HYDRAULIC DISPLACEMENT TYPE PUMPING SYSTEM

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UNITED STATES PATENTS
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2,892,416 6/1959 Alexander.......................... 417/138 X
3,155,049 11/1964 Mandelbaum .................... 417/125
3,262,396 7/1966 Kingsbury ......................... 417/101
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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 dangerous, 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
FIG. 8

Cycle 1

Simultaneously

Displ. Vessel (10a)

Fill slurry and drain liquor.

VCl V2 C T2-C O T2-C O

(75a) (76a) (112a)

Cycle 2

Simultaneously

Displ. Vessel (10b)

Discharge slurry and charge liquor.

VCl V2 C T3-C O T3-C O T2-C O

(75b) (76b) (111b) (112b)

FIG. 8

Cycle 1

Simultaneous operation of displacement vessels 10a and 10b

Cycle 2

Simultaneously

Displ. Vessel (10a)

Discharge slurry and charge liquor.

VCl V2 C T3-C O T3-C O T2-C O

(75a) (76a) (111a) (112a)
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 broadly 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 pumping 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 hydraulic 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 10a and 10b, 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 11a and 11b. A slurry or other mixture to be pumped as shown at 12a and 12b is delivered into the respective bottom or lower section of the displacement chambers 11a and 11b 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 11a and 11b, a clear propulsion liquid as shown at 15a and 15b 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 11a and 11b, 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 10a and 10b 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 10a and 10b 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 18a and 18b and the bottom flow baffles as at 19a and 19b in the respective displacement cylinders or vessels 10a and 10b, 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 18a and 18b can consist of screens or plates with small openings therein. However, the bottom baffles 19a and 19b 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 10a and 10b.

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 11a and 11b they can be coated with a non-stick coating or cladding such as polytetrafluoroethylene or the like 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 10a and 10b taper as at 20a and 20b to facilitate discharge of the mixture being pumped and at the lowermost portion are further provided with lower connecting conduits 21a and 21b. At the uppermost end of the displacement vessels 10a and 10b are upper connecting conduits 22a and 22b. The lower connecting conduits 21a and 21b provide means for connecting the displacement vessels or cylinders 10a and 10b respectively to the transport and discharge assembly 14 for the slurry and the upper connecting conduits 22a and 22b provide means for connecting the displacement vessels or cylinders 10a and 10b 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 13a which empties into the storage tank 13. Storage tank 13 is provided with an upper slurry level limit signal device 13b and a lower slurry level limit de-
vice 13c 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 13d which is operatively connected to actuate and deactivate the conveying means in feeding the chute and mixing means 13a. Upper and lower limit level devices are well known and easily purchasable 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 10a and 10b 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 level of the propulsion liquid in the storage tank 16, the lower will be the pressure head required in the respective displacement chambers 11a and 11b for displacement of the propulsion liquid by the slurry which is delivered from the storage tank 13 to the respective displacement chambers 11a and 11b 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 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 13a 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 10a and 10b as hereinafter described for flushing the displacement chambers 11a and 11b 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 32a and 32b to the inlet port 33 for the respective inlet check valves 34a and 34b which have their respective dual-ported outlets 35a and 35b in turn connected to connecting lines 36a and 36b which are connected individually to the lower connecting conduits 21a and 21b of the respective displacement vessels or cylinders 10a and 10b.

At the ends remote from their connection with the inlet check valves 34a and 34b, the connecting lines 36a and 36b are respectively connected to the inlet side of discharge check valves 37a and 37b for the respective displacement vessels or cylinders 10a and 10b. Discharge check valves 37a and 37b 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 34a and 34b and the discharge check valves 37a and 37b are unidirectional ball type check valves in which the ball members 40a and 40b are held in contact with seats on said valve outlet ports 35a and 35b by means of springs 41a and 41b. 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 34a and 34b are actuated to open position when the differential pressure across the valve outlet ports 35a and 35b exceeds the combined force being exerted on the balls 40a and 40b by the springs 41a and 41b respectively and the back pressure exerted through the liquid contained in the respective displacement chambers 11a and 11b 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 purchasable 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 40a and 40b of the respective inlet valves 34a and 34b exceeds the combined force being exerted by springs 41a and 41b 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 32a or 32b as the case may be.

As slurry is thus delivered to the respective inlet check valve 34a or 34b one or the other or both will be opened depending on the differential pressure acting therein to enable the balls 40a and 40b to move off their seats, and as the case may be slurry will pass into and fill the displacement cylinders 11a and 11b in the respective displacement vessels 10a and 10b, with which the inlet check valves 34a and 34b 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 10a or 10b 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 10a and 10b 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 34a and 34b 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 63a and 63b 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 22a and 22b 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 insures 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 13b and 13c. Signals are transmitted directly to the feeding means, not shown, which varies delivery of the slurry to the chute and mixing means 13a 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 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 delivery channel 10a and 10b 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 65a which delivers air through lines 65b and 65c through orifices 65d and 65e therein to the pressure sensors 65f and 65g.

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

Since the modulating control valve 65 illustrated is of the air operated type, the differential pressure transducer will deliver air signals by line 65j to an air operated motor 65k 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 over-heating 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 57 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 11a and 11b of the respective displacement vessels 10a or 10b, 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 11a or 11b, to provide a smooth uniform pumping action or flow of slurry.

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

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

The propulsion liquid inlet valves 75a and 75b which switch the flow of propulsion fluid to their associated displacement vessels 10a and 10b and propulsion liquid outlet valves 76a and 76b which permit propulsion liquid to be displaced from their associated displacement vessels 10a and 10b and returned to the propulsion liquid storage tank 16 are preferably valves of the same type in order to simplify operative connection 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 75a and one respective outlet valve 76a for the given displacement vessel 10a. Each of the propulsion liquid inlet valves 75a and 75b 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 tank 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 63a and 63b to the associated upper connecting conduit 22a and 22b 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 88a and 88b for each respective inlet valve. The pressure air operated actuators 88a and 88b include a spring 89 which acts against the diaphragm 87 to maintain the respective propulsion liquid inlet valves 75a and 75b normally closed.

Each of the propulsion liquid outlet valves 76a and 76b being similar in construction to the propulsion liquid inlet valves 75a and 75b 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 22a and 22b 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 76a and 76b 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 98a and 98b. The pressure air operated actuator 98a and 98b include a spring 99 which acts against the diaphragm 97 to maintain the respective propulsion liquid outlet valves 76a and 76b 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 88a, 88b and 98a and 98b for the respective propulsion liquid inlet valves 75a and 75b and propulsion liquid outlet valves 76a and 76b by an associated pilot valves generally designated 100a and 100b for the inlet valves and 101a and 101b for the outlet valves. The pilot valves 100a and 100b and 101a and 101b are connected by suitable pressure air supply lines 102a and 102b for the inlet valves 103a and 103b for the outlet valves to a common source 104 of pressure air. The pilot valves 100a, 100b, 101a and 101b are actuated by an electrically operated solenoid device 105a and 105b for the inlet valve and 106a and 106b for the outlet valves. The solenoid devices 105a and 105b, 106a and 106b are operated alternately and sequentially from control means as is more fully described hereinafter.

When a solenoid device as at 105a, 105b, 106a and 106b actuates a pilot valve as at 100a, 100b, 101a and 101b it will pass pressure air to the associated air operated actuator 88a, 88b, 98a and 98b. 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 105a, 105b, 106a and 106b is deactivated, 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 10a and 10b. These include an upper level temperature switch 111a and a lower level temperature switch 112a on displacement vessel 10a and an upper level temperature switch 111b and a lower level temperature switch 112b on displacement vessel 10b. Maximum upper level alarm switches 130a and 130b and minimum level alarm switches 131a and 131b are also temperature operated switches for actuating a parallel safety or takeover circuit which overrides the automatic system as well 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.

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 pumps is controlled depends on the proper sensing of the temperature conditions of the interface between the slurry being pumped and the propulsion liquid.

The conditions sensed by the upper temperature switches 111a and 111b and the lower temperature switches 112a and 112b on the respective displacement vessels 10a and 10b 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 75a and 75b and the propulsion liquid outlet valves 76a and 76b for the displacement vessels 10a and 10b 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
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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°F. These temperature ranges are common in systems to which the present invention is particularly applicable. For example in a slurry system for bauxite 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 111a and 111b to close and in the case of the lower thermal switches a drop in temperature in the ranges above indicated will cause the switches 112a or 112b 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 10a and 10b and the associated fail safe and takeover system with alarm signals. The dashed 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 10a and 10b maximum upper level temperature sensors 130a and 130b; minimum lower level temperature sensors 131a and 131b; and maximum upper alarm signals 132a and 132b associated with the sensors 130a and 130b, and minimum lower alarm signals 133a and 133b associated with the sensors 131a and 131b. Any suitable type of audio or visual alarm means may be used of which there are many that are well known and easily purchasable on the open market.

Current is delivered to the circuit through the main lines 120a and 120b 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 122a and 122b or the manual system contacts 123a and 123b. In either position of the switch 121 the circuits will be adapted to control respectively the inlet valves 75a and 75b and outlet valves 76a and 76b 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 120a and 120b through the selector switch 121 and the associated contacts 122a and 122b. Two lines are shown for either a direct current circuit or a circuit in which one of the lines is connected to ground.

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

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

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

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

Line 124b similarly will lead current to the operating side of switch 125b by connecting lines 124j and 124k and by connecting line 124l to the alarm side of switch 125b; and to the operating side of switch 126b by connecting lines 124m and 124n, and by connecting line 124n to the alarm side of switch 126b. Line 124c 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 125a, 126a, 125b and 126b 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 105a and outlet valve 106a on displacement vessel 10a and MLR-B for operating the inlet valve 105b and outlet valve 106b on displacement vessel 10b.

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 125a, 125b, 126a and 126b 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 105a and 105b and the outlet valves 106a and 106b in accordance with the desired sequencing of the valves to provide smooth pumping operation for the system. Further, however, operation of the inlet valves 105a and 105b for the respective displacement vessels 10a and 10b 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 134a and 134b. The magnetic latching relay MLR-a is so connected to cross-control relay 134a that it will actuate the cross-control relay 134a to open the current conducting line to the solenoid coil SC105b for inlet valve 75a for displacement vessel 10a. Similarly relay MLR-b acts with cross-control relay 134b to control inlet valve 75a for displacement vessel 10a. This is necessary to prevent premature or delayed delivery of propulsion fluid to displacement vessel because the filling of the displacement vessels 10a and 10b 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 134a and 134b will include respectively a switch 135a and 135b and a solenoid coil as at 136a and 136b.

When slurry rises in displacement vessel 10a so that either temperature sensor 111a or 130a acts to actuate either the operating side or the alarm side of switch 125a so as to close one or the other of those switches as the case may be, current will pass through either line 124a or 124c to a common connecting line 125c which is connected to one side of coil CR-2, the other side of the coil being connected to a line 137a which is part of a current return and/or grounded line generally designated 137. Line 137 will be connected to contact 122b 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 124C through switch M1 and line 138a to the solenoid coil 105a for the inlet valve 75a but only if the switch 135a in cross-over relay 134a whose coil 136a is disposed in the line 138a 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 106a and outlet valve 76a will move to the closed position.

If cross-over relay 135a is held open by relay 136b no current will pass to the solenoid coil SC105a and the inlet valve 75a will also remain closed and the slurry will hold in this upper position. When cross-over relay switch 135a moves to the closed position current will then flow to the solenoid coil SC105a and inlet valve 75a will be moved to the open position to permit propulsion liquid to enter and pump slurry from the displacement vessel 10a.

When slurry is discharged and falls in displacement vessel 10a so that either temperature sensor 112a or 131a acts to actuate either the operating side or the side of switch 126a so as to close one or the other of these switches, as the case may be, current will pass through either line 124a or 124b to a common connecting line 126c which is connected to one side of coil CR-1, the other side CR-1 being connected to return or ground line 137a 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 when 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 75a will not receive current and will automatically move to the normally closed position, conversely however current will pass from line 124c through switch M2 to line 139a to solenoid coil 106a which acts to actuate outlet valve 76a to open position and slurry under gravity lead or pressure will fill the displacement vessel 10a displacing the propulsion liquid back through the open outlet valve 76a to the propulsion liquid transport and return system.

The operation for displacement vessel 10b is similar to that above described for displacement vessel 10a. Thus when slurry therein raise temperature sensors 111b and 130b will actuate one or the other of the switches on the operating or the alarm side of switch 125b to pass current through common connecting line 125b to one side of coil CR-4, the other side of which communicates with the return or ground line 137b 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 124c to the solenoid coil SC106b and outlet valve 76b will move to its deactivating or normally closed position. Conversely since the switch arm as shown in the dotted position will close switch M3 current will flow from line 124c through the switch M3 and line 136b to solenoid coil SC105b, if switch 135b in the cross-over relay 134b is not being held in the open position.

If relay 136a is holding the switch arm for switch 135b of cross-over relay 134b in the open position then no current will pass through line 138b to the solenoid coil SC105b and inlet valve 75b will remain closed.

With both valves closed the slurry will hold at the upper level until the switch arm closes switch 135b of the cross-over relay 134b at which time current will flow and cause the solenoid coil SC 105b to open inlet valve 75b and propulsion liquid will be passed into and out to dispose the slurry in the displacement vessel 10b.
When the slurry is discharged and falls to cause the temperature sensors 112b or 131b to actuate the switches on either the operating side or the alarm side of switch 126h, current will flow from lines 124m and 124p through common connecting line 126d to one side of coil CR-3, the other of which is connected to the common return or ground line 137b. The current flowing through coil CR-3 will cause the magnetic latching relay ML-R-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. 105b and inlet valve 75b will move to its normally closed position. However, current will flow from line 124 c through switch M4 and line 139b connected thereto and to solenoid coil SC 106b so as to cause the solenoid coil SC 106b to activate the outlet valve 76b to open position. In this position of the valves slurry under gravity head or pressure will act to displace propulsion liquid back through the open outlet valve 76b to the propulsion liquid transport and return system and to fill displacement vessel 10b once again.

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

It is believed clear that the dwell systems provided by the cross-over relays 134a and 134b 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 76a or 75b for delivering propulsion liquid.

The alarm side of the switches 125a, 125b, 126a and 126b 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 130a and the lower level limit temperature sensor 131a on displacement vessel 10a and similarly an upper level limit temperature sensor 130b and a lower level limit temperature sensor 131b on the displacement vessel 10b. For displacement vessel 10a the upper level limit thermal sensor 130a is connected by line 126a to the alarm side of switch 126a and the lower level limit thermal sensor 131a is connected by line 131c to the alarm side of switch 126a. Similarly, for displacement vessel 10b the upper level limit thermal sensor 130b is connected by line 130d to the alarm side of switch 125b and the lower level limit thermal sensor 131b is connected by line 131d to the alarm side of switch 126b. Responsive to an excessive rise in the level of the interface in either displacement vessel 10a or 10b upper limit temperature sensors 130a and 130b will actuate the alarm side of the respective switches 125a and 125b and causes the respective alarm signals 132a and 132b associated therewith to be actuated. Similarly, responsive to the level of the interface in either displacement vessel 10a or 10b the lower limit temperature sensors 131a and 131b actuate the alarm side of the respective switches 126a and 126b and cause the alarm signals 133a and 133b associated therewith to be actuated. This takeover alarm arrangement is necessary to protect against failure of the primary sensors 111a, 111b, 112a and 112b 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 125a, 125b, 126a and 126b are disposed to actuate the solenoid coils designed S.C. for the respective solenoid devices 105a, 105b, 106a and 106b by delivering current thereto when the switches are actuated in accordance with signals from the temperature sensors 111a, 111b, 112a and 112b or the takeover sensors 130a, 130b, 131a and 131b as the case may be.

Actuation of the inlet valves 75a and 75b and the outlet valves 76a and 76b for the respective displacement vessels 10a and 10b 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 10a and 10b.

When the circuit is switched to the manual position by moving then a secter switch 121 into engagement with contacts 123a and 123b, 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 140a is provided for operating the inlet valve 75a and push button switch 141a is provided for operating outlet 76a. Similarly, push button switch 140b is provided for operating inlet valve 75b and push button switch 141b is provided for operating outlet valve 76b. Additionally, the circuit shows that there is associated with each of the solenoid coils S.C. for the respective solenoid valves 105a, 105b, 106a and 106b, 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 142a is provided for inlet valve 75a and an amber light 143a is provided for outlet valve 76a. Similarly, a green light 142b is provided for inlet 75b and an amber light 143b is provided for outlet valve 76b.

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

Line 145a is connected to one side of manual push button switch 140a. The other side of which is connected by line 146a to solenoid coil S.C. 105a and by line 147a to the green light 142a.

The opposite sides of the solenoid coil S.C. 105a and the green light 142a are connected respectively by lines 146b and 147b to a
common return or ground line systems 160 for manual operation which in turn is connected to contact 123b. Lines 145 is connected to one side of manual push button switch 140b the other side of which is connected by line 148a to solenoid coil SC 105b and by line 149a to the green light 142b. The opposite sides of the solenoid coil SC 105b and the green light 142b are connected respectively by lines 148b and 149b to the common return or ground line system 160.

Line 145c connects with one side of manual push button switch 141a the other side of which is connected by line 150c to solenoid coil SC 106a and by line 151c to the amber light 143a. The opposite sides of the solenoid coil SC 106b and the amber light 143a are connected respectively by lines 150b and 151b to the common return or ground line system 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 145e, 145f, 145g and 145h pass current to the respective switches 125a, 125b, 126a and 126b which are operated by the temperature sensors 111a and 130a; 111b and 130b; 112a and 131a; and 112b and 131b respectively.

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

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

Additional lines 159a and 159b connect at one end to the respective lines 145e and 145f and at the end remote therefrom one side of coils 170a and 170b of control switches 171a and 171b dispersed in lines 145c and 145d respectively, the other side of which coils are connected by lines 172a and 172b to the common return or ground line system 160. These respective control switches 171a and 171b will be actuated normally closed to open position when the temperature sensors 111a or 111b actuate the switches on the operating side of switches 125a and 125b to the close position. In effect this will open the circuit to either solenoid coil 106a or 106b depending on which push button is in operation and will cause one or the other of the outlet valves 76a or 76b 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 140a, 140b, 141a and 141b may be operated to pass current to the associated solenoid SC 105a, SC 105b, SC 106a and SC 106b for operating the respective inlet valves 75a, 75b, 76a and 76b associated therewith from closed to open position.

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

It is thought clear that both displacement vessels 10a and 10b can be similarly operated and that the alternate and sequential operations of the push buttons 140a, 140b, 141a and 141b 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 10a and 10b so they can be back flushed by a suitable solen 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 acting 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 13b signals the feed system to stop delivering slurry to the chute and mixing means 13a for feeding the slurry storage tank 13.
The propulsion liquid transport and return system is then placed into operation by starting pump 58. So long as the inlet valves 75a and 75b 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 than the pressure setting of the relief valve 72.

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

The system can now be set up for manual or automatic operation by manually signalling the solenoid SC 106b to open the outlet valve 76b 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 delivery line 29, the connecting line 35a and the inlet valve 37b into the displacement chamber 11b where it will displace the propulsion liquid therein through the open outlet valve 76b, transport line 63b and return line 64 to the propulsion liquid storage tank 16.

As the slurry enters the displacement chamber 11b, it will rise therein until the upper thermal sensor 111b and red light 15b indicates that the interface between the propulsion liquid and the slurry has reached the level of this sensor. The propulsion liquid outlet valve 76b is then manually closed and further filling of the displacement chamber 11b 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 11a and 11b.

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 10a filled with propulsion liquid and displacement chamber 10b filled with slurry. In regard to the operation is noted again that the valves in the slurry transport and delivery system 14 are check valves. The opening of inlet valves 37a and 37b will depend on the back pressure acting in the associated displacement chambers 11a and 11b with which the respective inlet valves 37a and 37b communicate. However, opening of the outlet valves 39a and 39b 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 75a and 75b and outlet valves 76a and 76b 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 propulsion 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 graphically 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 11a 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 10b will drive or pump the slurry in the displacement chamber 11b from the displacement vessel 10b and fill the displacement chamber 11b with propulsion liquid.

During Cycle II, displacement vessel 10a will be charged with propulsion liquid to drive the slurry from the displacement chamber 11a. Simultaneously, the displacement chamber 11b in the displacement vessel 10b will be filled with slurry and the pressure head of the slurry will drive the propulsion liquid in the displacement vessel 10b 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 111a and 112b will signal outlet valve 76a and inlet valve 75b to open position. This will cause displacement chamber 11a 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 11a back through the open outlet valve 76a, transverse line 63a and return line 64 to the propulsion liquid storage tank 16. Simultaneously, since displacement vessel 10b 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 75b, transverse line 63b to the displacement chamber 11b and will displace the slurry present in the displacement chamber 11b of displacement vessel 10b through the slurry discharge valve 37b 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 111a in displacement chamber 11a the temperature thereof is signalled to the controller 125a. The controller automatically closes outlet valve 76a and opens the propulsion liquid inlet valve 75a. Simultaneously or approximately as the descending interface passes, the lower temperature sensor 112b in displacement chamber 11b, the temperature condition at the interface is signalled to the controller 126b causing inlet valve 75b to be closed and the propulsion liquid outlet 76b to be opened.

The graphical analysis of the cycles shows that the outlet valve 76a closes shortly before the inlet valve 75b closes and inlet valve 75a opens. In this respect, the opening of the inlet valves 75a and 75b 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 75a and outlet valve 76b are opened. In these valve positions, propulsion liquid will pass through the open inlet valve 75a and the transverse line 63a into the displacement chamber 11a through the slurry discharge valve 37a 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 35b and slurry inlet valve 34b into the displacement chamber 11b. The displacement head of
slurry will displace the propulsion liquid in displacement chamber 11b back through the open outlet valve 76b, the transverse line 63b 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 11a is sensed by the lower temperature sensor 112a which will signal the outlet valve 76b and inlet valve 75a to closed position. Similarly, the temperature of the rising interface in displacement vessel 10b will be sensed and at the proper temperature will open the inlet valve 75b for displacement vessel 10b and open valve 76a for displacement vessel 10a.

Since the valve condition namely outlet valve 76a and inlet valve 75b 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 75a and 75b and outlet valve 76a and 76b are operated to manually discharge the slurry present in the displacement chambers 11a and 11b.

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

Since the back pressure of the flushing system can be raised high enough to open the discharge valves 37a and 37b, 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 11a and 11b 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 storage 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 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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