March 21, 1961 C. ARNE 2,975,927

STORAGE TANK

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Fig. 1.

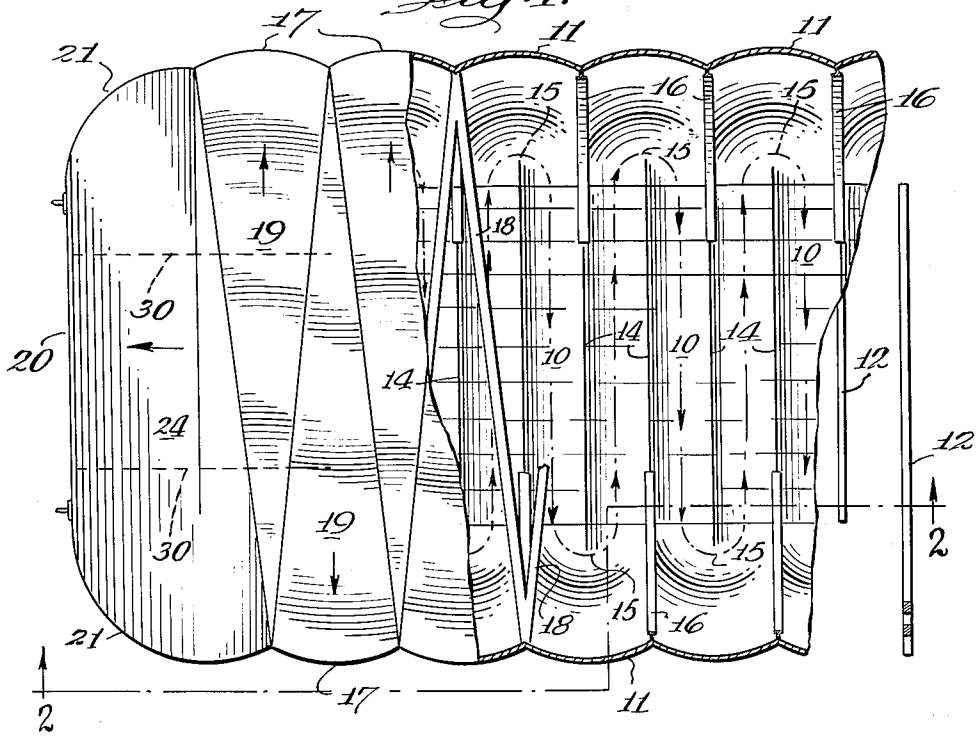
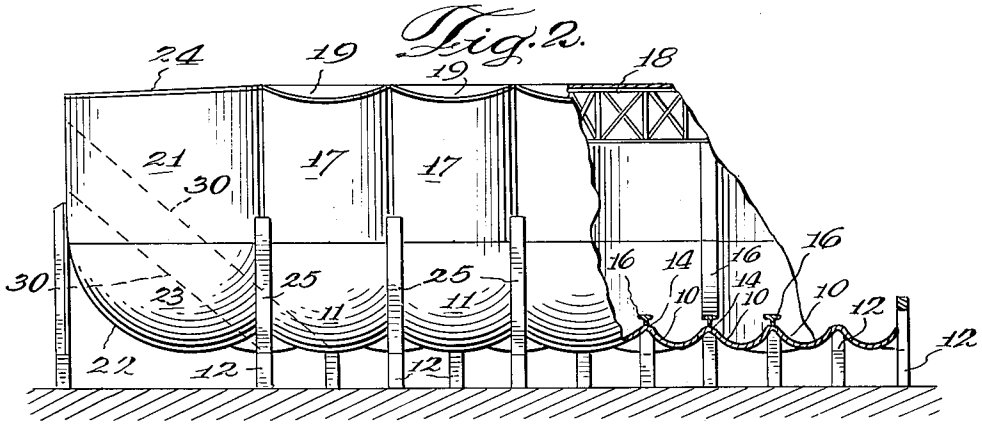


Fig. 2.



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Fig. 3.

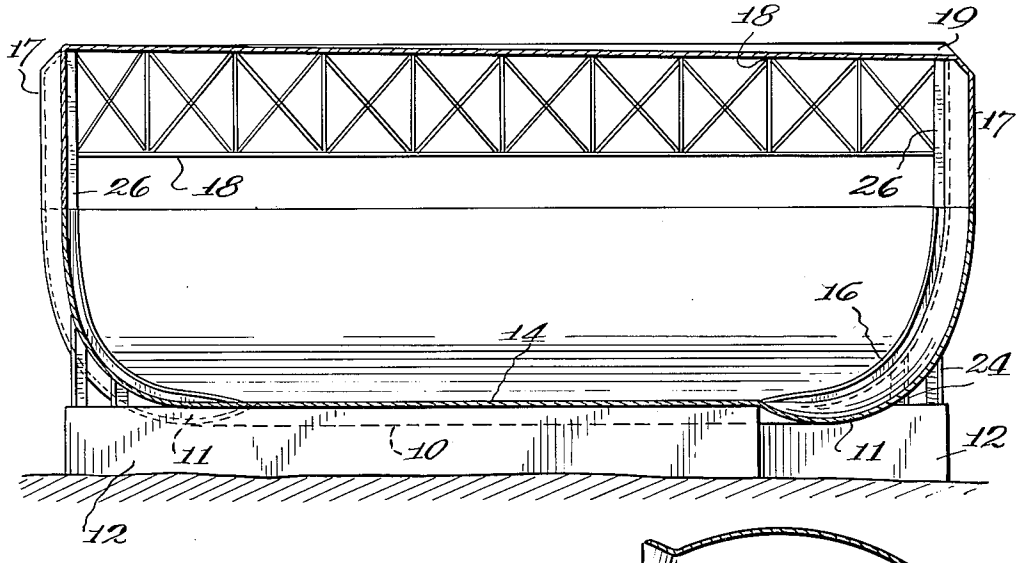
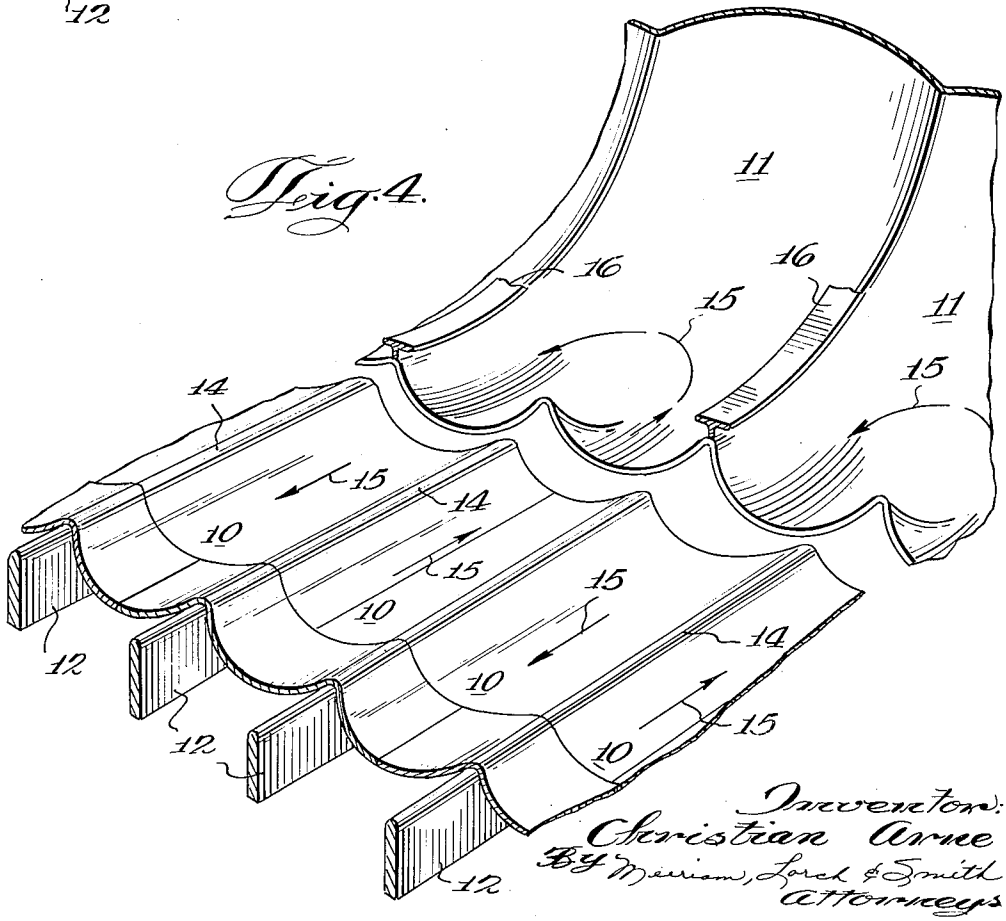


Fig. 4.



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2,975,927

STORAGE TANK

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11 Claims. (Cl. 220—1)

This invention relates to a storage tank. It is particularly directed to storage tanks having large capacities.

In large capacity, cylindrical, field storage tanks having capacities in excess of 200,000 barrels, stresses are developed in the shell plates which require the use of plates of a considerable thickness. For example, the plates employed in the lower shell courses of a conventional 200,000 barrel oil storage tank are 1¼ to 1½ inches thick. Accordingly, large capacity, cylindrical, storage tanks have a high, and therefore uneconomical, ratio of pounds of metal used per unit of liquid stored. In addition, the welded seams of the heavy steel plates must be stress relieved. This must be done in the field which is inconvenient and undesirable.

According to this invention, there is provided a storage tank of modular construction having a low ratio of pounds of metal used per unit of fluid stored which can be built in a wide variety of sizes and capacities. The tank is so designed that the bottom and side portions are subjected only to membrane stresses, and no primary bending stresses, thereby permitting relatively thin shell plates to be more efficiently utilized because of the higher allowable stresses permitted when membrane stresses only need be considered. A tank built in accordance with this invention has a serpentine bottom channel which facilitates complete drainage of the tank, leaving no "dead storage" in the tank. The tank roof, which is constructed inexpensively of flat plates, forms a plurality of conical segments which permit rapid drainage of rain water from all portions of the roof.

Figure 1 shows a partially cut away plan view of a preferred embodiment of this invention, in which the left hand portion shows the tank with roof in place, the left center portion shows the roof plates removed but the roof girders in place, the right center portion shows the roof plates and roof girders removed but the bottom and bottom reinforcement in place, and the extreme right hand portion shows the bottom and bottom reinforcement removed but the bottom supports in place.

Figure 2 shows a partially cut away elevation view of the tank of Figure 1, being cut away approximately in the same manner as described above as to Figure 1.

Figure 3 is a vertical cross sectional view of the tank of Figure 1.

Figure 4 is a fragmentary perspective view of a portion of the bottom illustrating the serpentine continuous channel bottom and the toroidal transition elements interconnecting adjacent channels and providing a base for the cylindrical wall elements.

Referring to the drawings, the preferred illustrative specific embodiment has a bottom composed of a plurality of horizontal cylindrical segments 10 joined at their ends to a plurality of toroidal segments 11. The bottom rests upon a plurality of horizontal supports 12 which may be made of concrete, steel, or other suitable material. The cylindrical portions of the bottom rest against and are supported by the supports 12 along the lines of juncture 14 of adjacent cylindrical segments. The toroidal segments 11 which join adjacent cylindrical segments at their respective ends are so placed as to be staggered with respect to opposed ends of said cylindrical segments, thus achieving a bottom having a serpentine trough indicated generally by serpentine dotted line 15. At the lines of juncture between adjacent toroidal segments a plurality of curved reinforcing members 16 are located.

The side walls of the tank are composed of a plurality of vertical cylindrical segments 17 joined at their bottom ends either to the toroidal bottom end segments 11 or to a transition section located between toroidal segments 11 and cylindrical segments 17.

A plurality of roof girders 18 is arranged in zigzag pattern between the opposed vertical lines of intersection of the vertical cylindrical segments 17 forming the side walls. The word "girder" as used here encompasses both the single member type and the truss type of girder. A roof deck is laid over these roof girders 18 and is supported thereby. A preferred type of roof is illustrated. In this embodiment the roof is made of thin plates which span the zigzag arrangement of the roof girders 18. The dead load weight of the roof deck causes the portions of the deck between girders to sag down, the amount of sag being proportional at any point to the span between girders, thereby forming a plurality of opposed conic segments 19 which afford drainage slope in the direction shown by the arrows.

In the illustrative embodiment the end closures of the tank are of somewhat different construction, in that the end wall 20 is a flat plate connected at its vertical edges to cylindrical segments 21 and at its bottom edge to a cylindrical end segment 22. Two toroidal end transition segments 23 having the same peripheral outline as toroidal segments 11 accomplish the joining of bottom end segment 22 to the vertical cylindrical end closure segments 21. The roof area 24 over the end closure portions is supported by any convenient means, such as by rafters extending from the closest roof girder to the upper edge of the end wall. It is desirable to slope this portion of the roof slightly so as to provide for drainage of rain water. Other end wall designs can also be used. For example, instead of flat end wall panels, the end wall could be vertically scalloped using a construction similar to that employed in fabricating the side walls. A horizontally scalloped end wall can also be used.

When the tank is either partly or totally full of stored liquid, there will be a hydrostatic force acting outwardly against the end wall 20, and it is therefore necessary to brace the end section by suitable reinforcing of the end wall section 20 to keep it from buckling. This can be done by means of internal trusses 30 (shown schematically in the drawings) extending diagonally from the end wall 20 to one or more bottom supports 12. Other trussing can also be employed and the design of such trusses is well known in the art.

Figure 3 is a vertical cross section taken through the plane 3—3 of Figure 2, except that certain lines which ordinarily would be in the background and which would detract from the clarity of the drawing have been omitted. As can be seen from Figure 3, the central portion of the bottom 14 rests upon the spaced, horizontal, parallel supports 12 with the cylindrical segments 10 of the bottom draping down between adjacent parallel supports, forming a trough 15. The toroidal end segments 11 of the bottom are attached to the respective ends of the horizontal cylindrical segments 10, said toroidal end segments being staggered at the opposing ends of each horizontal cylindrical segment so as to form a serpentine trough 15 represented by the dotted line in Figures 1 and 4. Where the tank bottom curves upward to connect with the side walls it does not rest against the spaced horizontal supports 12 and it is therefore neces-

sary to reinforce the bottom in these regions by means of curved reinforcing girders 16 attached at the lines of intersection of adjacent toroidal bottom segments. As shown in the preferred embodiment, the curved reinforcing girders 16 are located inside the tank, but it should be understood that they may as well be placed outside the tank at the same lines of intersection. Columns 25 are placed on supports 12 so as to help carry the vertical load of the stored liquid acting against the toroidal end segments 11 of the bottom. Vertical cylindrical segments 17 are attached to the toroidal end segments 11 to form the scalloped side walls of the tank. A pair of roof girders 18 extend across the tank from each cusp formed at the juncture of the sidewall cylindrical segments. The girders are arranged in a zigzag pattern to support the roof and also to restrain the side walls against a tendency to spread apart when liquid is in the tank. A plurality of roof panels 19 is used to span the girders 18. Because of the arrangement of roof girders 18 employed, the portions of the roof panels between adjacent girders, if fabricated from a sufficiently thin sheet of metal, drape down so as to form a plurality of opposed conic segments which facilitate drainage. In Figure 3, the sectioned portion of the roof is shown to drain from the left toward the right of the figure.

In order to provide increased stiffness at the lines of juncture between adjacent vertical cylindrical segments forming the side walls of the tank, and also in order to help carry the vertical load of the roof and roof girders, flanges 26 can be attached to the side walls at the lines of juncture of adjacent cylindrical side wall segments 17.

Other expedients can also be utilized in joining the edges of the bottom toroidal and side wall elements in assembling the storage tank of this invention. For example, structural H-shapes can be used to provide the stiffeners employed in conjunction with the toroidal elements and side walls whereon the toroidal elements and side walls are affixed along the opposed edges of one flange.

Suitable inlet and outlet fittings, which for convenience are not shown, are installed in the tank where desired to effect the loading and unloading. It is preferred that the outlet means be positioned in the bottom of the trough segments in order to take advantage of the absence of "dead storage" in the bottom of the tank. Positioning of these inlet and outlet means will, of course, depend upon the service in which the tank is used.

The tank shown in the drawings and described in the foregoing description has the advantage of unlimited size. Being of modular design, the length of the tank may be increased by adding additional identical components. This flexibility of design provides a storage tank especially adapted for large tanks having a liquid storage capacity in excess of 500,000 barrels. The instant invention, however, can also be used for smaller tanks, if desired.

No allowance need be made for thermal expansion or contraction resulting from temperature variations either of the atmosphere or of the stored product, because the entire unit acts in a sylphon bellows-like manner. That is, thermal expansion and contraction of the tank materials merely causes an increase or decrease in the curvature of the cylindrical, toroidal, or other arcuate segments which make up the tank, and the over-all lineal dimensions from end wall to end wall remain constant. The dimensions from side wall to side wall can, of course, be limited to practical thermal tolerances.

In fabricating the tank conventional materials of construction are used. Steel, however, is generally used. Because all of the plate members of the storage tank of this invention are in tension when the tank is in service, the plate members of the tank are being used most efficiently. This permits the use of plate thicknesses considerably less than those required for conventional cylindrical tanks of corresponding capacity. Accordingly large tanks having capacities in excess of 500,000 barrels can be constructed in accordance with this invention using steel plates of the type steel normally used for such construction having thicknesses within the range of about ¼ to ½ inch instead of plates having thicknesses of 1¼ to 1½ inches required for the construction of cylindrical tanks of conventional design. Obviously, plate thicknesses outside this range can be used if desired.

The instant invention is especially adaptable for tanks having a capacity of 500,000 barrels or more although it can be employed in the construction of smaller capacity tanks. In the construction of a 500,000 barrel crude petroleum oil storage tank, the cylindrical segment troughs forming the bottom portion of the tank are 80 feet long and are formed from ⅜ inch thick steel plate to have a radius of curvature of 22 feet. The width of the trough is 16 feet. Each trough spans a pair of horizontal foundation supports located on 16 feet centers. The toroidal segments forming the return bend for each pair of contiguous trough elements and the transition element for joining the side walls to the bottom portion are shaped from ⅜ inch thick steel plate and have a compound curved surface generated by rotating a curve having a first, circularly arcuate portion having a radius of 22 feet and a second arcuate portion having a radius of curvature in the vertical direction gradually increasing from 22 feet to 48 feet, and at the top having a radius of 32 feet about the axis of revolution. The first portion which is connected to the bottom portion has a vertical height at least as great as the height of the bottom portion. As it was noted above, the radii of the transition section change within the height from above the bottom to below the vertical cylindrical sides as desired. The axis of revolution is positioned at the terminal extremity of the juncture between adjacent bottom troughs. The radius of the generated surface about the axis of revolution at a vertical height of 32 feet will be 32 feet; the upper portion of the toroidal transition connects with side wall cylindrical segments 32 feet wide and is shaped to a 32 foot radius about the axis of revolution from ⅜ inch steel plate. The end section assemblies are similarly fabricated to provide 32 foot modular units from corresponding thicknesses of steel plate with the end wall being a 5/16 inch thick plate. The height of the tank is 52 feet, and its width is 144 feet. The total length is 408 feet.

In the foregoing discussion reference was made to bottom cylindrical segments. It is preferred that such cylindrical segments be circular cylindrical segments. They can, if desired, be cylindrical segments having an arcuate cross section in the shape of a catenary or a similar noncircular curve. In either instance the arcuate cross section of the segment is selected to provide a tank bottom portion in which all of the plate members are subject only to membrane stresses and to eliminate substantially all of the bending stresses from the bottom plate members. Each cylindrical segment can be formed as an individual trough or fabricated from a series of staggered plate members formed to permit the construction of several segments upon assembly of the individually formed plate members. In employing this latter method of construction plate members long enough to be supported on two foundation supports are used with sufficient overlap to form one-half of the next adjacent trough.

Likewise, the toroidal bottom segments need not be of the shape of a circle revolved about an axis. In fact, the desired shape for such segments is a curve of the same cross section as that of the cylindrical bottom segments, revolved about an axis. In most instances the axis of revolution will intersect the curve which is generated into the toroidal transition segment as shown in the illustrative embodiment because the preferred cylindrical bottom segment is less than a hemicircle.

Where the bottom segment has a hemicircular cross section the axis of revolution will be tangential. Where the bottom cylindrical segment is circularly arcuate, the radius of the circle used as a circle of revolution in developing a portion or all of the toroidal segment is equal to the radius of curvature of the bottom cylindrical segment. As shown in the illustrative embodiment the transition section will preferably have a compound surface. In addition to functioning as return bends for adjacent cylindrical bottom segments, the toroidal segments also serve to compensate for any imbalance in the stress pattern in the tank shell during the various stages of tank loading or unloading resulting from any difference between the hydrostatic pressure exerted on the end wall section and the tension occurring in the bottom cylindrical segment.

The stresses in the transition section are significant at the balanced stage, which in the illustrative embodiment occurs when the liquid height in the tank is at 44 feet, the total load of liquid pressure on the ends of the tank will be balanced by the tension in the bottom plates. At other liquid level stages the tension and the pressure will not be balanced. At lower stages the tension will be greater. The entire tank will tend to get shorter like an accordion. The tank, however, is kept from contracting in length by a horizontal compression stress in the plates of the transition section. At liquid heights above the balance stage the tank will tend to increase in length, but the tank is kept from getting longer by a horizontal tensile stress in the plates of the transition section.

While these changes in stress are occurring, the plates of the transition section must also sustain a tension in the vertical direction. In accordance with this invention the transition section will have a configuration which will provide a transition section which will not buckle and not be over stressed when the liquid in the tank is at any level. This latter function can be effected without the need for internally or externally bracing the upper side walls of the toroidal segment as shown in the illustrative embodiment, although bracing can be used if desired.

The vertical cylindrical side wall segments shown in the illustrative embodiment are of circular cross section, having radii equal to the arcuate configuration of the upper portion of the toroidal bottom segments to which they are attached. It is to be understood, however, that, depending on what product is stored, in some instances the sides will not be vertical, and in some instances the sides will not be cylindrical. For example, if the tank is used to store water where ice will form on the water, the sides may be sloped outward or inward in order that the horizontal pressure from the sheet of ice shall be directed toward the sides at an angle which is not 90°, but more or less than 90°. With the sides sloped in this manner the pressure within the ice will buckle and break the ice before the pressure on the sides becomes too great, and the ice sheet will be broken up along the sides as the water level is raised or lowered. If the tank is at a location where hurricanes are likely to occur it may be preferable to eliminate the side wall elements and extend the transition section to the roof line and not have any part of the side in the shape of a cylinder with its axis vertical. The side for the full height of the tank might then be formed into double curvature, or the upper part might be curved primarily in the vertical direction. By these means the side is stabilized against wind pressure, the wind forces on the roof are reduced, and the tank becomes capable of withstanding a greater internal gas pressure. The latter is especially true if the roof plates are curved upwards between trusses.

While the storage tank has been shown on supports resting on the ground surface and preferably supported by a pile cap cast in place over a sufficient number of driven piles, it should be understood that the tank may, if desired, be elevated, in which case the spaced supports might be in the form of structural bents; that is, horizontal girders resting upon vertical or battered colums.

While the invention has been shown and described to include a roof of specified conformation as well as a bottom of specified conformation, it should be understood that the container portion of the tank can be utilized with a different type of roof and roof support. For example, the roof can be similar in design to the concatinated trough bottom portion of the tank, the roof collecting all drainage water to one point. Or the roof can be similarly fabricated with the roof plates being curved upward. This latter roof design provides a structure capable of withstanding internal gas pressure. Conversely, the roof shown and described may be adapted to a tank of different character.

Although the instant invention has been illustrated by specific embodiments, variations can be made by one skilled in the art without departing from the spirit of this invention.

What is claimed is:

1. A storage tank comprising a bottom; scalloped side walls comprising an interconnected continuous series of upright cylindrical segments attached to said bottom, and end walls attached to said side walls and to said bottom; said bottom comprising a plurality of cooperating pairs of open-ended, parallel cylindrical bottom segments, the adjacent side edges of each pair being joined together in side by side relationship to form a continuous bottom, a plurality of toroidal segmental return bends, each of said return bends having its axis of rotation normal to the juncture between the individual members of each pair and interconnecting the adjacent open ends of said individual members, said return bends joining opposing ends of pairs of cylindrical bottom segments with the opposing return bends being arranged in staggered relationship each to the other with one member of each of said pairs of bottom segments being common to opposing cooperating return bends to provide a continuous serpentine trough in said bottom; said scalloped side walls being joined at their bottom edges to corresponding toroidal segmental return bends; and a plurality of spaced horizontal supports supporting said bottom, said supports being coextensive with said cylindrical bottom segments and being positioned at each juncture of contiguous bottom segments.

2. A storage tank comprising a bottom; scalloped side walls comprising an interconnected continuous series of upright cylindrical segments attached to said bottom, and end walls attached to said side walls and to said bottom, said bottom comprising a plurality of cooperating pairs of open-ended, parallel cylindrical bottom segments, the adjacent side edges of each pair being joined together in side by side relationship to form a continuous bottom, a plurality of toroidal segmental return bends, each of said return bends having its axis of rotation normal to the juncture between the individual members of each pair and interconnecting the adjacent open ends of said individual members, said return bends joining opposing ends of pairs of cylindrical bottom segments with opposing return bends being arranged in staggered relationship each to the other with one member of each of said pairs of bottom segments being common to opposing cooperating return bends to provide a continuous serpentine trough in said bottom, said scalloped side walls being joined at their bottom edges to corresponding adjacent toroidal segmental return bends; a plurality of roof girders spanning the cusp points of opposed side walls, and a roof portion supported on said girders; and a plurality of spaced horizontal supports supporting said bottom, said supports being coextensive with said cylindrical bottom segments and being positioned at each juncture of contiguous bottom segments.

3. The storage tank of claim 2 in which said roof is made of panels of flexible metallic material, whereby

said material by its own weight sags between adjacent roof girders thereby forming opposed conical segment drainage areas.

4. A storage tank comprising a bottom; scalloped side walls comprising an interconnected continuous series of upright cylindrical segments attached to said bottom; end walls attached to said side walls and to said bottom; and a roof enclosing said tank; said bottom comprising a plurality of cooperating pairs of open-ended, parallel cylindrical bottom segments, the adjacent side edges of each pair being joined together in side by side relationship to form a continuous bottom, a plurality of toroidal segmental return bends, each of said return bends having its axis of rotation normal to the juncture between the individual members of each pair and interconnecting the adjacent open ends of said individual members, said return bends joining opposing ends of pairs of cylindrical bottom segments with the opposing return bends being arranged in staggered relationship each to the other with one member of each of said pairs of bottom segments being common to opposing cooperating return bends to provide a continuous serpentine trough in said bottom; said toroidal segmental return bend being generated from a circular segment of a circle having a radius equal to the radius of said cylindrical bottom segments; said scalloped side walls being joined at their bottom edges to corresponding adjacent toroidal bottom segments; a plurality of roof girders spanning the cusp points of opposed side walls and supporting said roof; and a plurality of spaced horizontal supports supporting said bottom, said supports being coextensive with said cylindrical segments and being positioned at each junction of contiguous bottom segments.

5. A storage tank in accordance with claim 4 in which said cylindrical bottom segments have a cross section substantially less than a hemicircle and said toroidal segmental bend is generated about an axis located within the circle.

6. A storage tank comprising a bottom; scalloped side walls comprising an interconnected continuous series of upright cylindrical segments attached to said bottom; end walls attached to said side walls and to said bottom; and a roof enclosing said tank, said bottom comprising a plurality of cooperating pairs of open-ended, parallel cylindrical bottom segments, the adjacent side edges of each pair being joined together in side by side relationship to form a continuous bottom, a plurality of toroidal segmental return bends, each of said return bends having its axis of rotation normal to the juncture between the individual members of each pair and interconnecting the adjacent open ends of said individual members, said return bends joining opposing ends of pairs of cylindrical bottom segments with the opposing return bends being arranged in staggered relationship each to the other with one member of each of said pairs of bottom segments being common the opposing cooperating return bends to provide a continuous serpentine trough in said bottom; said circular bottom segments having a cross section substantially less than a hemicircle, said toroidal segmental return bend being generated from a circular segment of a circle having a radius equal to the radius of said cylindrical bottom segments and having an axis of revolution located within said circle, said adjacent toroidal segmental return bends being partially supported by curved structural reinforcing members attached and conforming to the line of intersection of said adjacent toroidal segmental return bends, said reinforcing member extending beyond the interconnection between said toroidal segmental return bend and bottom segment, said scalloped side walls being joined at their bottom edges to corresponding adjacent toroidal bottom segments; a plurality of roof girders spanning the cusp points of opposed side walls and supporting said roof; and a plurality of spaced horizontal supports supporting said bottom, said supports being coextensive with said cylindrical bottom segments and being positioned at each juncture of contiguous bottom segments.

7. A tank in accordance with claim 6 in which said upright cylindrical segments comprise segments of a circular cylinder having radii equal to the distance from the axis of revolution to the point of vertical tangency of said toroidal segments.

8. A storage tank comprising a bottom; scalloped side walls comprising an interconnected continuous series of upright cylindrical segments attached to said bottom and end walls attached to said side walls and to said bottom, said bottom including a plurality of cooperating pairs of open-ended, parallel cylindrical bottom segments, the adjacent side edges of each pair being joined together in side by side relationship to form a continuous bottom, a plurality of toroidal segmental return bends, each of said return bends having its axis of rotation normal to the juncture between the individual members of each pair and interconnecting the adjacent open ends of said individual members, said return bends joining opposing ends of pairs of cylindrical bottom segments with the opposing return bends being arranged in staggered relationship each to the other with one member of each of said pairs of bottom segments being common to opposing cooperating return bends to provide a continuous serpentine trough in said bottom, said circular bottom segments having a cross section substantially less than a hemicircle, said toroidal segmental return bend being generated from a circular segment of a circle having a radius equal to the radius of said cylindrical bottom segments and having an axis of revolution located within said circle, said adjacent toroidal segmental return bends being partially supported by curved structural reinforcing members attached and conforming to the line of intersection of said adjacent toroidal segmental return bends said reinforcing member extending beyond the interconnection between said toroidal segmental return bend and bottom segment, said scalloped side walls being joined at their bottom edges to corresponding adjacent toroidal segmental return bends; a plurality of roof girders spanning the cusp points of opposed side walls, and a roof portion supported on said girders, said roof being made of panels of flexible metallic material, whereby said material by its own weight sags between adjacent roof girders thereby forming opposed conical segment drainage areas; and a plurality of spaced horizontal supports supporting said bottom, said supports being coextensive with said cylindrical bottom segments and being positioned at each juncture of contiguous bottom segments; and a plurality of upright columns resting on said horizontal supports and supporting said toroidal segments.

9. A storage tank having a bottom portion comprising a plurality of cooperating pairs of open-ended, parallel cylindrical bottom segments, the adjacent side edges of each pair being joined together in side by side relationship to form a continuous bottom, a plurality of toroidal segmental return bends, each of said return bends having its axis of rotation normal to the juncture between the individual members of each pair and interconnecting the adjacent open ends of said individual members, said return bends joining opposing ends of pairs of cylindrical bottom segments with the opposing return bends being arranged in staggered relationship each to the other with one member of each of said pairs of bottom segments being common to opposing cooperating return bends to provide a continuous serpentine trough in said bottom portion; and a plurality of spaced horizontal supports supporting said bottom, said supports being coextensive with said cylindrical bottom segments and being positioned at each juncture of contiguous bottom segments.

10. A storage tank in accordance with claim 9 in which the surface of said toroidal segmental return bends has a compound curvature.

11. A storage tank having a bottom comprising a plurality of cooperating pairs of open-ended, parallel cylin-

drical bottom segments, the adjacent side edges of each pair being joined together in side by side relationship to form a continuous bottom, a plurality of toroidal segmental return bends, each of said return bends having its axis of rotation normal to the juncture between the individual members of each pair and interconnecting the adjacent open ends of said individual members, said return bends joining opposing ends of pairs of cylindrical bottom segments with the opposing return bends being arranged in staggered relationship each to the other with one member of each of said pairs of bottom segments being common to opposing cooperating return bends to

provide a continuous serpentine trough in said bottom the surface of said toroidal segmental return bends having a compound curvature; end walls mounted on the opposed ends of said bottom portion; and a roof enclosing said storage tank and spanning the opposed free upper terminal ends of said toroidal segmental return bends.

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