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QUARTERLY REPORT PUMPS - STATUS OF SLURRY PUMPS IN COAL LIQUEFACTION PROCESSES

PREPARED FOR DEPARTMENT OF ENERGY
BY
MOUND FACILITY
MONSANTO RESEARCH CORPORATION

THIRD QUARTER - CY 1981 FOR REFERENCE
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1.0 Introduction

This paper summarizes recent slurry pumps (centrifugal and reciprocal) operating experience in the liquefaction pilot plants. In addition, the activities concerning slurry pumps conducted in supporting research facilities are also noted. The purpose of the summary is to concentrate on the critical component problems common to all the liquefaction plants to avoid duplication of efforts, and to help provide timely solutions to the pump problems.

The summary information used in this paper was obtained primarily from the Critical Component and Materials Meetings which are sponsored by the Office of Coal Processing of the Fossil Energy, The Department of Energy. Information from various Technical Reports published by the liquefaction plant personnel are also reviewed based on availability and relevance to topics covered in this report.

It is intended that this report will be followed by updates as pertinent information concerning problem pumps becomes available.

The following sections of the paper will provide a brief outline of early slurry pump experience as background material followed by a summary of recent slurry pump operating experience at liquefaction pilot plants.

2.0 Background

Slurry pump (centrifugal and reciprocal) requirement for liquefaction plants are unique because the high pressure hot, ash/coal/oil process fluids, which at times exist in three different phases (solid, liquid, and vapor) are extremely corrosive and erosive.

2.1 General Process Conditions

There are three general process conditions for which slurry pumps are required. These process conditions are summarized in Table 1. In general, centrifugal pumps are most commonly used in the low pressure areas. An example is the slurry recirculation part of the process. The reciprocating pumps are useful in the high pressure process areas such as the slurry feed and charge areas. A list of slurry pumps, service conditions and the liquefaction plants utilizing the pumps are given in Table 2.

TABLE 1: GENERAL PROCESS CONDITION
FOR SLURRY PUMPS OPERATION

Process Area	Pumping Pressure, Psi	Temp $^{\circ}$ F	Process Stream	% Solid
Slurry Recirculation	40-150	100-350	Coal/Ash/Oil	25-50
Slurry Charge	400-4000	100-350	Coal/Ash/Oil	25-50
Slurry Feed	40-4000	100-850	Coal/Ash/Oil + Hydrogen	25-50

TABLE - 2 SUMMARY PUMPS INFORMATION

	Manufacturer	Service	Type	Model	GPM	Operating Pressure (PSI)	Temp °F	Seal Type & Sealants	Flush or Purge	Solids %	Problems	Plant
1.	IR	feed slurry	piston	?	125-200	100/3300	450	packing	yes	40		H-Coal
2.	Lawrence	" solvents	centri-fuge	3" & 4"	100	150-300	200-750	dbl mech	"	40		"
3.	Goulds	VF feed filter fd	"		50-150	9.5 - 1.50	150-600	single-dbl	"	0-15	lots	Ft. Lewis
4.	Lawrence	coal slry			100-200	"	"	"	"	5-45	some wear	"
5.	Morris	coal slry	centri-fuge		"	"	150-300	"	"	45	slight wear (T limit)	"
6.	Durco	"	"		"	"	150-350	single	"	45		"
7.	Wilson Snyder	"	piston		20-40	2000+	150-350	dbl pack	"	35-50		"
8.	Goulds	UTB	centri-fuge		150	50	600	single	"	25-35		"
9.	Union	feed slry	piston	tri plex	3-4	2000+	215	packing	no	38		Wilson-ville
10.	Crane Deming	vac btms	centri-fuge		120	20-30	600	dbl mech	seal oil	25% max		"
11.	Lawrence	filter fd	"	A1 1 1/2"	P 100	80	600	"		10%		"
12.	Worthington	feed slry	"	3 CNG	80	80	215	"		38%		"
13.	Lawrence	slry circ	"	4" AL lined	400	160 2-stage	300	single	solvent	45%		ECLP
14.	IR	"	"	new		160	"	dbl mech	"	"	test proto type	"
15.	Worthington	ATM btm	"	new	50	100	600- 775	"	LVGO		" "	"
16.	Worth	feed slry	recip	VTEH	80	3000	300	packing	solvent	45		"
17.	Worthington	vac btms	screw		16	25-100	600 - 775	dbl mech	LVGO			"
18.	Milton Roy	feed slry	recip			20/3000	250	packing	no	30-40		HRI(PDU)
19.	Worthington	feed re-circulat	centri-fuge			20	250	mech	no	30-40		"
20.	Durco	hydro-clone fd	"			100	500	dbl mech	yes	20-25		"
21.	Chempump	internal recycle	"			3000	850	dbl mech	"	15-25		"
22.	Moyno	vac btms	single screw			20	600	packing	no	40-60		"

In the petroleum industry, it was anticipated that the major pump problems would involve the ordinary clean liquid pump problems; i.e., cavitation, packing and seals, and bearings. In the early pump operating experiences with slurries, it was found that the corrosion/erosion factor became dominant, manifesting itself in magnifying the ordinary pump problem areas mentioned above.

Much of the earlier slurry pump development efforts in liquefaction pilot plants involved changes in pump design criteria, materials and quality control procedures. For commercial liquefaction plants additional pump studies addressed the pump and line manifolding, industrial pump manufacturing capability and costs.

The results of these studies are documented in published position type papers (1-8) and in State-of-the-Art (SOA) type assessments (9, 10). The information used in the above studies was obtained from the petroleum industry experience, the early liquefaction pilot plants, (SRC I & II) operating experiences, pump manufacturers, and engineering consultant firms. The recommendations for reciprocal and centrifugal slurry pumps developed in these studies are summarized in Table 3 and 4, respectively.

TABLE 3: RECIPROCATING PUMPS: SUMMARY
OF PROBLEMS AND PROPOSED SOLUTIONS

<u>Problem</u>	<u>Proposed Solution</u>
Plunger wearing surfaces	a) Frequent maintenance b) Use of replaceable erosion resistant materials; i.e., tungsten carbide sleeves, etc.
Plunger packing	a) Frequent replacement of packing b) Flushing and better grade oil and packings systems
Discharge check valves	a) Use of precision parts b) Use of hard ball-bearing type materials and tungsten carbide seats c) Frequent replacement of balls and seats.

TABLE 4: CENTRIFUGAL PUMPS:
SUMMARY OF PROBLEMS AND PROPOSED SOLUTIONS

<u>Problem</u>	<u>Proposed Solutions</u>
Cavitation	<ul style="list-style-type: none"> a) Improved pump design, equipment layout and proper pump selection to match process conditions. b) Avoid process condition changes which cause decreased suction pressure and increase vapor content.
Seals (Mechanical and Packing)	<ul style="list-style-type: none"> a) Proper mechanical seal design and application. b) Quality installation. c) Use of double seals. d) Flushing of seal cavities. e) Maintain high quality of real fluid-alarms to ensure fluid availability to seal. f) Seal heating with external flushing. g) Use of mechanical seals for high temperature applications. h) Proper selection and use of packings.
Bearings	Not a problem if seal failures are avoided.
Corrosion/Erosion	<ul style="list-style-type: none"> a) Proper material selection for casing, stationary face and impellers. b) Use of large diameter impeller and lower pump speeds.

The goal of the recommendations made in the early studies was to develop a high performance slurry pump with the following characteristics:

- 1) High reliability,
- 2) Rugged use,
- 3) Continuous duty,
- 4) Long life,
- 5) Combine the standards API-610 (Centrifugal) and API-674 (Reciprocating) with the features of the slurry pump.

2.2 Pump Studies for Commercial Plants

Along with the efforts to develop high performance slurry pumps for use in liquefaction pilot plants, considerable effort was exerted in developing slurry pumps for service in commercial coal liquefaction plants. It was shown in the earlier literature (2, 8) that any one SOA slurry pump could not provide the required services; i.e., pressures > 4000 psia, temperatures of about 750°F , flow rates as high as $14,000$ gal/min and handle slurry concentrations up to 60% solids by wt. It was suggested that using more than one pump either by use of multiple positive displacement pumps to obtain required flow or by multiple single-stage centrifugal pumps to achieve the required pressure would be too complex and expensive.

As a result of these early findings, research efforts have been directed towards the development of new pump designs capable of economically handling the large-capacity, high-pressure liquefaction plant process streams. Some of the new pump designs (10) under development or study are as follows:

Multiple stage centrifugal pump

High suction pressure recirculating pump

Hydraulic diaphragm pump

Pipe-feeders and hydrohoist

Long stroke power recovery devices

Progressing cavity power recovery device

Lockhopper pumping and power recovery.

Examples of the slurry pumping service, approximate operating conditions and proposed design criteria for liquefaction plant pumps have been taken from one of the earlier studies (3) and are shown in Attachment A.

3.0 Current Liquefaction Plant Operating Experience

In the recent critical components and materials meeting (#6) for liquefaction pilot plants, it was the consensus that the major slurry pump problems involved the following areas:

- a) Reciprocal Pumps (Packing and Plungers)
- b) Centrifugal Pumps (Seals)
- c) All pumps--including the Screw Pump
(performance test methods)

These problems will be briefly discussed below:

3.1 Reciprical Pumps

In the slurry feed and the vacuum bottoms areas, the major problems involved the packing and plungers of the reciprocating pumps. In general, the size of the pump and the temperature of the process stream affect the operating life of the pump. The smaller pumps had the longest life; whereas all pumps, regardless of size, had

the longest life at the lower process temperatures (250-300 °F). At temperatures over 400 °F, ten to twenty days operating times were common to the liquefaction pilot plants. Typical life of the packings was only ten to thirty-five days. Other reciprocal pump problems concerned pulsation dampeners and pump valves. The reciprocal pump problems currently experienced at the liquefaction plants are summarized in Table 5.

Reciprocal charge pumps were found to get better service life when teflon is used as packing instead of grafoil. The short packing life is the consequence of plunger alignment and coatings, packing lubrication systems and because the flushing procedure apparently does not effectively clear adherent, erosive particulate matter from getting between packing and the plunger. A variety of packing materials are being tested. Kalrez, Vitron and Teflon are being compared. Vitron appears to distort and some difficulty was expressed in obtaining Kalrez packing. Teflon frequently becomes embedded with hard materials and consequently is abrasive.

Many of the reciprocal charge pump problems experienced in early liquefaction plant tests were caused by the use of inferior materials, by the use of improper materials and specification for balls and seats in ball check valves, and in the use of poor flushing procedure. Most of the pilot plant have now adequately addressed these problems and future problems in these areas are expected to be minimal. The best candidate reciprocating pumps being evaluated at the various pilot plants are given in Table 6.

TABLE 5: SUMMARY OF RECIPROCATING PUMP PROBLEMS

Liquefaction Plant/pump	PROCESS CONDITIONS						PUMPS		
	Stream	Temp (°F)	Pressure (psi) In Out	Flow (gpm)	Specific Gravity	Solids (wt.%)	Life	Part	Problems
EDS/ P-102NB	Coal Slurry Feed	300	135 3310	79.4	1.09	40	15 days to 6 6 days	Packing	Leakage
				73.8		45.6	6 mos.	Plunger	Coating Failures
							6 mos.	Stuffing Box	Wear
							6 mos.	Valves	Miss stroke and sometimes plug
							-	Pulsation Dampener(s)	Useless
							-	Pump Gear	Vol. Eff. Low Teeth Wear - Impact
EDS/ P-204A/B	Atm. Frac. Bottoms	775	24 500	40	1.0	27.4	5-15 days	Packing Plunger Valves Pump Pulsation Dampeners	Leakage Coating Failures Plugging Vol Eff. Low Ineffective
EDS/High Pressure Flush Oil	Solvent	400	241 3000	85	0.87	0	10-20 days	Packing Plunger Pulsation Dampener	Leakage Coating Failures Useless

TABLE 5: (contd.)

Liquefaction Plant/pump	PROCESS CONDITIONS							PUMPS		
	Stream	Temp (°F)	Pressure (psi) In Out	Flow (gpm)	Specific Gravity	Solids (wt.%)	Life	Part	Problems	
HRI PDU	Feed Slurry	250	20 3000	1.0	1.1	30-40				
Wilsonville SRC-I (P103)	Cold Slurry	250	50 2800	3-5	1.1	38 1/2%	6 mos.	Packing Green Tweed	Abrading short stroking	
Wilsonville SRC-I (P-180)	Hot Slurry	550	65 1000	7-1	1	20%	1 mo.	TFE imp. Asbestos	Packing Life Plunger Wear Valve Sticking Internal Relief Wear	
Ft. Lewis SRC-II	Coal Slurry Charge	350	199 2400	10	1.2	45%	300-400 hours	Packing		
							300-400 hours	Plunger		
							3000 hours	Balls Seats		
H-Coal	Reactor Feed	300	90 3120	80-100		2:1	15 days	Packing		
							20 days	Plunger Wear		

TABLE 6: BEST CANDIDATE RECIPROCATING SLURRY PUMP

	<u>EDS</u>	<u>HRI</u>
Manufacturuer	Worthington	Milton Roy__
Model	3 3/8 x 7 Triple-S.A. VTEH	MR 1-105-140T (Model C) one stage
Capacity	79.4 gpm	57.4 gal/hr.
Pressure (Psig, In/Out)	135/3310	20/3300
Casting	12% Chrome Alloy	Steel
Plunger	12% Chrome Alloy WC coating	Special steel with grafoil
Valve	440 C (hardened) with WC Seat	316 SS & 440 SS balls
Gasket	---	326 SS liquid end gasket
Seal Type	Utex 4511-4	---
Pulsation Damper Type	Fluid Kinetics and others	None
Process Stream	Feed Slurry	Coal slurry in process derived recycle oil

3.2 Reciprocal Pump Development Studies

Current pump development studies, which involve testing new abrasive resistant materials and new pumps designs, are detailed in Table 7. Recent pilot plant test results show that pump service life can be increased with the use of erosion resistant materials of increased hardness (1, 12, 15) especially in the plungers, valve, and seat applications. Typical erosion resistant material under study for use in various pump components, as well as high pressure letdown and block valves are listed in Table 8. Other test results show that pump service life can be increased by properly sizing the pumps and by regular maintenance and replacement of the packing. As a general rule slurry pumps should be run at half speed because of valve dynamics (open and close speed) to avoid cavitation problems.

3.3 Centrifugal Pumps

Centrifugal pump problems addressed at the recent Critical Components and Materials Meeting (#6) concerned the erosive wear on the pump casings, stationary face, impellers and pump seals. The specific problem areas are summarized in Table 9.

The pumping requirement in the vacuum bottoms area presents the most challenging conditions for the centrifugal pumps. Temperatures in this process area are 600 to 800° F; with process streams of 20 to 40 wt % solids and very high viscosities. Under such conditions it is difficult to meet suction head requirements and where the pumps deliver

(cont'd to p. 18)

TABLE 7: RECIPROCAL SLURRY FEED PUMPS
DEVELOPMENT STUDIES

Problem Area	Objectives	Design Approaches
Stuffing Box Design (throat bushings, packing, etc.)	Eliminate hazardous leaks & yield reasonable life	Study barrier fluids
Plungers/Plungers Coatings/Alignment	Low, even wear with long life	Fluid arrangements
Cooling/Flushing	Provide adequate cooling & flushing	Surge leg
Valves	Increase reliability	Alternate coatings
Pulsation Dampening	High efficiency with low maintenance	Flushing methods
Manifold Design	Low pulsation in fluids	Plunger guidance
Emissions Control		Bore/Stroke/Speed (new approaches-others) Seat Design (valve geometry & materials) Alternate designs of dampening Make fluid too cold to leak from stuffing box

TABLE 8: TYPICAL EROSION RESISTANT MATERIALS
(1, 5, 14, 15)

Material	Composition
<u>A. Cemented Carbides</u>	
K701 (reference)	13% Co-Cr
K703	7% Co-Cr
K714	20% Co-Cr
K602	1.5% Co
K801	6% Ni
K802	10% Ni
GEM 550	Co-Cr
BCL-1	WC-2% Co (5 m WC)
BCL-2	WC-2% Co (sub m WC)
895 (Carboloy)	WC-6% Co
883 (Carboloy)	WC-6% Co
CA306 (Carmet)	WC-6% Co
CA4 (Carmet)	WC-6% Co
VR54 (Fansteel)	WC-7% Co
2A5 (Fansteel)	WC-6% Co
Stellite 6B (Cabot)	Co Alloy
<u>B. Ceramics</u>	
Titanium carbide	Boron carbide
Tantalum carbide	Zirconium diboride
Silicon carbide alumina	Carboforax (carbon)
Aluminum nitride	BT-10 ($Al_2O_3 + TiB_2 + WC + MgO$)

TABLE 9: SUMMARY OF CENTRIFUGAL PUMPS
PROBLEMS

Liquefaction Plant/Pump	Stream	PROCESS CONTDITIONS						PUMP		
		Temp (°F)	Pressure (psig)		Flow (gpm)	Specific Gravity	Solids (wt)	Life	Part	Problem
HRI PDU	Feed Recirculation	250	5	20	20	1.1	30-40	1 yr.	Shaft	Scoring
HRI PDU	Hydroclone Feed	500	25	100	2-20	1.1	10-20	6 mo.	Seal	Solids
HRI PDU	Reactor Internal Cyclone	850	3000	3000	70	.85	15-40	Preventive	Maintenance	
Wilsonville (P102)	Cold Slurry	250	Floor	70	70	1.1	38-1/2	1 yr.	Casing & Impeller	Wear
Ft. Lewis	Cold Slurry	350	5	120	80	1.2	45%	5000 hrs.	Casting liner cutwater	Wear
	Slop Oil	350	150	300	100	1.1	5%	3000 hrs.	Casting cutwater	Wear
H-Coal Slurry System Low Pressure		Range:	15	50	10-100				Mech seals liner failure Impeller failure	

TABLE 9: SUMMARY OF CENTRIFUGAL PUMPS
PROBLEMS

Liquefaction Plant/Pump	Stream	Temp (F)	Pressure (psig)		Flow (gpm)	Specific Gravity	Solids (wt)	PUMP		
			In	Out				Life	Part	Problem
EDS P-101A/C P-101B/D	Coal Slurry Feed Booster	300	9	85	400	1.09	45.6	3 mos. to 9 mos. (not failed)	Seals	Leak - esp. w/loss of seal flush
			85	161				2000 hrs.	Volute & wear Plates	
									Performance	Unknown
									Impeller	Plugging w/solids
EDS Feed Booster Test Pump P-101E	Coal Slurry	300	9	161	400	1.09	45.6		Impeller	Plugging w/solids
									Seals	Leakage- esp. w/loss of seal flush
EDS P-216	Atm. Frac. Bottom	643- 775	24	99	50	1.0	27.4		Seal	Leakage

sufficient pressure, the service life is too short. It was found that little wear is observed for centrifugal pumps that are operated at conservative impeller tip speeds on the impellers and liners. Some pilot plants have experienced problem with cracked pump liner due to rapid temperature changes. It was also observed that liner life can be increased (from 300 to 1500 hrs) by the installation of a piece of Stellite in the center of the cut water which resulted in the wear to move to the sides of the cut water.

Best candidate centrifugal slurry pumps under evaluation at the liquefaction plants is given in Table 10.

3.4 Centrifugal Pump Seals

In addition, erosive wear the centrifugal pumps seal failures were considered two major problem areas. The seals and service life under study at the liquefaction plants are given in Table 11. Best candidate seals under evaluation are given in Table 10.

TABLE 10: CANDIDATE CENTRIFUGAL SLURRY PUMP ‡

	<u>EDS</u>	<u>HRI(NJ)</u>	<u>SRC-I</u>	<u>SRC-II</u>
Manufacturer	Lawrence	Worthington	Lawrence	Lawrence
Model	4" AL	D-1011	1 1/2" AL	1 1/2" AL
Capacity (gpm)	400	30 at 22 psig	75	80
Pressure (psig) In/Out	9/85	Flooded	85/161	115/245
Casting	Carbon Steel	Ductile Iron	HC-250	---
Impellers	HC-250	316 SS (open)	HC-250	---
Seal	JC-8B CH-880 Seal oil 624	Packed-Grafoil	Dura Double	---
Gaskets	Grafoil, Jna-60	Asbestos	ASB/Flexitallic	---
Bearing/Shaft	Ball	Steel Shaft and 416 SS Sleeve	316 SS	Abex HC-250 Wear Parts
Tip Speed (RPM)	1167	1750	119	95
Process Stream	Coal Slurry Feed	Coal Slurry in process derived recycle oil	Filter Feed	Coal & Recycl Slurry and Vacuum Botto

‡ Not an endorsement

TABLE 11: SUMMARY OF CENTRIFUGAL PUMP SEALS SERVICE EXPERIENCE

Pump Type	Seal Type	Process Location	Stream	Temp (F)	Pressure (psi)		Flow (gpm)	Specific Gravity	Solids (Wt.%)	Life	P R O B L E M S	
					In	Out					Part	Nature
Wilson- ville R434 Crane Deming	Use Durametallic double mech seal in all process centrifugal pumps. Type RO-DHT RO-TT ROD/ROD									6 mos slurry	Shaft seal	Solids Deteriora- tion Operation- al upset
										1 yr clean	Shaft seal	
H-Coal Cent.	Double	Slurry pumps		750- 450	15	200	15-100			2-10 days	Seal rings	Heat checking
Ft. Lewis												Failure to flush over pressuring vibration from mis- alignment
HRI-PDU												
Centri- fuge	Dura- metal- lic double R.O.	Hydro- clone	Hydro- clone feed	500	25	100	2-20	1.1	10-20	6 mos	Seal	Solids

TABLE 11: SUMMARY OF CENTRIFUGAL PUMP SEALS SERVICE EXPERIENCE

Pump Type	Seal Type	Process Location	Stream	Temp (F)	Pressure (psi)		Flow (gpm)	Specific Gravity	Solids (Wt.%)	P R O B L E M S		
					In	Out				Life	Part	Nature
EDS												
Law 4" AL	JC 9 BE*	Feed slurry		300	9	161	400	1.09	45.6		Sleeve	Worn by wedge
	JC 8 B											
	CH 880											
	Seal 624											
IR 3x9 ATM	Dura BPO											
Law	B-W BRL	ATM wash		700	35	81	47	0.80	4.1		Low	Worn & leaked
Worth 1-1/2 M-12 (1H)	Dura BRO (DBL)	ATM bott. test		775	24	99	50	1.0	27.4		Low	Leak
	B-W BxR(H)											Slight drip

*JC- John Crane

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ATTACHMENT A

4.0 Attachment A: Anticipated Commercial Liquefaction Plant Pump Designs

4.1 Service - Coal Slurry Feed Booster and Pumparound

Approximate Operating Conditions

Fluid	Fresh coal/solvent slurry
Pumping Temperature	275 ^o F
Suction Pressure	16 PSIA
Discharge Pressure	103 PSIA(1)
Differential Pressure	87(1)
Specific Gravity @ P.T.	1.08
Head	186 ft.
Flow Rate Per Process Line	12,800 or 16,800 GPM
Viscosity	20.4 Centipoises (3)
Solids Content	45 weight % coal
Max. Particle Size	8 mesh

Pump Design Anticipated

Type	Centrifugal; API steel casing with replaceable casing linings
Multiplicity design, Per process line	2-100% (1 op, 1 sp) with constant speed drive (preferred) 3-60% (2 op, 1 sp) with variable speed drive (alternative) (2)

- NOTE: (1) This value is not yet accurately defined.
(2) More pumps of smaller capacity in parallel are possible, but much less desirable.
(3) Non-Newtonian behavior is not yet accurately defined.

4.2 Service - Coal Slurry Feed to Preheat Furnace and Liquefaction Reactor

Approximate Operating Conditions

Fluid	Fresh coal/solvent slurry
Pumping Temperature	275°F (2)
Suction Pressure	75 PSIA
Discharge Pressure	2500 PSIA
Differential Pressure	2425 PSI
Specific Gravity @ P.T.	1.08
Head	5190 ft.
Flow Rate Per Process Line	2160 or 3360 GPM (1)
Viscosity	20.4 Centipoises
Solids Content	45 weight % coal
Max. Particle Size	8 mesh

Pump Design Anticipated

Type	Reciprocating plunger pump with variable speed drive
Multiplicity design, Per Process Line	3-60% (2 op, 1 sp) (preferred) 3-50% (2 op, 1 sp) (alternative) 4-33% (3 op, 1 sp) (alternative) 5-25% (4 op, 1 sp) (least attractive alternative)

NOTE: (1) Non-Newtonian behavior is not yet accurately defined.
(2) This value is not yet accurately defined.

4.3 Service - Effluent Separator Wash Oil Circulator

Approximate Operating Conditions

Fluid	Hydrocarb on liquid
Pumping Temperature	650° F
Suction Pressure	1915 PSIA
Discharge Pressure	1975 or 2015 PSIA
Differential Pressure	60 or 100 PSI
Specific Gravity @ P.T.	0.61
Head	227 or 380 ft.
Flow Rate per Process Line	320 or 350 GPM
Viscosity	0.22 Centipoises
Solids Content	0 to 5% coal fines carryover;; (content and character cannot be predicted accurately yet)
Max. Particle Size	About 30 mesh

Pump Design Anticipated

Type	Centrifugal, canned type pump/motor without external shaft seal, with hard surfaced wear areas, and with flushed motor enclosure
Multiplicity design, per Process Line	2-100% (1 op, 1 sp)

4.4 Service - Vacuum Fractionator Bottoms Transfer to Bottoms
Processing Unit and/or to Intermediate Storage

Appropriate Operating Conditions

Fluid	Vacuum Fractionator Bottoms
Pumping Temperature	703°F
Suction Pressure	5 PSIA
Discharge Pressure	55 to 115 PSIA (possibly higher)
Differential Pressure	50 to 110 PSI
Specific Gravity @ P.T.	1.29 @ 36% solids
Head	98 to 206 ft.
Flow rate per Process Line	675 GPM
Viscosity @ P.T.	800 Centipoises Non-Newtonian, shear thinning
Solids Content	36 to 47 weight %
Max. Particle Size	Coal up to 4 mesh Coal up to 30 mesh Coke up to 1" x 1" x 1/4"

Pump Design Anticipated

Type	Two-rotor screw pump with external timing gears and bearings and double mechanical shaft seals
Multiplicity design, per Process Line	2-100% (1 op, 1 sp)

4.5 Service - Feed to Reactor of Bottoms Processing Unit

Approximate Operating Conditions

Fluid	EDS Vacuum Fractionator_Bottoms
Pumping Temperature	500 to 600°F
Suction Pressure	10 to 40 PSIA
Discharge Pressure	415 to 615 PSIA
Differential Pressure	420 to 620 PSI
Specific Gravity @ P.T.	1.22
Head	800 to 1180 ft.
Flow Rate per Process Line	680 GPM
Viscosity @ 500°F	Non-Newtonian, shear thinning (1) 6000 centipoises @ shear rate 1 sec ⁻¹ 2000 centipoises @ shear rate 20 sec ⁻¹ 700 centipoises @ shear rate 350 sec ⁻¹ 550 centipoises @ shear rate 1000 sec ⁻¹
Solids Content	36 to 47 weight %
Max. Particle Size	Coal up to 4 mesh Ash up to 30 mesh Coke up to 1" x 1" x 1/4"

Pump Design Anticipated

Type	Two rotor screw pump with external timing gears and bearings and mechanical shaft seals
Multiplicity design, per Process Line	2-100% (1 op, 1 sp)

NOTE: (1) Viscosity may be found to differ significantly from the present estimate shown here.

4.6 Service - Feed to Bottoms Processing Unit of Different Type

Approximate Operating Conditions

Fluid	EDS Vacuum Fractionator Bottoms
Pumping Temperature	650 to 750°F
Suction Pressure	40 to 70 PSIA (provided by a booster pump)
Discharge Pressure	1000 to 1200 PSIA
Differential Pressure	960 to 1160 PSI
Special Gravity @ P.T.	1.13 to 1.20
Head	1960 to 2370 ft.
Flow Rate per Process Line	680 to 860 GPM
Viscosity @ P.T.	120,000 to 650,000 Centipoises (2) Non-Newtonian, shear thinning
Solids Content	36 to 47 weight %
Max. Particle Size	Coal up to 4 mesh Ash up to 30 mesh Coke up to 1" x 1" x 1/4" (1)

Pump Design Anticipated

Type	Reciprocating plunger type with variable speed drive
Multiplicity Design, per Process Line	2-100% (1 op, 1 sp) or 3-60% (2 op, 1 sp)

NOTES: (1) Coke particles of sizes in excess of pump passing capacity must be pulverized or removed upstream.

(2) Viscosity behavior is not yet accurately defined.