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FLUID MIXING SYSTEM

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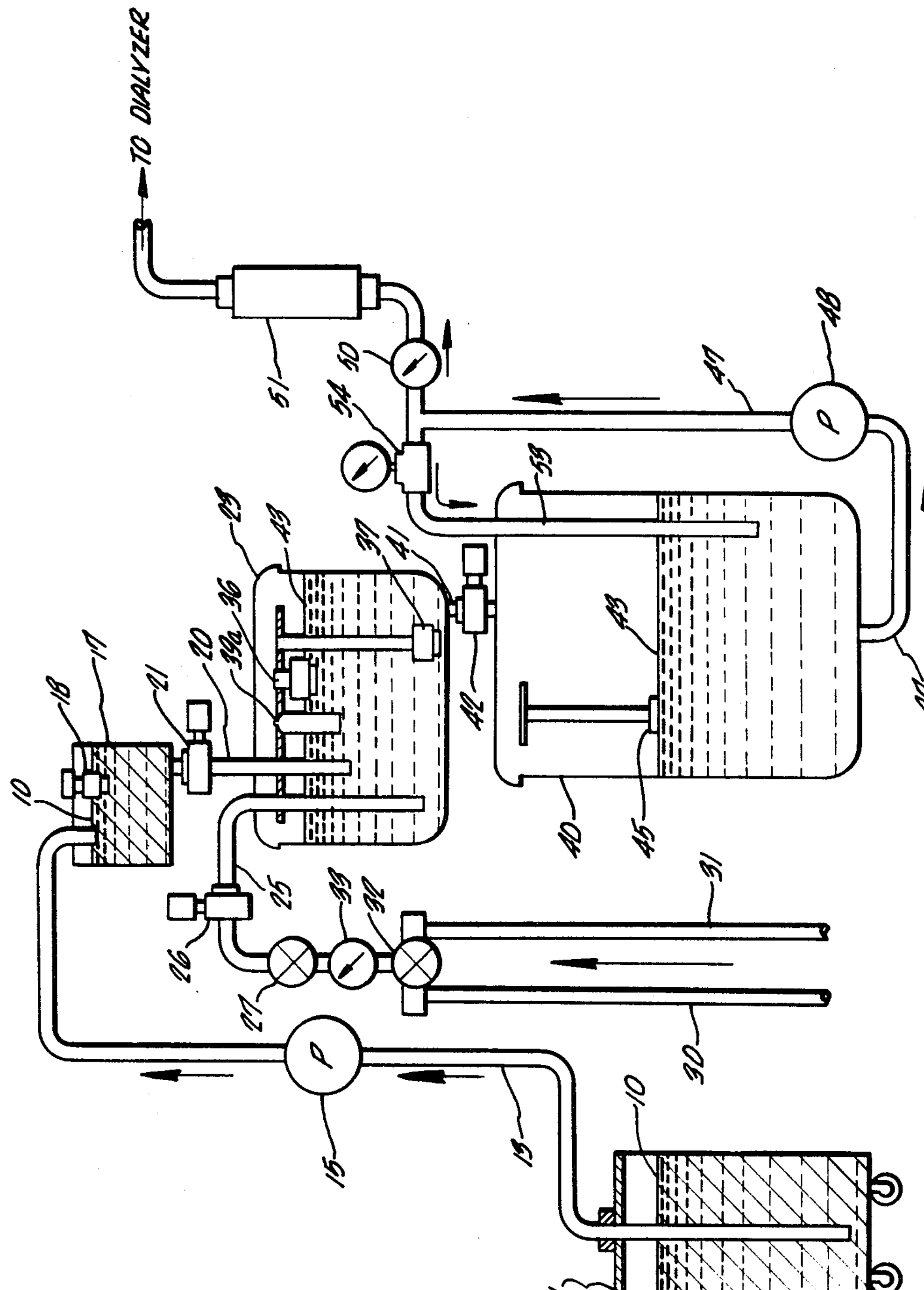

FIG. 1

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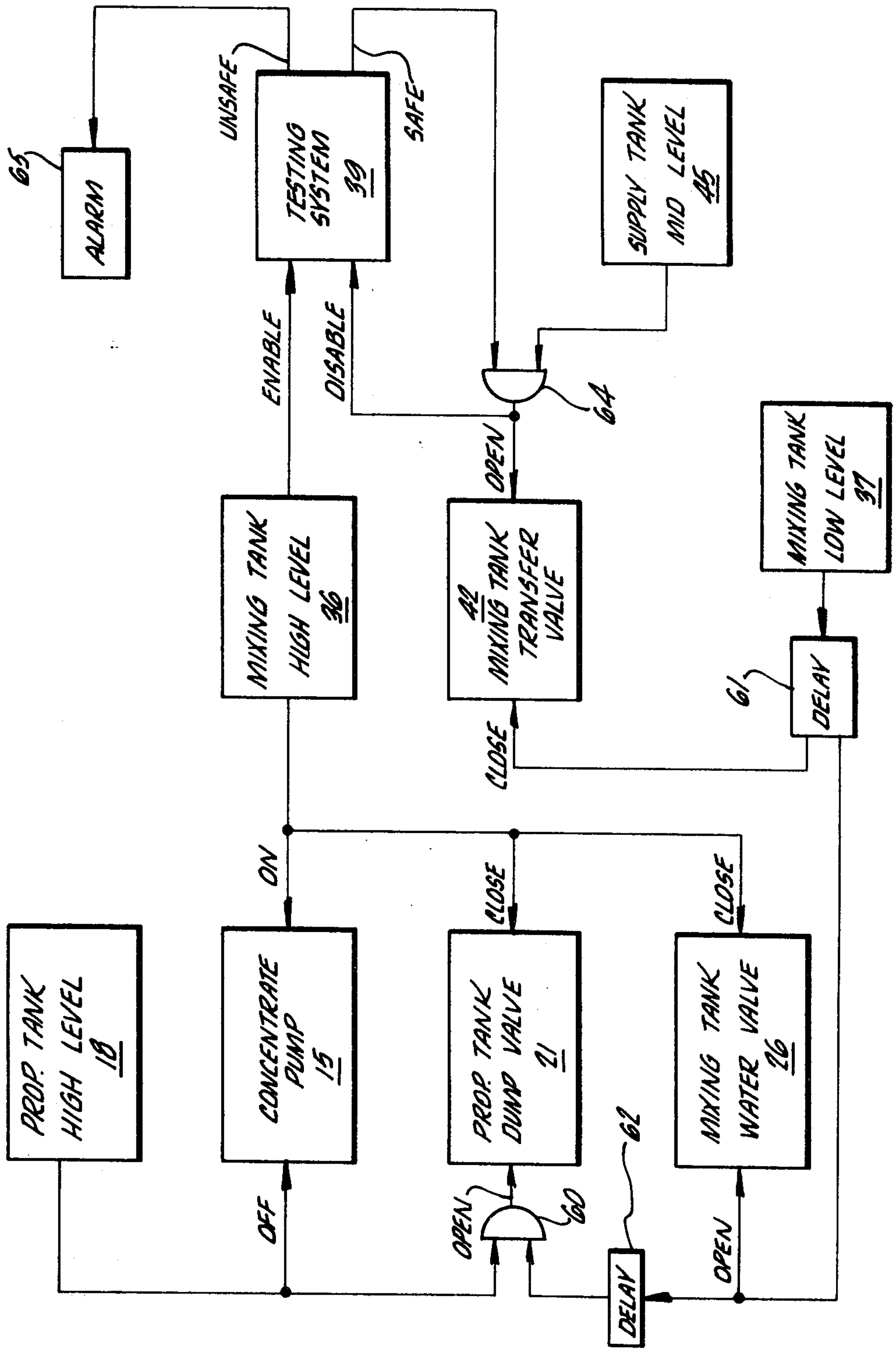
FIG. 2



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FLUID MIXING SYSTEM

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ABSTRACT OF THE DISCLOSURE

A fluid mixing system for mixing two fluids and delivering the composite fluid to a device. The system includes a mixing tank for receiving the components of the composite fluid and a supply tank for storing the mixed fluid. The supply tank has a capacity substantially larger than the capacity of the mixing tank and has an outlet providing a continuous flow of the composite fluid to the device. A transfer valve is located between the mixing tank and supply tank and is actuable to empty the entire contents of the mixing tank into the supply tank. A testing means associated with the mixing tank is coupled to the transfer valve for preventing actuation of the transfer valve when the composite fluid does not meet a predetermined composition standard.

This invention relates to a fluid mixing system, and specifically to a system adapted for continuous mixing and delivery of a multi-component fluid required for operation of an external device. The invention is especially useful for mixing and delivering a dialysate fluid to a dialysis apparatus such as an artificial kidney, and will be described in terms of this application.

Dialysis is a process for separating compounds or materials by the difference in their rates of diffusion through a semipermeable membrane. A dialyzer is an apparatus for carrying out the dialysis process, and typically consists of two chambers which are separated by a semipermeable membrane. A fluid to be treated is passed through one chamber, and a dialysate fluid or solvent is passed through the other chamber. Substances composed of small particles diffuse from the solution through the membrane and into the solvent much more rapidly than amorphous substances, colloids, or large molecules, whereby a selective, predictable purification of the fluid being treated is accomplished.

The dilalysis process has been used in recent years in artificial-kidney devices to aid patients who have experienced kidney-function failure. A blood-purification process is accomplished by flowing the patient's blood through one chamber of a dialyzer. An approximately isotonic, aqueous solution of glucose and salts is pumped through the other dialyzer chamber. Certain materials which are normally removed by the natural kidneys from the blood pass from the blood through the membrane into the isotonic solution or dialysate. The blood is thereby purified to an extent somewhat similar to that achieved by natural kidneys, and then leaves the dialyzer to be returned to the patient's body.

In a typical hemodialysis treatment program, the patient is coupled to the artificial-kidney dialyzer for perhaps two 12-hour periods per week to accomplish the blood purification normally performed by natural kidneys. During these treatment periods, it is important that a continuous flow of dialysate be delivered to the dialyzer. For simplicity and economy, it is desirable to provide a dialysate source capable of delivering dialysate to a number of dialyzers to permit simultaneous treatment of a number of patients.

Dialysis fluid is commercially available in concentrated

form, and is mixed and diluted with water in a prescribed ratio before delivery to the artificial-kidney dialyzer. In the past, mixing and dilution has been accomplished manually, or with conventional proportioning pumps, the pump output flowing directly to the dialyzer. Instrumentation is normally used to monitor the composition of the diluted dialysate, and if an improper mixture is detected, immediate and hurried corrective action must be taken to maintain a flow of dialysate of proper concentration to the dialyzer. The mixing and pumping system must therefore be monitored constantly by a relatively skilled person to insure continuous delivery of correctly mixed fluid.

Another problem with the conventional mixing and delivery apparatus is that it is not well adapted to varying flow rates which are needed in a multiple-patient installation as individual dialyzers are added to or removed from the dialysate line. In conventional systems, it has been necessary either to vary the stroke rate of the proportioning pump, or to pump at high flow rates with excess fluid being discarded. Changing the pump stroke rate requires either manual adjustment or a relatively complex automatic-control system, and the discard of excess dialysate is wasteful and costly.

The fluid mixing system of this invention overcomes these problems, and provides continuous delivery of dialysate which has been tested for correct composition. Blending of the dialysate concentrate and water is accomplished in a separate step and the blended solution is tested for proper concentration before introduction into a tank from which dialysate is continuously delivered to one or more dialyzers. If the testing process discloses an out-of-tolerence dialysate solution resulting from either improper blending or perhaps from impurities in the water or concentrate supply, delivery of pure dialysate continues while the improper solution is discarded and replaced. Adequate time is thus available for a calm appraisal of the source of the improper mixture, and rational corrective action can be taken without interruption of patient treatment.

Briefly stated, the fluid mixing system of this invention is adapted to mix, test and store a fluid composed of at least two components, and is further adapted to deliver a continuous flow of the fluid to one or more devices such as dialyzers in artificial kidneys. The system includes a mixing tank for receiving the components of the fluid, and a supply tank for storing the mixed fluid. The supply tank has a capacity substantially larger than the capacity of the mixing tank and has an outlet providing a continuous flow of fluid to the device. A transfer valve is coupled between the mixing tank and the supply tank, and is actuable to empty the mixing tank into the supply tank.

A quantity-sensing means is associated with the supply tank, and is coupled to the transfer valve for actuating the transfer valve when the amount of fluid in the supply tank has decreased sufficiently for the supply tank to receive and store the contents of the mixing tank. A testing means in association with the mixing tank is coupled to the transfer valve for testing the composition of the fluid in the mixing tank, and for preventing actuation of the transfer valve when the composition does not meet a predetermined standard.

The invention will be described with reference to the attached drawings, in which:

FIG. 1 is a diagram showing the interconnection of tanks, valves, and other components making up the fluid mixing system; and

FIG. 2 is a block diagram illustrating the control logic incorporated in the system.

Referring to FIG. 1, a supply of dialysate concentrate **10** is stored in a drum **11**. This concentrate is commercially available, and is typically supplied by the manufacturer in fifty-gallon drums. A concentrate supply line **13** is submerged in the concentrate through the top of the drum, and a pump **15** is provided in the line for pumping concentrate out of the drum.

A concentrate proportioning tank **17** receives the concentrate pumped through line **13**. A high-level sensor **18**, such as a float-actuated switch, is mounted in the proportioning tank, and generates a signal when the proportioning tank has been filled to a specific level with concentrate. A drain line **20** is secured to the bottom of the proportioning tank, and a solenoid-operated valve **21** in the line is actuable to dump the concentrate in the proportioning tank through the drain line.

A mixing tank **23** is positioned below the concentrate proportioning tank to receive concentrate flowing through drain line **20**. A water supply line **25** extends into the mixing tank, and includes a solenoid-operated valve **26** in series with a manual shutoff valve **27**. A hot-water line **30** and cold-water line **31** are coupled to a conventional thermostatically controlled mixing valve **32** which is coupled to valve **27** and provides a stream of controlled-temperature water to line **25**. A temperature gage **33** is coupled in the line between valve **27** and the mixing valve to monitor the temperature of the mixing valve output stream.

The mixing tank includes a high-level sensor **36** (such as a conventional float-actuated switch) for generating a signal when the mixing tank has been filled to a specific, predetermined level. The mixing tank also includes a low-level sensor **37** for generating a signal when the tank has been emptied or almost emptied. A probe **39*a*** is mounted in the mixing tank in contact with fluid stored in the tank, and is coupled to a testing system **39** (FIG. 2). The probe and testing system may be of a conventional, commercially available type such as a conductivity meter for measuring total electrolyte concentration of a fluid in the mixing tank.

The proportioning tank and mixing tank are selected to have capacities in accordance with the desired degree of dilution of the concentrate. For example, if a 35-to-1 dilution of concentrate is prescribed for dialysate to be pumped to a dialyzer, the proportioning tank will have a capacity which is one-thirty-sixth the capacity of the mixing tank. Tank sizes of course depend upon the demands of the particular dialysis system being supplied, and a typical mixing tank capacity is fifty gallons. In practice, the tanks have a capacity somewhat larger than necessary, and the desired quantity of fluid in each tank is sensed by high-level sensors **18** and **36**. The position of these sensors can of course be adjustable to alter the mixture ratio of concentrate and water.

A dialysate supply tank **40** is positioned below the mixing tank, and a drain line **41** secured to the bottom of the mixing tank and having a solenoid-operated transfer valve **42** permits dialysate **43** in the mixing tank to be drained into the supply tank. The supply tank has a capacity substantially larger than the capacity of the mixing tank. For example, the supply tank will typically accept and store about one hundred gallons of dialysate in contrast to the mixing-tank capacity of approximately fifty gallons.

The supply tank includes a midlevel sensor **45** (such as a float-actuated switch) for generating a signal when the amount of dialysate in the supply tank has decreased sufficiently that the full contents of the mixing tank may be emptied into the supply tank. The exact level at which this signal is generated of course is determined by the relative capacities of the supply and mixing tanks. For example, if the supply tank has a capacity of one hundred and fifty gallons, and the mixing tank a capacity of fifty gallons, the mid-level signal is generated when the contents of the supply tank have been reduced to about one hundred gallons or two-thirds total capacity.

An outlet line **47** is secured to the bottom of the supply

tank, and a pump **48** in the line pumps dialysate from the supply tank through a temperature gage **50** and flow meter **51** to one or more dialyzers (not shown) requiring a continuous flow of dialysate. A return line **53** having a conventional constant-head pressure regulator **54** is coupled to line **47** on the downstream side of pump **48**.

Each dialyzer typically incorporates a flow regulator, so output flow regulation of dialysate from the mixing system is not required. Constant-head pressure regulator **54** establishes a pressure in line **47** to insure continuous flow of dialysate as dialyzers are added to or substracted from the output of the mixing system. For example, a typical mixing system will provide a continuous flow of dialysate from one to ten dialyzers, with no adjustment being required as individual dialyzers are coupled to or de-coupled from the mixing-system output.

Operation of the fluid mixing system will now be described with reference to FIG. 2 which shows the logical organization of one form of the system. The output of high-level sensor **18** in the proportioning tank is coupled to an "OFF" control on concentrate pump **15**, and is also coupled to means analogous to an "AND" gate **60**. It is to be understood that the "AND" gate is illustrated in a functional sense, and may be a conventional "AND" gate electrical circuit (as used in electronic digital apparatus) if electric signals are derived from the level sensors, or may be a mechanical apparatus (for generating an output motion, for example, whenever two input motion signals are present) if the output of the level sensors is mechanical. The output of "AND" gate **60** is coupled to dump valve **21** on the proportioning tank, and is arranged to toggle the dump valve into a latched, open position whenever signals are present at each input to the "AND" gate. For example, an "AND" gate electrical output can be used to actuate a solenoid for opening the dump valve.

High-level sensor **36** on the mixing tank is coupled to concentrate pump **15** and testing system **39** whereby the concentrate pump is turned on and the testing system is activated or enabled when the mixing tank is filled to a level which actuates sensor **36**. The high-level sensor in the mixing tank is also coupled to proportioning-tank dump valve **21** and mixing-tank water valve **26**, and is arranged to toggle both valves to a closed position when sensor **36** detects that the mixing tank has been filled to the desired level.

Low-level sensor **37** in the mixing tank is coupled to a delay means **61** which may be of any conventional electrical or mechanical type for delaying a signal received from the low-level sensor. The exact delay introduced by means **61** depends on the characteristics of the particular mixing system, and is typically in the range of a few seconds to perhaps a minute. Outputs from the delay means are coupled to transfer valve **42**, and to water valve **26** associated with the mixing tank.

The system is arranged whereby a delayed signal transmitted from low-level sensor **37** through the delay means will toggle open the water valve and will toggle the transfer valve into a closed position. An output from delay means **61** is also coupled to a second delay means **62** (which is similar to delay means **61**), and the output of the second delay means is connected to "AND" gate **60** to serve as a second input to this gate. Thus, proportioning-tank dump valve **21** is commanded to toggle open whenever a high-level signal is generated by sensor **18** in the proportioning tank, and a doubly-delayed signal is received from low-level sensor **37** in the mixing tank.

Mid-level sensor **45** in the supply tank is coupled to one input of an "AND" gate **64**, and the output of this gate is connected to transfer valve **42** on the mixing tank. Testing system **39** has a "SAFE" output which is connected to a second input on "AND" gate **64**. A signal appears on the "SAFE" output of the testing system whenever the testing system is activated and senses that dialysate of a desired composition has been mixed in the mixing tank. Thus, the solenoid-operated transfer valve on the mixing tank is commanded to open whenever a signal from mid-level sensor **45** and a "SAFE" signal from the testing system appear simultaneously as inputs to "AND" gate **64**.

The output of "AND" gate **64** is also connected to the testing system to de-activate or disable the testing system upon opening of the mixing-tank transfer valve. By this arrangement, the testing system is activated only when the mixing tank is full of dialysate, and cannot command closing of the mixing-tank transfer valve by a misleading loss of the "SAFE" signal as might occur when the dialysate in the mixing tank drains away from the testing-system sensor.

The testing system also has an "UNSAFE" output which is coupled to an alarm **65** which may be of a conventional audio-visual type such as a signal light and a warning horn or bell. An "UNSAFE" signal is generated by the testing system to activate alarm **65** whenever the testing system is enabled by high-level sensor **36** in the mixing tank and the testing system senses an improper mixture of dialysate in the mixing tank. False alarms as might occur when water and concentrate are first flowing into the mixing tank are avoided by not activating or enabling the testing system until the mixing tank is full as sensed by high-level sensor **36**.

To illustrate the operation of the system, assume that the mixing tank is full of previously mixed dialysate of a desired formulation, the proportioning tank is full of concentrate, the testing system is generating a "SAFE" signal, and dialystate is being pumped from the supply tank to one or more dialyzers. As the dialysate level in the supply tank decreases, mid-level sensor **45** will be actuated when the supply tank has been sufficiently drained to accept the full contents of the mixing tank. A "SAFE" signal from the testing system and the signal from mid-level sensor **45** then appear simultaneously as inputs to "AND" gate **64**, and the output of this gate commands opening of mixing-tank transfer valve **42** whereby the contents of the mixing tank are emptied into the supply tank.

The transfer valve is arranged to latch in the open position, so loss of the "SAFE" signal from the testing system (which is disabled upon opening of the transfer valve) will not interfere with draining of the mixing tank into the supply tank. Disabling of the testing system can of course be delayed within the testing system to insure that an output is present at "AND" gate **64** for a sufficient period to toggle the transfer valve into the latched, open position. Similarly, the other valves in the system are of a conventional bi-stable or latching type, and therefore toggle into a commanded position until a contrary command is received.

When emptying of the mixing tank is sensed by low-level sensor **37**, a delay is introduced by delay means **61** to insure that the full contents of the mixing tank have drained through the transfer valve. At the end of the delay period, the transfer valve is commanded to close by the delayed signal from the mixing-tank low-level sensor. Simultaneously, this delayed signal commands opening of water valve **26** to begin filling of the mixing tank. Delay means **62** is set to allow water to cover the bottom of the mixing tank before introduction of the concentrate from the proportioning tank, insuring thorough mixing of the concentrate with the inflowing stream of water.

At the end of the delay introduced by delay means **62**, the doubly-delayed signal from low-level sensor **37** appears at the input to "AND" gate **60**. As the proportioning tank is full of concentrate, a signal from high-level sensor **18** will also appear as an input to the "AND" gate, and an output from the gate will therefore command opening of the proportioning-tank dump valve to drain the concentrate into the mixing tank. Drain line **20** is dimensioned such that the proportioning tank is fully drained well before water flowing through line **25** has filled the mixing tank to actuate high-level sensor **36**.

When high-level senosr **36** senses that the mixing tank has been filled, the testing system is enabled to test the contents of the mixing tank for proper concentration or other properties. The mixing-tank high-level sensor also closes the proportioning-tank dump valve and water valve **26**. Simultaneously, high-level sensor **36** commands actuation of concentrate pump **15** to pump concentrate from drum **11** into the proportioning tank. When high-level sensor **18** detects filling of the proportioning tank, the concentrate pump is turned off. Thus the system is restored to the condition assumed at the beginning of the cycle, with the proportioning tank full of concentrate, and the mixing tank full of dialysate ready for transfer to the supply tank.

Should the testing system detect an out-of-tolerence condition in the dialysate stored in the mixing tank, a "SAFE" signal will not be generated, and the mixing-tank transfer valve will therefore fail to operate when the supply tank level drops sufficiently to actuate mid-level sensor **45**. This is because the transfer valve can only be actuated when a signal from the mid-level sensor and a "SAFE" signal are present simultaneously as inputs to "AND" gate **64**.

An "UNSAFE" signal from the testing system activates alarm **65**, and alerts hospital personnel to drain the contents of the mixing tank through a drain valve (not shown) and to search for the source of the trouble. A large supply of previously tested dialysate remains in the supply tank, and is adequate to permit continuous operation of dialyzers coupled to the mixing system for a period of perhaps one hour or more. Hospital personnel can therefore analyze the source of the problem in a calm, analytical way, and are not forced to take hurried, emergency action.

The various components of the mixing system of this invention have not been described in detail as they may be of conventional, commercially available types. Those skilled in the art will recognize that pumps, solenoid-operated valves, pressure regulators, level or quantity sensors, and other components of the system are readily available in a variety of different forms. It is also to be understood that the scope of the invention is not limited to the specific application in a dialysis system described above. The system is useful wherever blending and testing of a multi-component fluid mixture is to be accomplished before introduction of the mixture into a continuous-flow system.

Similarly, the invention is not limited to the specific types of level sensors, valves, and other components described above. For example, the quantity of dialyzer in the several tanks may be sensed by weight sensors or any other conventional quantity-sensing means instead of level sensors. Similarly, the various valves in the system may be mechanically actuated by linkages coupled to the level sensors, rather than by electrical signals as discussed above. Various types of testing systems may be used, including those sensitive to concentration of selected, specific ions in the mixed fluid.

Many variations in the control logic are also practical, and are easily made to adapt the system to specific requirements. For example, the signal which commands operation of the concentrate pump can be interlocked through the proportioning-tank dump valve to insure complete closing of the dump valve before introduction of fresh concentrate into the proportioning tank. Similarly, the mid-level sensor signal can be delayed through suitable means and used to actuate an alarm to alert personnel that fluid in the supply tank has been depleted without replenishment. All of these variations are intended to be within the scope of the invention as defined in the appended claims.

There has been described a simple, economical, and failsafe fluid mixing system which can be operated by inexperienced personnel and which reliably provides a continuous flow of a fluid to an external device. If an improper mixture is detected in the mixing tank, ample time is permitted to diagnose the problem and take corrective action without interruption of the continuous flow of fluid to the device.

What is claimed is:

1. A fluid mixing system for mixing, testing and storing a fluid composed of two components and for delivering a continuous flow of said fluid to a device, said system comprising,

a proportioning tank for receiving a first component of said fluid,

a mixing tank for receiving said first component from said proportioning tank and for receiving said second component,

a first bistable transfer means coupled between said proportioning tank and said mixing tank and actuable to dump said first component from said proportioning tank into said mixing tank,

a supply tank for storing said fluid, said tank having a capacity greater than the capacity of said mixing tank and having an outlet for providing a continuous flow of said fluid to said device,

a second bistable transfer means coupled between said mixing tank and said supply tank and actuable to empty the entire contents of said mixing tank into said supply tank,

a first quantity sensing means associated with said supply tank and coupled to said second bistable means for opening said second bistable means when the amount of said fluid in said supply tank is decreased sufficiently for said supply tank to receive and store at least the entire fluid contents in said mixing tank,

a second quantity sensing means associated with said mixing tank and coupled to said second bistable means for closing said second bistable means and opening said first bistable means when said mixing tank is empty, and

testing means associated with said mixing tank and coupled to said second bistable means valve for testing the composition of said fluid in said mixing tank and for preventing the opening of said second bistable means when said composition does not meet a predetermined standard.

2. The fluid mixing system as defined in claim 1 further including disabling means for disabling said testing means in response to the opening of said second bistable means.

3. The fluid mixing system as defined in claim 1 wherein said first component is a dialysate concentrate and said second component is water and wherein said system further includes

a water supply line for delivering said water to said mixing tank,

a third bistable transfer means coupled between said water supply line and said mixing tank and actuable to permit said water to flow from said water supply line to said mixing tank, and

wherein said second quantity sensing means opens said third bistable means when said mixing tank is empty.

4. The fluid mixing system as defined in claim 1 further including a delay means coupled to said second quantity sensing means for delaying the closing of said second bistable means thereby insuring that the full contents of said mixing tank have drained to said supply tank.

5. The fluid mixing system as defined in claim 4 further including a third quantity sensing means associated with said mixing tank and operable in response to the filling of said mixing tank to a predetermined level to close with said first bistable means and said third bistable means.

6. The fluid mixing system as defined in claim 4 wherein said delay means further includes means for opening of said third bistable transfer means to begin filling said mixing tank with said water and further including a second delay member for preventing actuation of said first bistable means to thereby permit said water to cover the bottom of said mixing tank before introduction of said dialysate concentrate from said proportioning tank.

7. The fluid mixing system as defined in claim 4 wherein said first bistable transfer means comprises a dump valve and a conduit, said conduit having a diameter of such porportion that said porportioning tank is fully drained before said water flowing in said water supply line fills said mixing tank to actuate said third quantity sensing means.

8. The fluid mixing system as defined in claim 1 further comprising a pump coupled to the outlet of said supply tank and pressure regulating means coupled to the output of said pump for providing fluid at constant pressure to said device.

9. The fluid mixing system as defined in claim 3 wherein said testing means includes a conductivity meter for measuring the electrolytic concentration of the dialysate, said conductivity meter including means for actuating an alarm when the concentration does not meet a predetermined standard.

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