Fig. 11

Fig. 12

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This invention relates to storage tanks for liquids, and more particularly to tanks which are partially immersed in water or are erected on soft or marshy ground and which are employed to store liquids lighter than water, such as oil, or the like.

A main object of the invention is to provide a novel and improved method and means for storing liquids, especially liquids which are of less density than and are immiscible with water, such as oil, or the like.

A further object of the invention is to provide an improved storage means for oil or other liquids, said means being simple in construction, being easy to erect, and requiring no expensive excavations or foundations.

A still further object of the invention is to provide an improved storage tank for oil or similar liquids, said tank being partly submerged in water and utilizing the hydrostatic pressure of the water to balance a large portion of the hydrostatic pressure of the contents of the tank, whereby the stresses in the walls of the tank are greatly reduced, and whereby said walls may be made of relatively light and inexpensive materials.

A still further object of the invention is to provide an improved liquid storage tank which may be located on relatively cheap land, which are protected against fire hazards, and which may therefore be placed relatively close together.

A still further object of the invention is to provide an improved liquid storage tank which is sturdy in construction, which may be built of cheap material, and which may be located on soft or marshy ground, or may be located in shallow water, without requiring the use of expensive foundations or of an excessively large number of piles or other supports.

Further objects and advantages of the invention will become apparent from the following description and claims, and from the accompanying drawings, wherein:

Figure 1 is an elevational view, partly in vertical cross-section, taken through a liquid storage tank according to the present invention, shown installed in a shallow excavation in marshy ground.

Figure 2A is a fragmentary vertical cross-sectional view of the storage tank of Figure 2, shown with the tank filled substantially to its maximum capacity.

Figure 2B is a fragmentary vertical cross-sectional view, similar to Figure 2A, but showing the tank of Figure 2 substantially with the storage space thereof empty.

Figure 3 is an elevational view, partly in vertical cross-section, of another form of liquid storage tank according to this invention, shown located in a shallow excavation in soft or marshy ground.

Figure 4 is an elevational view, partly in vertical cross-section, of a modification of the liquid storage tank of Figure 3.

Figure 5 is an elevational view, partly in vertical cross-section, showing a further form of liquid storage tank according to the present invention.

Figure 6 is a vertical cross-sectional view taken through a still further form of liquid storage tank according to this invention, shown filled substantially to maximum capacity.

Figure 6A is a vertical cross-sectional view of the tank of Figure 6 with the storage space thereof substantially empty.

Figure 7 is an elevational view, partly in vertical cross-section, of a further form of liquid storage tank according to this invention.

Figure 8 is a view similar to Figure 7, showing the tank of Figure 7 in a substantially empty condition.

Figure 9 is an enlarged fragmentary perspective view of a strip element which may be employed in constructing a tank such as is shown in Figures 6 and 7.

Figure 10 is a fragmentary elevational view, partly in vertical cross-section, of a further modified form of liquid storage tank according to the present invention.

Figure 11 is a vertical cross-sectional view taken through a tank generally similar to that shown in Figure 2A, but somewhat modified to accommodate a liquid heavier than water.

Figure 12 is a vertical cross-sectional view taken through a further form of liquid storage tank according to this invention, of a type provided with a floating roof.

Referring to the drawings, and more particularly to Figure 1, 11 generally designates an oil storage tank according to the present invention, shown positioned in a shallow excavation 12 in soft or marshy ground. The tank 11 comprises a generally cylindrical vertical shell 13 of relatively thin material, such as sheet metal, sheet plastic, a combination of wire mesh (or perforated metal) and sheet plastic, or the like, provided with an apertured conical roof 14, the aperture thereof being shown at 15 and providing access to the contents of the tank.

Designated at 16 is a flanged supporting ring which is secured to the exterior of the shell 13 at the intermediate portion thereof and which rests on vertical piles 17 spaced around the shell and embedded in the soft ground at the bottom of the excavation 12.

As shown, the piles are of sufficient height to support the ring 16 substantially at the water level plane, shown at 18, and the ring is secured to the shell 13 substantially at a location thereon such that the height of the portion of the tank above outside water level 28 is equal to the total height of the tank approximately as the difference between the densities of water and the liquid to be stored, for example, a quantity of oil 19, is to the density of water.

A safety margin may be provided by locating ring 16 slightly higher on shell 13 than would be determined by the above ratio.

The dotted right triangle 21 in Figure 1 graphically shows the variation of hydrostatic pressure on the outside of shell 13 with depth, produced by the outside water. Since the density of water is considerably more than that of oil, the water enters the open bottom of shell 13 and supports the lighter oil at a horizontal interface 22, the hydrostatic pressures of the water and oil being balanced at said interface. The level of the top surface of the oil, shown at 23, is thus elevated above the outside water level 18, and the variation of hydro-
static pressure on the inside of the shell 13 is graphically illustrated by the dotted right triangle 24. The variation of unbalanced hydrostatic pressure on the shell is graphically shown in Figure 1 by the small inner triangle formed by connecting the points a, b, and c.

Figure 1A shows this graphical construction to a larger scale. In this figure, the line 2b represents the maximum unbalanced hydrostatic pressure on the shell 13, and is designated hereafter as \( p_{\text{m}} \). Similarly, the line 2c, designated as \( p_{\text{w}} \), represents the hydrostatic pressure of the oil at the interface 22, which is balanced by the hydrostatic pressure of the water, designated as \( p_{\text{w}} \). The height of the oil is designated as \( h_o \). The height of the outside water level from interface 22 is designated as \( h_w \).

Since the density of water, designated as \( D_w \), is different from the density of the oil, designated as \( D_o \),

\[
\frac{h_o}{h_w} = \frac{D_o}{D_w}
\]

Subtracting 1 from each side of the equation,

\[
\frac{h_o - h_w}{h_w} = \frac{D_o - D_w}{D_w}
\]

Or,

\[
\frac{h_o - h_w}{h_w} = \frac{D_o - D_w}{D_o}
\]

Multiplying both sides of the Equation by \((-1)\),

\[
\frac{h_o - h_w}{h_w} = \frac{D_o - D_w}{D_o}
\]

But

\[
P_w = (h_o - h_w)D_o
\]

Therefore,

\[
p_w = h_oD_o - \frac{(D_o - D_w)}{D_w}
\]

Thus, it is seen that the maximum hydrostatic pressure on the tank wall is limited to the product of the hydrostatic pressure at the interface 22 and the difference in density between the stored liquid and water divided by the density of water.

The bottom safety margin, namely the distance between the interface 22 and the bottom of shell 13 when the tank is filled to its rated maximum capacity, should be at least four times as great as the freeboard, namely, the distance between the top surface of the oil and the top of the shell.

If the freeboard is designated as \( A \), the distance \( d_o \) from the top of the tank to the point of support thereof, i.e., the outside water level, will be given by

\[
d_o = A + h_o\left(\frac{D_o - D_w}{D_w}\right)
\]

where \( h_o \) is in this case the rated maximum height of the oil in the tank.

It will be further seen that the maximum hydrostatic pressure on the shell occurs at the line 2b, and that this maximum pressure is relatively small as compared with the balanced pressure values at a point \( a \). In other words, by submerging the shell in the manner illustrated, the effective maximum hydrostatic pressure on the shell is reduced by a coefficient determined by the difference in densities of the oil and water divided by the density of water.

In view of this, the shell can be constructed of relatively thin, inexpensive material, since it is never required to resist any substantial amount of hydrostatic pressure. The ring 16 serves as a reinforcement at the area of maximum hydrostatic pressure on the tank, further reducing the maximum load on the tank wall.

Since the oil 19 is supported by the outside water at the interface 22, the piles 17 are required only to support the unbalanced weight of the tank, namely, the difference between the weight of the tank (including roof 14 and ring 16) and the buoyant force acting on the submerged portion of shell 13. Therefore, relatively few piles are required, and the piles need not be driven to a great depth.

In the embodiment of Figure 2, the tank, shown at 11', is similar in construction to the tank of Figure 1, except that a flexible bag or diaphragm 25 of watertight, impermeable material is sealingly secured to the inside wall surface of shell 13 at a level approximately half-way between the outside water level 18 and the bottom of the tank. The flexible bag or diaphragm 25 may be of any suitable flexible, readily foldable sheet material, such as thin polyethylene, or the like, so that it may readily fold or crumple as the quantity of oil 19 changes and as the unbalanced hydrostatic pressure in the upper portion of the tank similarly changes. The bag or diaphragm 25 will assume a substantially horizontal folded or crumpled position, as in Figure 2, when the oil level 23 is such that the hydrostatic pressure acting on its bottom surface is sufficient to substantially balance the weight of the oil 19 therein. Thus, by employing the bag or diaphragm 25, positive separation of the oil and water is obtained, and the hydrostatic pressure of the outside water may still be utilized to greatly reduce the loading on the shell 13.

When the tank is substantially full, as shown in Figure 2A, the bag or diaphragm will assume a distended configuration. The bag is preferably of a depth approximately equal to one half of the height of the outside water level from its bottom wall when thus distended, and preferably is sealingly secured to the inside surface of the shell 13 at a level midway between said outside water level and said bottom wall, as shown in Figure 2A.

Thus, when the tank is empty, the bag or diaphragm 25 will be distended upwardly, as shown in Figure 2B, and the inside water level will be substantially the same as the outside water level.

The bag 25 is substantially cylindrical in shape when distended, in which position the bottom wall thereof will be flat and horizontal. The outside diameter of the distended bag is slightly less than the inside diameter of the vertical shell member 13.

In the form of the invention shown in Figure 3, the tank is designated generally at 31 and comprises a shell 13 having an apertured roof 14 and having spaced floats 32 secured to its outside wall surface at a level such that the height of the portion of the tank above the floats is to the total height of the tank approximately as the difference between the densities of the oil and water is to the density of water. Thus, the floats 32 correspond to and perform the same function as the piles 17 in Figure 1. The tank may be moored in any suitable manner to the excavation 12 so as to maintain it in a stationary position.

In the modification illustrated in Figure 4, a flexible bag or diaphragm 25 is secured inside the shell 13 in the same manner as in Figure 2, but the tank is supported on floats 32 instead of piles.

In the form of the invention shown in Figure 5, the tank merely comprises a shell 13 supported by an annular float ring 32' and provided with an internal flexible bag or diaphragm 25, as in Figure 4, the roof being omitted.

As in Figure 3, the floats 32 and the float ring 32' in Figures 4 and 5 respectively are secured to the outside wall surface of the shell 13 at a level such that the height of the tank above the floats or float ring is to the total height of the tank approximately as the difference between the densities of the oil and water is to the density of water.

Referring now to the form of the invention shown in Figure 6, 41 generally designates a tank adapted to be used substantially in the same manner as the tanks previously described. Tank 41 comprises an outer substantially rigid shell 13 provided with an apertured roof 14.
Secured inside the shell 13 is a vertically flexible bag or diaphragm generally of bellows form so that it can be extended or contracted vertically to change its volume. The bellows member 42 has a flat, substantially rigid base against which all 43 against which all the major portions of the opposing hydrostatic forces of the liquid contents of the tank, for example, a quantity of oil 19, and the outside water act, whereby the bellows member is distended downwardly in the manner shown in Figure 6 when a substantial amount of liquid 19 is in the tank. The top rim of the bellows member 42 is secured to the inside surface of shell 14 at a level sufficiently above the outside water level so that the bellows member will be able to be substantially completely collapsed when the tank is empty and so that under these conditions, the inside water level and the bottom wall 43 will be substantially the same as the outside water level, as is shown in Figure 6A.

While Figures 6 and 6A show a tank provided with a support ring 16, this structure can also be employed in a tank provided with floats or a flat ring for supporting same in the water.

The bellows member 42 may be formed of any suitable material, for example, polyethylene plastic, or the like, having the required amount of flexibility and toughness to withstand repeated vertical extension and contraction as the amount of liquid 19 in the tank changes.

In the form of the invention shown in Figures 7 and 8, the tank is designed generally at 51 and comprises a flexible bellows member 52 having a rigid bottom wall 53 and a rigid top wall 54 provided with a central rigid vertical conduit 55 which is of substantial height and extends downwardly a substantial distance into the tank, providing access to the liquid contents 19 thereof. The top rim of the bellows member 52 is stiffened around the conduit 55 and beneath the level 54 by suitable truss framework 56. Thus, an air space is defined in the upper portion of the tank which is of sufficient volume to float the tank when empty, as shown in Figure 8.

The bellows member 52 is sufficiently flexible vertically to distend from the substantially empty condition thereof, shown in Figure 8, to the expanded condition thereof, shown in Figure 7, wherein the tank is substantially full. The bellows member 52 may be fabricated in any suitable manner from material of requisite flexibility and toughness. Thus, the bellows member may comprise a series of joined flexible annular ring elements 47 which are generally V-shaped in transverse cross-section, each ring element having a top flange 46 to which the bottom edge of the upwardly adjacent ring element is secured. The top wall 54 is secured to the top flange 46 of the uppermost ring element. The lowermost ring element, shown at 47, has a depending annular flange 48 in which the bottom wall 53 is secured.

The ring elements 47 may be formed from generally V-shaped strips of flexible material, such as plastic material, light gauge metal, or the like, such as is shown in Figure 5, which may be manufactured by extrusion, rolling, or any other well-known process. The strips may be prepared in the form of suitable lengths fastened in bundles, or in the form of a continuous length wound on a reel, so that the tank may be fabricated in the field by first forming the annular rings from the strips and then joining the rings to produce the bellows structure.

Any of the tanks previously described having bottom wall members for positive separation of the stored liquid from the outside water, can be used to store liquids which are miscible with water, heavier than water, or both. Figure 11 shows a tank generally similar to that of Figure 2, but slightly modified to accommodate a liquid 15' which is heavier than water. In this case, the pressure diagram shows that the maximum unbalanced pressure b'd is directed inwards and occurs at the level of the maximum top surface 23' of the liquid 19', which is below the outside water level. The support ring 16 is thus located at the same level as the maximum top level 23' of the liquid 19' and is secured to the shell 13 in a manner to resist the inward crushing pressure b'd.

Figure 12 illustrates a form of the invention comprising a shell 13 having a floating roof 60 resiliently and sealingly connected to its top rim portion, as by a flexible annular corrugated sleeve member 61. As in Figure 1, the bottom of the tank is open and the oil, or other stored liquid (which must be immiscible with water) is retained in the shell 13 beneath the buoyant roof 60. The roof 60 has sufficient buoyancy to support itself when the tank is empty.

As shown, the roof 60 has a central rigid, depending, vertical conduit member 55 and internal truss framing 56' to stiffen same.

As previously mentioned, the vertical shell in any of the tanks described herein may comprise any suitable sheet material. For example, as shown in Figure 10, the shell, designated as 63, may comprise an inner thin plastic sleeve 64 to which is secured, in any suitable manner, an outer reinforcing sleeve 65 of wire mesh material. The outer reinforcing sleeve may be made, alternatively, of expanded metal, perforated metal, or any other suitable formable sheet material having the required strength.

While certain specific embodiments of liquid storage tanks have been disclosed in the foregoing description, it will be understood that various modifications within the spirit of the invention may occur to those skilled in the art. Therefore it is intended that no limitations be placed on the invention except as defined by the scope of the appended claims.

What is claimed is:

1. A storage tank comprising a relatively thin vertical shell member open at its bottom end and immersed in a body of water so that water is free to enter the bottom portion of said shell member and can exert upward force therein, a quantity of liquid of lesser density than water contained in said shell member and supported by the water in the bottom portion thereof so that the level of the top surface of said liquid is substantially higher than the level of the outside water, whereby the liquid exerts a maximum outward bursting force on the shell member at the level of the outside water, an annular continuous hollow reinforcing member secured externally to said shell member at the level of the outside water and opposing said outward bursting force on the shell member, said hollow reinforcing member being of sufficient size to buoyantly support said shell member at a constant depth of immersion, and an impervious flexible member substantially in the form of a cylinder with a closed flat bottom, said cylinder having an outside diameter slightly less than the inside diameter of the vertical shell member, the upper rim of said cylinder being impermeably attached to the inside surface of the shell member at a level located substantially midway between said reinforcing member and the flat bottom when the flexible member is in a completely downwardly distended condition, said flexible member being sufficiently thin so that by flexing, folding and crumpling it can dispose itself to constitute an approximately flat and level surface separating said liquid from the water in the bottom portion of the shell member, said shell member extending downwardly a sufficient distance to completely surround said flexible member in said completely downwardly distended condition.

2. The structure of claim 1, and wherein said shell member is open at its top end.

3. The structure of claim 1, and wherein said shell member is provided with an apertured roof.

4. The structure of claim 1, and wherein said impermeable flexible member comprises thin polyethylene sheet material.

5. The structure of claim 1, and wherein said shell member is made of sheet metal.
6. The structure of claim 1, and wherein said shell member comprises an inner thin sleeve and an outer reinforcing sleeve of foraminous sheet material.

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