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METHOD AND APPARATUS FOR PUMPING VOLATILE LIQUIDS

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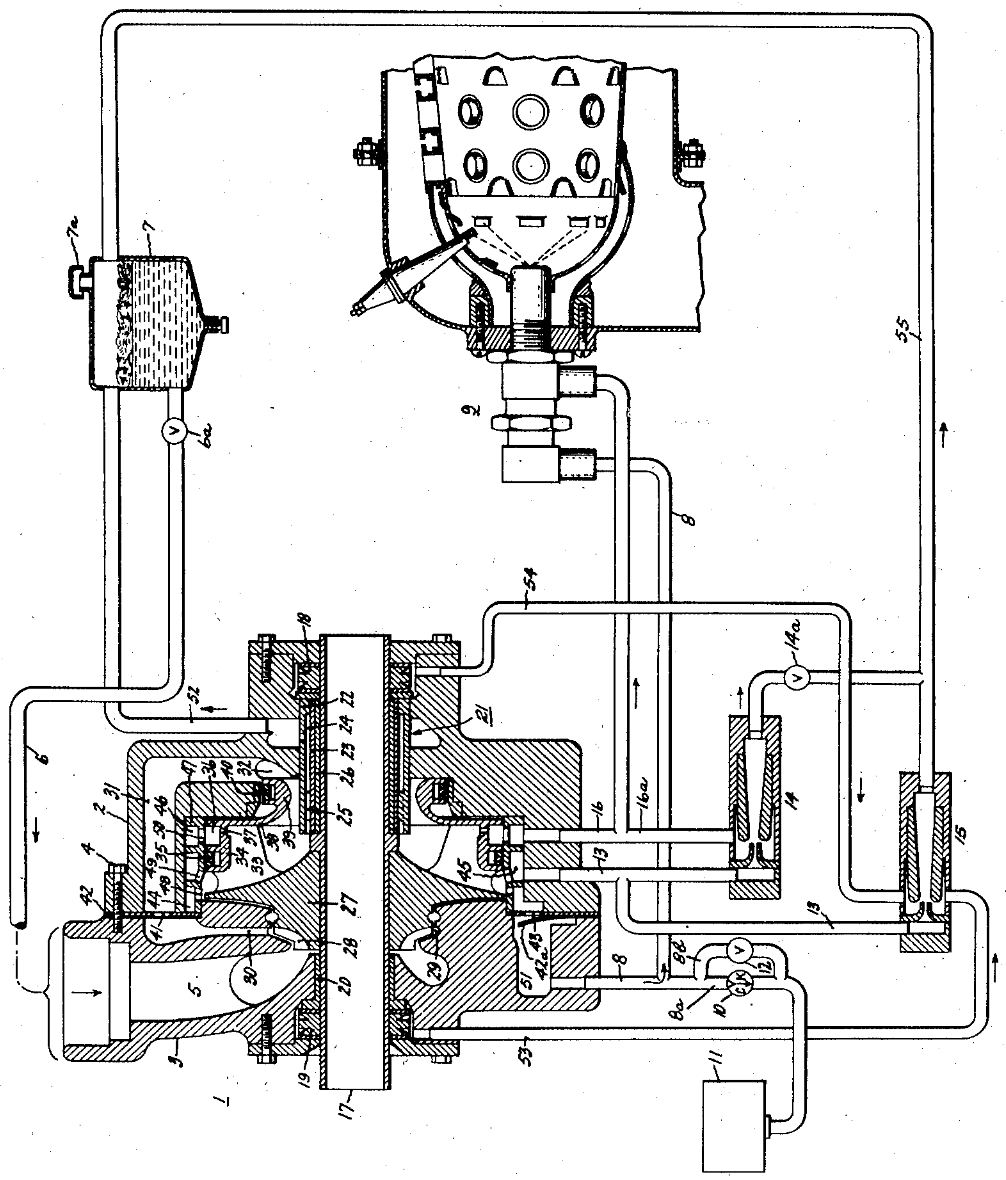

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METHOD AND APPARATUS FOR PUMPING VOLATILE LIQUIDS

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7 Claims. (Cl. 103—2)

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This invention relates to an improved method and apparatus for pumping volatile liquids, especially useful in connection with the fuel supply systems of gas turbine combustors, though of course not necessarily limited to such applications.

Particularly in connection with small gas turbine powerplants having a net output less than 500 H. P., where the rotational speeds are extremely high and simplicity and low first cost are important, it is highly desirable to employ a fuel pump having a single rotating element capable of operating at the rotor speed of the powerplant, so that no speed change gearing is required. Heretofore, centrifugal type pumps have been considered impracticable for such service because of their unstable and unreliable operation when pumping comparatively light hydrocarbons such as kerosene, which tend to volatilize, entrain, and release dissolved air, with resulting excessive foam formation when put through a conventional centrifugal impeller. Such pumps become inoperative at high speeds and have heretofore been limited to low pressure applications. An object of the present invention is therefore to provide an improved liquid supply system employing a centrifugal pump especially arranged to separate dissolved gases from the liquid, and then separate the resulting foam so as to deliver gas-free liquid to the fuel spray nozzle of the combustor.

A further object is to provide an improved system for supplying fuel to a wide range dual or duplex type spray nozzle requiring separate supplies of liquid at differing pressure levels.

Other objects and advantages will be apparent from the following description taken in connection with the accompanying drawing, in which the single figure represents schematically a fuel system incorporating my improved centrifugal pump.

The centrifugal pump, indicated generally at 1 has a casing which may conveniently be formed in two sections 2 and 3 secured together by suitable threaded fastenings 4. The casing portion 3 defines an inlet passage 5 to which liquid is supplied by a suction conduit 6 communicating with the lower portion of the liquid fuel reservoir 7 and having a shut-off valve 6*a*. Tank 7 is provided with an atmospheric vent 7*a*. Pump casing portion 3 is provided with a discharge conduit 8 adapted to supply liquid to the fuel spray nozzle indicated generally at 9 and through a branch conduit 8*a* containing a check valve 10 to a starting fuel tank or accumulator 11, in a

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manner described more particularly hereinafter. A bypass conduit 8*b* in parallel with the check valve 10 contains a manually controlled starting valve 12.

The pump casing portion 2 is provided with a high pressure outlet supplying liquid to a conduit 13 for actuating jet pumps 14, 15, and a second port arranged to deliver liquid at a somewhat lower pressure to a conduit 16, which is also connected with the fuel spray nozzle 9.

While the spray nozzle 9 may be of the so-called "duplex" type, as described in the copending application of C. D. Fulton and D. C. Ipsen, Serial No. 622,604, filed October 16, 1945, and assigned to the same assignee as the present application, it is preferably of the "dual" vortex type disclosed in the copending application of Kenton D. McMahan, Serial No. 72,216, filed January 22, 1949 now Patent 2,551,276 dated May 1, 1951. Wide range nozzles of these types have vortex or "spin" chambers to which liquid is supplied at low rates of flow through a first set of orifices referred to as "small slots," designed to give an effectively atomized spray at fuel pressures corresponding to the ignition and idling speeds of the powerplant. For increasing speeds and loads, additional fuel is supplied through a separate conduit to a second set of "large slots." The mechanical details of such nozzles are not material to an understanding of the present invention; and it need only be noted that the conduit 8 supplies liquid to the small slots in nozzle 9, while conduit 16 supplies the large slots. While the details of the combustor structure are likewise unnecessary to an understanding of the present invention, it may be noted that the combustor shown is disclosed fully in the copending application of Kenton D. McMahan, Serial No. 705,866, filed October 26, 1946, now Patent 2,510,645 dated June 6, 1950 and assigned to the same assignee as the present application.

The detailed construction of the improved centrifugal pump 1 is as follows.

The pump rotor includes a shaft 17, which may be an integral extension of the main rotor shaft of the gas turbine powerplant. The respective casing portions 2, 3 contain suitable shaft seal devices 18, 19, the details of which are not important to an understanding of the present invention. In casing 3, shaft 17 is supported by a journal bearing 20, and in casing 2 by a second journal bearing 21, the latter bearing consisting of a composite shell having an outer cylindrical portion 22 pressed or otherwise secured in the casing 2, with an inner cylindrical sleeve 23 defining with the outer portion 22 longitudinal and radial passages 24, the purpose of which will be seen hereinafter. Shell 23 may be spaced from the outer shell 22 by means of a plurality of circumferentially spaced ribs 25, which of course may be formed integral with either the outer member 22 or the inner member 23. The inner sleeve 23 is provided with a babbitted or silver alloy bearing surface indicated at 26.

Pressed, keyed, or otherwise secured to shaft 17 is a centrifugal rotor indicated generally at 27. This is actually a composite rotor having at the left-hand side thereof circumferentially spaced radially extending blades 28 forming a first centrifugal pumping element, receiving liquid from the suction passage 5. Actually, the impeller 28 is not intended primarily to serve as a pumping device, but is designed as an "agitator" for literally beating the dissolved gases out of solution from the incoming liquid. Since there is a certain pressure rise through the centrifugal impeller 28, and since there are certain pressure losses in the suction pipe 6 and inlet passage 5, the liquid will be subjected to a somewhat decreased pressure adjacent the inlet of the centrifugal element 28, as compared with the supply pressure in the suction conduit 6. Impeller 28 serves to violently agitate the incoming liquid at a reduced pressure; and both the reduced pressure and the mechanical agitation tend to separate dissolved gases from the liquid. Thus the impeller 28 delivers a mixture of liquid and foam into the annular discharge passage 29 formed around the impeller in the casing portion 3. From passage 29, this mixture of foam and liquid is delivered by a radially extending conduit 30 and a cored passage 31 formed in casing portion 2 to the inlet chamber 32 of a second centrifugal pumping element formed at the other end of the rotor 27 and including circumferentially spaced radially extending blades 33 carrying a rather complex shroud structure consisting of a first portion 34 defining a first circumferential groove containing sealing rings 35 and a second circumferential chamber 36, the latter communicating with the flow paths defined by blades 33 by means of a few small radial drilled holes 37. This shroud portion 34 is connected to or formed integral with other shroud portions including a radially extending wall 38 with an enlarged central annular portion 39 having an outer circumferential groove containing packing rings 40. It will be understood by those skilled in the art that the packing devices 35, 40 are of a type consisting of a plurality of separate ring members having an outer circumferential surface carefully machined to sealingly engage a cooperating annular surface in the housing, while the fluid pressure difference across the sealing rings forces them axially in one direction so as to sealingly engage a radial surface of the rotor member. This type of sealing device has become well known in the art and need not be further described here.

In order to limit the flow of impeller 28 so as to keep it within its stable range of operation, the passages 30, 31 contain a flow restricting orifice in the form of an opening 41 formed in a plate or diaphragm 42, which may be conveniently clamped by threaded fastenings 4 between the casing halves 2, 3. This plate 42 is annular, and is provided with a second restricted opening 43 serving a purpose noted hereinafter.

It is to be particularly noted that, while the impeller 28 has a substantial number of blades, for instance 12, so as to produce maximum agitation of the incoming liquid, the number of blades 33 is kept to the absolute minimum required in order to effectively maintain a "forced vortex." Thus, although both impellers serve to increase the pressure of the liquid, the element 28 serves an extremely important function of agitating the liquid at a comparatively low pressure to effect separation of dissolved gases, while the second element 33 acts as a centrifuge. It will also be observed that the first impeller is comparatively small while the second is much larger than actually needed to pump the flow of liquid required by the nozzle 9. Thus the mixture of liquid and foam remains in the large centrifuge chamber formed by the inner edges of blades 33 for a sufficient length of time so that foam and liquid have an opportunity to separate. The blades 33 are comparatively short in a radial direction thus providing a large central centrifuge chamber adjacent the shaft.

The impeller 33 is arranged to supply liquid to a plurality of separate annular discharge chambers 44, 45, 46 defined by a ring member 47, which may be pressed or otherwise secured in a cylindrical recess in the housing portion 2. As will be apparent from the drawing, discharge chambers 44, 45, are supplied with liquid at the full discharge pressure of the impeller 33 by way of a plurality of circumferentially spaced openings 48, 49, while the collector passage 46 receives liquid from chamber 36 by way of circumferentially spaced openings 50. It will also be apparent that the shroud portion 34 of the impeller 33 has circumferential edge portions defining close clearances with the stationary member 47, this clearance being sealed by packing rings 35. It should also be noted that the chamber 36 receives liquid by way of drilled holes 37 from the impeller 33 at a radius substantially less than the full tip radius of the impeller. Thus the liquid supplied to chambers 36, 46 is at a substantially lower pressure than that supplied to chambers 44, 45. It will also be seen in the drawing that collector 44 communicates with a cored passage 51 in housing 3, which in turn communicates with conduit 8, while collector passage 45 communicates with conduit 13, and passage 46 with conduit 16. The aggregate area of the discharge openings 48, 49, 37 is made small to restrict the rate of flow of liquid from impeller 33, thus insuring that the liquid will remain in the centrifuge chamber long enough to permit separation of the gas and liquid.

From the above description of the structure, it will be seen that my improved pump is specifically designed to perform the following process:

(1) Liquid from supply tank 7, being substantially at ambient pressure by reason of vent 7a, is supplied to the first impeller 28, which subjects the incoming mixture of liquid and entrained gases to a sub-atmospheric pressure and at the same time thoroughly agitates the mixture so as to beat the dissolved gases out of solution.

(2) The discharge pressure of agitator 28 is comparatively low, for instance in the neighborhood of only ten per cent of the total pressure rise produced in the liquid by the pump 1. This may be on the order of sixty pounds per square inch gage at full speed. Thus the mixture of foam and liquid in the intercommunicating passage 30, 31 is maintained at a comparatively low pressure, which tends to prevent the separated gases from going back into solution in the liquid, yet substantially above atmospheric pressure. Since

there will be a pressure drop across the orifice 41, the static pressure in the passage portion 31 will be even lower than that in the passage portion 30 upstream from orifice 41. The strong suction effect produced by the impeller 33 in the conduit 31, in combination with the flow restricting effect of orifice 41, also insures that the pressure will be low in the passage 31, which comprises the major part of the passage between the impellers. Also the passages 30, 31 are of relatively large cross-section area so that the liquid velocities will be low so as to give a time interval in which the gases can further separate from the liquid.

(3) Through the centrifuging action created in the forced vortex whirl maintained by impeller blades 33, the gas-free liquid is thrown outwardly, while foam and entrained gases tend to remain at the radially inner portion of the vortex. While, as noted above, the static pressure in the inlet chamber 32 of the second impeller is comparatively low, it is still substantially above atmospheric pressure, with the result that foam and entrained gases are bled off through the axial passages 25 in the bearing sleeve member 24, thence through a return conduit 52 to the upper portion of reservoir 7. It will be understood that the reservoir 7 is made of sufficient capacity that the liquid-foam mixture will have an opportunity to cool and separate to some extent, so that comparatively foam-free liquid is drawn off adjacent the bottom of the tank through suction conduit 6.

Entirely gas-free liquid at a pressure on the order of 600 pounds per square inch is supplied from collector passage 44 through orifice 43 and chamber 51 to conduit 8, thence to the small slots of nozzle 9. Likewise, liquid at the full discharge pressure of impeller 33 is supplied from collector passage 45 to conduit 13 for actuating the jet pumps 14, 15, in the manner described hereinafter. Liquid at full discharge pressure also passes from conduit 8, through branch conduit 8a, past check valve 10 to the starting fuel tank or accumulator 11. It is to be noted that the orifice 43 in plate member 42 is arranged to be covered by a "feather" or "flapper" member 42a, forming another check valve for preventing flow of high pressure liquid from the accumulator tank 11 backward through chamber 51 into the pump 33.

The jet pump 15 actuated by high-pressure liquid received through conduit 13, is a scavenger for drawing off through conduits 53, 54 any liquid leaking past the shaft seals 18, 19. The mechanical construction of jet pump 15 will be obvious from the drawing.

The jet pump 14 serves a very different purpose. As indicated above, it is actuated by high pressure motive liquid received from conduit 13, and has a suction conduit 16a communicating with the large slot supply conduit 16. The function of the pump 14 is to variably draw off liquid from conduit 16 so as to alter the pressure therein in a desired manner, as determined by a manual control valve 14a which regulates the discharge of the jet pump 14 into the common return conduit 55.

The integrated operation of the entire system may be summarized briefly as follows. Ordinarily when the power-plant is shut down, the manual control valve 14a will be open, the starting valve 12 will be closed, and the accumulator tank 11 will be fully charged. To start the powerplant, the rotor, including the pump rotor 17, is brought up to a suitable starting speed by means of an external source of power, for instance an electric starting motor (not shown). This causes air to be supplied from the compressor of the powerplant (not shown) to the combustor at a rate sufficient to initiate combustion. The igniting device in the combustor is then energized and the starting fuel valve 12 opened, so that the stored pressure in accumulator tank 11 causes liquid to flow through the bypass conduit 8b and conduit 8 to the small slots of nozzle 9. Any flow of this starting fuel backward through the pump 33 is prevented by the check valve 42a. This supply of starting fuel to the small slots of nozzle 9 produces a fuel spray, ignition is effected, and the powerplant now operates under its own power. As the rotor comes up to idling speed, the discharge pressure of pump 33 becomes sufficient to force liquid past check valve 42a so that the small slots are supplied through conduit 8, and the tank 11 is re-charged through conduit 8a past check-valve 10. The manual starting valve 12 may now be closed, and the plant will be self-supporting at idling speed with the small slots supplied from the pump 27. Since the manual control valve 14a is wide open, the jet pump 14 will be effective to draw off the fuel from conduit 16 so that there is no flow to the large slots through conduit 16. To accelerate the powerplant to full rated speed the manual control valve 14a is slowly closed, with the result that less liquid is bled off through conduit 16a and the pressure builds up in conduit 16 so that an effective flow is produced to the large slots. This additional fuel flow to the large slots results in increased combustor temperatures, increased energy available to the turbine, and therefore a higher speed. Thus by suitably controlling the manual valve 14a, the speed and output of the plant can be varied. When the valve 14a is opened wide, the fuel flow will return to that value required for idling or "no-load" operation, with this minimum supply of fuel being furnished by the small slots above. Thus the dual or duplex nozzle 9 is effectively controlled by a single, simple control valve. To stop the powerplant it is only necessary to positively shut off the supply of fuel by means of the valve 6a.

A fuel system in accordance with my invention has been found to be very effective in supplying and controlling a small gas turbine powerplant of about 300 H. P., having a rated normal speed of around 40,000 R. P. M., an idling speed in the neighborhood of 10,0000 R. P. M., and a fuel pump with a maximum discharge pressure in the neighborhood of 600 lbs. per square inch. Efficient use of a centrifugal type fuel pump in such an application is made possible by our novel method and apparatus for separating entrained gases from the liquid fuel and insuring that completely gas-free liquid is supplied to the fuel nozzle.

While one modification has been specifically illustrated herein, it will be apparent that many changes may be made in the apparatus employed. For instance, instead of the simple starting fuel tank 11, a liquid accumulator of a well-known type having a flexible diaphragm or bladder, with a compressible gas on one side thereof, may be used. Also, the method of operation described herein may be performed by very different apparatus. For example, the agitator 28 and centrifuge 33 need not be arranged on a common rotor but might be entirely separate machines, separately driven by any suitable means. We of course intend to cover by the appended claims all such modifications as fall within the true spirit and scope of the invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. In a continuous method of delivering a liquid at a high pressure free of dissolved gases and foam, the steps which include drawing liquid continuously from a reservoir, agitating the liquid violently at a pressure below that in the reservoir to effect separation of gases from the liquid, causing the resulting mixture of form and liquid to flow at comparatively low velocity and at a relatively low pressure through a conduit of such length as to provide an appreciable time interval to permit the gases to further separate from the liquid, the low velocity and pressure in said conduit reducing the tendency of the gases to go back into solution in the liquid, subjecting the mixture of liquid and foam to strong centrifugal forces with a minimum of agitation whereby gas-free liquid is centrifuged from the foam, and separately drawing off the gases and foam adjacent the center of the centrifuge and drawing off gas-free liquid at the outer periphery of the centrifuge at a limited rate, so that the mixture is retained in the centrifuge chamber for an appreciable time interval to effect thorough separation of liquid and gas.

2. Apparatus for supplying substantially gas-free liquid at a high pressure including a liquid reservoir, a first high-speed rotor having fluid flow passages for violently agitating liquid from said reservoir at a pressure below that in the reservoir and then raising it to a pressure above that in the reservoir, a second high-speed centrifugal rotor defining a centrifuge chamber in which the mixture of foam and liquid is caused to whirl as a forced vortex with a minimum of agitation, stationary walls defining a conduit of substantial length connecting the discharge of the first rotor with the inlet of the second rotor and including a flow-restricting orifice adjacent the exit of the first rotor to limit the discharge therefrom, whereby the major portion of said conduit is maintained at a pressure below the discharge pressure of the first impeller and the tendency of the gases to re-enter solution in the liquid is reduced, walls defining a conduit connecting the centrifuge chamber with the reservoir for drawing off foam and entrained gases from the radially inner portion of said centrifuge chamber and returning the gas and foam mixture to the reservoir, and other restricted conduit means communicating with radially outer portions of said centrifuge chamber for drawing off substantially gas-free liquid at a high pressure.

3. In a system for delivering a supply of liquid at two different pressure levels, the combination of a liquid supply reservoir, a two-element centrifugal pump including a first rotor member supported on a shaft with at least one shaft seal device, said rotor having circumferentially spaced radially extending blades defining flow paths receiving liquid from said reservoir and agitating it violently at a pressure below that in the reservoir to effect separation of entrained gas from the liquid, said first rotor having a discharge pressure above that in the reservoir, said centrifugal pump also including a second rotor element defining a centrifuge chamber of substantially larger volume than the aggregate volume of the flow paths of the first rotor, whereby the mixture of liquid and foam is retained in the centrifuge chamber for a time interval sufficient to effect centrifugal separation of foam and gas-free liquid, walls defining a first conduit connecting the discharge of the first rotor with the inlet of the second rotor and including a flow restricting orifice adjacent the exit of the first rotor for limiting the discharge thereof so that said rotor is kept within its stable operating range and the major portion of said conduit is maintained at a pressure substantially below the discharge pressure of the first rotor but above the reservoir pressure, walls defining a passage communicating with the radially inner portion of said centrifuge chamber and including conduit means connected to the reservoir whereby foam and entrained gases are forced to return to the reservoir by the pressure at the second impeller inlet, second conduit means communicating with the centrifuge chamber at its maximum radius for supplying gas-free liquid at the full discharge pressure of the second impeller, third conduit means connected to withdraw gas-free liquid from the centrifuge chamber at an intermediate radius for supplying liquid at a lower pressure, first jet pump means actuated by liquid at the full discharge pressure of the second impeller and having a suction conduit connected to withdraw liquid from said third conduit, control valve means for varying the discharge of the first jet pump, a second jet pump actuated by liquid at the full pressure of the second impeller and having a suction conduit connected to withdraw leakage liquid from said shaft seal device, return conduit means connecting the discharge ports of both jet pumps with the reservoir, and means for supplying liquid during the starting cycle of the system including a liquid accumulator, fourth conduit means connecting said second conduit with the accumulator, said second conduit including a first check-valve adjacent the centrifuge chamber outlet for preventing backward flow thereinto, said fourth conduit having a second check-valve preventing discharge of the accumulator, and a controllable valved bypass around said second check-valve for effecting discharge of liquid from the accumulator into the second conduit.

4. In a system for delivering a supply of liquid at two different pressure levels, the combination of a liquid supply reservoir, a first pump rotor having circumferentially spaced fluid passages to receive liquid from said reservoir and agitate the liquid violently at a pressure below that of the reservoir to effect separation of entrained gas from the liquid, said first rotor having a discharge pressure above that in the reservoir, a second centrifugal pump element having a minimum number of short radially extending blades defining a centrifuge chamber of a substantially larger volume than the aggregate volume of the flow paths of the first rotor, whereby the mixture of liquid and foam is retained in the centrifuge chamber for a time interval sufficient to effect centrifugal separation of foam and gas-free liquid, walls defining a first conduit connecting the discharge of the first rotor with the inlet of the second rotor and including flow restricting means adjacent the exit of the first rotor for limiting the discharge thereof and maintaining the major portion of said conduit at a pressure below the discharge pressure of the first rotor but above reservoir pressure, walls defining a conduit connected to the reservoir and communicating

with the central portion of the centrifuge chamber whereby the foam and entrained gases are forced to return to the reservoir by the pressure differential between the second impeller inlet and that in the reservoir, second restricted conduit means communicating with said centrifuge chamber at its maximum radius for supplying gas-free liquid at the full discharge pressure of the second impeller, third restricted conduit means withdrawing gas-free liquid from the centrifuge chamber at an intermediate radius for supplying liquid at a lower pressure, valved conduit means for withdrawing liquid from the third conduit at a variable rate, and means for supplying liquid during the starting cycle of the system including a liquid accumulator, fourth conduit means connecting the second conduit with the accumulator, a first check valve adjacent the centrifuge chamber outlet for preventing backward flow thereinto from the second conduit, said fourth conduit having a second check valve preventing discharge of the accumulator, and a controllable valved bypass around the second valve for effecting discharge of liquid from the accumulator into the second conduit for supplying fuel when the discharge pressure of the second impeller is insufficient to open said first check valve.

5. In a system for delivering a supply of liquid at two different pressure levels, the combination of a liquid supply reservoir, a first pump rotor having circumferentially spaced fluid passages to receive liquid from said reservoir and agitate the liquid violently at a pressure below that of the reservoir to effect separation of entrained gas from the liquid, said first rotor having a dischange pressure above that in the reservoir, a second centrifugal pump element having a minimum number of short radially extending blades defining a centrifuge chamber of substantially larger volume than the aggregate volume of the flow paths of the first rotor, whereby the mixture of liquid and foam is retained in the centrifuge chamber for a time interval sufficient to effect centrifugal separation of foam and gas-free liquid, walls defining a first conduit connecting the discharge of the first rotor with the inlet of the second rotor and including flow restricting orifice means adjacent the exit of the first rotor for limiting the discharge thereof and maintaining the major portion of said conduit at a pressure below the discharge pressure of the first rotor but above reservoir pressure, walls defining a conduit connected to the reservoir and communicating with the central portion of the centrifuge chamber whereby the foam and entrained gases are caused to return to the reservoir by the pressure differential between the second impeller inlet and that in the reservoir, second restricted conduit means communicating with said centrifuge chamber at its maximum radius for supplying gas-free liquid at the full discharge pressure of the second impeller, third restricted conduit means withdrawing gas-free liquid from the centrifuge chamber at an intermediate radius for supplying liquid at a lower pressure, and valved conduit means for withdrawing liquid from said third conduit whereby the total flow of liquid delivered may be regulated.

6. In a continuous method of delivering a liquid under pressure free of dissolved gases and foam, the steps which include drawing liquid continuously from a reservoir, agitating the liquid violently at a reduced pressure to effect separation of gases from the liquid, causing the resulting mixture of foam and liquid to flow at comparatively low velocity and at a relatively low pressure through a conduit of such length as to provide an appreciable time interval to permit the gases to further separate from the liquid, the low velocity and pressure in said conduit reducing the tendency of the gases to go back into solution in the liquid, subjecting the mixture of liquid and foam to strong centrifugal forces whereby gas-free liquid is centrifuged from the foam, and separately drawing off the gases and foam adjacent the center of the centrifuge and drawing off gas-free liquid adjacent the outer periphery of the centrifuge at a limited rate, so that the mixture is retained in the centrifuge chamber for an appreciable time interval to effect thorough separation of liquid and gas.

7. In a system for delivering a volatile liquid under pressure, the combination of a liquid supply reservoir, a first pump rotor adapted to receive liquid from the reservoir and agitate the liquid violently at a reduced pressure to effect separation of entrained gas from the liquid, a second centrifugal pump rotor forming a centrifuge chamber of substantially larger volume than the aggregate volume of the flow paths of the first rotor whereby the mixture of liquid and foam is retained in the centrifuge chamber for a time interval sufficient to effect centrifugal separation of foam and gas-free liquid, walls defining a first conduit of substantial length connecting the discharge of the first rotor with the inlet of the second rotor and including orifice means adjacent the exit of the first rotor for restricting the discharge therefrom and maintaining the major portion of said conduit at a pressure below the discharge pressure of the first rotor, walls defining a second conduit communicating with the central portion of the centrifuge chamber and connected to discharge into a lower pressure space whereby foam and entrained gases are expelled from the centrifuge chamber by the pressure existing at the second impeller inlet, and third restricted conduit means communicating with the centrifuge chamber at an outer peripheral portion thereof for supplying gas-free liquid at substantially the full discharge pressure of the second impeller.

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