Dec. 1, 1953 H. EDHOLM 2,661,062

CONTAINER FOR STORING OIL AND LIKE FLUIDS

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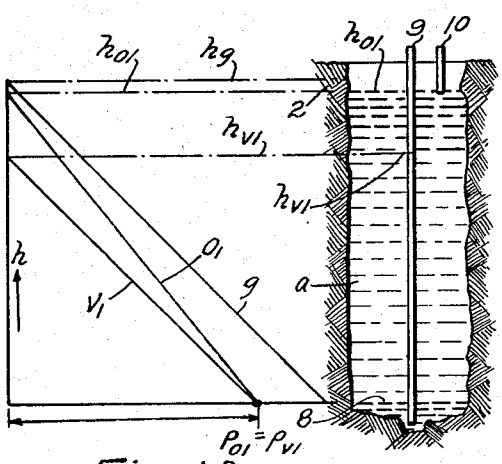


Fig. 1A.

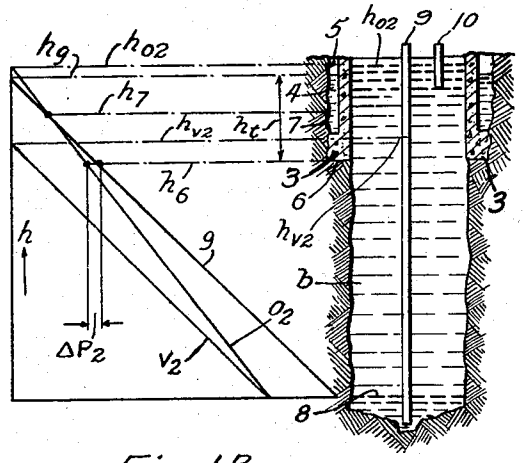
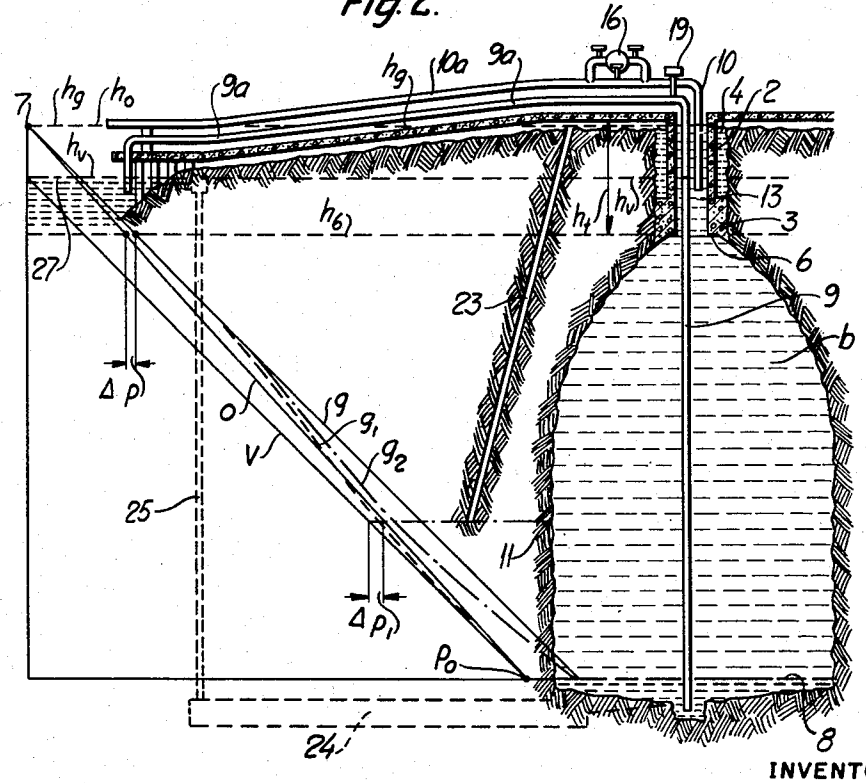


Fig. 1B.

Fig. 2.



INVENTOR.
HARALD EDHOLM
BY
ATTORNEYS.

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Fig. 3

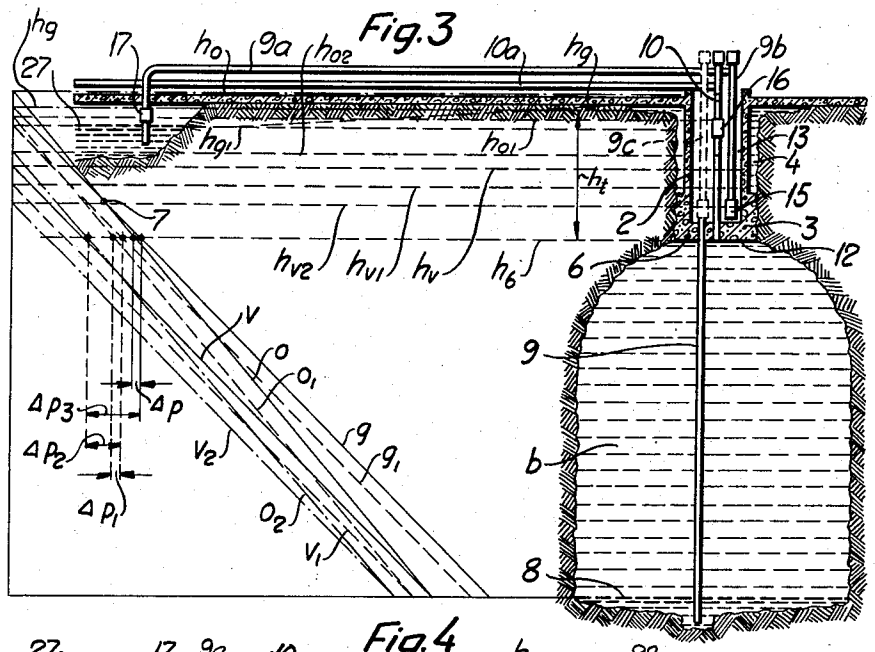
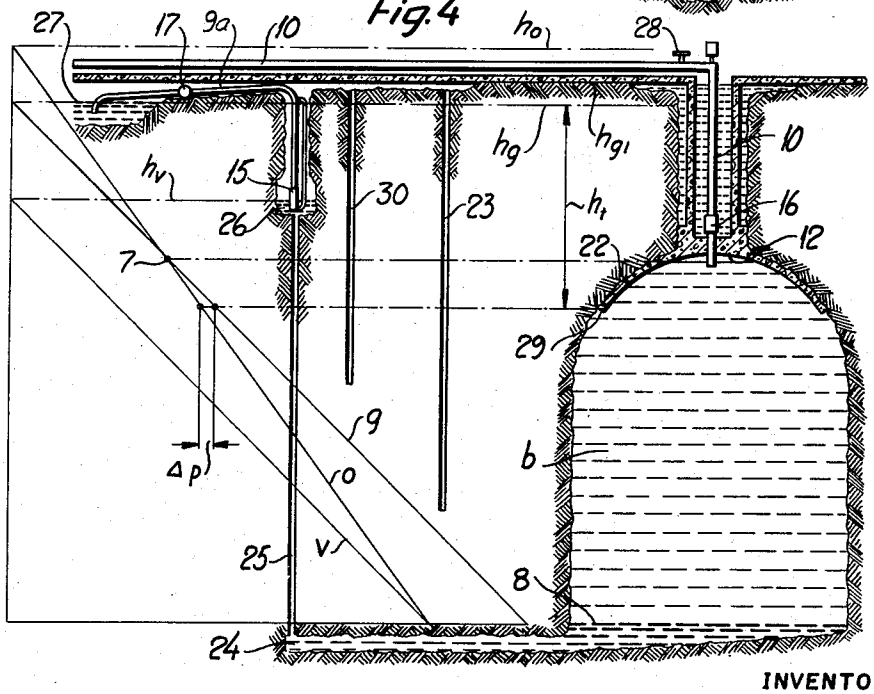


Fig. 4



INVENTOR.
HARALD EDHOLM
BY
Burton & Hardy
ATTORNEYS.

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Fig. 5

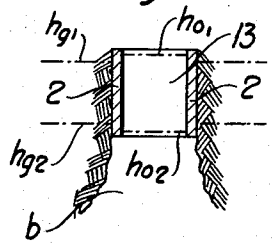


Fig. 6

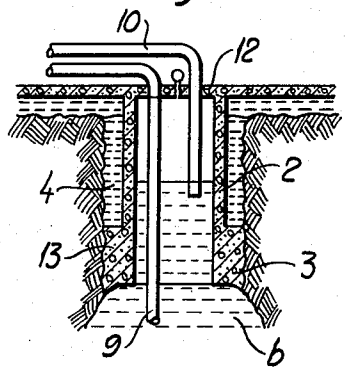


Fig. 7

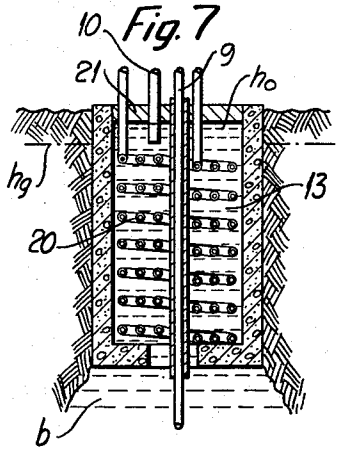


Fig. 8

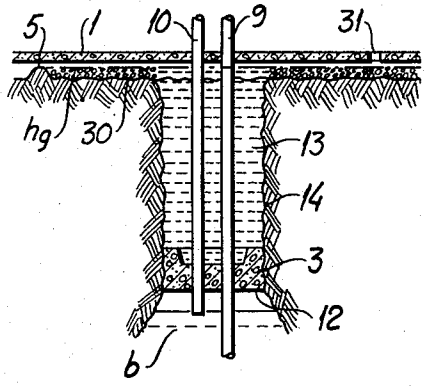


Fig. 9

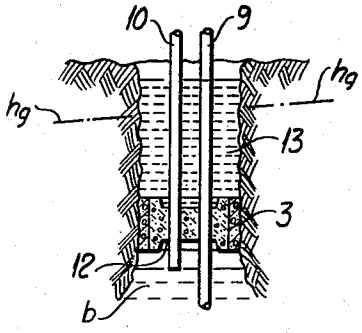
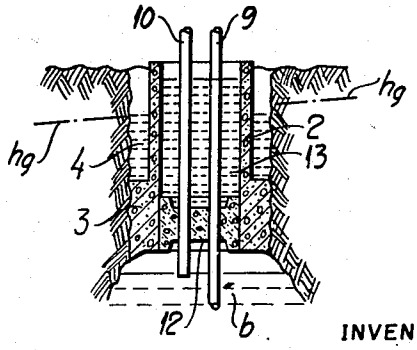


Fig. 10



INVENTOR.
HARALD EDHOLM
BY
Burns & Hardy
ATTORNEYS.

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Fig. 11

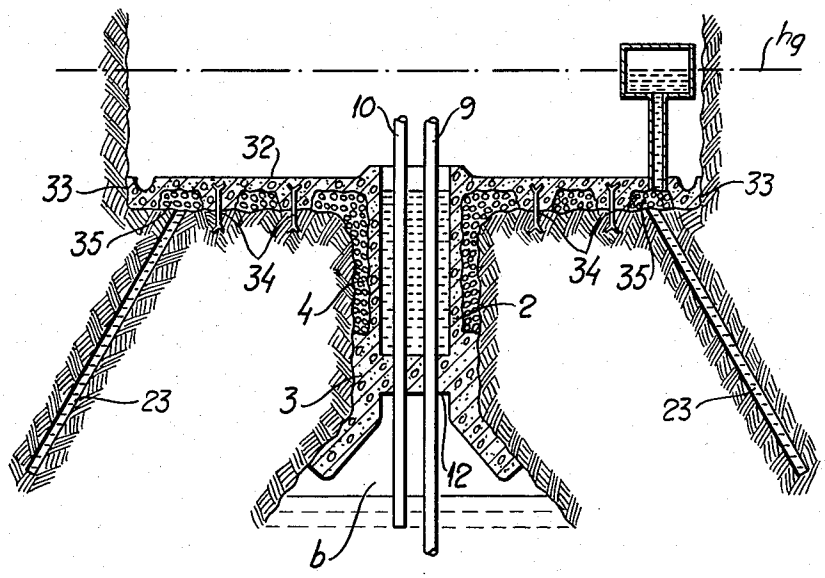
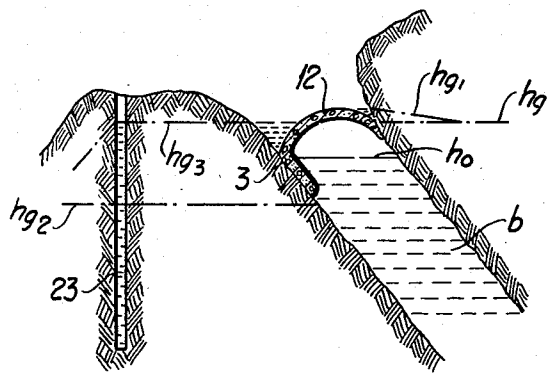


Fig. 12



INVENTOR.
HARALD EDHOLM
BY
Russell & Harding
ATTORNEYS.

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UNITED STATES PATENT OFFICE

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CONTAINER FOR STORING OIL AND LIKE FLUIDS

Harald Edholm, Solsidan, Saltsjobaden, Sweden

Application June 26, 1950, Serial No. 170,333

Claims priority, application Sweden June 28, 1949

14 Claims. (Cl. 166—1)

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This invention relates to underground containers for storing water-immiscible fluids having specific gravities less than that of water, and in particular relates to storage of such liquids in underground cavities having pervious walls.

The storage of liquids such as oil, gasoline, or the like in metal containers above ground is well known. Storage in metal or concrete containers below ground is also known but involves particular difficulties not only in maintenance of the containers but in the provision of the cavities for their reception.

In accordance with the present invention, provision is made for the storage of oil, gasoline, or the like in underground cavities having pervious walls. Briefly stated, this is made possible by taking advantage of underground water pressure to cause water to seep into the cavity and by virtue of such seepage and the attendant hydraulic pressure exerted inwardly to insure against loss of the stored liquid. In accordance with the invention, controls are exercised, as will appear hereafter, to maintain the required pressure conditions and to remove accumulation of water as well as to maintain proper control irrespective of variations in the volume of the stored liquid.

Leakage of water into a highly mobile oil is generally not harmful provided the water sinks to the bottom of the container without emulsification with the oil. If the oil is viscid or has become solidified, the seepage of water into the oil is less desirable particularly if the seepage occurs above the oil level with resultant dripping of water upon the oil surface. Under such circumstances the dripping water may undergo emulsification in the oil to the end of deteriorating the stored oil.

Consideration must also be given to variations of level of the water about the container. The general objects of the present invention relate to the provision and control of a subsurface container of the type indicated. These and other objects of the invention particularly relating to details of construction and control will become apparent from the following description read in conjunction with the accompanying drawings, in which:

Figure 1A shows a section of one form of container, there being associated therewith at its left a pressure diagram explanatory of conditions which exist in and about the container;

Figure 1B is a similar showing of an alternative form of container with a diagram showing the conditions existing in and about the container;

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Figures 2, 3 and 4 are sections through several other container arrangements also showing pressure diagrams corresponding thereto; and

Figures 5 to 12, inclusive, illustrate particularly different embodiments of the upper portions of containers.

Referring first to Figure 1A, there is illustrated therein a container provided in accordance with the invention in its simplest elementary form of an open topped unlined cavity *a* in the earth. The walls of this cavity are permeable through all or some portions thereof. The figure shows oil floating on water in the cavity, the oil-water interface being indicated at 8. The term "oil" may be herein considered to be generic to water immiscible liquids having a specific gravity less than water (fresh or salt) and may be considered to include such mobile liquids as gasoline, or the like. There is indicated at 10 a pipe through which the oil is introduced or withdrawn, while there is indicated at 9 a pipe open at the bottom of the cavity below the lowest water level attained therein, which pipe provides for the introduction or removal of water. The pipes 9 and 10 may be assumed associated with pumps as will hereafter appear in the more specific disclosure. The level of the subsoil water in the ground and which may be assumed to permeate the cracks and pores in the entire region about the container is indicated at h_g. The level of the surface of the oil is designated h_{o1}. The level of water in the pipe 9 is designated h_{v1}.

At the left of Figure 1A there is provided an equilibrium digram in which levels as ordinates are plotted against pressures existing at various levels as abscissae. The lower left corner of the diagram is the origin for the indication of heights or levels h and this origin corresponds to the level 8 of the oil-water interface. The axis at the left of Figure 1A represents zero gauge pressure.

In the case of the column of water existing in the pipe 9, the pressure p_{v1} is given by

$$p_{v1}=1(h_{v1}-h)$$

and this equation is that of the line v_1 having an abscissa value of 0 at $h=h_{v1}$. In the foregoing equation 1 is the proportionality factor suitable for the units of pressure and height and corresponds to the specific gravity of water involved. Similarly, in the case of the column of oil existing in the cavity, the pressure

$$p_{o1}=\gamma(h_{o1}-h)$$

and this equation is that of the line o_1 but the proportionality factor corresponds to the units

used and the specific gravity of the oil. It will be evident that under equilibrium conditions there must exist at the interface 8 equality of the pressures of the water and oil in the container so that the lines v_1 and o_1 intersect at this level corresponding to $h=0$. It follows then that the relative levels h_{v1} and h_{o1} are related by $1h_{v1}=\gamma h_{o1}$ as graphically indicated in the diagram. It will be evident that if the level of the oil surface is to be maintained constant, water must be introduced or removed through pipe 9 as the oil is removed or introduced or in correspondence with water seepage into the container. If the quantity of oil in the container remains constant over a period of time, water must be removed through pipe 9 at the same rate as that at which it enters through the container walls. From the practical standpoint, of course, such removal of water may be effected intermittently rather than continuously to maintain approximately constant level of the oil surface. Alternatively, if oil is removed at a rapid rate such that seepage throughout the time of removal is negligible, water must be introduced at a volumetric rate corresponding to the volumetric rate of oil removal. Similar reverse conditions are involved to take care of the introduction of oil, the interface level 8 being correspondingly lowered as oil is introduced. In actual practice, of course, during removal or introduction of water, some water seepage will occur into the container and the rates of water flow will be correspondingly adjusted.

The foregoing indicates the maintenance and attainment of the desired equilibrium conditions in the container. For proper storage conditions these must be correlated with the water conditions existing outside the container so as to insure water flow inwardly through the pervious walls at all levels at which the oil contacts the pervious walls of the containers. This condition is assured if the pressure exerted by the stored oil at any point on the pervious wall of the container is maintained at a pressure less than that exerted by the subsoil water at the same point. Assuming, for example, that the level of the subsoil water is at h_g immediately outside the wall of the container, the pressure curve of the subsoil water outside the container will be as indicated at g in the diagram. The straight line constituting this curve has the same slope as the line constituting curve v_1. It will be evident that this curve represents at any level of contact of oil with the container walls excess of external subsoil water pressure over the oil pressure o_1. These conditions are proper for storage since water will then continuously seep inwardly into the container through all cracks or fissures and flow of oil outwardly will be prevented. The water thus seeping inwardly will flow downwardly along the walls of the container, accumulating in the pool of water below the interface 8. Under most actual conditions, however, there is another factor to be considered, namely, the so-called cone of depression which exists whenever water is withdrawn from a well or its equivalent and the water can flow to the well only through passages offering some resistance to flow. In the vicinity of the well the surface of the water will be below the level of the surface at more remote locations and the local depression of the surface forms the cone of depression which in Figure 1A is indicated at 2. If such cone of depression exists, the more remote water level h_g will not represent the effective level at the container walls, but the latter level will be somewhat lower in the case of a container such as in Figure 1A. This must be taken into account and the upper most limit for the level of the oil surface will be below the lowest level of this cone of depression. Such a condition is, of course, achieved by proper withdrawal of water from the pipe 9.

The conditions just indicated, however, are not the only ones which must be taken into account in determining the maximum height of the surface of the oil. The level of the subsoil water in most localities, i. e. the "water table" is subject to seasonal or other periodic fluctuations and in the case of a container of the simple type illustrated in Figure 1A such variations may seriously limit the oil level, requiring the earth cavity to be excessively deep with attendant increase in its initial cost of production and with wastage of volume. Accordingly, the upper portion of the cavity may be lined with an impervious liner as will now be described with reference to Figure 1B.

In Figure 1B the cavity b is provided with a liner 3 at its upper portion extending from the surface of the ground down to the level h_6. This liner may be of concrete, metal plate, or the like, and is sealed against the rock. Exterior to the liner there is provided a well 4 which communicates with any cracks in the rock in its vicinity and collects water therefrom so as to provide a free subsoil water surface having the same level h_g around the entire container. This subsoil water level may be raised at will by filling the well with water so that, in effect, the subsoil water forms a cone of elevation rather than depression around the container. This subsoil water level affects pressures about the lower portion of the cavity and, hence, serves to control pressure and leakage conditions thereat. Desirably, the wall liner 3 is constructed when the blasting of the cavity has proceeded to a level slightly lower than that indicated at h_6. The subsoil water surface will then set itself in balance in approximate correspondence with the future level during operation. As the blasting or excavation is continued, all the water-bearing cracks and their mouths in the cavity may be detected and may be successively sealed or partially filled with cement so that the ultimate inward leakage of water is restricted, if required, to an acceptable value. When the excavation of the cavity has been completed and the cracks have been sealed to the extent desired, the container is filled first with water and then with oil, the latter taking place during withdrawal of approximately the same quantity of water. The position of the subsoil water surface may be then observed as well as the leakage, if any, as a function of the thickness of the oil layer. In this way there may be determined the operation characteristic of the cavity which will serve for determination of the control of operation in the future use of the container. Control of the leakage of the cavity is valuable in avoiding the necessity for excessive pumping of water flowing thereinto. Lining the cavity at the top has the advantage in that leakage of water into the oil is eliminated at the upper portion of the cavity which is generally that at which most water influx would occur.

At the left of Figure 1B there is a diagram similar to that shown at the left of Figure 1A but indicative of conditions which may exist for satisfactory storage using the cavity or con-

tainer *b*. In Figure 1B, v_2 represents the pressure condition existing in the water control pipe **9** in which, at equilibrium, it may be assumed that the water is at the level h_{v2}. o_2 is the curve of pressure existing in the oil the upper level of which is at h_{o2}. The level at Figure 1B is shown at the extreme upper end of the liner **3**.

Assuming the subsoil water level h_g established by the level of water in the well **4** to be the same as in the case of Figure 1A, it will be noted that the curve *g* intersects the curve o_2 at the level h_7 which is intermediate the upper and lower ends of the liner **3** above the level h_6. The oil pressure exceeds the subsoil water pressure and, if it were not for the presence of the impervious liner, the oil would flow outwardly and so be lost or would contaminate the subsoil water. Below the level h_7 at which subsoil water pressure exceeds the oil pressure and, consequently, where the container is porous, i. e. below the level h_6, inflow of water will take place as described in connection with Figure 1A. At the level h_6, for example, the excess water pressure over oil pressure is indicated at ΔP_2. As already pointed out, the amount of this influx may be controlled to some extent by the sealing off of large fissures or cracks in the container wall; however, some will remain unsealed and water will accordingly flow inwardly, accumulating in the pool of water below the interface **8**.

What has just been described indicates the function of the impervious liner **3** in taking care of variations in the subsoil water level and in permitting a rise in the level of the surface of the oil. So long as the level of the intersection of the curves o_2 and *g* is between the level of the upper and lower ends of the impervious liner **3**, the container will function properly without loss of oil and with influx of water. Accordingly, variations of level h_g within the reasonable limits determined by the impervious liner will be acceptable and, at the same time, it will generally be possible to maintain the level of the surface of the oil higher with respect to the subsoil water surface level than in the case of the container of Figure 1A.

Referring to Figure 5, there is indicated therein the minimum desirable vertically extending impervious wall consistent with complete utilization of the advantages of the invention under different conditions of operation. Assuming that the level of the subsoil water may vary between the limits h_{g1} and h_{g2}, the impervious liner should extend beyond these levels. The impervious liner should, in any case, include the highest occurring oil level at the walls of the container to prevent the oil from flowing out into the rock above the upper limit of the impervious layer. It is further preferable, particularly in storing viscid oil, to have the impervious wall include also the lowest occurring oil level to prevent dripping of water down into the oil surface with possible attendant emulsification.

Referring again to Figure 1B, when oil is removed through the pipe **10** and replacing water is introduced through pipe **9**, the interface **8** will be raised. If the water level h_{v2} is maintained constant or approximately so, the oil pressure curve o_2 in the diagram will, in effect, move toward the left because it must still intersect the stationary line v_2 for the water pressure at the level of the interface **8** which is now higher. The excess pressure of the subsoil water over the oil thus increases and, accordingly, there also increases the leakage of water below the bottom of the liner **3**. However, if the water level h_{v2} is caused to rise by introduction of additional water through the pipe **9** or by decreasing the withdrawal of the water through pipe **9** permitting seepage to supply additional water, the pressure differential may be kept at a suitable constant value to maintain approximately constant the rate of influx of water.

The advantages of a cavity having an impervious liner at the upper portion thereof will now be clear. Not only can the oil level be higher, giving the advantage of larger storage volume while still preventing loss of oil even though in the uppermost portions of the container the oil pressure may exceed the subsoil water pressure, but variations in level of the subsoil water will not, within the limitations for which the design is made, result in the existence of conditions inconsistent with proper storage, i. e. excess of oil pressure at any level over the subsoil water pressure where the walls are pervious.

The actual container *b* shown in Figure 1B has the drawback that the impervious wall in the upper portion of the cavity has the same large circumference as the container itself. Considerable improvement is obtained by making the upper impervious portion of the cavity in the form of a vertical or other upright shaft having a comparatively small circumference and, consequently, comparatively low construction cost. Due to the fact that the shaft may be restricted in circumference, it may sometimes be made impervious to both oil and water simply by selecting the location of the shaft so that the rock about the shaft is free from large cracks. If the rock around the shaft is cracked to a minor extent, a sufficiently impervious condition may be secured by locally sealing the individual cracks. In most cases, however, special measures should be taken to make the shaft tight and arrangements for this purpose are illustrated in Figures 2 to 11, inclusive.

Figure 2 shows a container *b* intended particularly for heavy oil such as fuel oil. The water in the container communicates through the water pipes **9** and **9***a* with a comparatively large water accumulation **27** having the average level h_v. This accumulation may, for example, be the sea, a lake, a river or a pond or some other body of water of substantial volume. The subsoil water is around the entire container and is artificially raised to, and maintained at, the level h_g at the ground surface through an additional supply of water through the cracks and their mouths in the ground surface and in the interspace or well **4**. The lower portion of the cavity may, if desired, communicate through a horizontal tunnel **24** and a vertical bore **25** with the supply of water having the level h_v. The pressure line *g* for the subsoil water around the container starts at the level h_g of the ground surface. The pressure line *v* for the water in the supply pipe **9** starts from the surface h_v because the water in the container communicates with the water accumulation through the tunnel **24** and the bore **25**. The pressure line *o* for oil, the inclination of which is determined by the specific gravity of the oil, extends from the intersection of the pressure line *v* with the level of the interface **8** because the pressures of the water and of the oil are equal at the lowermost portion of the oil layer. The top layer of the oil in the case illustrated is level with the subsoil water surface and is indicated at h_o. The points of intersection be-

tween the horizontal line h_6 from the lower limit 6 of the impervious liner 3 with the pressure lines g and o indicate that at the lower portion of the liner the subsoil water pressure is the quantity Δp higher than the oil pressure at the same level so that oil cannot flow out of the container. If the surface of the water accumulation having the level h_v rises, or if the oil has a lower specific gravity, the oil level will rise and the quantity Δp will be reduced. This is permissible so long as the quantity Δp is positive. If the water level h_v is reduced or the oil is heavier, the oil surface will fall below the subsoil water surface h_g. Then the quantity Δp rises and the leakage of water into the container will increase. If there is a leak in the cavity wall at a point such as 11 which communicates with the water accumulation at the level h_v but not, or at least not to the same degree, with the surrounding subsoil water, oil would flow out into the rock under the pressure Δp_1. In the diagram the line for the subsoil water pressure may then appear as indicated by the dashed line g_1. The fundamental condition for the provision of raised subsoil water around the upper portion of the cavity in Figure 2 is either that the natural subsoil water pressure is sufficiently high around the lower portion of the container and higher than the pressure p_o or that the water pressure there is raised through one or more bores 23 acting as shielding holes, which bores are supplied with water and cross the cracks, if any, in the formation so that the subsoil water pressure is sufficiently raised around the lower portion of the container, for example, according to the curve g_2.

Full guarantee against oil leakage from the lower portion of the container is gained, however, if the oil level is lowered to a height corresponding to the lowest subsoil water surface h_v.

In Figure 2 the walls of the shaft are made tight by means of a concrete wall or liner 2 joined firmly with the rock as by casting. Reference may be made to Figure 6 wherein there is additoinally a horizontal tight roofing surface 12 through which the necessary pipe lines extend in tightly fitting relationship to prevent gases from forcing their way out.

In storing viscid oils it is often necessary to heat the oil before it can be transported through pipe lines. The heating can be performed so that the oil when being withdrawn from the container will have to pass a space provided with a heating coil. According to the present invention, the space 13 in Figure 7 may be used for this purpose. The heating coil 20 is lowered into the space 13 and may be raised up for supervision of its operation. This space is covered by lid 21. The heated oil is withdrawn from the upper portion of the container through the oil line 10. The water line 9 is heat insulated. Through this arrangement a considerable portion of the plant cost for an additional heating chamber is saved.

Figure 3 shows a container b such as might be used for the storage of combustible oil for engines. The walls of the shaft at the upper portion of the container are tight as in Figure 2. Further, there is in the lower portion of the shaft a tight cover 12 constituting part of the wall of the oil space which is tightly joined to the walls of the liner and through which the water line 9 and the oil line 10 extend with tight fit to prevent leakage thereabout. The interspace or well 4 and the ground surface around this are filled with water up to the level h_g either artificially or by means of subsoil water from a higher level. It may be assumed that this container is adjacent to the sea indicated at 27. Toward the sea side the subsoil water surface will then slope downwardly toward the level h_{g1}. In the upper portion of the container b the subsoil water pressure depends on the subsoil water level h_g in accordance with the line 9 in the diagram and the oil may be stored with a safety margin of pressure Δp as indicated by reference to the oil pressure line o. From this the pressure line v is obtained for the corresponding water pressure in the pipe line 9 having an upper water surface at the level h_v. In pumping oil into and out of the container through the pipe line 10, the supply and withdrawal of the water must be controlled in such a manner that the water pressure in the pipe line 9 does not rise so high that oil is forced out into the rock. This is rather difficult to accomplish if the lines 9 and 10 continue out of the container with directly connected lines, as indicated by the pipe 9c drawn in dashed lines and the pipes 9a and 10, respectively, in full lines. It is preferable to have the line 9 open into a buffer space 13, i. e. a reservoir having a considerably larger cross sectional area than the pipe line and to control the pumping into and out of said reservoir. In the lower portion of the space 13 the pipe 9 has an open end whereas junction pipe 9b opens at its lower end into the space 13 and is connected at its upper end to the pipe 9a.

According to the principles recited above in connection with the pressure diagram, the water in the space 13 reaches the level h_v. The external water line 9a has a pair of pumps 15 and 17 which may be operated automatically, if desired, for the removal and introduction of water to hold the water level at h_v or lower. If the rock around the container b in Figure 3 communicates with the water accumulation having the level h_{g1} and it is desired to store the oil under such conditions, the oil and water levels in the container may be regulated to h_{o1} and h_{v1}, respectively, in which case the excess pressure Δp_1 of the water in relation to the oil at the level h_6 will be as indicated by the dashed lines of the diagram. However, the oil and water levels in the container may be controlled at lower levels h_{o2} and h_{v2} in which case the excess pressure of the subsoil water over the oil pressure at the level h_6 becomes considerably higher, i. e. Δp_2 and Δp_3 in relation, respectively, to the lowest and highest subsoil water levels. From this it will be seen that it is possible according to the present invention to regulate the pressure conditions within a very wide limitation while maintaining good safety margin with respect to oil leakage.

Figure 4 shows a storage container particularly for gasoline. The tight zone of the container includes both the shaft and a portion of the cover of the container b at 22. The subsoil water has been raised to the level h_{g1} and the shielding hole 23 communicates with the subsoil water at its elevated surface. The aqueous communication with the bottom of the container extends through the tunnel 24 and the bore 25 which communicates with a water reservoir 26. It will be noted that in this case the bore 25 corresponds to the pipe 9 of the previous modification but is external rather than internal to the container. The reservoir 26 may be common to several containers and the water therein may be held at a desired level by pumping by means of pumps 15 and 17 by way of the pipe 9a communicating with the water accumulation 27. The gasoline is pumped

into the container *b* through the pipe line 10 with the aid of pumps which may, for example, be available on a tank boat in the water accumulation 27 supplying the gasoline. The gasoline is withdrawn by the pump 16. The gasoline line 10 opens slightly below the tight cover surface 12 so that there is formed an air cushion between the stored gasoline surface and the underside of the cover 12 to protect this, inter alia, against the chemical action of the gasoline. Provided that for safety's sake and in accordance with the pressure line *g* the subsoil water referring to the water surface 27 has the excess pressure Δp in relation to the oil pressure at the lowermost portion 29 of the tight zone in the container, there is obtained pressure line *o* for the gasoline, and, from this, pressure line *v* for the water in the container having its free surface at the level h_v in the reservoir 26. The highest level of the gasoline should be at h_o, i. e. higher than the pipe line 10. Through a valve 28 the gasoline is, however, prevented from flowing out of the container *b*. By displacement of the pressure line *o* to the left the safety margin *p* may be increased. In practice, this condition is realized by lowering the water level in the reservoir 26 and thus also the gasoline level h_o. Because under all conditions the water level in the container 26 in this case will be lower than the subsoil water surfaces h_{g1} and h_g, it may be preferable to provide a shielding hole 30 between the reservoir 26 and the container *b*.

In Figures 6 and 8 to 12 there are shown some further arrangements of the tight upper portion of the cavity and its surrounding subsoil water.

In Figure 6 in which the oil is considerably lower than the surrounding subsoil water the walls 2 need not, according to the present invention, be completely impervious because, in any case, the oil is prevented from flowing out through the walls due to the overpressure exerted by the leaking-in subsoil water. It is, however, advantageous to make them impervious to water to prevent the dripping of water into the container adjacent to the withdrawal pipe 10 for the oil.

Figure 8 shows the shaft shut off at its lower end by a tight cover 12 which forms part of the wall of the oil space and, together with the wall 14, a cup which is maintained filled with water up to the subsoil water level h_g with the result that it communicates with the subsoil water both adjacent to the ground surface and through the cracks in the wall 14. The water layer at the ground surface is covered by a loose stone filling 30 and above this there is a concrete floor 1. Water is supplied at 31 through this floor and any excess thereof runs off at overflow drain 5.

Figure 9 shows a similar arrangement but the cover or wall 12 is here adapted to be slightly permeable to water drops to protect the surface of the cover against damage by the oil. The water level in the shaft is in this case slightly higher than the natural level h_g.

Figure 10 shows an arrangement rather similar to that of Figure 9 but showing the walls entirely tight. Artificial supply of water is arranged both to the cup 13 and to the well 4 outside the wall 2.

Figure 11 shows a shaft having tight walls 2 and a tight cover 12 with pipe lines 9 and 10 for water and oil, respectively, projecting through the cover without clearance so as to provide tight closure for the container *b*. From the level h_g water is filled into the spaces 4 and 35 between the rock and the impervious wall 2 and concrete floor 32, respectively. This floor is tight against the rock at 33 and is secured to the rock with bolts 34. The shielding holes 23 communicate with the water in the interspaces 35. This disposition of subsoil water elevated above the floor is preferred particularly if the natural subsoil water level of the rock is to be maintained in elevated position.

Figure 12 shows an arrangement rather similar to those shown in Figures 6, 9 and 10 but applied to a cavity in the rock having an irregular form and with the natural subsoil water levels h_g and h_{g2} raised to h_{g1} and h_{g3}. The right-hand side of Figure 12 shows in the upper part of the container wall a section which is devoid of sealing means extending from below the oil surface h_o and the cover or upper part of the wall 12. Due to the high subsoil water levels h_g and h_{g1}, respectively, the wall is, according to the present invention, tight against oil tending to force its way out through the wall. While not shown in Figure 12, it will be understood that the oil floats on a body of water as in Figure 4 and as in this same Figure 4 the water in the bottom of the container communicates with a reservoir corresponding to 26 in Figure 4.

The drawings do not show any cover manholes, but these should be provided wherever required. The cavities may be shaped in different fashions. It is, however, preferable to make the container adjacent to the shaft sharply vaulted to obtain sufficient strength and ability to divert leakage. The shaft may, of course, be placed in any desirable position and even laterally of the main cavity. The walls of the container may consist of rock, concrete and/or other materials, where it is of importance to prevent the escape of oil or other fluid.

Of the various embodiments of the invention shown by way of example, those illustrated in Figures 3, 4, 6, 8, 9, 10, 11 and 12 are gas-tight which is of importance when volatile oils are being stored.

The introduction of oil into the container will generally be performed utilizing the pumps of a ship, whereas the withdrawal of the oil may be accomplished with pumps such as heretofore indicated at 16 in Figure 2 located at the ground surface or further down in a shaft or in a pipe line projecting downwards. When required the water may be supplied and withdrawn by a pair of pumps one at each end of the water line and arranged in such a manner that, as in the case of the oil pumps, the suction lift will not be too great. A single pipe line is preferably used for transporting each liquid in both directions in which case the idle pump may be shunted in known manner as is indicated in Figure 2 with respect to the pump 16 in the oil line 10.

The water pump 15 for outgoing water is preferably provided with automatic starting and stopping devices controlled by the water or oil level or by the pressure so that leakage water may be pumped out whenever required before the water level rises above an allowable maximum height. As above stated, it is to be preferred if the removal of water may be accomplished from a reservoir having a large free water surface as at 13 in Figure 3 or 26 in Figure 4.

The water pumps may be dispensed with if, as in Figure 2, the water line is made to establish communication between the bottom of the container *b* and the water accumulation 27 or if a special connection is arranged through tunnel

24 and bore or shaft 25. In the first instance, the water line 9a must be provided with an evacuation pump 19, Figure 2, which removes air from the uppermost portion of the line. In both arrangements the transporting of water into and out of the container takes place automatically so that the oil level may be held at a suitable nearly stationary position.

I claim:

1. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, and means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall on the container at a pressure less than that exerted by the subsoil water at the same point.

2. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, substantially impervious means providing a boundary for said cavity in the upper portion of said cavity, and means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of said container below said substantially impervious means at a pressure less than that exerted by the subsoil water at the same point, said last-named means including a bore hole adjacent to said cavity and communicating with a source of water.

3. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, substantially impervious means providing a boundary for said cavity in the upper portion of said cavity, said substantially impervious means forming the bottom of a well for the reception of water, and means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of said container below said substantially impervious means at a pressure less than that exerted by the subsoil water at the same point.

4. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, substantially impervious means providing a boundary for said cavity at the upper portion of said cavity, and means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of said container below said substantially impervious means at a pressure less than that exerted by the subsoil water at the same point.

5. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, substantially impervious means providing a boundary for said cavity in the upper portion of said cavity, said substantially impervious means having an annular well about a portion of the exterior thereof for the reception of water, and means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of said container below said substantially impervious means at a pressure less than that exerted by the subsoil water at the same point.

6. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, substantially impervious means providing a boundary for said cavity in the upper portion of said cavity, means for withdrawing the stored fluid at a point near the top of said cavity, and means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of said container below said substantially impervious means at a pressure less than that exerted by the subsoil water at the same point.

7. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, a substantially impervious liner in the upper portion of said cavity, said liner having a substantially fluid-impervious bottom therein and pipe means extending through said bottom, and means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of said container below said substantially impervious means at a pressure less than that exerted by the subsoil water at the same point.

8. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, substantially impervious means providing a boundary in the upper portion of said cavity, said impervious means having a substantially impervious top thereon, and

means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of said container below said substantially impervious means at a pressure less than that exerted by the subsoil water at the same point.

9. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layers, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, substantially impervious means providing a boundary in the upper portion of said cavity, said impervious means having a top thereon and an annular well around a portion of the exterior of sid impervious means for the reception of subsoil water, and means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of said container below said substantially impervious means at a pressure less than that exerted by the subsoil water at the same point.

10. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, substantially impervious means providing a boundary in the upper portion of said cavity, a heating coil positioned adjacent to said substantially impervious means to lower the viscosity of the stored fluid, and means for maintaining the pressure by the stored fluid at any point on the pervious wall of said container below said substantially impervious means at a pressure less than that exerted by the subsoil water at the same point.

11. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, and means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of the container at a pressure less than that exerted by the subsoil water at the same point, said last named means including a bore hole adjacent to said cavity and communicating with a source of water.

12. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of the container at a pressure less than that exerted by the subsoil water at the same point, said last named means including a bore hole adjacent to said cavity and communicating with a source of water, and means for withdrawing the stored fluid at a point near the top of said cavity.

13. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, a shaft connecting said cavity with the atmosphere, a fluid impervious liner closing said shaft, pipe means extending through said liner, and means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of said container at a pressure less than that exerted by the subsoil water at the same point.

14. An underground container for storing water-immiscible fluids having specific gravities less than that of water comprising a cavity in the earth having pervious walls exposed to external subsoil water and having a water layer in the bottom thereof, means for varying the level of said water layer, said means providing a water column substantially isolated from the stored fluid and in communication with said water layer beneath the stored fluid, means for maintaining the pressure exerted by the stored fluid at any point on the pervious wall of the container at a pressure less than that exerted by the subsoil water at the same point, and heating means for lowering the viscosity of the stored fluid.

HARALD EDHOLM.

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