United States Patent [19]

Kroeger

[11] **3,907,462**

[45] **Sept. 23, 1975**

[54] **HYDRAULIC DISPLACEMENT TYPE PUMPING SYSTEM**

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[73] Assignee: **Worthington Pump International Inc.,** Mountainside, N.J.

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[21] Appl. No.: **496,322**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 302,874, Nov. 1, 1972, abandoned.

[52] **U.S. Cl.** **417/102;** 417/138; 417/900

[51] **Int. Cl.**[2] **F04F 11/00;** F04B 15/02

[58] **Field of Search** 417/101, 102, 900, 125, 417/138, 33, 27, 141

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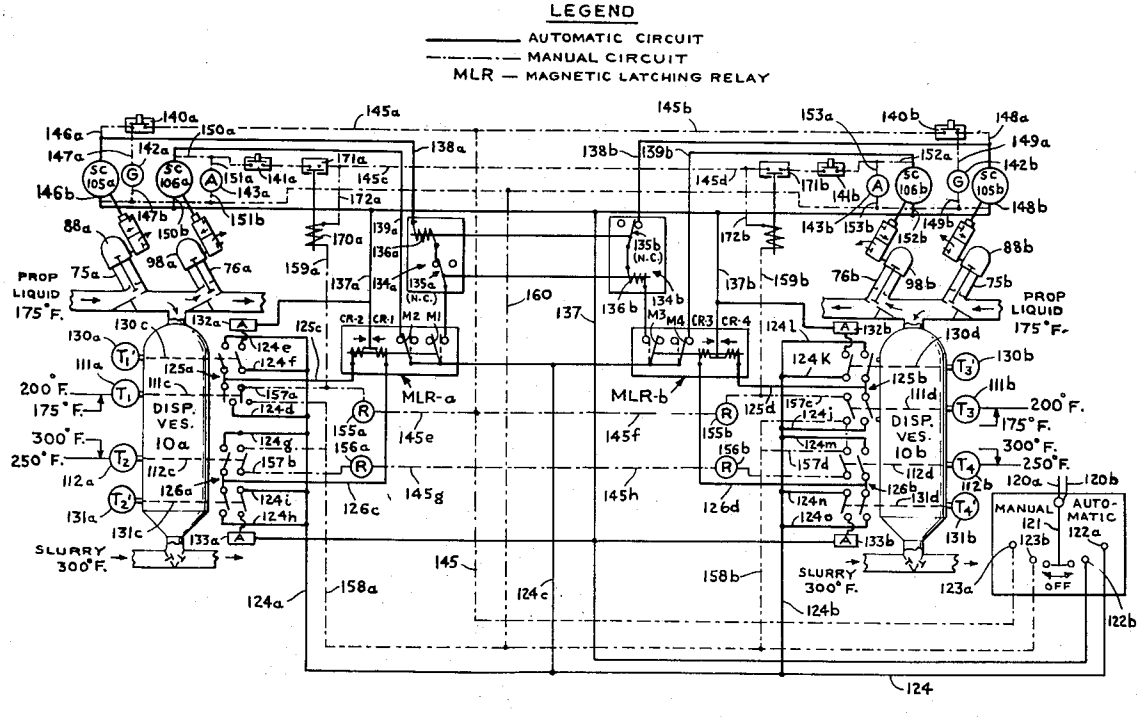
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[57] **ABSTRACT**

A hydraulic displacement type pumping system for pumping slurries or mixtures of solids and liquids of various types utilizing, at least one or more displacement vessels or cylinders, a first open transport system, i.e., one operating preferably at atmospheric pressure including; piping means for delivering slurry or other mixtures of solids and liquid to be pumped from a storage tank to the lower end of said displacement vessels or cylinders, slurry inlet valves and slurry discharge valves in said piping also at the lower end of the displacement vessels or cylinders which are connected to suitable piping to permit the slurry or other mixture being pumped to be passed from the displacement vessels or cylinders to the point of use; a second open transport system for propulsion liquid having preferably a high speed centrifugal pump for delivering a volume of pressurized propulsion liquid from a propulsion liquid storage tank to propulsion liquid inlet valves at the top of the displacement vessels or cylinders and propulsion liquid outlet valves generally connected adjacent the top of the displacement vessels or cylinders and piping for passing or returning propulsion liquid displaced from the displacement vessels or cylinders to the propulsion liquid storage tank during the operation of the system. The hydraulic displacement system includes, an electrical system having associated sensing means for monitoring operation of the hydraulic displacement type system and to signal changes therein to cause the automatic and selective actuation of the propulsion liquid inlet and outlet valves as a function of the sensed level of the interfaces between the slurry or other liquid being pumped and the propulsion liquid in the respective displacement vessels; and means to modulate the rate of operation of the system as a function of either the sensed level of the slurry or other mixture in the storage tank or the demand rate of the means for feeding slurry or other mixture into the storage tank for the first open transport system.

The electrical system includes failsafe and override means with associated alarm signals for signalling the development of damgerous, adverse or undesirable conditions of operation; and a parallel circuit for operating the Hydraulic Displacement Type System manually instead of automatically.

14 Claims, 8 Drawing Figures



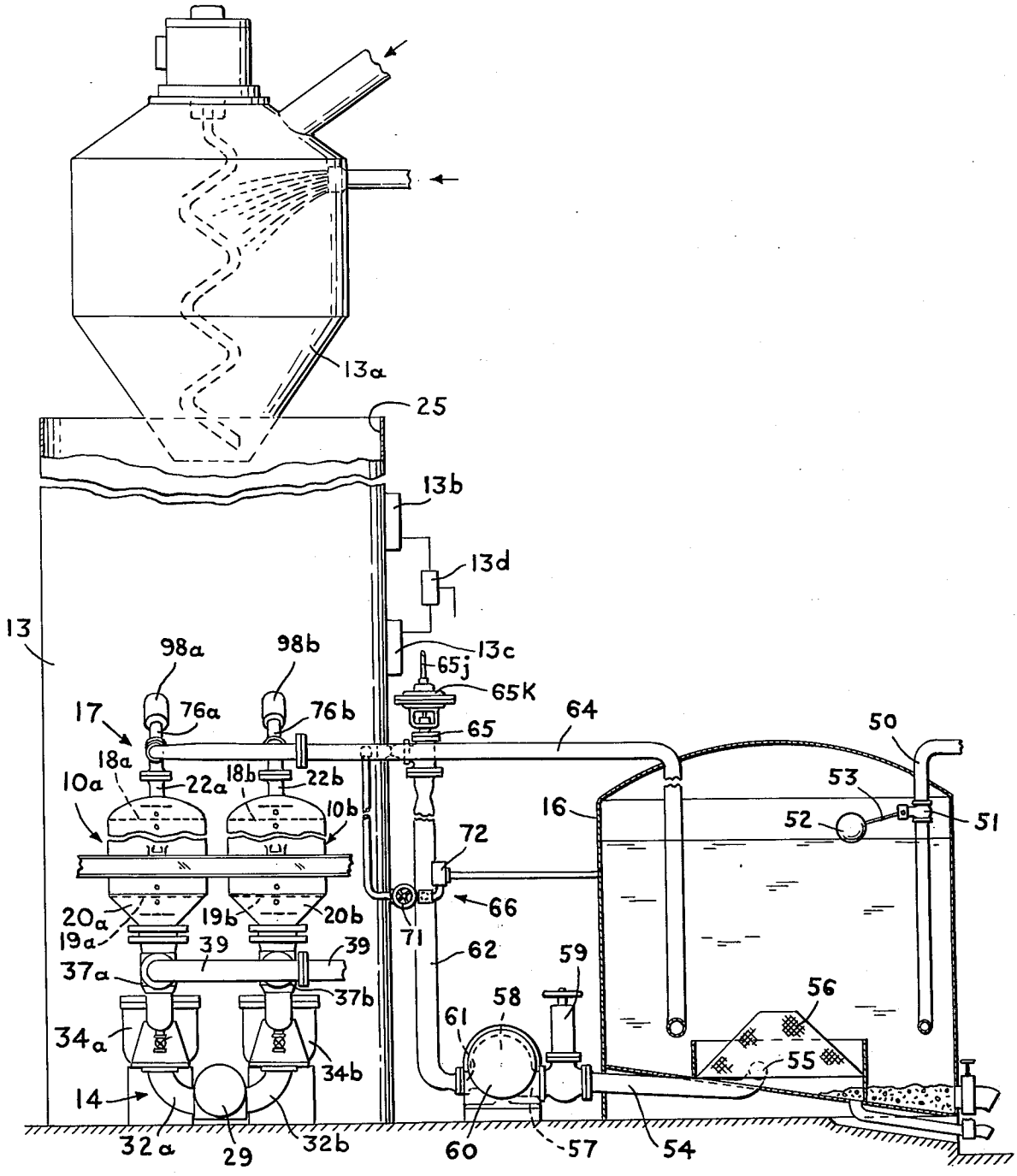

13a
25
13b
13d
13
13c
98a
98b
65j
65K
17
76a
76b
65
64
50
18a
18b
22a
22b
10a
10b
16
53
52
51
72
66
20a
19b
20b
19a
39
39
71
62
59
37a
37b
56
61
58
34a
34b
55
14
32a
29
32b
60
57
54

FIG. 1

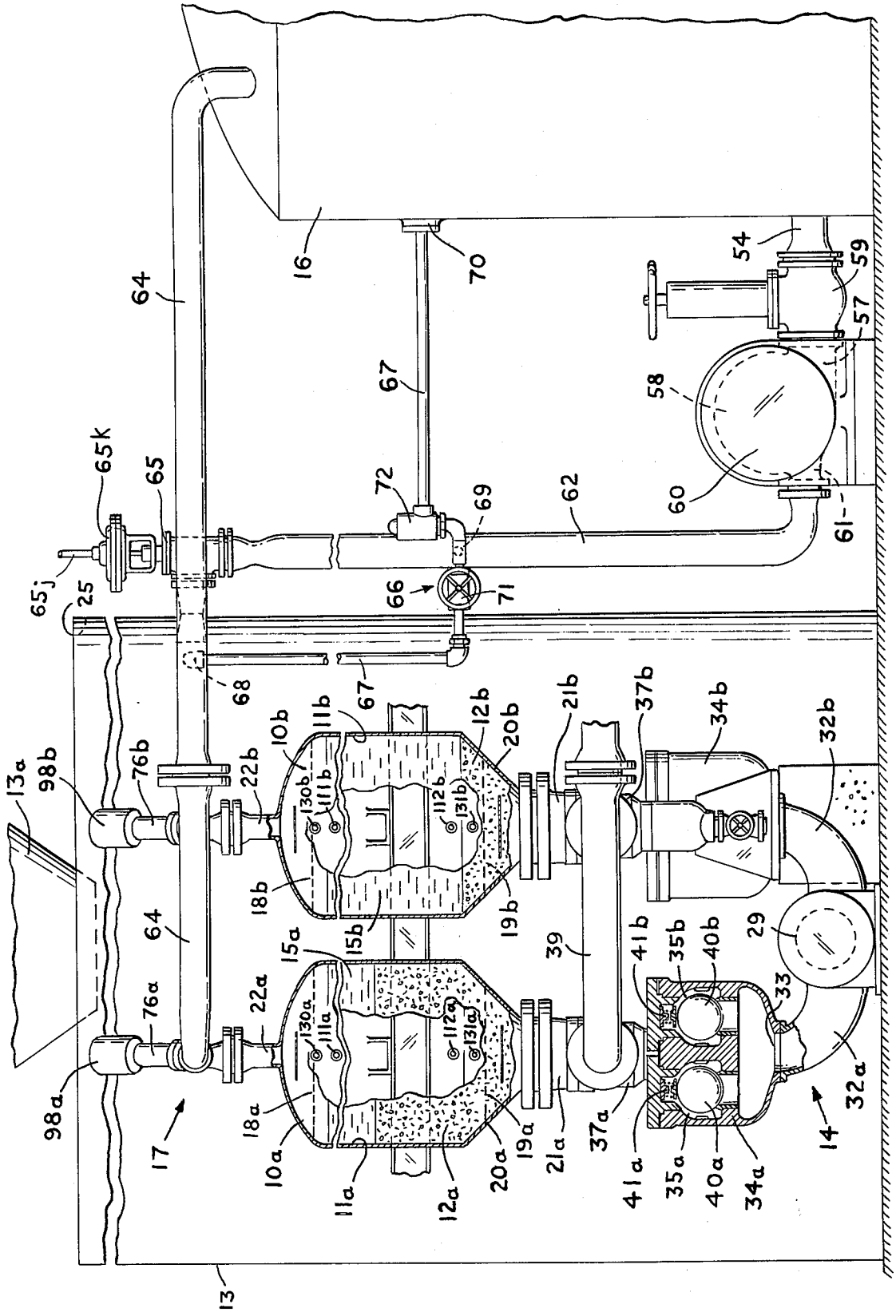

16
70
54
59
57
64
67
58
60
61
62
72
69
65k
65
65j
25
66
71
68
67
10b
11b
12b
20b
21b
37b
34b
32b
13a
98b
76b
22b
18b
19b
15b
15a
39
41b
35b
40b
29
33
64
76a
22a
98a
17
18a
10a
11a
12a
20a
19a
21a
37a
41a
35a
40a
34a
14
32a
13

FIG. 2

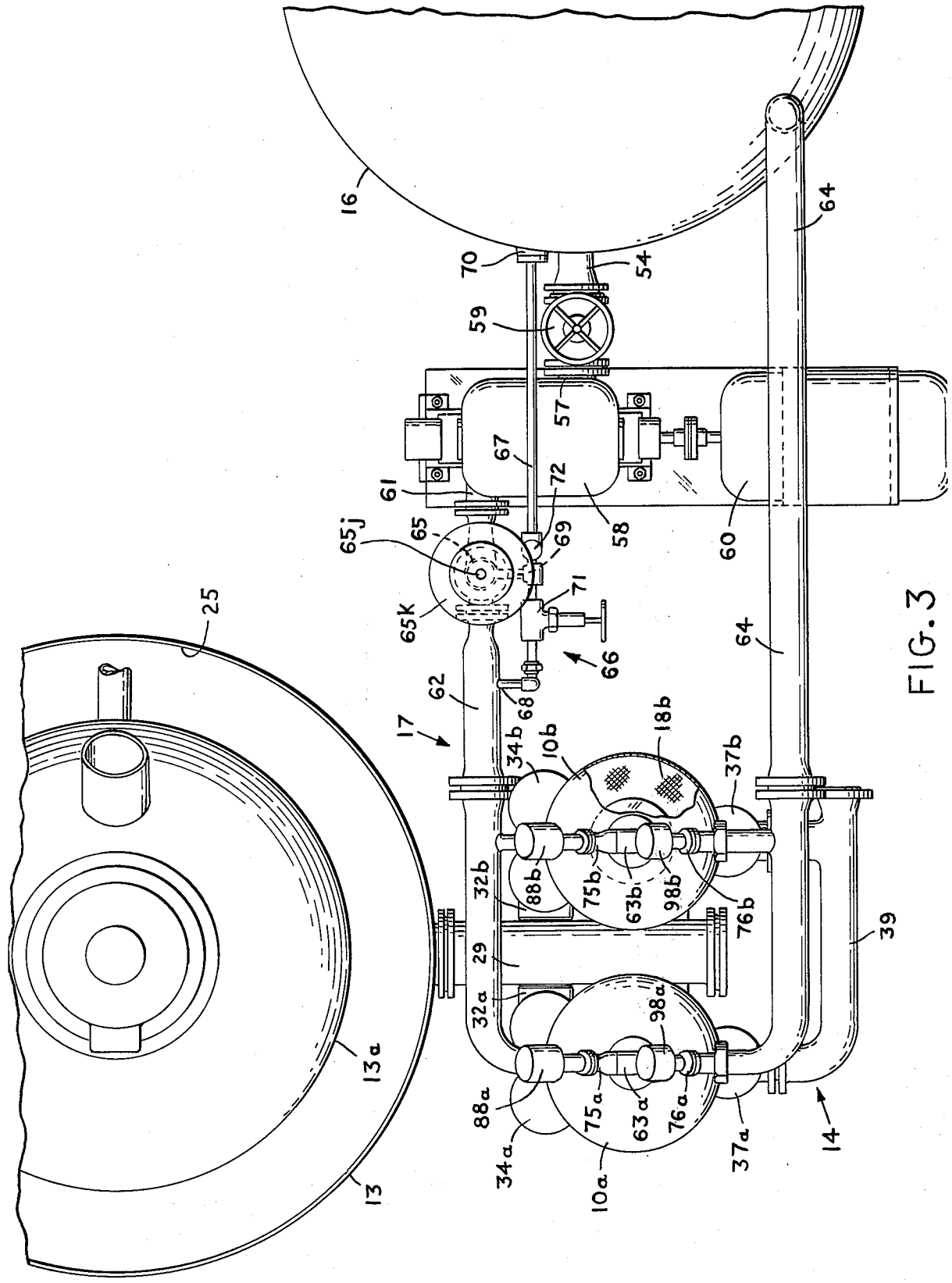

16
64
70
54
59
57
67
72
61
58
60
65j
65
69
71
65k
66
64
62
68
17
34b
10b
18b
37b
32b
88b
75b
63b
98b
76b
39
29
32a
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88a
75a
63a
76a
37a
14
34a
10a
25
13a
13

FIG. 3

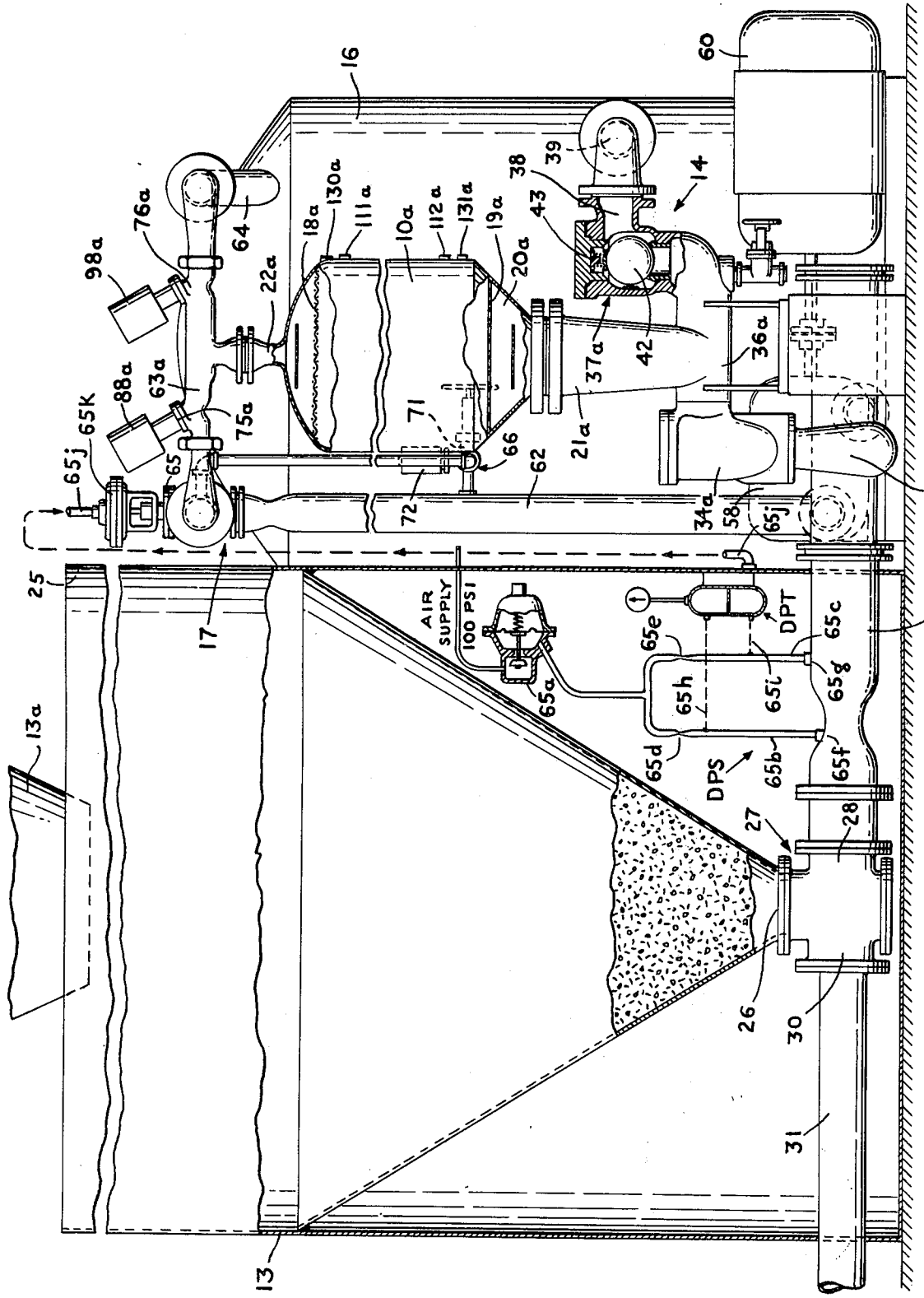

16
60
14
39
38
43
42
37a
36a
32a
34a
58
65j
29
DPT
65c
65e
65h
65i
65g
65d
65b
65f
DPS
27
28
26
30
31
AIR SUPPLY 100 PSI
65a
17
25
13a
13
76a
98a
64
18a
130a
111a
10a
112a
131a
19a
20a
22a
88a
63a
65K
65j
65
75a
71
66
62
72
21a

FIG. 4

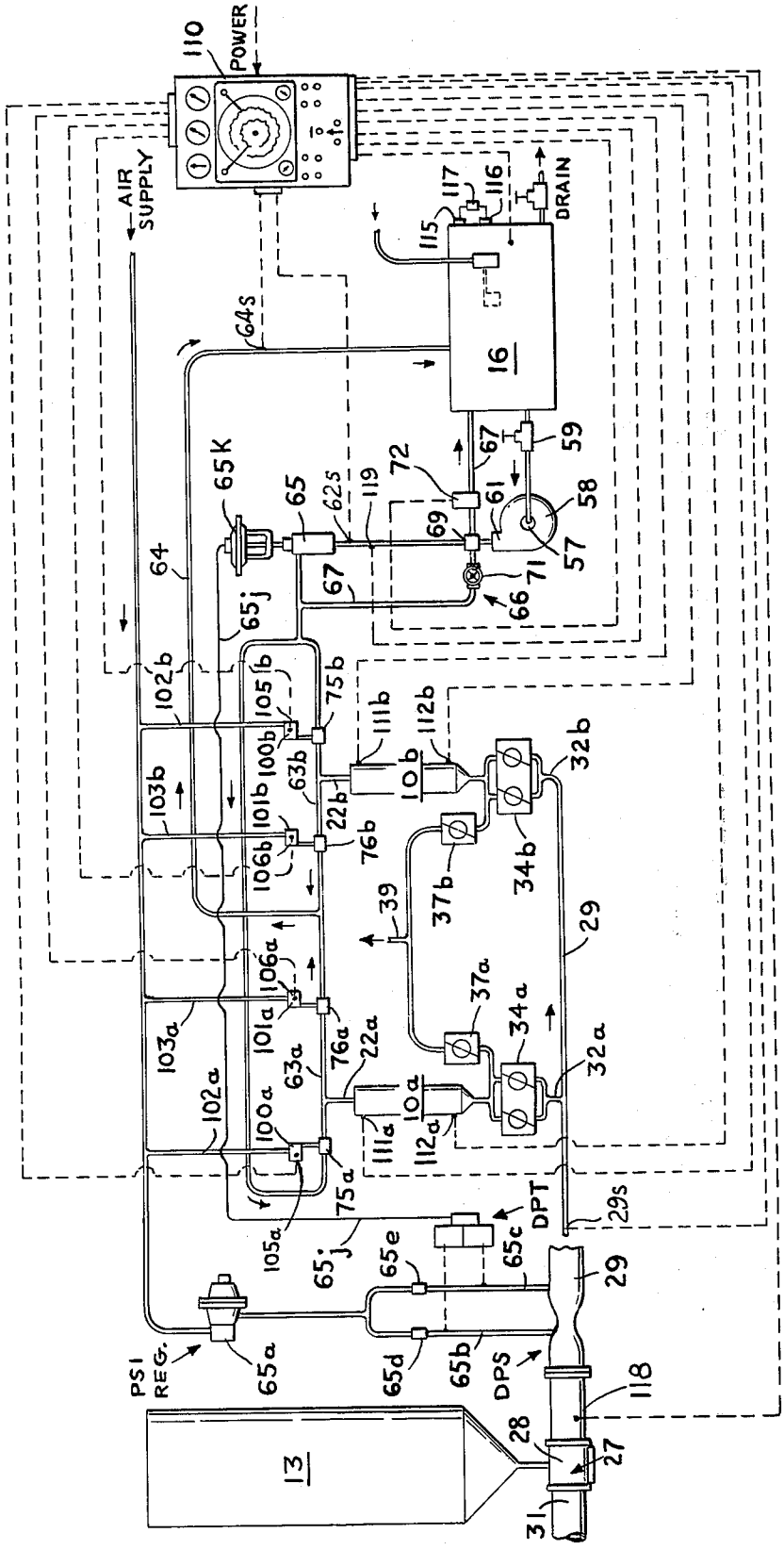

110
POWER
AIR SUPPLY
DRAIN
115
117
116
16
64S
65K
65
62S
119
72
67
59
61
58
69
57
71
66
64
65j
67
102b
105b
75b
111b
112b
10b
32b
103b
101b
100b
63b
22b
76b
106b
37b
34b
39
29
106a
37a
103a
101a
63a
76a
22a
34a
32a
102a
100a
10a
111a
112a
75a
105a
65j
65e
65c
DPT
29s
29
PSI REG.
65a
65d
65b
DPS
118
28
27
13
31

FIG. 6

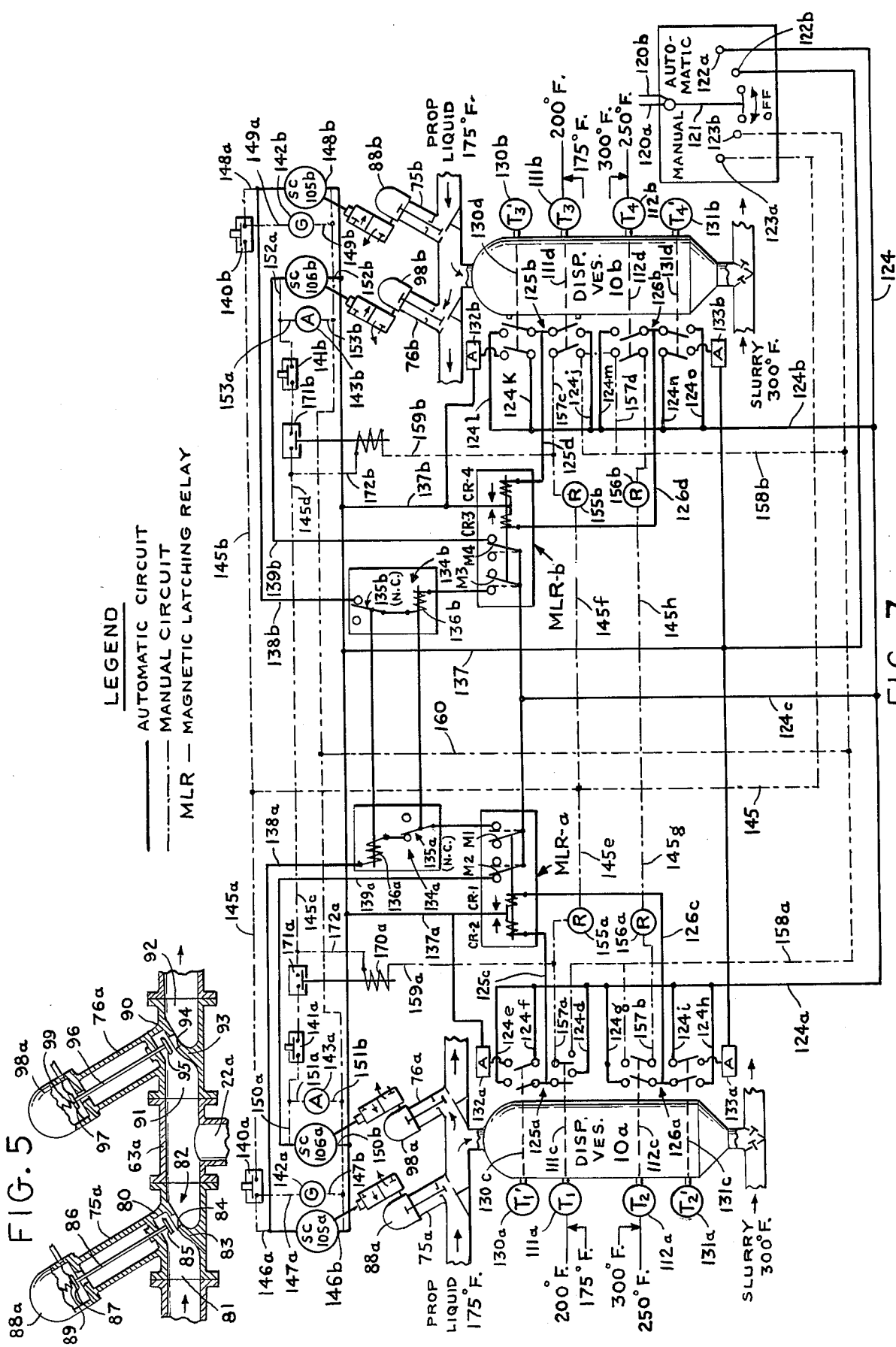

LEGEND
AUTOMATIC CIRCUIT
MANUAL CIRCUIT
MLR — MAGNETIC LATCHING RELAY
MLR-a
MLR-b
DISP. VES. 10a
DISP. VES. 10b
AUTO-MATIC
MANUAL
OFF
PROP LIQUID 175°F.
SLURRY 300°F.
200°F.
175°F.
300°F.
250°F.

FIG. 7

FIG. 5

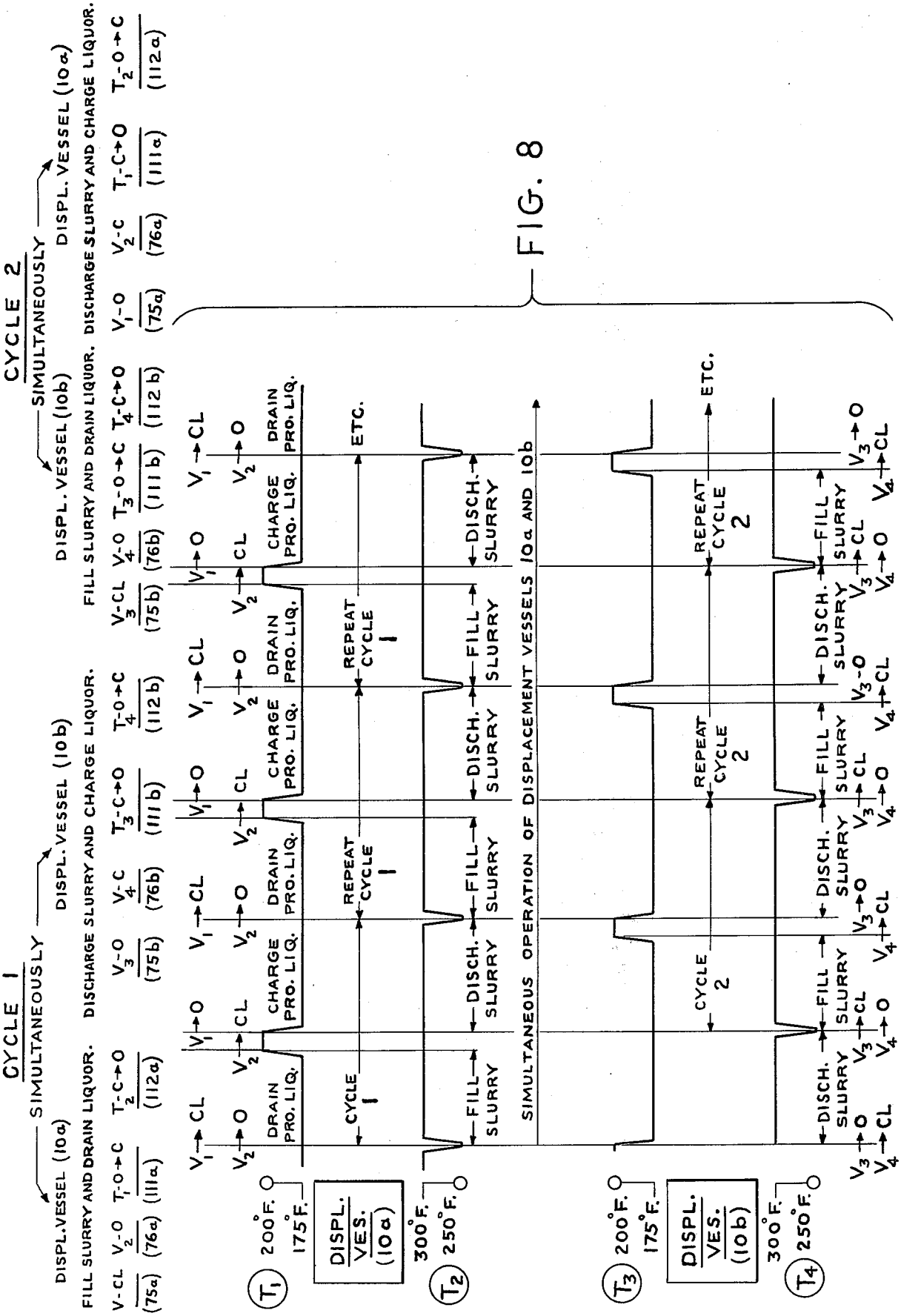

CYCLE 1
SIMULTANEOUSLY
DISPL. VESSEL (10a)
DISPL. VESSEL (10b)
FILL SLURRY AND DRAIN LIQUOR.
DISCHARGE SLURRY AND CHARGE LIQUOR.
CYCLE 2
SIMULTANEOUSLY
DISPL. VESSEL (10b)
DISPL. VESSEL (10a)
FILL SLURRY AND DRAIN LIQUOR.
DISCHARGE SLURRY AND CHARGE LIQUOR.
DRAIN PRO. LIQ.
CHARGE PRO. LIQ.
CYCLE 1
REPEAT CYCLE 1
ETC.
FILL SLURRY
DISCH. SLURRY
CYCLE 2
REPEAT CYCLE 2
SIMULTANEOUS OPERATION OF DISPLACEMENT VESSELS 10a AND 10b
T1 200°F. 175°F.
T2 300°F. 250°F.
T3 200°F. 175°F.
T4 300°F. 250°F.
DISPL. VES. (10a)
DISPL. VES. (10b)

FIG. 8

HYDRAULIC DISPLACEMENT TYPE PUMPING SYSTEM

This application is a continuation-in-part of pending application U.S. Ser. No. 302,874, filed Nov. 1, 1972, now abandoned.

BACKGROUND OF THE INVENTION

The pumping of slurry or other solid and liquid mixtures has been performed conventionally by heavy slow speed direct steam or crankshaft powered multipiston or plunger type reciprocating pumps having close fitting parts with relatively small tolerances. Contamination produced by the slurry or other mixture being pumped caused excessive wear and maintenance problems even when an intermediate buffer liquid is provided between the slurry and sliding parts of the reciprocating pumps.

One type pumping system to overcome these problems consists braodly of a vessel charged with the mixture to be pumped which utilizes a volume of pressurized fluid as a piston for driving the mixture from the vessel to the point of use. Patents have been granted on such systems as shown in U.S. Pat. Nos. 1,901,961; 2,704,034 and 3,449,013. An important aspect of such last mentioned system, is the control means for regulating the pumping operation of such systems as is shown in U.S. Pat. Nos. 3,449,013 and 3,155,049 and a recently published Australian Application Ser. No. 42058/**68**, also identified under U.S. Pat. No. 3,556,682.

Hydraulic displacement type pumping systems are advantageous because there are no close fitting sliding parts which can be subjected to contamination by the slurry or other mixture being pumped. They are replaced by a displacing volume of pressurized liquid in the hydraulic displacement type pumping system.

These known prior art hydraulic displacement type pumping systems, however, present some difficulties. For example, the pumping systems covered in U.S. Pat. No. 2,704,034 is based on the combination of a first pressurized propulsion liquid in a closed cycle and a second liquid slurry, etc. open cycle which are operatively interrelated. Thus, the first pressurized propulsion liquid in the closed cycle is hydraulically interconnected with the liquid being pumped and therefore an exact interaction of the first liquid with respect to the second liquid is required. This requires simultaneous switching of the inlet and outlet valves of both the first and the second liquid because there is no pressure absorbing buffer in the closed cycle from the pump to the displacement vessels and programming of this type system to prevent water hammer effects is not possible.

Further, this system requires the use of a positive displacement type pump such as a gear, vane or other suitable pump. Any fluid loss of the propulsion liquid must be balanced and this requires a separate make up water means for the storage tank for the propulsion liquid to make up for the fluid lost.

Both the positive displacement type pump and the make up arrangement between the overall cost of a system of this type.

Capacity modulation that is adjustment of the rate of operation as a function of either the level or the quantity of the slurry fed to the slurry storage tank would require on-off pump operation or bypass valve regulation in the propulsion liquid system, or variable capacity

pumps or variable speed pump drive means to meet this problem.

Additionally, in a hydraulic displacement type system of the type disclosed in U.S. Pat. No. 2,704,034, the propulsion liquid and the slurry or other mixture being pumped must be immiscible or a separation means must be maintained such as an impervious floating device or sealing piston if the system is to remain operable.

The present invention covers an improved hydraulic displacement type pumping system using a displacing volume of pressurized clear propulsion liquid delivered from a propulsion liquid transport loop which includes, a high speed centrifugal type pump and a stroke sequenced inlet and outlet valve system for continuously driving the slurry or other mixture to be pumped in said system, the automatic stroke sequencing additionally being automatically modulated as a function of the level in or the demand rate of the means for feeding slurry to the slurry feed tank. The system is provided with automatic controls for failsafe operation so that slurry or other mixture being pumped never penetrates into the propulsion liquid transport system and a selector switch for off, manual or automatic operation of the control system to provide for manual operation for flushing the slurry section with clear liquid, the entire system being operatively connectable to suitable recording equipment for performance analysis and range limit control at the central operation station all of which will be more fully described below.

Other objects and advantages of my invention will be apparent to those skilled in the art after a consideration of the following detailed description of the same taken in conjunction with the accompanying drawing in which:

FIG. **1** is a front elevational view of a gravity fed hydraulic displacement type pumping system in accordance with the present invention showing generally the relative heights of the elements of such system;

FIG. **2** is an enlarged front view of the hydraulic displacement type pumping system above in FIG. **1** showing portions of the displacement vessels or cylinders broken away and the slurry valve inlet means in vertical section;

FIG. **3** is a top plan view of the hydraulic displacement type pumping system shown in FIG. **1**;

FIG. **4** is a side view taken from the left side of the hydraulic displacement type pumping system shown in FIGS. **1, 2** and **3** showing the slurry valve outlet means in vertical section;

FIG. **5** is a side view partly in vertical section of a pair of propulsion liquid inlet and outlet valves and the piping connecting these valves to the associated displacement vessels;

FIG. **6** is a schematic diagram showing the operative interrelation of the propulsion liquid inlet and outlet valves at the top of each of the displacement vessels or cylinders, the slurry inlet and discharge valves at the bottom of the displacement vessels or cylinders, the air system and air operated valves for activating the propulsion liquid valves, the controls for actuating the air operated valves and the general wiring diagram to the controls of the system.

FIG. **7** is a schematic diagram of the electrical circuit, control elements and sensors for activating the air operated valves for activating the propulsion liquid inlet and discharge valves of the system shown in FIG. **6**;

FIG. 8 is a sequence diagram showing several operating cycles for the hydraulic displacement type pumping system of FIG. 1

The hydaulic displacement type pumping system of the present invention can be divided into four basic parts, First, the displacement vessels or cylinders.

Second, the transport and discharge assembly for slurry or other mixture to be pumped.

Third, the transport and return assembly for the propulsion liquid.

Fourth, the capacity modulation means for regulating the quantity of propulsion liquid as a function of the level of slurry or other mixture being pumped into the storage tank of the transport and discharge system or the connected feed and/or demand system and the control system for sequencing the valves in the propulsion liquid transport and return assembly.

These various portions of the overall system will now be described with respect to the figures in the drawings.

DISPLACEMENT VESSELS

Thus, referring to the drawings, FIGS. **1, 2, 3** and **4** show a plurality of displacement vessels or cylinders at **10***a* and **10***b*, respectively.

It will be understood that the system shown and described herein is merely illustrative. In fact, it can embody one or any number of such displacement vessels in which case the remaining functional portions of the system must be adjusted accordingly as will be understood by those skilled in the art.

The displacement vessels are elongated cylindrical members closed at each end to form displacement chambers therein as at **11***a* and **11***b*. A slurry or other mixture to be pumped as shown at **12***a* and **12***b* is delivered into the respective bottom or lower section of the displacement chambers **11***a* and **11***b* from a storage tank **13** in a transport and discharge assembly for slurry or other mixture to be pumped generally designated **14.** Into the respective top or upper sections of the displacement chambers **11***a* and **11***b*, a clear propulsion liquid as shown at **15***a* and **15***b* is charged into and returned from the propulsion liquid storage tank **16** in the propulsion liquid transport and return assembly generally designated **17** by a sequential stroking means to successively displace the slurry or other mixture being pumped from the displacement chambers **11***a* and **11***b*, all of which is hereinafter more fully described.

Each system in accordance with the present invention can be constructed for a given capacity range which will depend on the sum of the volumetric capacity of each of the displacement chambers times the given number of cycles per hour that the chamber of each respective displacement vessel are or can be emptied over any given average hour of operation of the system.

It will be noted that reference is made to slurry or other mixture to be pumped. Since this system is particularly applicable to the pumping of slurries such as bauxite which is used in the manufacture of aluminum the description that follows will continue to use slurry with reference to the mixture being pumped. However, it will be understood by those skilled in the art that this is merely used for illustration and applicant intends to encompass the pumping or mixtures other than slurry and that the use of the word slurry is not intended to limit the scope of the present invention.

The propulsion liquid storage tank **16** and the displacement vessels or cylinders **10***a* and **10***b* are approximately one-fifth the height of the slurry storage tank **13** as is schematically illustrated in FIG. 1 of the drawings to show one approximate ratio of the elements of a hydraulic displacement type pumping system wherein slurry is fed to the displacement vessels by gravity flow.

The displacement vessels or cylinders **10***a* and **10***b* will have a height to diameter ratio such that when coupled with interface stabilizers or flow baffle arrangements such as the top flow baffles as at **18***a* and **18***b* and the bottom flow baffles as at **19***a* and **19***b* in the respective displacement cylinders or vessels **10***a* and **10***b*, interface diffusion or mixing between the propulsion liquid and slurry will be minimized. This arrangement will even minimize interface mixing where the propulsion liquid and slurry being pumped are miscible with each other.

The top baffles **18***a* and **18***b* can consist of screens or plates with small openings therein. However, the bottom baffles **19***a* and **19***b* will remain larger openings to permit the solids and semi-solids of the slurry to pass easily therethrough during charging and discharging of the respective displacement vessels **10***a* and **10***b*.

The baffles act to deflect and stratify either the propulsion liquid entering at the top of the slurry entering at the bottom. Such stratification of the respective mixtures will sharpen the interface therebetween and this is important because the sensors used to effect sequencing of the operation of the respective displacement vessels respond as a function of the conditions at the interface as is described below in respect of the operation of the system disclosed herein.

To prevent a buildup of scale on the slurry wetted surfaces of the respective displacement chambers **11***a* and **11***b* they can be coated with a non-stick coating or cladding such as polytetrafluoroethylene or the like type fluorocarbon resins; silicon compounds and similar coating which are adapted to withstand the temperatures and the corrosive character of the slurry or other mixture being pumped.

The displacement vessels or cylinders **10***a* and **10***b* taper as at **20***a* and **20***b* to facilitate discharge of the mixture being pumped and at the lowermost portion are further provided with lower connecting conduits **21***a* and **21***b*. At the uppermost end of the displacement vessels **10***a* and **10***b* are upper connecting conduits **22***a* and **22***b*. The lower connecting conduits **21***a* and **21***b* provide means for connecting the displacement vessels or cylinders **10***a* and **10***b* respectively to the transport and discharge assembly **14** for the slurry and the upper connecting conduits **22***a* and **22***b* provide means for connecting the displacement vessels or cylinders **10***a* and **10***b* respectively to the propulsion liquid transport and return assembly **17** which respective assemblies will now be described.

SLURRY TRANSPORT AND DISCHARGE ASSEMBLY

This assembly includes the storage tank **13** which is one of the important components in the system because the rate of operation of the entire pumping system is tied to the feed rate of the slurry supplied from any suitable conveying system including the chute and mixing means **13***a* which empties into the storage tank **13.**

Storage tank **13** is provided with an upper slurry level limit signal device **13***b* and a lower slurry level limit de-

vice **13***c* for regulating the rate or demand for filling the storage tank **13** to maintain a predetermined level therein. The level is signalled through a transmitter **13***d* which is operatively connected to actuate and deactuate the conveying means in feeding the chute and mixing means **13***a*. Upper and lower limit level devices are well known and easily purchaseable on the open market hence, they are not more fully described herein.

The level of the slurry in storage tank **13** will be sensed by suitable means because the rate of operation of the system and the modulation of the system is a function of the sensed level in the storage tank **13** or the rate at which slurry is fed and/or the demand on the system.

By reference to FIG. **1** of the drawings, the storage tank **13** is schematically depicted as having a height considerably greater than the height of both the displacement vessels **10***a* and **10***b* and that of the propulsion liquid storage tank **16** in the propulsion liquid transport and return assembly **17.** Those skilled in the art will recognize that in the gravity fed system disclosed in FIGS. **1** to **4** of the drawings, the lower the level of the propulsion liquid in the storage tank **16,** the lower will be the pressure head required in the respective displacement chambers **11***a* and **11***b* for displacement of the propulsion liquid by the slurry which is delivered from the storage tank **13** to the respective displacement chambers **11***a* and **11***b* in accordance with the automatic sequential stroking of valves controlling, delivery to and return of propulsion liquid from the respective displacement cylinders.

Thus, the greater the difference in head or the greater the differential pressure the quicker the propulsion liquid will be displaced when the system is in operation. Thus, the greater the difference in the head or differential pressure between the slurry and propulsion liquid during the displacement phase of the operating cycle, the greater will be the possible number of cycles or rate of pumping operation.

The storage tank **13** has an inlet opening at the upper end as at **25** for delivery by the chute and mixing means **13***a* of the slurry to be pumped. At the lowermost end an outlet **26** is provided for discharging the slurry. Outlet **26** is in turn connected to a three-way valve **27** which has one outlet **28** connected to a delivery conduit **29.** A second outlet **30** is connected to a clear liquid flushing line **31** to permit clear liquid to be passed through the three-way valve **27** and delivery conduit **29** which communicates with the displacement vessels or cylinders **10***a* and **10***b* as hereinafter discribed for flushing the displacement chambers **11***a* and **11***b* as may be required from time to time for maintenance of the various elements of the system that are subjected to the slurry being pumped.

The delivery conduit **29** is in turn connected by lines **32***a* and **32***b* to the inlet port **33** for the respective inlet check valves **34***a* and **34***b* which have their respective dual-ported outlets **35***a* and **35***b* in turn connected to connecting lines **36***a* and **36***b* which are connected individually to the lower connecting conduits **21***a* and **21***b* of the respective displacement vessels or cylinders **10***a* and **10***b*.

At the ends remote from their connection with the inlet check valves **34***a* and **34***b*, the connecting lines **36***a* and **36***b* are respectively connected to the inlet side of discharge check valves **37***a* and **37***b* for the respective displacement vessels or cylinders **10***a* and **10***b*. Discharge check valves **37***a* and **37***b* in turn have their outlet ports **38** in communication with the common discharge manifold **39** for passing the slurry to any desired point of use, all of which is clearly shown in FIGS. **1,** 2 and **3** of the drawings.

The inlet check valves **34***a* and **34***b* and the discharge check valves **37***a* and **37***b* are unidirectional ball type check valves in which the ball members **40***a* and **40***b* are held in contact with seats on said valve outlet ports **35***a* and **35***b* by means of springs **41***a* and **41***b*. Similarly the outlet port **38** for the discharge valves has a ball **42** and a spring **43** to normally maintain the discharge valve closed.

Inlet check valves **34***a* and **34***b* are actuated to open position when the differential pressure across the valve outlet ports **35***a* and **35***b* exceeds the combined force being exerted on the balls **40***a* and **40***b* by the springs **41***a* and **41***b* respectively and the back pressure exerted through the liquid contained in the respective displacement chambers **11***a* and **11***b* as the case may be. Similarly discharge check valves will automatically open when the pressure exerted across the outlet port **38** in the given discharge check valve exceeds the pressure of the spring **43** acting to maintain the ball **42** seated over the outlet port **38.**

Inlet check valves and discharge check valves of the type illustrated in FIG. **2** and **4** of the drawings are easily purchaseable on the open market and are well known to those skilled in the art. Accordingly, no additional description of these valves is deemed necessary for the purposes of the present application.

Thus, whenever the differential pressure across balls **40***a* and **40***b* of the respective inlet valves **34***a* and **34***b* exceeds the combined force being exerted by springs **41***a* and **41***b* for maintaining the inlet check valves normally closed and the back pressure acting therewith, the inlet valve respectively will open.

Since there is a difference in head pressure being exerted by the slurry to be pumped by means of the level maintained in storage tank **13,** if three way valve **27** is positioned to permit flow through outlet **28,** the slurry will pass by gravity flow through distributing conduit **29** to connecting conduit **32***a* or **32***b* as the case may be. As slurry is thus delivered to the respective inlet check valve **34***a* or **34***b* one or the other or both will be opened depending on the differential pressure acting therein to enable the balls **40***a* and **40***b* to move off their seats, and as the case may be slurry will pass into and fill the displacement cylinders **11***a* and **11***b* in the respective displacement vessels **10***a* and **10***b*, with which the inlet check valves **34***a* and **34***b* are associated.

It will be understood by those skilled in the art that where the head room does not permit gravity feed that the storage tank **13** can be coupled with a constant feed pump with bypass means so that the constant head pressure required for the operation of the present system will be maintained.

Further, whether the system is operated by gravity or coupled with a constant feed pump it is clear that the slurry transport and discharge system is an open system subjected only to atmospheric pressure and that the pressure head of the slurry delivered is either that established by the height of the slurry storage tank **13** or of the constant delivery pump associated therewith if the head room for the storage tank is limited.

PROPULSION LIQUID TRANSPORT AND RETURN ASSEMBLY

After the slurry or other mixture flows into and substantially fills one or the other of the displacement vessels or cylinders **10***a* or **10***b* it is driven therefrom by a hydraulic piston in the form of a volume of propulsion liquid delivered from the propulsion liquid transport and return assembly **17** to the upper end of each of the respective displacement vessels or cylinders **10***a* and **10***b* through a valving arrangement which is controlled for delivery of the propulsion liquid in timed or stroked sequential order.

This assembly includes the propulsion liquid storage tank **16** shown in FIG. **1** of the drawings which preferably is limited in height to permit greater head at inlet valves **34***a* and **34***b* as explained above.

The propulsion liquid storage tank **16** is provided with an inlet line **50** connected to any suitable source of the propulsion liquid. Inlet line **50** is utilized both for filling the propulsion liquid storage tank **16** and for adding additional propulsion liquid when a liquid level valve **51** in the inlet line is actuated by open position by a level responsive member **52** connected by lever arm **53** to the liquid level valve opening mechanism (not shown). Such valves are purchaseable on the open market and are well known to those skilled in the art.

Propulsion liquid is drawn from the propulsion liquid storage tank **16** through a propulsion liquid outlet line **54.** Outlet line **54** has its inlet end **55** disposed within the tank and operatively associated with a suitable screen and filter means generally designated **56** and its outlet end connected to the suction inlet **57** of a high pressure centrifugal pump **58.** A shut-off valve **59** is provided in outlet line **54** to permit the pump **58** to be disconnected from the storage tank **16** for replacement or repair or to allow for maintenance or repair of the storage tank **16.**

Centrifugal pump **58** is driven by any suitable type of driver such as an electric motor **60.** The centrifugal pump **58** must deliver the propulsion fluid at the required operating pressure such as a centrifugal pump capable of delivering pressure fluid in a range from 700 to 2,150 GPM at 700 PSIG operating at speeds from 2750 to 3550 RPM. Pumps of this type are well-known and are easily purchaseable on the open market as will be understood by those skilled in the art.

The centrifugal pump **58** has its discharge outlet **61** connected to a propulsion liquid delivery line **62.** FIGS. **3** and **4** show that the delivery line **62** in turn is connected to a plurality of transverse connecting lines as at **63***a* and **63***b* there being one transverse connecting line disposed substantially transversely of each associated displacement vessel or cylinder in any given system so as to connect at an intermediate point therealong with the upper connecting conduits **22***a* and **22***b* respectively and at the end thereof remote from the delivery line **62** to the common return line **64.** The common return line **64** in turn extends and is connected so as to return the discharge liquid into the propulsion liquid storage tank **16,** all of which is clearly shown in FIGS. **1, 2, 3,** and **4** of the drawings.

FIGS. **1** to **4** further show in delivery line **62,** a modulating control valve **65** and by-pass system generally designated **66.**

Modulating control valve **65** acts to adjust the capacity of the system as a function of variations in level of the slurry in the slurry storage tank **13,** between predetermined upper and lower limits for the level of slurry in the slurry storage tank to insure the desired range of operation.

The level of the slurry will be maintained between the upper and lower limits as determined by the signal and alarm devices **13***b* and **13***c*. Signals are transmitted directly to the feeding means, not shown, which varies delivery of the slurry to the chute and mixing means **13***a* as may be required.

However, the rate at which slurry is being consumed in any given process is directly related to variations in the level of the slurry in the slurry storage tank and/or variations in the feed or of demand for slurry.

These variations are signaled to the modulating valve **65.** The modulating valve will automatically vary from the initial range and ratio setting so as to increase or decrease the flow rate of propulsion liquid being charged into the respective displacement vessels **10***a* and **10***a* during any given pumping stroke of the system.

Thus, with reference to FIG. **4,** a differential pressure sensing means generally designated DPS is shown to include a pressure regulator **65***a* which delivers air through lines **65***b* and **65***c* through orifices **65***d* and **65***e* therein to the pressure sensors **65***f* and **65***g*.

The difference in pressure between the lines **65***b* and **65***c* at a point downstream of the orifice is measured by a suitable differential pressure transducer DPT which receives signals from the connecting lines **65***h* and **65***i*.

Since the modulating control valve **65** illustrated is of the air operated type, the differential pressure transducer will deliver air signals by line **65***j* to an air operated motor **65***k* which will vary or adjust the setting of the modulating control valve **65** so that the operation of the system permits the slurry level to remain within the desired upper and lower limits.

The manner in which the modulating control valve **65** acts to adjust the rate of operation of the system will be referred to again below in respect of the overall operation of the system hereinafter described.

The by-pass system **66** is adapted for manual or automatic operation to by-pass propulsion liquid back to the propulsion liquid storage tank **16** to prevent overheating the pump when operating at low capacity or as may be otherwise required in the operation of the system. Such by-pass system **66** includes the by-pass line **67** having its inlet end connected as at **68** into the delivery line **62** downstream of the modulating control valve **65** an intermediate point in by-pass line **67** as at **69** connected into the delivery line **67** upstream of the modulating control valve **65** and the outlet end of by-pass line **67** as at **70** connected to the propulsion liquid storage tank **16.**

A manually operable globe valve **71** is disposed in by-pass line **67** to permit propulsion liquid to be circulated from the downstream to the upstream side of the modulating control valve **65** or conversely when the modulating control valve **65** is closed to permit propulsion fluid to be by-passed from the upstream to the downstream side of the modulating control valve **65** or to be by-passed back through the outlet **70** to the propulsion liquid storage tank **16.**

A relief valve **72** in by-pass line **67** between the intermediate connection **69** and the outlet connection **70** will act to automatically by-pass fluid back to the propulsion liquid storage tank **16** when the pressure of the

fluid in the by-pass line exceeds the predetermined pressure setting of the relief valve **72.**

Referring further to FIGS. **3** and **4,** it is noted that in accordance with applicant's invention in order to displace the slurry which has been charged into the chambers **11***a* and **11***b* of the respective displacement vessels **10***a* or **10***b*, the propulsion liquid transport and return system **17** is provided with a valving arrangement which is operated as is more fully described below for alternate or sequential delivery of propulsion liquid to each respective displacement cylinder **11***a* or **11***b*, to provide a smooth uniform pumping action or flow of slurry.

For delivering propulsion liquid, propulsion liquid inlet valves **75***a* and **75***b* are disposed in the respective transverse connecting lines **63***a* and **63***b* upstream of the point where the transverse connecting lines **63***a* and **63***b* are connected to the upper connecting conduits **22***a* and **22***b* of the displacement vessels **10***a* and **10***b*.

Conversely, to permit propulsion liquid to be displaced from each respective displacement vessel **10***a* or **10***b* and to be returned via return line **64** to the propulsion liquid storage tank **16,** propulsion liquid outlet valves **76***a* and **76***b* are disposed in the transverse connecting lines **63***a* and **63***b* on the downstream side of the point of connection of the transverse connecting lines **63***a* and **63***b* the the upper connecting conduits **22***a* and **22***b*.

The propulsion liquid inlet valves **75***a* and **75***b* which switch the flow of propulsion fluid to their associated displacement vessels **10***a* and **10***b* and propulsion liquid outlet valves **76***a* and **76***b* which permit propulsion liquid to be displaced from their associated displacement vessels **10***a* and **10***b* and returned to the propulsion liquid storage tank **16** are preferably valves of the same type in order to simplify operative coaction with a control system hereinafter more fully described which is required to manually or automatically, sequentially stroke these valves for the desired pumping operation.

Valves identified as high flow "Y" type valves are illustrated. These valves are available on the open market. However, as will be understood by those skilled in the art any equivalent type valve may be utilized for this purpose without departing from the scope of the present invention.

FIGS. **4, 5** and **6** illustrate one respective inlet valve **75***a* and one respective outlet valve **76***a* for the given displacement vessel **10***a*. Each of the propulsion liquid inlet valves **75***a* and **75***b* includes a valve housing as at **80** having an inlet **81** and an outlet **82.** A transverse partition **83** in the valve housing **80** separates inlet **81** from the outlet **82** and includes therethrough a valve port **84** so that propulsion liquid from the propulsion liquid storage means **16** entering these valves at the inlet must pass through valve port **84** in the transverse partition **83** to pass through the outlet **82** through transverse connecting conduits **63***a* and **63***b* to the associated upper connecting conduit **22***a* and **22***b* of the displacement vessels.

The valve port **84** is controlled by a valve head **85** connected to one end of a valve stem **86** in turn connected at the end remote from the valve head **85** to a diaphragm or piston type means **87** forming part of a pressure air operated actuator generally designated **88***a* and **88***b* for each respective inlet valve. The pressure air operated actuators **88***a* and **88***b* include a spring **89** which acts against the diaphragm **87** to maintain the respective propulsion liquid inlet valves **75***a* and **75***b* normally closed.

Each of the propulsion liquid outlet valves **76***a* and **76***b* being similar in construction to the propulsion liquid inlet valves **75***a* and **75***b* also includes a valve housing as at **90** having an inlet **91** and an outlet **92.** A transverse partition **93** in the valve housing **90** separates inlet **91** from the outlet **92** and includes therethrough a valve port **94** so that propulsion liquid from the associated upper connecting conduit **22***a* and **22***b* entering these outlet valves at the inlet must pass through valve port **94** in the transverse partition **93** to pass through the outlet **92** to the common return line **64.**

The valve port **94** of the respective propulsion liquid outlet valves **76***a* and **76***b* are controlled by a valve head **95** connected at one end of a valve stem **96** in turn connected at the end remote from the valve head **95** to a diaphragm or piston means **97** forming part of a pressure air operated actuator generally designated **98***a* and **98***b*. The pressure air operated actuator **98***a* and **98***b* include a spring **99** which acts against the diaphragm **97** to maintain the respective propulsion liquid outlet valves **76***a* and **76***b* normally closed. All of which is clearly shown at FIG. **5** of the drawings.

As shown in FIGS. **6** and **7,** pressure air is passed to each of the actuators **88***a*, 88*b* and **98***a* and **98***b* for the respective propulsion liquid inlet valves **75***a* and **75***b* and propulsion liquid outlet valves **76***a* and **76***b* by an associated pilot valves generally designated **100***a* and **100***b* for the inlet valves and **101***a* and **101***b* for the outlet valves. The pilot valves **100***a* and **100***b* and **101***a* and **101***b* are connected by suitable pressure air supply lines **102***a* and **102**b for the inlet valves and **103***a* and **103***b* for the outlet valves to a common source **104** of pressure air. The pilot valves **100***a*, 100*b*, 101*a* and **101***b* are actuated by an electrically operated solenoid device **105***a* and **105***b* for the inlet valve and **106***a* and **106***b* for the outlet valves. The solenoid devices **105***a* and **105** *b*, 106*a* and **106***b* are operated alternately and sequentially from control means as is more fully described hereinafter.

When a solenoid device as at **105***a*, 105*b*, 106*a* and **106***b* actuates a pilot valve as at **100***a*, 100*b*, 101*a* and **101***b* it will pass pressure air to the associated air operated actuator **88***a*, 88*b*, 98*a* and **98***b*. This will cause the associated diaphragm means **87** or **97** therein to move up and to compress the associated spring **89** or **99.** Simultaneously the respective valve stem **86** or **96** and valve head **85** or **95** connected to the diaphragm means being operated will act to open a valve port as at **84** or **94** in one or more of the respective propulsion liquid inlet valves or propulsion liquid outlet valves. When a solenoid devices as at **105***a*, 105*b*, 106*a* and **106***b* is deactuated, the associated pilot valve will cut off the supply of pressure air to the air operated actuator. Each pilot valve is provided with a conventional venting means so as to vent pressure air on the side of the diaphragm remote from the spring means to atmosphere and permit the spring means to move the diaphragm, the valve stem and valve head connected thereto so as to close the valve ports **84** or **94** as the case may require of the respective valves that are open.

Although a pneumatically operated system is illustrated it will be understood that the inlet and outlet valves of the propulsion liquid transport and return system can be hydraulically operated without departing from the scope of the present invention.

CONTROL AND CAPACITY MODULATING SYSTEM

In a hydraulic displacement system of the present type there are at least two factors that are most important. First, it is necessary to so adjust the operation of the system that the displacement head provided by the slurry storage tank will remain substantially constant. Second, it is necessary to provide smooth, uniform and continuous delivery of slurry or other mixture being pumped from the system to the point of use.

In the present invention this is accomplished by a control system which relates the slurry demand rate to the delivery rate of the slurry to the slurry storage tank. More specifically, a capacity control is provided which so adjusts the rate per minute of alternate and sequential cycling of the system that the displacement head or level of the slurry in the slurry storage tank is substantially maintained between predetermined minimum and maximum limits.

On such Control and Capacity modulation system to accomplish the above operation is shown schematically in FIGS. **6** and **7** wherein a control box generally designated **110** is shown with electrical lines connected thereto for receiving signals from various sensors and for transmitting the signal in accordance with the conditions sensed for actuating the solenoid devices to produce the desired automatic alternate and sequential pumping operation of the system hereinafter more fully described.

The sensed conditions for operating the system can be grouped generally in the following manner.

First, are the temperature sensors which are temperature operated switches disposed in the respective displacement vessels **10***a* and **10***b*. These include an upper level temperature switch **111***a* and a lower level temperature switch **112** a on displacement vessel **10***a* and an upper level temperature switch **111***b* and a lower level temperature switch **112***b* on displacement vessel **10***b*. Maximum upper level alarm switches **130***a* and **130***b* and minimum level alarm switches **131***a* and **131***b* are also temperature operated switches for actuating a parallel safety or takeover circuit which overrides the automatic system as will also be described hereinafter.

Temperature switches illustrated in the present control system are well known sensing expedients which are purchaseable on the open market and accordingly are not more fully described herein.

Further, while temperature sensors are used in the control system illustrated, other types of interface level sensing devices can be utilized without departing from the scope of the present invention.

For example, in addition to temperature sensing switches other types of sensors which are capable of distinguishing the conditions at the interface between the propulsion liquid and the slurry are the following:

1. Ultrasonic sensing systems having two liquid interface detectors with upper and lower limit switches for actuating the control system.

2. Resonance Vibrator type sensing systems with upper and lower level switches for actuating the control system.

3. Electrical conductivity systems with upper and lower electrode probes extending into the displacement cylinders which signal operation to the control system as conductivity changes.

4. Density sensing systems of the Nuclear (Kay Ray) or Air Bleed Type.

5. Torque sensor systems including spaced upper and lower rotary devices which will distinguish between slurry and clear liquid as a function of the power required for rotation of the rotary devices.

Second, are the slurry level sensors **13***b* and **13***c* and the transmitter **13***d* the associated differential pressure sensors DPS and transmitters DPT connected to modulating control valve **65** for modulating and controlling the pumping capacity of the system so that the displacement head of the slurry will remain substantially constant and to guard against overflow or depletion of the slurry storage tank **13** when the charging rate of the slurry to the storage tank and the pumping rate of the system become grossly unequal.

These sensors can take several forms. Such as the following:

a. A direct diaphragm sensor and its associated transmitter.

b. Continuous air bleed sensors and their associated transmitter.

c. A "Ronningten-Petter" full stream pressure sensor (fluid pre-loaded elastic sleeve in pipe section).

All the sensors above mentioned are well known and purchaseable on the open market and accordingly are not more fully described herein.

Third, are the liquid level alarm sensors and their associated switches for the slurry storage tank **13** and the propulsion liquid tank **16.** These are shown by reference to the drawings as including the high level alarm switch **13***b* and a low level alarm switch **13***c* for the slurry storage tank **13** and a high level alarm switch **115** and a low level alarm switch **116** for the propulsion liquid storage tank **16,** and their associated signal transmitters **13**d and **117** respectively.

Fourth, are the flow rate sensors such as are illustrated at **118** in the slurry delivery line **29** and **119** in the propulsion liquid delivery line **62.** These act as an alternate feed back to integrate the delivery and feed system of the slurry to the slurry storage tank.

Fifth, are sensors for miscellaneous purposes such as temperature sensor **29S** in the slurry delivery line **29** and the temperature sensor **62S** in the propulsion liquid delivery line **62** and temperature sensor **64S** in the propulsion liquid return line **64.** The significance of these temperature sensors will be apparent in the illustrated form of the present invention because the manner in which pumping is controlled depends on the proper sensing of the temperature conditions at the interface between the slurry being pumped and the propulsion liquid.

The conditions sensed by the upper temperature switches **111***a* and **111***b* and the lower temperature switches **112***a* and **112***b* on the respective displacement vessels **10***a* and **10***b* act to open and to close the circuits for actuating the control relays which operate the respective solenoid devices for actuating the propulsion liquid inlet valves **75***a* and **75***b* and the propulsion liquid outlet valves **76***a* and **76***b* for the displacement vessels **10***a* and **10***b* respectively from their normal closed position to open position.

In the temperature sensing thermal switches of the present invention the upper temperature sensing temperature switches are normally open. These upper temperature sensing switches close when the temperature sensed rises above approximately 200° F. Similarly, the

lower temperature sensing thermal switches are normally open. The lower temperature sensing switches close when the temperature drops below approximately 250° F. These thermal switches have an accuracy of approximately ± 10°.

These temperature ranges are common in systems to which the present invention is particularly applicable. For example in a slurry system for buaxite suspended in caustic soda the bauxite slurry will be delivered on the displacement vessels at about 300°F. The propulsion liquid piston in the displacement vessels for such system will be delivered at about 175°F. Thus at the interface there will be a temperature gradient across the interface from 175°F to 300°F. As the interface between the propulsion liquid and the slurry passes the respective upper and lower temperature sensing thermal switches they will move from a normally open to a closed position as a function of the temperature gradient across this interface. In the case of the upper thermal switches in the ranges above indicated a rise in temperature will cause the switches **111***a* and **11***b* to close and in the case of the lower thermal switches a drop in temperature in the ranges above indicated will cause the switches **112***a* or **112***b* to close.

When the upper thermal switch is sensing only propulsion liquid at 175°F it will remain open. As the interface passes, and the temperature rises to approximately 200°F, the upper switch will close and transmit a signal through the control box to the control relays for changing the setting of the solenoid devices which control the opening of the associated valves. Similarly when the lower thermal switch is sensing only slurry at 300°F, it will remain normally open until the temperature across the interface drops below approximately 250°F. Then the lower thermal switch will close and transmit a signal through the control box to the associated control relay for changing the setting of the solenoid devices which control the opening of their associated valves. All of the above is diagrammatically shown in FIGS. **6, 7** and **8** of the drawings.

ELECTRIC CIRCUIT ARRANGEMENT

FIG. **7** of the drawings show the wiring diagram for the various electrical circuits for the disclosed Hydraulic Displacement Pumping System. The solid lines show the automatic system for sequencing the charging and discharging of slurry into and out of the respective displacement vessels **10***a* and **10***b* and the associated fail safe and takeover system with alarm signals. The dash-dot lines show means for manually operating the system to provide the required sequencing steps for charging and displacement of slurry in the same manner as is accomplished by the automatic system. The failsafe and takeover system will coact with the manual system during operation to prevent contamination of the propelling liquid.

The failsafe and takeover system includes in the respective displacement vessels **10***a* and **10***b* maximum upper level temperature sensors **130***a* and **130***b;* minimum lower level temperature sensors **131***a* and **131***b* and maximum upper alarm signals **132***a* and **132***b* associated with the sensors **130***a* and **130***b*, and minimum lower alarm signals **133***a* and **133***b* associated with the sensors **131***a* and **131***b*. Any suitable type of audio or visual alarm means may be used of which there are many that are well known and easily purchaseable on the open market.

Current is delivered to the circuit through the main lines **120***a* and **120***b* and selector switch **121** which can be moved from the off position to either manual operation or automatic operation by engagement with the automatic system contacts **122***a* and **122***b* or the manual system contacts **123***a* and **123***b*. In either position of the switch **121** the circuits will be adapted to control respectively the inlet valves **75***a* and **75***b* and outlet valves **76***a* and **76***b* of the propulsion liquid system as will be more fully described.

When the selector switch **121** is moved to the automatic operation position, current will pass from the main lines **120***a* and **120***b* through the selector switch **121** and the associated contacts **122***a* and **122***b*. Two lines are shown for either a direct current circuit or a circuit in which one of the lines is connected to ground.

Contact **122***a* is connected to line **124** in turn connected to lines **124***a*, 124*b* and **124***c*.

Line **124***a* will lead current to the operating side of temperature sensing switches **111***a* and **130***a* of displacement vessel **1***a* through connecting lines **124***d* and **124***e*, and to the alarm side of temperature sensing switch **130***a* by connecting line **124***f*, and to the operating side of temperature sensing switches **112***a* and **131***a* through connecting lines **124***g* and **124***h*, and to the alarm side of temperature sensing switch **131***a* by connecting line **124***i*.

Similarly line **124***b* will lead current to the operating side of the temperature sensing switches **111***b* and **130** *b* of displacement vessel **10***b* through connecting lines **124***j* and **124***l*, and to the alarm side of temperature sensing switch **130***b* by connecting line **124***k*, and to the operative side of temperature sensing switches **112***b* and **131***b* through connecting lines **124***m* and **124***o*, and to the alarm side of temperature sensing switch **131***b* by connecting line **124***n*.

Line **124***b* is connected to the switches as at **1250**i b and **126***b* operatively associated with the temperature sensors on displacement vessel **10***b*, switch **125***b* being associated with the temperature sensors **111***b* and **130***b* at the upper end of the displacement vessel **10***b* and switch **126***b* being associated with the temperature sensors **112***b* and **131***b* at the lower end of displacement vessel **10***b*.

Line **124***b* similarly will lead current to the operating side of switch **125***b* by connecting lines **124***j* and **124***l* and by connecting line **124***k* to the alarm side of switch **125***a;* and to the operating side of switch **126***b* by connecting lines **124***m* and **124***o*, and by connecting line **124***n* to the alarm side of switch **126***b*. Line **124***c* is connected between line **124** and the switches **M1, M2, M3** and **M4** on magnetic latching relays generally designated MLR-*a* and MLR-*b*.

The switches **125***a*, 126*a*, 125*b* and **126***b* are operatively connected between the associated temperature sensors on the one side and on the other side to the magnetic latching relays MLR-*a* for operating the inlet valve **105***a* and outlet valve **106***a* on displacement vessel **10***a* and MLR-B for operating the inlet valve **105***b* and outlet valve **106***b* on displacement vessel **10***b*.

Magnetic latching relays are well known control devices which are purchasable in the open market such as those sold by Deltrol Controls of Milwaukee, Wisconsin and accordingly they are diagrammatically illustrated and not more fully described. These illustrated relays are characterized by the fact that they can operate in two directions as indicated by the arrows above

the coil sections designated CR-1 and CR-2 on magnetic latching relay MLR-*a* and CR-3 and CR-4 on magnetic latching relay MLR-*b* to in turn operate the two pole double throw switches M1, M2, M3 and M4.

In operation, the temperature sensors actuate the associated switches **125***a*, 125*b*, 126*a* and **126***b* from open to closed position to cause current to pass through one or the other of the coil sections CR-1, CR-2, CR-3 and CR-4 which in turn activates the switches M1, M2, M3 and M4 to operate the inlet valves **105***a* and **105***b* and the outlet valves **106***a* and **106***b* in accordance with the desired secquencing of the valves to provide smooth pumping operation for the system. Further, however, operation of the inlet valves **105***a* and **105***b* for the respective desplacement vessels **10***a* and **10** *b* must be coordinated in the present system so that propulsion liquid will be delivered in a manner to provide smooth and uniform pumping action.

For this purpose the magnetic latching relays MLR-*a* and MLR-*b* communicate with cross-over or cross-control relays generally designated **134***a* and **134***b*. The magnetic latching relay MLR-*a* is so connected to cross-control relay **134***a* that it will actuate the cross-control relay **134***a* to open the current conducting line to the solenoid coil SC**105***b* for inlet valve **75***b* for displacement vessel **10***b*. Similarly relay MLR-*b* acts with cross-control relay **134***b* to control inlet valve **75***a* for displacement vessel **10***a*. This is necessary to prevent premature or delayed delivery of propulsion fluid to displacement vessel because the filling of the displacement vessels **10***a* and **10***b* with slurry is slower than the discharging of the slurry from these respective vessels, the head or pressure extended by the propulsion liquid delivered by the propulsion liquid and transport system being higher than that for the gravity fed slurry.

The cross-over relays **134***a* and **134***b* will include respectively a switch **135***a* and **135***b* and a solenoid coil as at **136***a* and **136***b*.

When slurry rises in displacement vessel **10***a* so that either temperature sensor **111***a* or **130***a* acts to actuate either the operating side or the alarm side of switch **125***a* so as to close one or the other of those switches as the case may be, current will pass through either line **124***d* or **124***e* to a common connecting line **125***c* which is connected to one side of coil CR-2, the other side of the coil being connected to a line **137***a* which is part of a current return and/or grounded line generally designated **137.** Line **137** will be connected to contact **122***b* and the main switch means **121** when the switch means **121** is in the automatic operating position.

When the current is passed through coil CR-2 it will cause the magnetic latching relay MLR-1 to move the switch arms for switches M1 and M2 in the direction indicated by the arrow under the character numeral CR-2 so that the switch arms of the switches M1 and M2 will be positioned as shown by the dotted line in FIG. 7 of the drawings. When the switch arms of the switches M1 and M2 are so positioned, current will pass from line **124**C through switch M1 and line **138***a* to the solenoid coil **105***a* for the inlet valve **75***a* but only if the switch **135***a* in cross-over relay **134***a* whose coil **136***a* is disposed in the line **138***a* is in its normally closed position. Since the switch arm opens switch M2 in the dotted line position no current will pass to solenoid coil SC **106***a* and outlet valve **76***a* will move to the closed position.

If cross-over relay switch **135***a* is held open by relay **136***b* no current will pass to the solenoid coil SC**105***a* and the inlet valve **75***a* will also remain closed and the slurry will hold in this upper position. When crossover relay switch **135***a* moves to the closed position current will then flow to the solenoid coil SC**105***a* and inlet valve **75***a* will be moved to the open position to permit propulsion liquid to enter and pump slurry from the displacement vessel **10***a*.

When slurry is discharged and falls in displacement vessel **10***a* so that either temperature sensor **112***a* or **131***a* acts to actuate either the operating side or the side of switch **126***a* so as to close one or the other of these switches, as the case may be, current will pass through either line **124***g* or **124***h* to a common connecting line **126***c* which is connected to one side of coil CR-1, the other side CR-1 being connected to return or ground line **137***a* to complete the circuit in the automatic operating position.

When current is passed through coil CR-2 it causes the magnetic latching relay MLR-1 to move the switch arms for switches M1 and M2 in the direction indicated by the arrow under the character numeral CR-1 so that the switches M1 and M2 will now be positioned as shown by the solid lines in FIG. 7 of the drawings. When the switches M1 and M2 are so positioned, the inlet valve **75***a* will not receive current and will automatically move to the normally closed position, conversely however current will pass from line **124***c* through switch M2 to line **139***a* to solenoid coil **106***a* which acts to actuate outlet valve **76***a* to open position and slurry under gravity lead or pressure will fill the displacement vessel **10***a* displacing the propulsion liquid back through the open outlet valve **76***a* to the propulsion liquid transport and return system.

The operation for displacement vessel **10***b* is similar to that above described for displacement vessel **10***a*. Thus when slurry therein raise temperature sensors **111***b* and **130** *b* will actuate one or the other of the switches on the operating or the alarm side of switch **125***b* to pass current through common connecting line **125***d* to one side of coil CR-4, the other side of which communicates with the return or ground line **137***b* for the return or ground system **137.** This will move the switch arms for switches M3 and M4 on the direction indicated by the arrow under the character numbered for the coil CR-4 and shown by the dotted lines in FIG. 7 of the drawings. In this position no current will pass from line **124***c* to the solenoid coil SC**106***b* and outlet valve **76***b* will move to its deactuating or normally closed position. Conversely since the switch arm as shown in the dotted position will close switch M3 current will flow from line **124***c* through the switch M3 and line **138***b* to solenoid coil SC**105***b*, if switch **135***b* in the cross-over relay **134***b* is not being held in the open position.

If relay **136***a* is holding the switch arm for switch **135***b* of cross-over relay **134***b* in the open position then no current will pass through line **138***b* to the solenoid coil SC**105***b* and inlet valve **75***b* will remain closed.

With both valves closed the slurry will hold at the upper level until the switch arm closes switch **135***b* of the cross-over relay **134***b* at which time current will flow and cause the solenoid coil SC **105***b* to open inlet valve **75***b* and propulsion liquid will be passed into and out to dispose the slurry in the displacement vessel **10***b*.

When the slurry is discharged and falls to cause the temperature sensers **112***b* or **131***b* to actuate the switches on either the operating side or the alarm side of switch **126***b*, current will flow from lines **124***m* and **124***o* through common connecting line **126***d* to one side of coil CR-3, the other of which is connected to the common return or ground line **137***b*. The current flowing through coil CR-3 will cause the magnetic latching relay MLR-*b* to move the switch arms for switches M3 and M4 in the direction indicated by the arrow under the character numeral CR-3 and as shown by the solid lines in FIG. 7 this will cause switch M3 to open and switch M4 to close. When switch M3 is moved to open position no current will flow through solenoid S.C. **105***b* and inlet valve **75***b* will move to its normally closed position. However, current will flow from line **124** *c* through switch M4 and line **139***b* connected thereto and to solenoid coil SC **106***b* so as to cause the solenoid coil SC **106***b* to activate the outlet valve **76***b* to open position. In this position of the valves slurry under gravity head or pressure will act to displace prolulsion liquid back through the open outlet valve **76***b* to the propulsion liquid transport and return system and to fill displacement vessel **10***b* once again.

As the slurry rises and falls in the respective displacement vessels **10***a* and **10***b* the operations above described will continue automatically.

It is believed clear that the dwell systems provided by the cross-over relays **134***a* and **134***b* permits the faster rate for the discharging slurry to cooperate with the slower filling note for the gravity fed slurry and to prevent premature opening of the inlet valves **76***a* or **75***b* for delivering propulsion liquid.

The alarm side of the switches **125***a*, 125*b*, 126*a* and **126***b* is for signalling conditions which require immediate action for example when the maximum upper level limit or the minimum lower level limit is reached by the interface between the propulsion liquid and the slurry being pumped in a given displacement vessel. Thus, FIG. 7 shows the upper level limit temperature sensor **130***a* and the lower level limit temperature sensor **131***a* on displacement vessel **10***a* and similarly an upper level limit temperature sensor **130***b* and a lower level limit temperature sensor **131***b* on the displacement vessel **10***b*. For displacement vessel **10***a* the upper level limit thermal sensor **130***a* is connected by line **130***c* to the alarm side of switch **125***a* and the lower level limit thermal sensor **131***a* is connected by line **131***c* to the alarm side of switch **126***a*. Similarly, for displacement vessel **10***b* the upper level limit thermal sensor **130***b* is connected by line **130***d* to the alarm side of switch **125***b* and the lower level limit thermal sensor **131***b* is connected by line **131***d* to the alarm side of switch **126***b*. Responsive to an excessive rise in the level of the interface in either displacement vessel **10***a* or **10***b* upper limit temperature sensors **130***a* and **130***b* will actuate the alarm side of the respective switches **125***a* and **125***b* and causes the respective alarm signals **132***a* and **132***b* associated therewith to be actuated. Similarly, responsive to an excessive fall in the level of the interface in either displacement vessel **10***a* or **10***b* the lower limit temperature sensors **131***a* and **131***b* actuate the alarm side of the respective switches **126***a* and **126***b* and cause the alarm signals **133***a* and **133***b* associated therewith to be actuated. This takeover and alarm arrangement is necessary to protect against failure of the primary sensors **111***a*, 111*b*, **112***a* and **112***b* whether the system is on automatic or manual operation as is more fully described below. Those skilled in the art will recognize that contamination of the propulsion liquid supply by material amounts of slurry will adversely affect the mechanical elements such as the pump, the valves, the piping, etc. due to the abrasive and corrosive nature of the slurry. This is one of the means for safeguarding the operation of the system where limited operating personnel will be present such as occurs during a night shift.

FIG. 7 thus shows that the operating side of the switches **125***a*, 125*b*, 126*a* and **126***b* are disposed to actuate the solenoid coils designed S.C. for the respective solenoid devices **105***a*, **105***b*, 106*a* and **106***b* by delivering current thereto when the switches are actuated in accordance with signals from the temperature sensors **111***a*, 111*b*, 112*a* and **112***b* or the takeover sensors **130***a*, 130*b*, 131*a* and **131***b* as the case may be.

Actuation of the inlet valves **75***a* and **75***b* and the outlet valves **76***a* and **76***b* for the respective displacement vessel **10***a* and **10***b* occurs as a function of the associated temperature sensing switches on these vessels and by the automatic operating position of the system hereinafter more fully described the switches will operated alternatively and sequentially responsive to the movement of the slurry as it is charged and discharged from the displacement vessels **10***a* and **10***b*.

When the circuit is switched to the manual position by moving then a slector switch **121** into engagement with contacts **123***a* and **123***b*, a plurality of push button operated switches will permit the specific operation of each of the respective valves of the propulsion liquid transport and return system. This is important in the event of failure of the automatic system or of any of the sensing devices on which the automatic operation depends because it permits the propulsion liquid inlet and outlet valves to be switched by manual operation so that the system can be properly shut down without damage and to check any repair or maintenance in the system after it is completed.

Thus, push button switch **140***a* is provided for operating the inlet valve **75***a* and push button switch **141***a* is provided for operating outlet **76***a*. Similarly, push button switch **140***b* is provided for operating inlet valve **75***b* and push button switch **141***b* is provided for operating outlet valve **76***b*.

Additionally, the circuit shows that there is associated with each of the solenoid coils S.C. for the respective solenoid valves **105***a*, 105*b*, 106*a* and **106***b*, a light to indicate when the solenoid is in operation. For the inlet valves a green light generally designated G is provided, and for the outlet valves an amber light generally designed A is provided. Thus, when the system is functioning a green light **142***a* is provided for inlet valve **75***a* and an amber light **143***a* is provided for outlet valve **76***a*. Similarly, a green light **142***b* is provided for inlet **75***b* and an amber light **143***b* is provided for outlet valve **76***b*.

Under manual operation current flows from contact **123***a* through line **145** to connecting lines **145***a*, 145*b*, 145*c*, 145*d*, **145***e*, 145*f*, 145*g* and **145***h*.

Line **145***a* is connected to one side of manual push buttom switch **140***a*. The other side of which is connected by line **146***a* to solenoid coil S.C. **105***a* and by line **147***a* to the green light **142***a*. The opposite sides of the solenoid coil S.C. **105***a* and the green lignt **142***a* are connected respectively by lines **146***b* and **147***b* to a

common return or ground line systems **160** for manual operation which in turn is connected to contact **123***b*.

Lines **145***b* is connected to one side of manual push button switch **140***b* the other side of which is connected by line **148***a* to solenoid coil SC **105***b* and by line **149***a* to the green light **142***b*. The opposite sides of the solenoid coil SC **105***b* and the green light **142***b* are connected respectively by lines **148***b* and **149***b* to the common return or ground line system **160.**

Line **145***c* connects with one side of manual push buttom switch **141***a* the other side of which is connected by line **150***a* to solenoid coil SC **106***a* and by line **151***a* to the amber light **143***a*. The opposite sides of the solenoid coil SC **106***a* and the amber light **143***a* are connected respectively by lines **150***b* and **151***b* to the common return or ground line system **160.**

Line **145***d* connects with one side of manual push button switch **141***b* the other side of which is connected by line **152***a* to solenoid coil SC **106***b* and by line **152***a* to the amber light **143***b*. The opposite sides of the solenoid coild SC **106***b* and the amber light **143***a* are connected respectively by lines **152***b* and **153** to the common return or ground lines **160.**

Operation of the manual push button system requires not only means for establishing the alternate and sequential opening of the inlet and outlet valves as above described but further signal means for determining when the respective manual operations should terminate and safeguards to insure against contamination of the propulsion liquid transport and return systems with slurry and fail safe and take over systems which override any flagrant failure in the operation of the manual systems.

For this purpose lines **145***e*, 145*f*, 145*g* and **145***h* pass current to the respective switches **125***a*, 125*b*, 126*a* and **126***b* which are operated by the temperature sensors **111***a* and **130***a*; **111***b* and **130***b*; 112*a* and **131***a*; and **112***b* and **131***b* respectively.

Dispersed in each of the lines **145***e*, 145*f*, 145*g* and **145***h* is a signal light switch indicated by the letter R at **155***a*, **155***b*, 156*a* and **156***b* for the associate respective upper temperature operated switches **125***a* and **125***b* and the associate to respective lower temperatures operated switches **126***a* and **126***b*.

When the temperature sensors **111***a*, 111*b*, 112*a* or **112***b* actuate the operating side of the switches **125***a*, 125*b*, 126*a* and **126***b* to close position current will flow through the associate red light **155***a*, 155*b*, 156*a* and **156***b* and cause the same to light up and through the switch to return lines **157***a*, 157*b*, 157*c* and **157***d* which connect to the common return or ground lines **160** by means of line **158***a* and **158***b*.

Additional lines **159***a* and **159***b* connect at one end to the respective lines **145***e* and **145***f* and at the end remote therefrom the one side of coils **170***a* and **170***b* of control switches **171***a* and **171***b* dispersed in lines **145***c* and **145***d* respectively, the other side of which coils are connected by lines **172***a* and **172***b* to the common return or gorund lines system **160.** These respective control switches **171***a* and **171***b* will be actuated normally closed to open position when the temperature sensors **111***a* or **111***b* actuate the switches on the operating side of switches **125***a* and **125***b* to the close position. In effect this will open the circuit to either solenoid coil **106***a* or **106***b* depending on which push button is in operation and will cause one or the other of the outlet valves **76***a* or **76***b* as the case may be to move from open to the normally closed position and thus immediately prevent the propulsion liquid transport and delivery system from being contaminated by rising slurry in the system.

In manual operation any one of the push buttons **140***a*, 140*b*, **141***a* and **141***b* may be operated to pass current to the associated solenoid SC **105***a*, SC **105***b*; SC **106***a* and SC **106***b* for operating the respective inlet valves **75***a*, 75*b*, 76*a* and **76***b* associated therewith from closed to open position.

Thus, when push button switch **141***a* is closed solenoid coil SC **106***a* will open the outlet valve **76***a* and gravity fed slurry will rise and fill Displacement Chamber **10***a* until temperature sensor **111***a* signals the operating side of switch **125***a* to closed position. This causes the red light **155***a* to go on and the relay switch **121***a* to open the circuit to the solenoid coil SC **106***a*. When solenoid coil SC **106***a* opens the outlet valve **76***a* will move from open to its normally closed position. Push button **140***a* can now be operated to open inlet valve **76***a* for delivery of propulsion liquid to disperse the slurry from the displacement coil **10***a*. When the temperature sensor **112***a* senses the interface it actuates switch **126***a* and the red light **156***a* will light to signal termination of delivery of the propulsion liquid. The operator then releases push button **140***a* and repeats the filling process as above described closing push button switch **141***a* once again.

It is thought clear that both displacement vessels **10***a* and **10***b* can be similarly operated and that the alternate and sequential operations of the push buttons **140***a*, 140*b*, 141*a* and **141***b* can provide the same operation as was above described for the automatic operation position of the selector switch **121.**

Additionally manual operation will permit employing the displacement vessels **10***a* and **10***b* so they can be back flushed by a suitable solent delivered by gravity or pumps through line **31** and thru way valve **30** shown in FIG. **4** of the drawings.

OPERATION

While the approximate slurry demand for a given system can be estimated, the actual slurry requirements cannot be determined until the system is placed into operation. It is necessary therefore to select some intermediate operating point at which to start the system and set the control system to provide a charging rate into the respective displacement vessels such that the level of the slurry in the slurry storage tank **13** will be maintained between predetermined upper and lower levels for the desired operation. Then after the system is in operation it will automatically modulate the control valve **65** to either increase the rate or decrease the rate as the measured difference between the use of the slurry and the rate of charge of the slurry is determined from the level sensing system above described for actuating the modulating control valve **65.** Control valve **65** has conventional means thereon for establishing this initial setting.

Before placing this system into operation, valve **27** shown in FIG. **4** at the discharge end of the slurry storage tank **13** is first placed into the closed position. The slurry storage tank **13** is charged with slurry or other mixture to be pumped until the upper level control **13***b* signals the feed system to stop delivering slurry to the chute and mixing means **13***a* for feeding the slurry storage tank **13.**

The propulsion liquid transport and return system **17** is then placed into operation by starting pump **58.**

So long as the inlet valves **75***a* and **75***b* are closed, fluid will be by-passed back to the propulsion liquid storage tank **16** via the by-pass system **66** because the back pressure in the delivery line **62** will build up higher then the pressure setting of the relief valve **72.**

Inlet valves **75***a* and **75***b* can be actuated to open position by manually signalling the solenoid valves **105***a* and **105***b* to open these valves. When inlet valves **75***a* and **75***b* are opened, propulsion liquid will fill respectively the displacement chambers **11***a* and **11***b* in the displacement vessels **10***a* and **10***b*. Thereafter the solenoids **105***a* and **105***b* can be manually signaled to close the inlet valve **75***a* and **75***b*.

The system can now be set up for manual or automatic operation by manually signaling the solenoid SC **106***b* to open the outlet valve **76***b* so that when valve **27** on the slurry storage tank **13** is moved to open position, slurry will pass by gravity flow through the slurry delviery line **29,** the connecting line **35***a* and the inlet valve **37***b* into the displacement chamber **11***b* where it will displace the propulsion liquid therein through the open outlet valve **76***b*, transport line **63***b* and return line **64** to the propulsion liquid storage tank **16.**

As the slurry enters the displacement chamber **11***b*, it will rise therein until the upper thermal sensor **111***b* and red light **155***b* indicates that the interface between the propulsion liquid and the slurry has reached the level of this sensor. The propulsion liquid outlet valve **76***b* is then manually closed and further filling of the displacement chamber **11***b* will stop.

If operation is to continue manually, then the respective push buttons can be operated for opening and closing the respective inlet valves and outlet valves for charging and draining propulsion liquid for pumping the slurry from the displacement chambers **11***a* and **11***b*.

However, the present system is particularly adapted for automatic operation and this is best understood by reference to the graphical illustration of a plurality of slurry charging and discharging cycles as shown in FIG. **8.** The illustrated diagrammatic cycles in FIG. **8** start with displacement chamber **10***a* filled with propulsion liquid and displacement chamber **10***b* filled with slurry.

In regard to the operation it is noted again that the valves in the slurry transport and delivery system **14** are check valves. The opening of inlet valves **37***a* and **37***b* will depend on the back pressure acting in the associated displacement chambers **11***a* and **11***b* with which the respective inlet valves **37***a* and **37***b* communicate. However, opening of the outlet valves **39***a* and **39***b* will depend on the force or pressure exerted by the propulsion liquid on the slurry to be discharged from a given displacement chamber.

The inlet valve **75***a* and **75***b* and outlet valves **76***a* and **76***b* of the propulsion liquid transport and delivery system are normally closed and must be actuated to open position either manually or automatically to allow the pressure head of the slurry in the slurry storage tank **13** to flow by gravity and the propulsion liquid to be delivered in order to provide the desired operation as graghically illustrated at FIG. **8** of the drawings.

For a two displacement vessel system as illustrated herein there will be two cycles in which the actions in the respective displacement chambers will occur simultaneously. However, on each cycle the action in one chamber will be substantially the reverse of the action occurring in the other chamber. Thus, in Cycle I, as displacement chamber **11***a* fills with slurry the pressure head of the slurry will drive the propulsion liquid back to the propulsion liquid storage tank. Simultaneously, the propulsion liquid entering the displacement vessel **10***b* will drive or pump the slurry in the displacement chamber **11***b* from the displacement vessel **10***b* and fill the displacement chamber **11***b* with propulsion liquid.

During Cycle II, displacement vessel **10***a* will be charged with propulsion liquid to drive the slurry from the displacement chamber **11***a*. Simultaneously, the displacement chamber **11***b* in the displacement vessel **10***b* will be filled with slurry and the pressure head of the slurry will drive the propulsion liquid in the displacement vessel **10***b* back to the propulsion liquid storage tank.

The overall automatic operation of the system to produce these cycles will now be described.

During Cycle I, the thermal switches **111***a* and **112***b* will signal outlet valve **76***a* and inlet valve **75***b* to open position. This will cause displacement chamber **11***a* to fill with slurry by gravity flow from the slurry storage tank **13** as has been above described. The head of the slurry will act to displace the propulsion liquid in the displacement chamber **11***a* back through the open outlet valve **76***a*, transverse line **63***a* and return line **64** to the propulsion liquid storage tank **16.** Simultaneously, since displacement vessel **10***b* is full of slurry by reason of the initial start up conditions established as above described, propulsion liquid will be passed through the open inlet valve **75***b*, transverse line **63***b* to the displacement chamber **11***b* and will displace the slurry present in the displacement chamber **11***b* of displacement vessel **10***b* through the slurry discharge valve **37***b* and discharge manifold **39** to the point of use.

Since operation of the system is controlled by the temperature condition of the interface between the propulsion liquid and the slurry as the rising interface passes the upper sensor **111***a* in displacement chamber **11***a* the temperature thereof is signalled to the controller **125***a*. The controller automatically closes outlet valve **76***a* and opens the propulsion liquid inlet valve **75***a*. Simultaneously or approximately as the descending interface passes, the lower temperature sensor **112***b* in displacement chamber **11***b*, the temperature condition at the interface is signalled to the controller **126***b* causing inlet valve **75***b* to be closed and the propulsion liquid outlet **76***b* to be opened.

The graphical analysis of the cycles shows that the outlet valve **76***a* closes shortly before the inlet valve **75***b* closes and inlet vlave **75***a* opens. In this respect, the opening of the inlet valves **75***a* and **75***b* will be controlled by the operation of the cross-over relays **135** and **136** which prevent actuation of a new cycle until the previous cycle has been completed.

During Cycle II which commences a half cycle after Cycle I; inlet valve **75***a* and outlet valve **76***b* are opened. In these valve positions, propulsion liquid will pass through the open inlet valve **75***a* and the transverse line **63***a* into the displacement chamber **11***a* through the slurry discharge valve **37***a* and discharge manifold **39** to the point of use. Simultaneously, slurry will be delivered by gravity flow from the slurry storage tank **13** through valve **27** slurry delivery line **29** connecting line **35***b* and slurry inlet valve **34***b* into the displacement chamber **11***b*. The displacement head of the

slurry will displace the propulsion liquid in displacement chamber **11***b* back through the open outlet valve **76***b*, the transverse line **63***b* and return line **64** to the propulsion liquid storage tank **16.** As Cycle II proceeds, the temperature condition of the falling or descending interface between the propulsion liquid and the slurry mixture being pumped from displacement chamber **11***a* is sensed by the lower temperature sensor **112***a* which will signal the outlet valve **76***b* and inlet valve **75***a* to closed position. Similarly, the temperature of the rising interface in displacement vessel **10***b* will be sensed and at the proper temperature will open the inlet valve **75***b* for displacement vessel **10***b* and open valve **76***a* for displacement vessel **10***a*.

Since the valve condition namely outlet valve **76***a* and inlet valve **75***b* are now in open position, this corresponds to the Cycle I operation position and I will repeat itself. This will again be followed by II and alternately and sequentially these Cycles will continue so long as slurry is fed and the propulsion liquid pumping system continues in operation.

When it is desired to terminate the operation of the system, the valve **27** or the slurry storage tank **13** is closed and the propulsion liquid inlet valve **75***a* and **75***b* and outlet valve **76***a* and **76***b* are operated to manually discharge the slurry present in the displacement chambers **11***a* and **11***b*.

The valve **27** is then moved to the flushing position. The inlet valves **75***a* and **75***b* are closed and outlet valves **76***a* and **76***b* are opened. Flushing fluid is delivered to the displacement chambers **11***a* and **11***b* until the displacement chambers are filled, and then the outlet valves **76***a* and **76***b* are also closed.

Since the back pressure of the flushing system can be raised high enough to open the discharge valves **37***a* and **37***b*, flushing fluid will be discharged through these valves to the lines **39** where it can be passed to waste until the displacement chambers are completely clean and free from slurry or propulsion liquid.

Valve **27** is then again placed at the closed position and the flushing fluid is allowed to drain from the displacement chambers **11***a* and **11***b* by gravity flow leaving the respective displacement chambers ready for the next cycle of operation as above described.

It will be understood that the invention is not to be limited to the specific construction or arrangement of parts shown but that they may be widely modified within the invention defined by the claims.

What is claimed is:

1. In a system for hydraulically displacing slurry with a direct contact propulsion liquid,

a. a plurality of displacement vessels each respectively forming a displacement chamber,

b. each of said displacement vessels having a lower opening for charging and discharging slurry into and out of the displacement chamber and an upper opening for charging and discharging a propulsion liquid into and out of the displacement chamber,

c. a first open transport system having storate means for slurry, means connecting said slurry storage means into the lower opening of each respective displacement vessel for delivering slurry therefrom to the displacement chamber of any given displacement vessel including, inlet check valve means, for each displacement vessel and means connected to the lower opening of each displacement vessel independent of the slurry delivering means for each given displacement vessel including, discharge check valve means for each displacement vessel to permit slurry to be discharged from the displacement chamber of each given displacement vessel to any suitable point of use,

d. a second open transport system having storage means for propulsion liquid, means connecting said propulsion liquid storage means to the upper opening of each respective displacement vessel for delivering propulsion liquid therefrom to the displacement chamber of any given displacement vessel including, normally closed inlet valve means for each displacement vessel for controlling charging of propulsion liquid to each displacement chamber of a given displacement vessel, and means connected to the upper opening of each displacement vessel independent of the propulsion liquid delivery means for each given displacement vessel including, normally closed outlet valve means to control return of propulsion liquid to the propulsion liquid storage means, and a high speed centrifugal pump,

e. an upper sensing means and a lower sensing means on each respective displacement vessel to sense the position of the interface between the slurry and propulsion liquid in the associated displacement chamber formed by the displacement vessel as the same are alternately and sequentially charged into and discharged from the given discharge chambers,

f. control means for operating the inlet valve means and the outlet valve means of said second open transport system operatively connected to the respective upper sensing means and lower sensing means to alternately and sequentially charge and return propulsion liquid into and out of each displacement chamber to pump slurry from the respective displacement chambers to any suitable use, and

g. means in said control means to delay operation of the inlet valve means on each respective displacement vessel until any other associated displacement vessel has the slurry therein substantially discharged from the displacement chamber of such other associated displacement vessel.

2. In a system for hydraulically displacing slurry with a direct contact propulsion liquid as claimed in claim **1** including,

a. means to adjust the rate of the alternate and sequential charging and return of propulsion liquid into and out of each respective displacement chamber,

b. and, said means operative to increase or decrease the rate of operation of the system as a function of the use of the slurry delivered from the first open transport system.

3. In a system for hydraulically displacing slurry with a direct contact propulsion liquid as claimed in claim **1** including,

a. means for adjusting the rate of the alternate and sequential operating cycle for the propulsion liquid,

b. and, said last mentioned means operative to increase and decrease the operating cycle as a function of the level of the slurry in the slurry storage means of the first open transport system.

4. In a system for hydraulically displacing slurry with a direct contact propulsion liquid as claimed in claim 1, including,

a. an upper limit alarm sensing device and a lower limit alarm sensing device on each of said displacement vessels disposed to extend into each respective displacement chamber thereof for sensing predetermined maximum and minimum level limits for the interface between the slurry and the propulsion liquid in each of said respective displacement chambers,

b. said control system including, an alarm means,

c. and, said alarm means in the control system operatively associated with the respective upper limit alarm sensor and lower limit alarm sensor to signal the occurrence of said condition during the operation of the system.

5. In a system for hydraulically displacing slurry with a direct contact propulsion liquid as claimed in claim 1, wherein said control system includes,

a. means to operate the control system manually disposed in parallel with the system operating as a function of the sensed upper and lower limits of the interface,

b. and, switch means adapted to place the system on automatic or manual operation.

6. In a system for hydraulically displacing slurry with a direct contact propulsion liquid as claimed in claim 1 wherein each of the respective displacement chambers are coated with a substance to prevent corrosion and sticking of slurry on the inner wall of the displacement vessel.

7. In a system for hydraulically displacing slurry with a direct contact propulsion liquid as claimed in claim 6 wherein the coating material is a fluorocarbon resin.

8. In a system for hydraulically displacing slurry with a direct contact propulsion liquid as claimed in claim 1 wherein the upper sensing means and lower sensing means are temperature operated switches normally open and disposed to close at a predetermined temperature variation.

9. In a system for hydraulically displacing slurry with a direct contact propulsion liquid as claimed in claim 1 including,

a. air operated means for actuating said inlet valve means and said outlet valve means in the second open transport system,

b. solenoid operated pilot valve means for delivering air to the air operated means for each of said inlet valve means and outlet valve means,

c. and, said control means operatively connecting the upper sensing means of a given displacement vessel to the solenoid operating means of the associated inlet valve means for said displacement vessel and similarly connecting said lower sensing means to the solenoid operating means for the associated outlet valve means for the displacement vessel.

10. In a system for hydraulically displacing slurry with a direct propulsion liquid as claimed in Claim 1 including,

a. means to adjust the rate of the alternate and sequential operating cycle for charging and returning propulsion liquid into and out of each displacement chamber,

b. means for measuring the level of the slurry in said slurry storage means in the first open transport system,

c. and, said adjustment means operatively responsive to the level measuring means to increase and decrease the operating cycle as a function of the level of the slurry in the storage means.

11. In a system for hydraulically displacing slurry with a direct contact propulsion liquid as claimed in claim 10, said measuring means including,

a. an upper limit level and a lower limit level for sensing predetermined maximum and minimum levels of slurry in said slurry storage means,

b. transducer means, and

c. means to transmit the maximum and minimum signals from said upper level sensors and said lower level sensors to said transducer means.

12. A circuit for controlling the operating cycle of a system for hydraulically displacing slurry that includes,

a. a plurality of displacement vessels connected in parallel and each having an upper opening and a lower opening,

b. means for delivering slurry to the lower opening of each displacement vessel from a slurry storage tank, and means independent of the slurry delivery means for discharging slurry from the lower opening of each displacement vessel,

c. each of said displacement vessels having a normally closed inlet valve means connected to the respective upper opening thereof at one end and to a source of pressurized propulsion liquid at the end remote therefrom and each of said displacement vessels having a normally closed outlet valve means connected to the upper opening thereof for returning the propulsion liquid from the respective displacement vessel to the source of the propulsion liquid,

d. upper sensing switches and lower sensing switches extending into said displacement vessels for sensing the level of the interface between the propulsion liquid and the slurry in the said respective displacement vessels after a given level of said interface in the vessel has been reached,

e. and said control circuit comprising,

1. a first actuating circuit means electrically connected to said inlet valve means on each respective displacement vessel,

2. said first actuating circuit operatively connected to the associate upper sensing switch for the displacement vessel of the inlet valve means to actuate the valve from normally closed to open position when the interface signals that the slurry has been charged into the displacement vessel,

3. a second actuating circuit means electrically connected to said outlet valve means to actuate said outlet valve means to open position and operatively associated with the lower sensing means to sense the level of the interface between the propulsion liquid and the slurry when the slurry has been discharged from the displacement vessel,

4. said first and second actuating circuit means electrically connected to each other so as to actuate the inlet valve means and outlet valve means of the respective displacement vessels alternately and sequentially to permit the uniform flow of slurry from the displacement vessels,

5. and cross over means connected to said first and second actuating circuit means so as to effect the deactuating of said inlet valve means and outlet

valve means of one vessel before the inlet valve means and outlet valve means of the next associated displacement vessel are actuated.

13. In the circuit for controlling the operation of a system for hydraulically displacing slurry as claimed in claim **12** including,

a. means for placing said controlling circuit on manual operation,

b. and, switch means for changing from automatic to manual operation.

14. In a circuit for controlling the operation of a system for hydraulically displacing slurry as claimed in claim **12** including,

a. upper and lower alarm sensing switches,

b. alarm signals means,

c. and, means connecting said upper level alarm sensors and said lower level alarm signal switches to said alarm signal means.

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