUSHING OIL SUPPLY (FIGURE 1)

1. Hydrogenated recycle solvent is the preferred flushing oil medium. A backup connection to the spent solvent tankage should be provided for use during periods of low recycle solvent inventory.
2. Reciprocating pumps are shown for the high pressure flushing oil supply. If centrifugal pumps can be found which satisfy the system's high head and large flow requirements, they should be utilized.
3. Recycle or spent solvent will be provided from tankage at temperatures as high as 300°F. Specific users may have lower temperature limitations. One such user is the high pressure liquefaction slurry feed pumps which require flushing oil at a maximum temperature of 180°F to protect their teflon-based packing material. In such instances, a cooler should be provided in the lateral from the main supply header to the user location.
4. The high pressure header should be maintained at a pressure equivalent to that normally provided by the high pressure liquefaction slurry feed pumps. For the WYQBR Addendum, this pressure was approximately 2850 psia.
5. The low pressure header should be maintained at a pressure equivalent to the maximum pressure normally found at user locations. For the WYQBR Addendum, this corresponds to the slurry drier booster pump discharge and was approximately 130 psia.
6. The flow rate for each high pressure supply pump should be set equivalent to the rate of recycle solvent plus vacuum gas oil normally supplied to each liquefaction line. For the WYQBR Addendum, this rate was 2400 GPM.
7. The flow rate for each low pressure supply pump should be set equivalent to the rate of effluent separator slurry normally produced from each of the four liquefaction lines. For the WYQBR Addendum, this rate was 3400 GPM.
8. Either steam turbines or electric motors can be used as the drivers for the high and low pressure supply pumps as long as the power supply source is protected during emergency situations. Driver selection should be the responsibility of the offsite designers once plant-wide driver requirements and emergency power requirements have been identified.
9. Recycle solvent should be solids-free since it is provided as a product from the catalyst-filled solvent hydrogenation unit. Consideration should be given to installation of a filter in the spent solvent supply line since this source has a greater likelihood to contain solids. A preferred option would be to filter spent solvent, or certain fractionation sidestreams which contribute to spent solvent, at the processing unit source.

FIGURE 2
VACUUM GAS OIL FLUSHING OIL SUPPLY

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NOTES: VACUUM GAS OIL FLUSHING OIL SUPPLY (FIGURE 2)

1. Preheaters are provided to raise the temperature of vacuum gas oil from tankage from approximately 450°F to 550°F. A minimum flushing oil supply temperature of 550°F was recommended based on ECLP experience to prevent potential solidification of process fluids. If experience shows that 450°F is sufficient to prevent localized solidification, the system could be simplified by deleting these exchangers. Note that 450°F represents the maximum allowable storage temperature within tankage.
2. The vacuum gas oil flushing oil supply header should be maintained at a pressure equivalent to the maximum pressure normally found at user locations. For the WYOBRA Addendum, this corresponds to the vacuum fractionator bottoms/flux booster pump and was approximately 190 psia. In future designs, there is a possibility that this booster pump will not be required if sufficient head can be made available with only the vacuum bottoms pump. The maximum pressure location would then be either the vacuum bottoms pump discharge or the atmospheric bottoms pump discharge.
3. The flow rate for each vacuum gas oil flushing oil supply pump should be set equivalent to one-half the rate of atmospheric bottoms normally produced from each liquefaction train. For the WYOBRA Addendum, this rate was 3800 GPM.
4. Either steam turbines or electric motor drivers can be used as the drivers for the vacuum gas oil flushing oil supply pumps as long as the power supply source is protected during emergency situations. Driver selection should be the responsibility of the offsite designers once plant-wide driver requirements and emergency power requirements have been identified.
5. Vacuum gas oil flushing oil should be solids free. Consideration should be given to installation of a filter in the supply line from tankage. A preferred option would be to filter vacuum gas oil as it is generated from the processing unit source.

NOTES:

1. EQUIPMENT SHOWN FOR ONE OF TWO PARALLEL COLLECTION SYSTEMS REQUIRED FOR THE FULL PLANT.

FIGURE 3			
RECYCLE SOLVENT BLOWDOWN COLLECTION			
DATE			DRAWING NO.

NOTES: RECYCLE SOLVENT BLOWDOWN COLLECTION (FIGURE 3)

1. The blowdown collection header should be continuously sloped downward toward the collection drum. At ECLP, a slope of one-quarter inch per 10 foot of length proved to be acceptable.
2. The normal drawoff from the collection drum should be located off the vessel straight-side such that an inventory of slurry is maintained in the collection drum to help dampen temperature and solids concentration fluctuations.
3. The steam coil should be used to maintain a minimum temperature of 250°F in the collection drum. This minimum temperature is desired to allow the vaporization of any water from the collected blowdown before transport to slop tankage.
4. Determination of the emergency firewater quench cut-in setpoint is related to the worm cooler design capability. It should be set equivalent to the design temperature at the inlet of the worm cooler.
5. Commercial experience may indicate that disposal of vapors from the collection drum by burning at the flare is economically wasteful. An alternate scheme would require balancing to a dedicated fuel user (e.g., offsite boilers) with capability of utilizing fuel gas to maintain the collection drum at a minimum pressure.
6. Blowdown must be cooled to a maximum temperature of 180°F before transport to the slop tankage. Higher temperatures are not acceptable since residual water in the blowdown could vaporize and result in unacceptable vapor releases in tankage.
7. Either steam turbines or electric motor drivers can be used as the drivers for the blowdown transfer pumps as long as the power supply source is protected during emergency situations. Driver selection should be the responsibility of the offsite designers once plant-wide driver requirements and emergency power requirements have been identified.
8. Centrifugal pumps are shown for the blowdown transfer service. ECLP's encouraging experience with centrifugal slurry pumps for a wide range of conditions led to this selection rather than use of reciprocating pumps. Centrifugal pumps typically have better service factor performance than reciprocating pumps but more importantly, have lower seal flush oil requirements relative to reciprocating pumps. Since flush oil adds to slop tankage inventory, use of centrifugal pumps is preferred if capable of handling the expected range of slurry concentrations in the blowdown drum. Since slurry concentrations will normally be low, the centrifugal blowdown transfer pumps can be designed with high impeller tip speeds to impart the needed head without undue worry about impeller erosion.

9. Since the worm cooler will be sized for a worst case emergency, during most operations, excess cooling capacity will be available. To avoid undue cooling of the blowdown, a temperature bypass control valve has been specified. Commercial experience may indicate that the worm cooler is an overly conservative piece of equipment and that an airfin cooler could adequately provide emergency cooling protection.

NOTES:

- 1 EQUIPMENT SHOWN FOR ONE OF TWO PARALLEL COLLECTION SYSTEMS REQUIRED FOR THE FULL PLANT.

FIGURE 4
VACUUM GAS OIL BLOWDOWN COLLECTION

DATE _____ OF _____ DRAWING NO. _____

NOTES: VACUUM GAS OIL BLOWDOWN COLLECTION (FIGURE 4)

1. The blowdown collection header should be continuously sloped downward toward the collection drum. At ECLP, a slope of one-quarter inch per 10 foot of length proved to be acceptable.
2. The normal drawoff from the collection drum should be located off the vessel straight-side such that an inventory of slurry is maintained in the collection drum to help dampen temperature and solids concentration fluctuations.
3. Commercial experience may indicate that disposal of vapors from the collection drum by burning at the flare is economically wasteful. An alternate scheme would require balancing to a dedicated fuel user (e.g., offsite boilers) with capability of utilizing fuel gas to maintain the collection drum at a minimum pressure.
4. Blowdown must be cooled to a maximum temperature of 450°F before transport to slop tankage. Tankage storage temperatures above 450°F are not allowed.
5. Either steam turbines or electric motor drivers can be used as the drivers for the blowdown transfer pumps as long as the power supply source is protected during emergency situations. Driver selection should be the responsibility of the offsite designers once plant-wide driver requirements and emergency power requirements have been identified.
6. Centrifugal pumps are shown for the blowdown transfer service. ECLP's encouraging experience with centrifugal pumps for a wide range of conditions led to this selection rather than reciprocating pumps. Centrifugal pumps typically have better service factor performance than reciprocating pumps, but more importantly, have lower seal flush oil requirements relative to reciprocating pumps. Since flush oil adds to slop tankage inventory, use of centrifugal pumps is preferred if capable of handling the expected range of slurry concentrations in the blowdown drum. Since slurry concentrations will normally be low, the centrifugal blowdown transfer pumps can be designed with high impeller tip speeds to impart the needed head without undue worry about impeller erosion.
7. Since the worm cooler will be sized for a worst case emergency, during most operations, excess cooling capacity will be available. The worm cooler design must insure that excessive cooling does not occur during lower flow operations since this could result in fluid solidification. Bypassing the worm cooler with a portion of the blowdown is not acceptable since the portion passing through the cooler would be excessively cooled and also would have a low velocity which could promote saltation. One possible design is shown, which utilizes a temperature indicator from the combined blowdown to tankage as a reset signal for water level in the worm cooler.

8. Because water must be kept from the high temperature, low pressure vacuum gas oil blowdown collection system to avoid vaporization to steam, use of an emergency water quench system is unacceptable. Use of a vacuum gas oil emergency quench system would be possible. However, the preferred solution is to set the design temperature of the collection drum equivalent to the maximum design temperature of all equipment which discharges to the vacuum gas oil blowdown collection header.

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