April 6, 1965 J. W. MEERMANS 3,176,882

LIQUID RESERVOIR

Filed Dec. 11, 1962

Fig. 1.

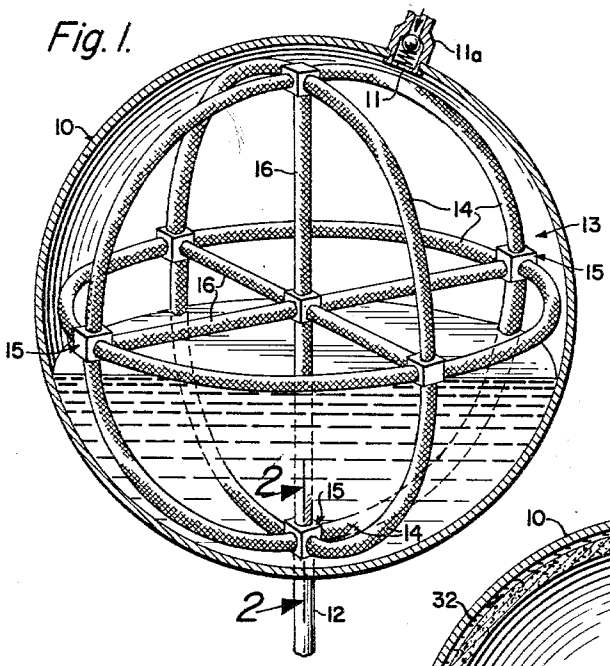


Fig.3.

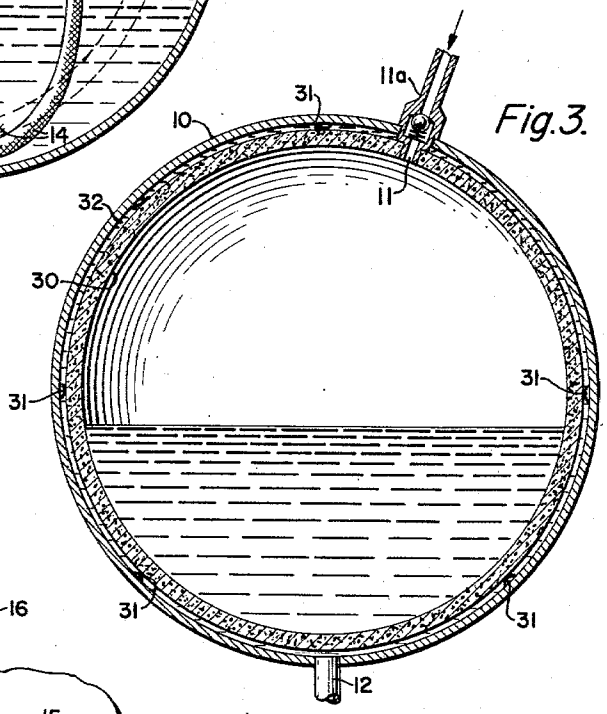
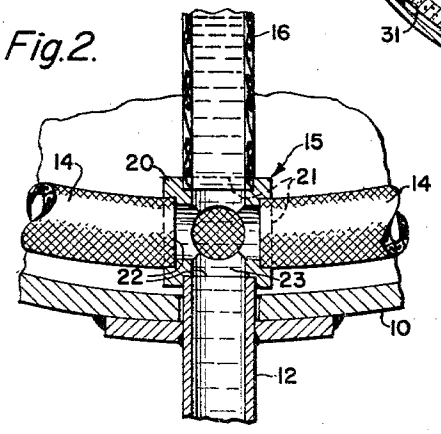


Fig.2.



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LIQUID RESERVOIR

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My invention relates to an improvement in liquid storage vessels and, more particularly, to a storage vessel adapted to dispense a continuous supply of liquid independently of variations in the magnitude and direction of the static pressure thereof.

This application is a continuation-in-part of application, Serial No. 35,065 filed June 9, 1960, now abandoned, entitled Liquid Reservoir.

In the operation of portable or vehicular machinery it is often desirable to maintain a uniform continuity in the supply of certain liquids, for example, fuel, lubricant or coolant, regardless of changes in the attitude or state of motion to which such machinery may be subjected. Where the character of the particular liquid permits, this may be accomplished by means of various well known expedients wherein a suitable storage vessel is provided internally with a displaceable partition member, for example a piston or a resilient diaphragm, whereby a pressurizing medium may be confined in one portion of the vessel and placed in pressure transmitting relation with liquid stored in a second portion thereof. Though such devices are adaptable to use with a wide variety of liquids and gaseous pressurizing media therefor, the physical and chemical properties of certain liquids, for instance liquids suitable for extremely low temperature or so-called "cryogenic" refrigeration, may be incompatible with the provision of a displaceable partition member fully effective to isolate the liquid from the gaseous fluid and at the same time to afford satisfactory pressure communication therebetween. Particularly in applications calling for storage and delivery of liquefied atmospheric gases, which are generally characterized by temperatures lower than −150° C., the selection of resilient materials appropriate for use in a movable seal or diaphragm is severely limited.

It is an object of my invention, therefore, to provide a liquid reservoir capable of maintaining uniform continuity of liquid delivery, throughout a wide range of variation in the static pressure due to the liquid, without the use of a displaceable partition member to effect separation between the liquid and the gas which expels the liquid from the reservoir.

Another object of my invention is to provide a liquid reservoir wherein the surface tension occurirng at the interface between the liquid and the gas which expels the liquid from the reservoir is sufficient to preclude entrainment of said gas with the liquid effluent.

Another object of my invention is to provide a liquid reservoir wherein the stored liquid is free to move in response to changes in the attitude or state of motion of said reservoir without impairing the continuity of delivery therefrom.

Another object of my invention is to provide combined fluid pressure and capillary means whereby liquid lodged in any portion of a reservoir may be conducted to a delivery outlet located in the same or any other portion thereof.

Another object of my invention is to provide a reservoir having combined liquid withdrawal and filtration means operable in all attitudes of said reservoir.

Further objects of my invention will be made apparent to those skilled in the art through the following discussion which, taken in conjunction with the appended drawings illustrating two embodiments of the invention, particularly describes a preferred practice thereof.

My invention makes use of the well known capillary property of a porous material, for example sintered metal, fictilia, or cloth, whereby the entire surface thereof may be wetted through only partial immersion in a liquid; and of the further property that the meniscus interface occurring between the wetting liquid and a contiguous liquid expelling gas at each non-immersed pore of such material has sufficient strength, by virtue of the phenomenon of surface tension and adhesion between the liquid and the wall of the pore to withstand a pressure differential which would otherwise be sufficient to establish a gaseous flow through said pore in the absence of such an interface. Thus a multiplicity of such meniscus interfaces distributed over the surface of a wetted porous material act in the manner of correspondingly distributed valve means effective to oppose gaseous flow through the individual pores thereof below a certain threshold pressure, the magnitude of such pressure being functionally related to the size of the pores and the surface tension characterizing the interface of the liquid and gaseous fluids. The non-immersed, wetted portion of a porous material may therefore be arranged so as to present a continuum of such meniscus valves defining a surface which may confine a uniform flow of liquid, the meniscus valves being effective to preclude entrainment therein of a contiguous liquid-expelling gas. Using this principle, a liquid reservoir embodying my invention is provided internally with an annularly disposed porous structure defining liquid collection, filtration and conduit means, the non-immersed portion of said porous structure affording an effectively continuous wall for said conduit means whereby liquid may be transferred from any portion of said reservoir to an outlet or delivery pipe located in any other portion thereof.

The invention may be more clearly understood by reference to the acocmpanying drawings, in which:

FIG. 1 is a perspective view of a liquid reservoir embodying the invention, one-half of the reservoir being broken away to reveal the internal construction thereof;

FIG. 2 is cross-sectional view along the line 2—2 of FIG. 1;

FIG. 3 is a cross section of a second reservoir embodying an alternate form of the invention.

The reservoir shown in FIG. 1 comprises an outer vessel **10**, preferably of spherical shape though not necessarily limited thereto, an inlet port **11** containing a spring loaded check valve **11***a*, an outlet passage **12**, and an internal armillary network **13** of porous ducts **14**. As shown in the drawing, the ducts **14** intersect each other at joints **15** and are preferably oriented so as to define mutually perpendicular toroids concentric with the outer vessel **10**. Where it is anticipated that continuity of delivery may be required under conditions in which no static pressure due to the stored liquid is developed, it is desirable to provide additional porous ducts **16** communicating with the ducts **14** and substantially diametric to the toroids formed thereby.

The joints **15** may be of any suitable form to provide structural connection and flow communication between adjoining segments of the ducts **14** and **16**, one form of preferred construction therefor being shown in FIG. 2, which particularly illustrates the manner in which the network of ducts is connected with the outlet passage **12**. As shown in the drawing, the joint **15** comprises a substantially cubical member **20** provided with bores **23** adapted to receive the ends of adjoining duct segments, which may be soldered, brazed, welded or otherwise secured therein according to the character of the materials employed. In order to afford each of assembly, it is desirable that the bores **23** be provided with shoulders **22** serving to limit the length of engagement therein of each

duct segment, such shoulders being formed, for example, by counterbores **21**.

As previously discussed, the ducts **14** and **16** may be formed of any suitable material compatible with the liquid to be stored and possessing the requisite porosity and structural strength. In a liquid nitrogen reservoir similar to that shown in the drawing, for example, tubular ducts of woven stainless steel wire have been successfully used, the ducts being secured by silver solder in the joints **15**, which are also stainless steel. It will be obvious, however, to those skilled in the art that alternate constructions being sintered, fictile or other porous material may be devised to meet particular requirements and specifications.

According to one mode of operation of the present reservoir, the vessel **10** is filled to an intermediate level with the liquid to be stored and pressurized by introducing a suitable pressurizing gas into the vessel through the inlet **11**. The reservoir outlet **12** is connected to a valved delivery line (not shown) leading to the point of utilization of the liquid. Now it is obvious that if the reservoir is required to operate only in the position of FIG. 1, wherein the reservoir outlet **12** is lowermost, it is immaterial whether or not the pressurizing gas in the vessel **10** can penetrate the pores in the non-immersed portions of the porous ducts **14** and **16** since pressurized gas within, as well as on the outside of the ducts, will act on the stored liquid to expel the latter through the reservoir outlet when the delivery valve (not shown) is open. A continuous uniform flow of liquid from the reservoir is thereby attained under the conditions described above.

The present reservoir, however, is designed for use on a vehicle and to supply a continuous, uniform flow of liquid regardless of the changes in the attitude and state of motion of the reservoir, changes in the actual location and configuration of the body of liquid in the reservoir, and changes in the static pressure of the liquid which occur as a result of changes in the attitude and state of motion of the vehicle and other factors.

To this end, the number and arrangement of the porous ducts **14** and **16** are such as to assure contact of liquid in the reservoir with at least one duct regardless of the location and configuration of the body of liquid in the reservoir. For example, during motion of the vehicle which carries the reservoir, the stored liquid may remain in a single intact body whose position with respect to the reservoir continuously changes because of vibration, acceleration and deceleration forces and/or changes in the attitude of the reservoir. Alternatively, the body of liquid in the reservoir may be broken up into a multiplicity of separate liquid globules by vibration and/or other forces to which the liquid is subjected during motion of the vehicle or as a result of other factors which influence the state or configuration of the body of stored liquid. In either case, it is evident that the porous ducts **14** and **16** are sufficiently uniformly dispersed about the interior of vessel **10** to assure contact of the stored liquid with at least one duct at all times. Obviously, additional ducts could be provided to increase the total liquid-duct contact area.

Mere continuous contact of the stored liquid with at least one of the porous ducts **14** or **16** in the reservoir is not sufficient in itself, however, to maintain uniform continuity in the flow of liquid from the reservoir during changes in the attitude of the reservoir and in the location and configuration of the body of liquid with respect to the reservoir. Two other requirements must be met. Firstly, passage of the pressurizing gas from the interior of the vessel **10** to the interior of the porous ducts must be prevented, and secondly, all air and pressurizing gas which initially exists in the interior duct passages must be removed and such passages must be completely filled with the stored liquid. If gas or air-filled spaces exist in the ducts, or if pressurizing gas can flow through the duct pores to the interior duct passages, of course, the uniform continuity of liquid flow from the reservoir will be interrupted by slugs of gas as the position of contact of the liquid with the porous ducts changes due to changes in the attitude of the reservoir, or in the other factors discussed above.

According to the present invention, flow of the pressurizing gas through the pores of the porous ducts **14** and **16** is prevented by the meniscus valve action described earlier. Thus, when the stored liquid contacts the porous ducts, capillary action causes migration of the liquid over, and thereby wetting of, the entire duct surfaces. Thus, referring to FIG. 1, it is evident that all of the ducts **14** and **16** below the joints **15** are wetted by direct contact with the stored liquid and by capillary action. In the case of some liquids, capillary action may even be effective to cause migration of the liquid across the non-porous joints **15** to the non-immersed ducts **14** and **16** above the joints in FIG. 1, thereby wetting the latter ducts by capillary action. Thus, it is well known that some liquids, depending upon their wetting, surface tenison and viscosity, will migrate across the surfaces of a machined or cast part, such as the joints **15**, because of the capillary action created by the minute machining marks or depressions which invariably exist in a machined, drilled, or cast surface which has not been polished. This capillary action or carry-over at the joints **15**, however, can be created otherwise, such as by making the joints of porous material also.

Whether or not the stored liquid migrates across the joints by capillary action, however, is immaterial when the present reservoir is used in its intended operational environment, discussed earlier, i.e. on a vehicle. Thus, as noted earlier, it is essential to uniform continuity of liquid flow from the reservoir when the latter is installed on a vehicle that the porous ducts **14** and **16** be continuously filled with the stored liquid. Assuming for the moment, then, that the ducts are continuously filled with liquid, it is evident that all of the porous surfaces of the ducts will be wetted with liquid, thus creating in each duct pore, not actually immersed in the main body of stored liquid, a meniscus interface between the pressurizing gas on the outside of the ducts and the interior passages of the ducts.

The inward pressure of the pressurizing gas on each of these meniscus interfaces is resisted by the surface tension of the liquid at the interface and the adhesive force between the wall of each pore and the liquid in the pore. These forces are capillary forces which tend to retain each interface in effective gas sealing relation in its respective pore and whose magnitude is a function of pore size, characteristics of the liquid, and other factors. The meniscus interfaces continue to seal the pores against passage of gas therethrough so long as the pressure differential across the pores creates a pressure force on the interfaces which is less than the capillary forces tending to retain the interfaces in sealing relation in the pores. It is apparent, of course, that the capillary forces, and hence the critical pressure differential which the meniscus interfaces can withstand without permitting gas flow into the ducts, can be determined, for a particular pore size, from a knowledge of the pertinent characteristics of the liquid.

The meniscus interfaces exist, of course, only in the non-immersed portions of the ducts **14** and **16**, that is only in the duct pores which are exposed to the pressurizing gas in the vessel **10**. The meniscus interfaces do not exist in the portions of the ducts which are immersed in or contact the body of liquid in the vessel **10** on the outside of the ducts. The pressure of the pressurizing gas on the body of liquid on the outside of the ducts **14** and **16**, then, is effective to create a flow of the liquid through the immersed pores to the interior duct passages and through the latter to the reservoir outlet **12** when the delivery valve (not shown) is open. During operation of the reservoir in its intended operational environment, the relative movement which occurs between the body of liquid in the vessel **10** and the porous ducts **14** and **16** will,

of course, result in alternate exposure of each duct pore to the pressurizing gas and immersion of the pore in or contact of the pore with the liquid. It is immediately evident to those skilled in the art that the meniscus interface in each pore forms instantaneously upon exposure of the pore to the pressurizing gas and disappears instantaneously upon immersion of the pore in or external contact of the pore with the body of liquid in the vessel 10.

Thus, there is provided an instantaneous meniscus valve action which closes each pore upon exposure of the pore to the pressurizing gas to prevent passage of the gas to the interior of the respective duct 14 or 16 and which opens each pore upon external contact of the pore with the body of stored liquid to permit the liquid to enter the respective duct, through the open pore, under the action of the pressurizing gas.

Up to this point, it has been assumed that the porous ducts 14 and 16 are completely filled with the stored liquid, as is essential to maintain uniform continuity of liquid flow from the reservoir regardless of the changes in attitude and state of motion of the reservoir. It is immediately evident that the ducts can be initially filled with liquid in various ways. According to one method of filling the reservoir, for example, the vessel 10, while in its position of FIG. 1, is initially filled completely with the liquid to be stored through the inlet port 11 and the latter is connected to a pressurizing source (not shown) at the proper pressure to force the liquid through the pores of the ducts 14 and 16 to the interior duct passages without rupturing the meniscus valves. The delivery valve (not shown) is then opened until all of the air and gas within the ducts has been bled off and the liquid in the vessel has dropped to the desired initial level.

Once the ducts 14 and 16 are filled in this way, the meniscus interfaces which are thereby formed in the non-immersed portions of the ducts and the external pressurizing gas pressure on these interfaces will prevent the liquid in the ducts from flowing outwardly through the non-immersed ducts. The pressurizing gas pressure acting on the body of liquid in the vessel 10, of course, will prevent the liquid in the ducts from flowing outwardly through the immersed pores. Thus, the ducts will remain filled with the liquid, both when the delivery valve is closed and when it is open to effect expulsion of the liquid from vessel 10, through the immersed pores in the duct, to the reservoir outlet 12.

According to an alternative method of filling the reservoir, the vessel 10 is filled to a level somewhat in excess of its initial operating level and is then pressurized to the proper operating pressure. Thereafter, the reservoir is inverted to place its outlet 12 uppermost and the delivery valve is opened to bleed off the air and/or gas from the ducts 14 and 16 and enough liquid to return the liquid in the vessel to its proper initial level. The reservoir can then be left to operate in this inverted position or return to its original position of FIG. 1.

Once the reservoir has been charged with liquid, a continuous uniform flow of liquid will occur from the reservoir whenever the delivery valve is opened regardless of changes in the attitude or state of motion of the reservoir.

A second embodiment of the invention, providing annular liquid collection, filtration, and conduit means substantially coextensive with the internal surface of the reservoir is illustrated in FIG. 3. In the drawing, a liquid reservoir comprising a spherical outer vessel 10 having an inlet port 11 and an outlet passage 12, is provided with a spherical porous shell or liner 30 substantially concentric with the outer wall 10 and supported inwardly therefrom by spaced support members 31 so as to define a spherically annular space 32. As can be seen from the drawing, the space 32 provides a continuous duct whereby liquid withdrawn from the sphere enclosed by the porous shell 30 may be conducted to the outlet passage 12. As in the case of the embodiment illustrated in FIGS. 1 and 2, where operation of the reservoir under a condition in which no static pressure due to the liquid is anticipated, additional diametrical ducts (not shown) in flow communication with the annular space 32 may be provided. When preparing the reservoir of FIG. 3 for use, the flow space 32 must be completely filled with the stored liquid as were the interior passages of the porous ducts 14 and 16 in FIG. 1, to assure a continuous uniform flow of liquid from the reservoir regardless of the changes in attitude and state of motion thereof. This can be accomplished in substantially the same way as explained earlier in connection with FIG. 1, the reservoir being filled and pressurized through the inlet 11, as before.

According to an alternative mode of operation of the illustrated liquid reservoirs, the pressure differential for expelling the liquid from the reservoirs is created by placing a suction pump (not shown) in the delivery line (not shown) connecting the reservoir outlet 12 to the point of utilization of the stored liquid. In this case the vessel 10 of the illustrated reservoirs may be filled completely with liquid. As before, all air and gas must be bled from the interior passages of the porous ducts 14 and 16 in FIG. 1 and from the flow space 32 in FIG. 3.

When the delivery pump (not shown) is operated to withdraw liquid from either of the illustrated reservoirs, the check valve 11*a* on the vessel 10 of the reservoir opens to vent the vessel, whereby the liquid flows from the vessel, through the porous ducts, or porous liner, as the case may be, to the reservoir outlet 12 under the action of the pressure differential created by the delivery pump. As before, a meniscus valve action occurs in the pores of the porous structure of the reservoirs to preclude the passage of air from the vessel 10 of the reservoirs to the reservoir outlet 12.

It will be apparent from the foregoing description that my invention provides a new and useful construction for a liquid reservoir whereby continuous filtration and delivery of the stored liquid may be maintained throughout all variations in the attitude and state of motion of the reservoir. It is anticipated that those skilled in the art will have occasion to practice numerous variations on particular details of the two embodiments shown and described and it is intended that all such variations falling within the spirit of the invention be secured to me by United States Letters Patent.

I claim:

1. A liquid reservoir which comprises:

a vessel having an outer wall and an interior space to contain a supply of liquid,

porous interior wall means within said vessel immediately adjacent said outer vessel wall,

said interior wall means substantially completely encircling said interior space of said vessel in a plurality of intersecting planes passing through the approximate center of said space and defining at least in part annular passage means substantially completely encircling said interior space in each of said planes,

said passage means communicating to said interior space through pores in said wall means,

an outlet on said vessel opening at one end directly to said passage means and at the other end to the exterior of the vessel for communicating said passage means to a pressure less than the pressure existing in said interior space of the vessel, thereby to create a pressure differential between said passage means and said interior space tending to cause liquid and gaseous flow from said interior space to said passage means through said pores,

said wall means comprising a material which is wetted by said liquid,

the cross-sectional dimension of said pores being such that when said wall means is wetted by said liquid, the liquid enters said pores by capillary action to form meniscus interfaces exposed to said interior space across the pores not in direct contact with the

liquid in said interior space of said vessel and gaseous flow from said interior space to said passage means is resisted by said meniscus interfaces when said pressure differential is less than that required to overcome the surface tension of the liquid at said interfaces and the adhesion between said liquid and the walls of said pores, and

said wall means being adapted to pass liquid from said interior space of said vessel to said passage means through pores in direct contact with the liquid in said interior space.

2. A liquid reservoir which comprises:

a vessel having an outer wall and an interior space to contain a supply of liquid,

porous interior wall means within said vessel immediately adjacent said outer vessel wall,

said interior wall means substantially completely encircling said interior space of said vessel in a plurality of intersecting planes passing through the approximate center of said space and defining at least in part annular passage means substantially completely encircling said interior space in each of said planes,

said passage means communicating to said interior space through pores in said wall means,

an outlet on said vessel opening at one end directly to said passage means and at the other end to the exterior of the vessel for communicating said passage means to a pressure less than the pressure existing in said interior space of the vessel, thereby to create a pressure differential between said passage means and said interior space tending to cause liquid and gaseous flow from said interior space to said passage means through said pores,

said wall means comprising a material which is wetted by said liquid,

the cross-sectional dimension of said pores being such that when said passage means is filled with said liquid, the liquid enters said pores by capillary action to form meniscus interfaces across the pores not in direct contact with the liquid in said interior space of said vessel and gaseous flow from said interior space to said passage means is resisted by said meniscus interfaces when said pressure differential is less than that required to overcome the surface tension of the liquid at said interfaces and the adhesion between said liquid and the walls of said pores, and

said wall means being adapted to pass liquid from said interior space of said vessel to said passage means through pores in direct contact with the liquid in said interior space.

3. A liquid reservoir which comprises:

a vessel having an outer wall and an interior space to contain a supply of liquid,

porous interior wall means within said vessel immediately adjacent said outer vessel wall,

said interior wall means substantially completely encircling said interior space of said vessel in a plurality of intersecting planes passing through the approximate center of said space and defining at least in part annular passage means substantially completely encircling said interior space in each of said planes,

said passage means communicating to said interior space through pores in said wall means,

an outlet on said vessel opening at one end directly to said passage means and at the other end to the exterior of the vessel for communicating said passage means to a pressure less than the pressure existing in said interior space of the vessel, thereby to create a pressure differential between said passage means and said interior space tending to cause liquid and gaseous flow from said interior space to said passage means through said pores,

said wall means comprising a material which is wetted by and has good capillarity to said liquid at least over substantially the entire surface area of said wall means exposed to said interior space of the vessel, whereby when at least a portion of said wall means contacts the liquid in said interior space, substantially said entire surface area of said wall means is wetted by said liquid,

the cross-sectional dimension of said pores being such that when said wall means is wetted by said liquid, the liquid enters said pores by capillary action to form meniscus interfaces across the pores not in direct contact with the liquid in said interior space of said vessel and gaseous flow from said interior space to said passage means is resisted by said meniscus interfaces when said pressure differential is less than that required to overcome the surface tension of the liquid at said interfaces and the adhesion between said liquid and the walls of said pores, and

said wall means being adapted to pass liquid from said interior space of said vessel to said passage means through pores in direct contact with the liquid in said interior space.

4. A liquid reservoir which comprises:

a vessel having an outer wall and an interior space to contain a supply of liquid,

a plurality of interconnected, annular, tubular, porous ducts within said vessel immediately adjacent said outer vessel wall,

said ducts being disposed in intersecting planes, respectively, passing through the approximate center of said interior space of said vessel and containing communicating passage means which communicate with said interior space through pores in the duct walls,

an outlet on said vessel opening at one end directly to said passage means and at the other end to the exterior of the vessel for communicating said passage means to a pressure less than the pressure existing in said interior space of the vessel, thereby to create a pressure differential between said passage means and said interior space tending to cause liquid and gaseous flow from said interior space to said passage means through said pores,

said ducts comprising a material which is wetted by said liquid,

the cross-sectional dimension of said pores being such that when said ducts are wetted by said liquid, the liquid enters said pores by capillary action to form meniscus interfaces exposed to said interior space across the pores not in direct contact with the liquid in said interior space of said vessel and gaseous flow from said interior space to said passage means is resisted by said meniscus interfaces when said pressure differential is less than that required to overcome the surface tension of the liquid at said interfaces and the adhesion between said liquid and the walls of said pores, and

said ducts being adapted to pass liquid from said interior space to said passage means through pores in direct contact with the liquid in said interior space.

5. A liquid reservoir according to claim 4 including:

at least one additional porous duct extending diametrically across and interconnected to one of said annular ducts.

6. A liquid reservoir which comprises:

a vessel having an outer wall and an interior space to contain a supply of liquid,

a porous liner within said vessel immediately adjacent but spaced from said outer vessel wall,

said liner substantially completely enclosing said interior space of said vessel,

there being passage means between said liner and outer vessel wall communicating to said interior space through pores in said liner,

an outlet on said vessel opening at one end directly to said passage means and at the other end to the ex-

terior of the vessel for communicating said passage means to a pressure less than the pressure existing in said interior space of the vessel, thereby to create a pressure differential between said passage means and said interior space tending to cause liquid and gaseous flow from said interior space to said passage means through said pores,

said liner comprising a material which is wetted by said liquid,

the cross-sectional dimension of said pores being such that when said liner is wetted by said liquid, the liquid enters said pores by capillary action to form meniscus interfaces exposed to said interior space across the pores not in direct contact with the liquid in said interior space of said vessel and gaseous flow from said interior space to said passage means is resisted by said meniscus interfaces when said pressure differential is less than that required to overcome the surface tension of the liquid at said interfaces and the adhesion between said liquid and the walls of said pores, and

said liner being adapted to pass liquid from said interior space of said vessel to said passage means through pores in direct contact with the liquid in said interior space.

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