

March 29, 1927.

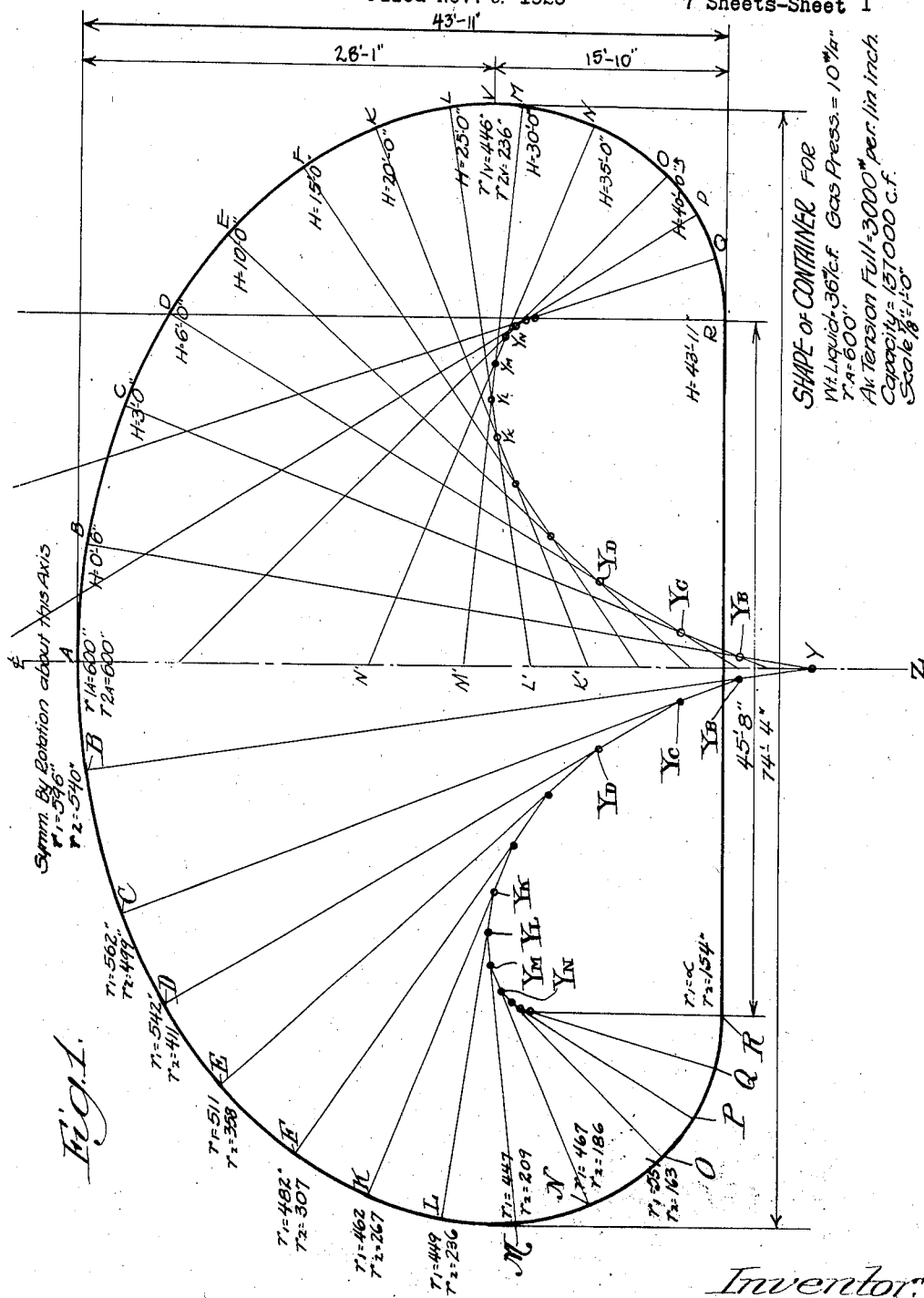
G. T. HORTON

1,622,787

CONTAINER

Filed Nov. 5. 1925

7 Sheets-Sheet 1



SHAPE OF CONTAINER FOR

Wt. Liquid = 367 c.f. Gas Press. = 10 ³/₄"
T.A. = 600"
Air Tension Full = 3000 ³/₄ per. lin inch.
Capacity = 137000 c.f.
Scale ¹/₈" = 1'-0"

At Tension Full=3000⁺ per lin inch.
Capacity=137000 c.f.
Scale $\frac{7}{8}$ "=1'-0"

Capacity = 101,000 cu. ft.
Scale $\frac{1}{8}" = 1'-0"$

Fig. 1.

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Atkins

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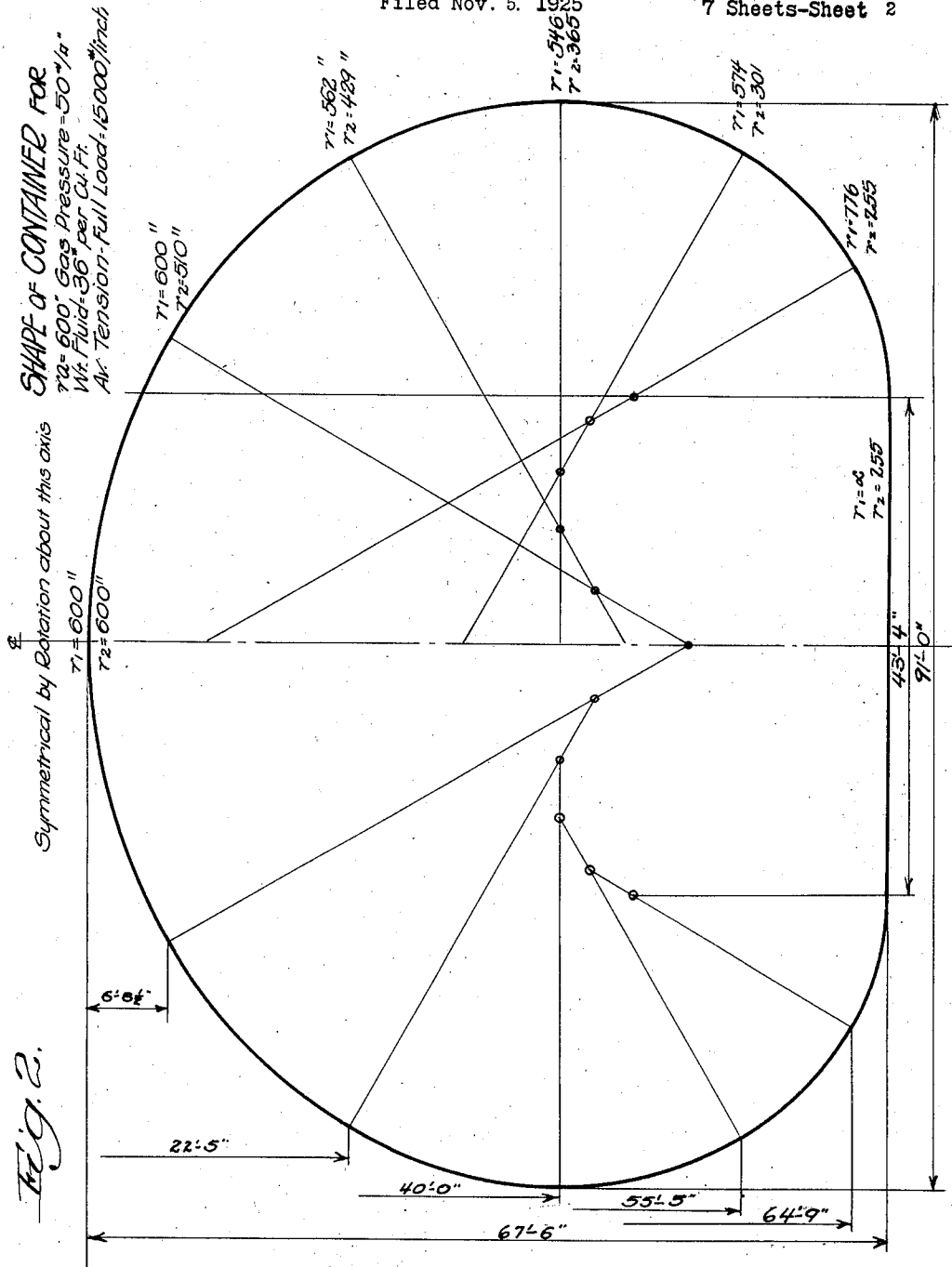
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1,622,787

CONTAINER

Filed Nov. 5, 1925

7 Sheets-Sheet 2



Inventor:
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March 29, 1927.

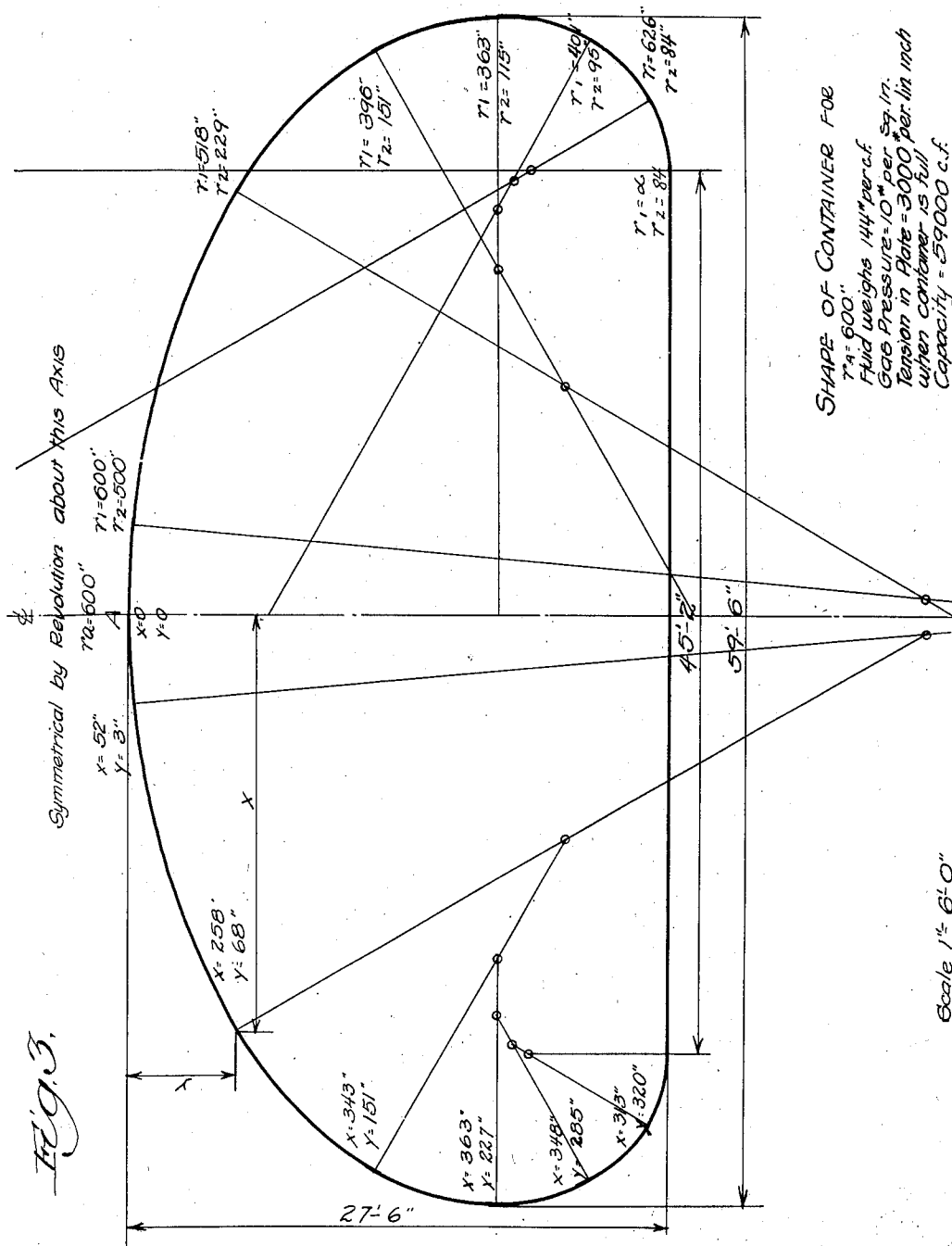
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G. T. HORTON
CONTAINER

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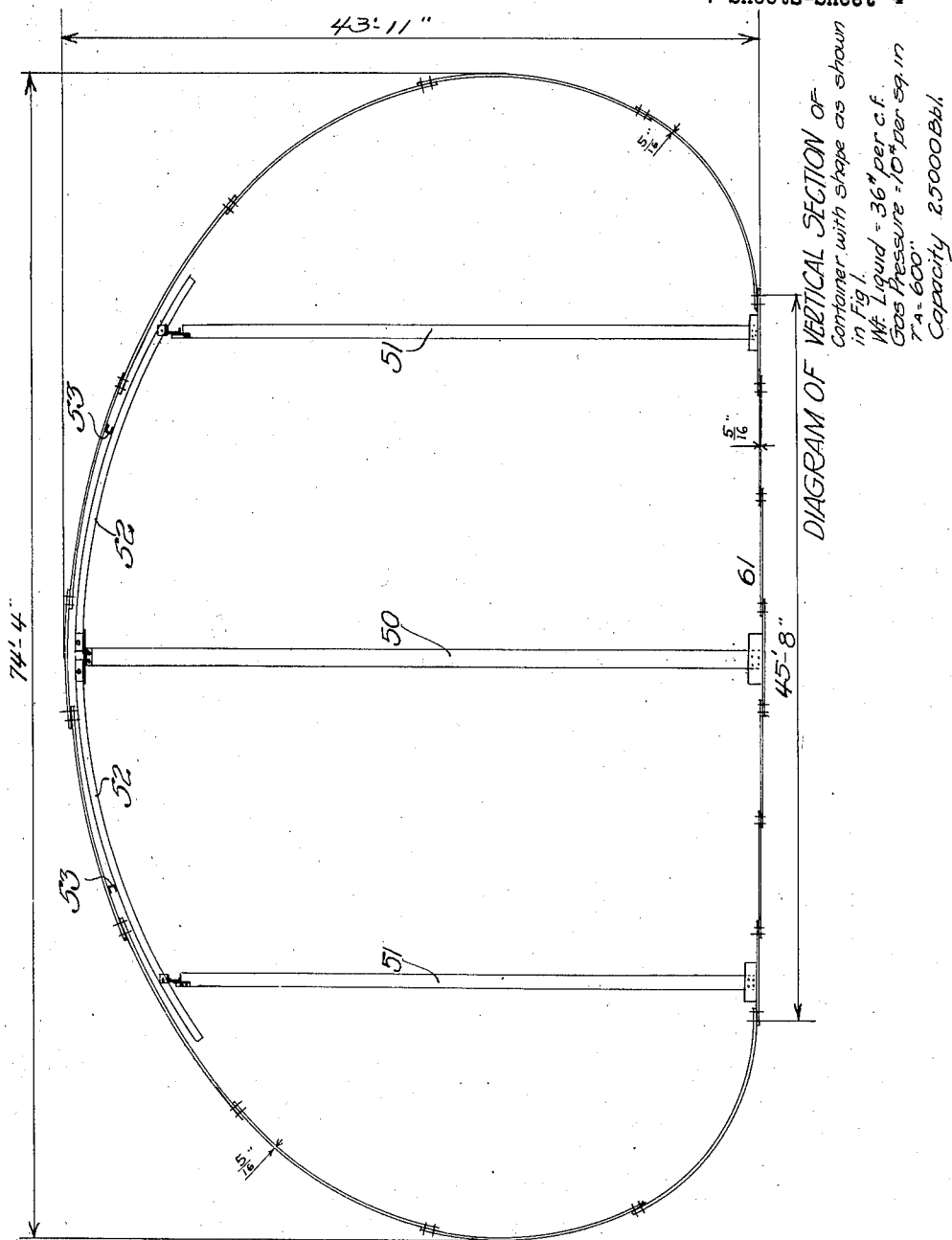


Fig. 4.

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1,622,787

CONTAINER

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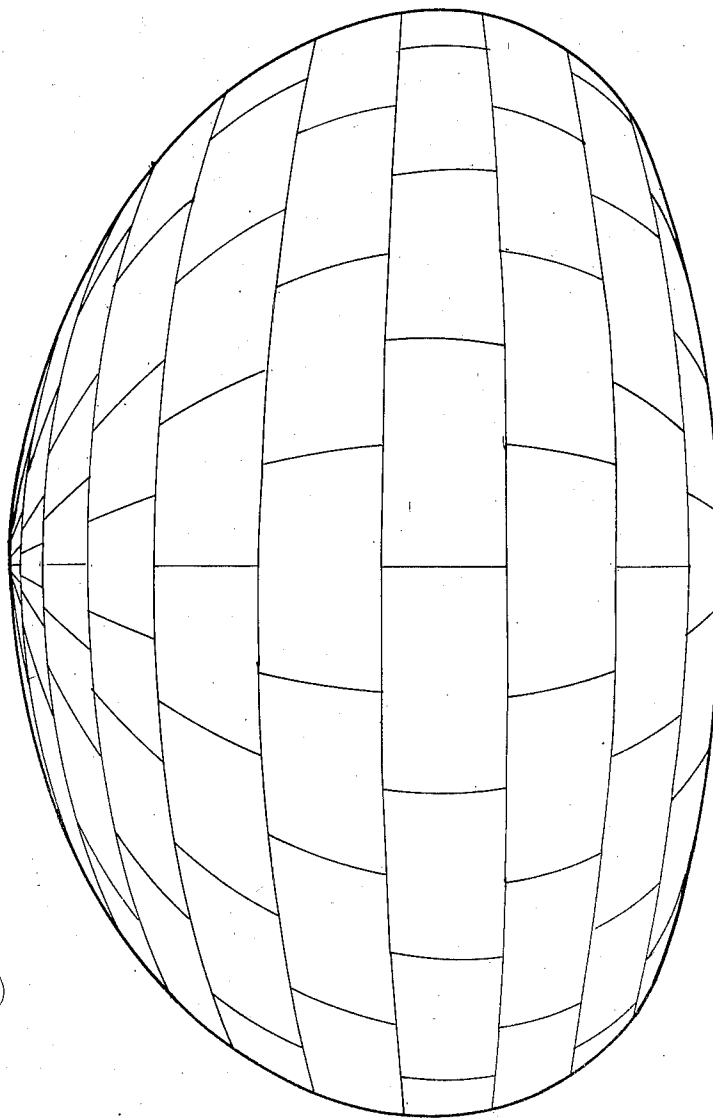


Fig. 5

PERSPECTIVE
of Container
74'-4" Diam. x 43'-11" High

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x = Horizontal radius at any point

d = Vertical distance from top of tank at any point

r = Radius of curvature at any point in plane perpendicular to paper

r_2 = Radius of curvature at any point in plane of paper

$\bar{P}$ = Pressure at any point

P_a = Average pressure on horizontal section at any point.

Volume A represents total upward pressure due to gas

Volume B represents total upward pressure due to liquid

Volume C represents total downward pressure due to liquid

T_1 = Stress in shell at any point in horizontal direction

T_2 = Stress in shell at any point in vertical direction

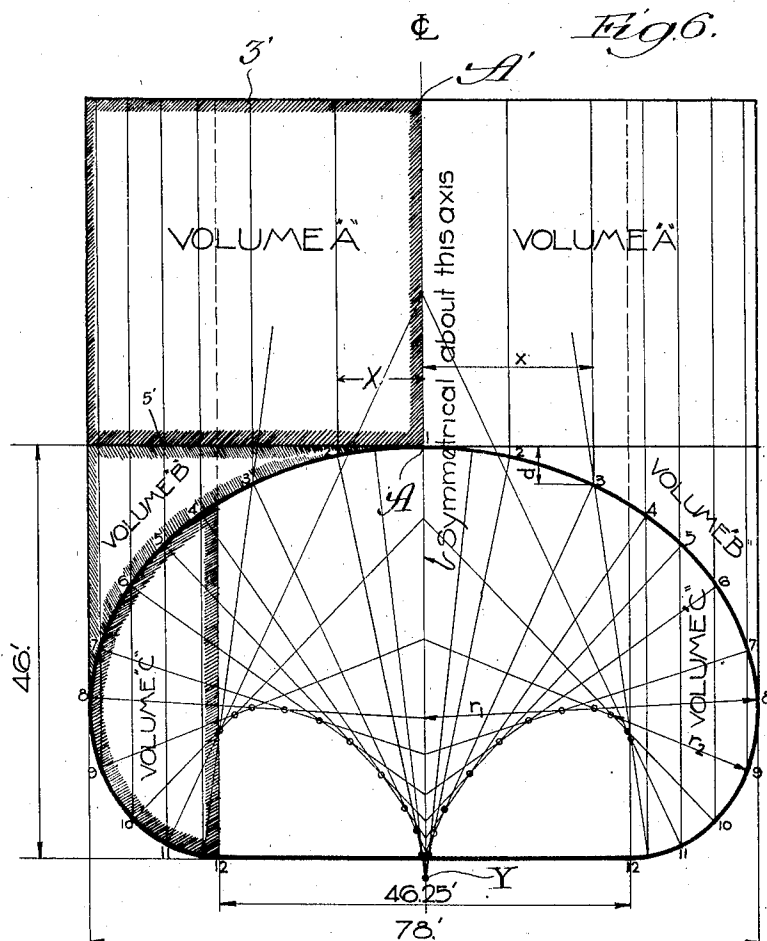


Fig. 6.

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1,622,787

CONTAINER

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Fig. 7.

PROPERTIES OF CURVE & THEORETICAL STRESSES

X	Y	Depth	r	h	Gas	Liquid	Total	Total upward	Aver press	T ₂ /in	T ₁ /in	T ₂ /in	T ₁ /in	T ₂ /in	T ₁ /in
in	in	ft	ft	ft	#/sq	#/sq	press	# force due to	#/sq	Liquid	Gas	Liquid	Gas	Liquid	Gas
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	10	34	10	42	0	0	10.27	7600	17	3000	2800	2950	2720	50	100
3	20	125	42	47.2	10	107	11.07	101700	56	2990	2820	2830	2320	160	410
4	26	2150	78	47.3	10	197	11.97	294000	97	3000	2860	2720	2170	260	750
5	30	2830	111	44.0	10	278	12.78	536000	132	2990	2500	2650	1530	350	930
6	34	3640	156	42.0	10	390	13.90	930000	178	3000	2450	2520	1260	450	1300
7	38	4750	231	40.1	10	578	15.78	1570000	240	3000	2300	2410	550	580	1750
8	39	4790	286	39.2	10	715	17.15	1810000	262	3020	2100	2350	50	620	2140
9	38	4750	370	40.8	10	925	19.25	1478000	226	2900	2400	2450	6735	550	3250
10	34	3640	433	49.0	10	1008	20.08	-162400	-0.31	3040	2240	2950	63520	6100	6260
11	30	2830	460	70.5	10	1150	21.50	-1175000	-2.90	3000	2900	4250	612800	61250	16000
12	24	1820	470	∞	10	1175	21.75	-2750000	-10.00	3000	3000				

Inventor:
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UNITED STATES PATENT OFFICE.

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CONTAINER.

Application filed November 5, 1925. Serial No. 67,094.

This invention relates to improvements in containers and is here shown as embodied in a container especially adapted for holding liquids under pressure. For example, in the storage of volatile liquids such as gasoline, crude petroleum and the like, in open tanks there is a certain loss by evaporation. If the tank is closed, this loss by evaporation may be prevented but there is then created in the tank a certain amount of internal pressure depending upon the vapor pressure of the liquid stored. The amount of vapor pressure, of course, depends upon several factors such as the volatility of the liquid and the temperature. If the tank or container, however, is closed and able to withstand the internal pressure created, loss by evaporation is prevented.

One of the objects of my invention is to design a container which will withstand such vapor pressure. Where the container is designed to withstand a certain maximum vapor pressure, a safety valve, or other suitable vent, may be provided to permit escape of the vapor in the event that the maximum pressure should, for some reason or other, be exceeded.

Obviously, in addition to this vapor pressure which is the same at all points on the shell, there is the additional pressure caused by the weight of the liquid itself or the head. This pressure, obviously depends upon the density or weight of the liquid, and varies at different points on the container depending upon the head of the liquid or height of the liquid above the particular point.

One of the principal objects of my invention is to provide a closed container of the kind described, for the storage of liquids under pressure, of such a shape that the vertical tension is substantially the same at every point on the shell. In a container of this type the horizontal tension is always less than the vertical tension. By tension, I mean the stress on the shell tending to make it part, break, or rip at a particular point. There is a great advantage in making a container of this kind of such a shape that this tension will be substantially the same at every point; because when so made, the material of which it is composed may be of a uniform thickness. For example, by the use of my invention a closed tank may be made designed for the storage, for example, of gasoline of a certain specific grav-

ity with a certain vapor pressure. The shape of the tank, if made by the use of my invention, would be such that when filled with gasoline of the given density, and subject to an internal pressure equal to the given vapor pressure plus the liquid pressure of the gasoline, the tension or stress in a vertical direction on all points of the shell would be the same. In such a tank, therefore, material of a uniform thickness could be used. Since, in a container of this type, the horizontal tension is always less than the vertical tension, it is sufficient if such vertical tension is substantially the same at every point on the shell. The vertical tension is always greater than the horizontal tension because, at every point on the shell, the radius of curvature in the vertical plane is less than the radius of curvature in the plane at right angles thereto. The shell then must be strong enough to withstand such vertical tension, and the horizontal tension can be disregarded. If such vertical tension, which is always greater, is substantially the same at all points on the shell, the shell may be made of material of a uniform thickness. Since, in making containers of this kind, it is necessary to have the material thick enough to withstand only the vertical or the horizontal tension, whichever is greater; and since the lesser of these two tensions always may be disregarded; hereinafter, in using the term tension only, it is to be understood that I refer always to the greater of the two tensions. It is also to be understood, that in containers embodying the features of this invention, that the greater of such two tensions is always the vertical. In speaking of the vertical plane at any point on the shell, I refer to such a vertical plane passing through a line normal to the surface at such point; and in speaking of a plane at right angles to such vertical plane, I also refer to a plane passing through a line normal to the surface.

One of the features of the invention, is the making of the container in such a shape that material of a uniform thickness can be used throughout. Obviously, the construction of the shell is thus greatly simplified. All that is necessary, is to compute the thickness of the metal necessary to withstand the tension at any given point; and this metal may be used for the entire shell, provided it is made in the proper shape. In the case of a container for holding a liquid where there

is no vapor pressure, or other internal pressure, except that resulting from the weight or head of the liquid itself, the tension on the shell is always greater near the bottom than at the top. This is due to the increase in the weight or head of the liquid toward the bottom. In such containers, therefore, the shell must be made thicker at the bottom than at the top. In the case of a container such as contemplated by this invention, however, where there is a certain amount of vapor or other internal pressure inside of the shell in addition to the pressure caused by the weight or head of the liquid itself, I have found that by making the container in the proper shape, the tension can be made to be substantially the same at all points on the shell; with the result that material of uniform thickness can be used throughout.

It is to be understood, also, that although I speak of vapor pressure, I do not intend to be limited to this particular kind of internal pressure. Broadly, my invention contemplates the construction of a closed container adapted to hold a liquid, there being confined in said container a certain internal pressure in addition to the pressure caused by the mere weight or head of the liquid. This internal pressure may be caused by vapor pressure from the liquid itself, or may arise from any other cause. For example, it might be desired to make a container adapted to hold water, there being in said container also a certain amount of air pressure. In such case, the weight of the water being known, and the air pressure also being known, by the practice of my invention, the container could be so shaped that the tension at all points would be substantially the same thus permitting the use of material of a uniform thickness throughout. Such a container for water with additional air pressure therein might be used, for example, in connection with water supply systems in which the storage tank is located at a lower level than the outlets; and a certain amount of air pressure introduced into the tank in order to cause the water to flow up to the outlets at a desired pressure.

In speaking of a container for a liquid having inside an additional internal pressure such as vapor pressure, it is to be understood, also, that there may be, and usually must be, a certain amount of space at the top of the container free from liquid. Theoretically, this space may be exceedingly small and possibly eliminated. In determining the shape of the container, I am disregarding this space at the top which is free from liquid. This space may be quite small; and by disregarding the same, it merely follows that I disregard the absence of pressure resulting from the absence of weight or head of liquid in this space. It is obvious, however, that

since this space is comparatively small and at the top, that any pressure which might result from the weight or head of liquid therein is negligible. In any event, as will be seen hereinafter, in the practice of my invention, in determining the shape of the container, it is assumed that the container is entirely filled with liquid; with the result that, if, in fact, there is a space at the top free from liquid, it merely follows that the pressure or tension of the shell at the top and surrounding the space is assumed to be slightly larger than it actually is. Since the metal is thick enough to withstand the tension so computed, it is obvious it is also thick enough to withstand any lesser tensions that there might be at the top if the tank is not entirely filled with liquid.

It is obvious that, although a tank be designed for a certain liquid and a certain vapor pressure, that in actual use there may be variations in the density of the liquid contained in the tank, the amount of liquid in the tank, or in the actual internal pressure. In the practice of my invention, therefore, the container preferably should be designed for a certain liquid and a certain normal vapor pressure; but should have sufficient rigidity and sufficient excess of tensile strength to permit suitable variations from the normal conditions for which the tank is designed. Suitable safety valves or vents may also be provided to relieve pressures which might exceed the margin of safety.

In general, the shape of the tank resembles the shape of a drop of mercury resting on a flat surface such as, for example, glass. Or it may be stated that in general the container will have somewhat the same shape that would naturally be assumed by a container with a flexible wall if filled with a given liquid and also containing the given vapor or other internal pressure. That is, it is spheroidal in shape with a flattened bottom, or, it may be described as being a flattened sphere with a flat circular bottom. It is also a solid of revolution about a vertical axis. The relative proportions of the tank will vary depending upon the weight of liquid it is to contain and the amount of vapor or other internal pressure inside of the tank. It may be stated, in general, that increasing the vapor pressure tends to make the container somewhat higher in proportion to its width; and increasing the weight of the liquid inside tends to make it somewhat wider in proportion to its height. In other words, the particular shape will depend upon the particular liquid and particular vapor pressure considered as normal for which the tank is designed. I will show how the particular shape for any tank can be determined for any liquid and any vapor or other inter-

nal pressure which may be chosen as normal.

After the shape has been determined, the tank may be built in a number of ways; preferably, by riveting, welding, or otherwise fastening together plates, each of which has been previously formed to the required curvature for its position in the completed structure.

In the accompanying drawings, Figure 1 is a diagrammatic central vertical sectional view showing the shape of a container designed for a liquid weighing 36 pounds per cubic foot and a vapor pressure of 10 pounds per square inch, Fig. 2 is a similar view showing the shape of a container designed for a fluid weighing 36 pounds per cubic foot and a vapor pressure of 50 pounds per square inch, Fig. 3 is a similar view of a container for fluid weighing 144 pounds per cubic foot and a vapor pressure of 10 pounds per square inch, Fig. 4 is a diagrammatical vertical section of a completed tank made in the shape shown in Fig. 1, Fig. 5 is a view in perspective of a container similar to the one shown in Fig. 4, Fig. 6 is a diagram showing a graphical method of determining the shape of a container embodying the features of my invention, and Fig. 7 is a table showing the properties of the curve shown in Fig. 6 and the theoretical stresses on a container shaped according to such curve.

I will now describe more in detail the method of determining the curvature or shape of a tank embodying my invention. The density or specific gravity of the liquid to be stored is known. The vapor pressure or other internal pressure (in addition to that caused by the weight of the liquid) which the tank is to withstand as normal is also known. Assume that this vapor pressure is ten pounds per square inch and that a cubic foot of the liquid weighs 36 pounds. In designing the tank it may be assumed that it is full or substantially full of liquid as a normal condition. These are the conditions assumed in plotting the curve shown in Fig. 1. The line A—Z indicates the vertical central axis of the tank extended downwardly. A therefore indicates the topmost point of the tank. On the line A—Z there is laid off the line A—Y which is the radius of curvature at A. This radius may be taken any desired length and determines the capacity of the tank. As the capacity is made larger, however, the tension on the shell increases and consequently stronger material must be used. The radius A—Y is chosen, therefore, to give the desired capacity provided the material has sufficient strength to withstand the resulting tension. Since the completed tank is in the shape of a spheroid, there are obviously at each point two curvatures in planes at right angles to

each other. At each point I will represent the two radii of the curvature by r_1 and r_2 , respectively. r_2 indicates the radius of the curvature lying in the plane of the paper (the vertical plane of the tank), and r_1 indicates the radius of the curvature lying in a plane at right angles to the paper (it being understood that both of such planes pass through a line normal to the surface at such point). Since the tank is a solid of revolution, r_1 in each case will be the length of a line normal to the curved surface at any point on the surface from such point produced until it meets the line A—Z. In other words, for any points on the surface r_1 will be equal to r_2 produced until it intersects the line A—Z. At the point A obviously r_2 and r_1 will be equal. Under the assumed conditions the pressure at A will be ten pounds per square inch since this was taken to be the normal internal pressure. There being no height of liquid above A, or head, the only pressure at A will be ten pounds. r_2 at A is taken as the distance A—Y which, as stated before, may be any desired distance depending upon the capacity desired. Since r_1 is equal to r_2 at A, r_1 at A is also represented by the distance A—Y.

The vertical tension at any point on the shell equals the pressure at that point divided by

$$\frac{1}{r_2} + \frac{r_2}{(r_1)^2}; \quad 100$$

that is,

$$T = \frac{P}{\frac{1}{r_2} + \frac{r_2}{(r_1)^2}}, \quad 105$$

where P represents pressure and T the vertical tension which, as has been stated above, is the greater tension. Since the pressure at A is 10 pounds per square inch,

$$T = \frac{10}{\frac{1}{r_2} + \frac{r_2}{(r_1)^2}}. \quad 115$$

As stated, r_2 at A is the chosen length and in Fig. 1 this length is taken as 50 feet, or 600 inches. At A, r_2 and r_1 are equal in length, consequently, the tension at A may be expressed by the equation

$$T = \frac{10}{\frac{1}{600} + \frac{600}{(600)^2}}. \quad 120$$

Solving this equation gives $T=3000$. The tension being known, the proper thickness and size of material can be chosen to withstand such tension. With the radius r_2 at 600 and the center at Y, a short arc A—B is drawn. It will be seen that the point B is

somewhat lower than the point A. The distance A—Y represents 600 inches. The height of the point B can be determined by measurement. Assume that point B is found to be .50 foot lower than point A. Then the pressure at B will be 10.125 pounds per square inch. This figure is found in the following manner. Under the assumed conditions the internal pressure or vapor pressure is ten pounds per square inch and this is the same at all points on the shell. Under the assumed conditions, also, the weight of the liquid in the shell is .25 pound per square inch for each foot of head or height of the liquid. The head at B is .50 foot. Consequently, the pressure from the head alone at B is .125 pound per square inch. The total pressure at B is ten pounds plus .125 pound or 10.125 pounds per square inch. The vertical tension at any point in the container may be expressed by the equation

$$T = \frac{P}{\frac{1}{r_2} + \frac{r_2}{(r_1)^2}}$$

The arc A—B was drawn with r_2 taken at 600 inches. This was the correct radius for the arc A with the tension at A equal to 3000. Since the container is to be in such a shape that the vertical tension or T shall be substantially constant at 3000, it will be seen that r_2 at B does not equal exactly 600 but is slightly shorter. The exact length of r_2 at B can, however, be calculated from the formula

$$T = \frac{P_b}{\frac{1}{r_2} + \frac{r_2}{(r_1)^2}}$$

in which P_b equals the pressure at B. I wish to keep T substantially constant at 3000. P at B equals 10.125. r_1 at B is the length of r_2 extended until it intersects the line A—Y. This distance is substantially 600 inches. Substituting these known values in the equation just given, and we get the equation

$$3000 = \frac{10.125}{\frac{1}{r_2} + \frac{r_2}{(600)^2}}$$

Solving this equation for r_2 we find that r_2 equals 540 inches at B. We find then that at point B the true value for r_2 is 540 inches. With this distance as the exact radius the arc B—C is then drawn. In drawing this arc, the center is taken on the line B—Y at a distance from B equal to 540 inches. This point is indicated on the drawing at Y_b . r_1 at C may now be found by extending the line C— Y_b until it intersects the line A—Y. The true length of r_2 at C

may now be determined by the same formula; namely,

$$T = \frac{P_c}{\frac{1}{r_2} + \frac{r_2}{(r_1)^2}} \quad 70$$

where P_c equals the pressure at C. The pressure at C will be 10 pounds per square inch, (the internal pressure which is the same all over) plus the pressure due to the head at C. By measurement, it will be found that at C there is approximately 3 feet of head. This will give a pressure of .75 pound per square inch due to the head so that the total pressure at C will be 10.75. T is to be kept constant at 3000. r_1 may be measured and will be found to be substantially 562 inches. Using the same equation as before and solving for r_2 gives r_2 at C equal to 499 inches. With this as a radius, the arc C—D is then drawn taking the center on the line C— Y_b . This center may be referred to as Y_c . The true value of r_2 at D is then calculated in the same manner and the arc D—E drawn. In a similar manner the curve is completed. For example, K— Y_k is r_2 for the arc K—L. This distance is 267 inches. r_1 for the arc K—L is the line K— Y_k produced until it intersects the line A—Y which is 38½ feet or 462 inches. By making the arcs A—B, B—C, C—D, . . . K—L, L—M, M—N, etc., very short, the accuracy of the curve may be increased. It will be seen that as the curve proceeds, r_2 becomes shorter and r_1 becomes longer until it reaches infinity. It will be seen, therefore, that as the curve comes around to points P, Q, and R, it becomes horizontal and thus indicates the bottom of the tank.

If desired, the curve can be constructed from a mathematical equation instead of graphically as shown. If this is done, the equation or formula of the curve will have to be derived from the equation

$$T = \frac{P}{\frac{1}{r_2} + \frac{r_2}{(r_1)^2}} \quad 110$$

in which T is the vertical tension at any given point, P the pressure at that point, r_2 the radius in the plane of the paper at that point and r_1 the radius in a plane at right angles to the paper at that point.

The equation

$$T_2 = \frac{P}{\frac{1}{r_2} + \frac{r_2}{(r_1)^2}}$$

is derived in the following manner: In such equation T_2 is the vertical tension which is the greater. In such a container

$$T_2 = \frac{T_1 r_1}{r_2} \quad 130$$

where T_1 is the horizontal tension, r_1 the radius in a plane at right angles to the paper and r_2 the radius in the plane of the paper. In a container of this kind we note that at
5 any one point

$$P = \frac{T_1}{r_1} + \frac{T_2}{r_2},$$

where T_1 equals the horizontal tension and T_2 the vertical tension, and r_1 the radius of curvature in a plane at right angles to the paper and r_2 the radius of curvature in the plane of the paper.

$$T_1 = \frac{T_2 r_2}{r_1}.$$

Substituting the value of T_1 in the equation

$$P = \frac{T_1}{r_1} + \frac{T_2}{r_2},$$

gives the equation

$$T_2 = \frac{P(r_1)^2(r_2)}{(r_1)^2 + (r_2)^2}$$

or

$$T_2 = \frac{P r_2}{1 + \left(\frac{r_2}{r_1}\right)^2}$$

or

or

$$T_2 = \frac{P}{\frac{1}{r_2} + \frac{r_2}{(r_1)^2}}$$

The approximate shape of the curve can also be found by using the equation

$$T = \frac{P}{\frac{1}{r_1} + \frac{1}{r_2}},$$

in which T is the tension, at any point, assuming the vertical and horizontal tensions to be the same. This is the equation for expressing the surface tension in a drop of liquid, such as, for example, in a drop of mercury and from it, the shape of the drop can be computed. This equation is theoretical, however, and is not exact for determining the shape of a steel or other container.

In Fig. 2, I have shown the shape of a tank found in the same manner, assuming that the liquid weighs 36 pounds per cubic foot and that there is a normal vapor pressure of 50 pounds per square inch.

In Fig. 3 I have shown a form or shape for a container constructed in the same manner but designed to hold normally a liquid weighing 144 pounds per cubic foot and to contain an internal vapor or gas pressure of ten pounds per square inch.

From an examination of the curves in Figs. 1, 2 and 3, it will be seen that as the

internal pressure in relation to the density of the liquid is increased, the tank becomes more spherical. As the weight or density of the liquid is increased relatively to the internal pressure, the tank flattens out.

In Fig. 4 there is shown a diagrammatical vertical cross-section view of an actual tank of the shape shown by the curve in Fig. 1.

It will be seen that the curvature of the tank conforms to the curvature shown in the graph in Fig. 1. The tank here shown is built to normally hold a liquid weighing 36 pounds per square foot with an internal pressure of 10 pounds. The radius of curvature at A is taken at 50 feet or 600 inches. The tension at A is therefore, 3,000 pounds. Since the curve is constructed as described above, the vertical tension is likewise 3,000 pounds at any point in the shell assuming the tank to be substantially full of the liquid with an internal pressure of 10 pounds. Since the vertical tension is the same at all points, metal of uniform thickness may be used. It should, of course, be strong enough to withstand the given tension. If the tension is too great, the radius of curvature at A may be made less with the result that the tank will be smaller in capacity and the tension less. The radius at A may be chosen as desired to give the requisite capacity provided metal of requisite strength is used. The tank as actually constructed may also contain a central vertical pillar or strut at A as indicated by the reference numeral 50 and also other vertical struts 51 at or near the periphery of the flat circular base of the tank. The strut 50 alone may be used, or the struts 51 alone or both together in order to give any desired extra rigidity or strength to support the tank when empty or partially empty or when the normal internal pressure is exceeded or the tank contains a liquid having a weight or density greater than that for which the tank is normally designed. The upper ends of the struts 50 and 51 may be attached directly to the shell or such upper ends may be joined by curved members 52, 52, upon which the upper plates of the shell may rest. The members 52, if desired, may be joined to the shell by brackets 53, 53 as shown.

It is to be noted that a tank shaped in accordance with my invention has a flat bottom as indicated by 61 so that it may rest on a flat surface and be entirely self-supporting thereon. When thus resting, and filled with liquid at the normal internal pressure, the greater, or vertical tension at all points will be the same and there will therefore be no undue stresses or strains at any point. The tank may be built, therefore, without the use of any outside posts or members to support the same.

In Fig. 6 I have shown another graphical method for determining the shape of a con-

tainer in the practice of my invention. I am here showing, as in Fig. 1, the shape for a container adapted to normally contain liquid weighing 36 pounds per cubic foot and an internal vapor pressure of ten pounds per square inch. As in Fig. 1, I lay out a center line A—Y and produce the same upwardly. On this line with point Y as a center a radius Y—A is taken, A lying at point 1 at the center of the top of the container. With this radius the arc 1—2 is described. X equals the horizontal radius at any point. For example, X is a horizontal radius from 1 to a vertical line produced upwardly from point 2. d equals the vertical distance from the top of the tank at any point. For example, d is the vertical distance from point 3 to a horizontal line produced from the point 1. r_1 equals the radius of curvature at any point in a plane perpendicular to the paper. r_2 equals the radius of the curvature at any point in the plane of the paper. P equals the pressure at any point. P_A equals the average upward pressure on the horizontal section at any point. T^2 equals the vertical tension or stress at any point. T_1 equals the horizontal tension or stress at any point.

In Fig. 6 the volumes are indicated by the shaded areas as follows: Volume A when extended as far to the left as a vertical line from a given point represents the volume of the given liquid whose weight equals in amount the total upward gas pressure on a horizontal section at that point. Volume B when extended as far to the left as a vertical line from a given point represents the total upward pressure from the weight or head of the liquid at that point. Volume C when extended as far to the right as a vertical line above a given point represents the downward force or pressure from weight or head of the liquid on a horizontal section at that point. That is, for example, volume A for the point 3 is represented only by that portion of the rectangle indicated "Volume A" lying to the right of the line 3—3'. Likewise, for example, volume B for the point 5 is represented only by that portion of the area marked "Volume B" lying to the right of the line 5—5'. Likewise, for example, volume C for the point 10 is represented only by that portion of the area marked "Volume C" lying to the left of the line produced upwardly vertically from the point 10. All actual volumes are computed by revolving the represented area about the vertical central axis.

For points on the upper portion of the curve the total upward force equals volume A plus volume B. For points on the lower portion of the curve the total force in a vertical direction is volume A plus volume B minus volume C. When volume A plus volume B equals volume C there is no verti-

cal force and the curve becomes tangent to the bottom.

In making the curve, as stated before, an arbitrary radius, for example, 50 feet is taken for the distance A—Y and a short arc 1—2 described. At this point 2, then, volume A and volume B can be determined graphically as above described. There can, therefore, be calculated for point 2 volume A and volume B. Volume A represents the internal vapor or gas pressure. This is here shown as equivalent to an additional head or height of liquid of the same density as contained in the container. Under the assumed conditions the gas pressure is ten pounds per square inch and the liquid weighs 36 pounds per cubic foot. Consequently, a gas pressure of ten pounds per square inch would be equivalent to an additional head or height of liquid of 40 feet. Consequently, the line A—A' is laid out as being 40 feet in length.

Since volumes A and B can be determined for point 2, the average pressure on a horizontal section at this point can be determined. In drawing the arc 1—2, the arbitrary radius of 50 feet was used for r_2 . At this point, from the average pressure at point 2 caused by volumes A and B at this point, the exact length of r_1 can be computed so that the vertical tension at 2 will not exceed that at 1. With this length as a radius and point 2 as a center strike an arc so that it intersects the line A. Y. The line between this intersection and point 2 will be the new r_1 . By new r_1 I mean the r_1 for the portion of curve 2—3. The intersection of the r_1 for the curve 2—3 with the r_1 for the curve 1—2 will obviously determine the center of curvature and therefore the (r_2) for the portion of the curve 2—3. The shape can then be extended to the point 3 by drawing the arc 2—3. The process is merely repeated for the remainder of the curve. The determination of the correct r_1 at each point can be found by the use of the engineering formula

$$T_2 = \frac{P_A \times r_1}{2}$$

in which T_2 is the vertical stress at the point, P_A is the average unit pressure on a horizontal section in an upward direction, and r_1 is the radius of curvature at right angles to the plane of the paper.

After point 8 is reached, the pressure at any point, for example, at point 9, is found by taking the sum of volumes A and B for such point and subtracting therefrom volume C at such point.

In Fig. 7 I have shown a table indicating the properties of the curve shown in Fig. 6, and the theoretical stresses at the different points thereon in accordance with the method just described.

While I have shown and described certain

embodiments of my invention, it is to be understood that it is capable of many modifications. Changes, therefore in the construction and arrangement may be made without departing from the spirit and scope of the invention as disclosed in the appended claims, in which it is my intention to claim all novelty inherent in my invention as broadly as possible in view of the prior art.

What I claim as new, and desire to secure by Letters Patent, is:

1. A closed container substantially in the shape of a solid of revolution about a vertical axis and having a supported bottom, said container so shaped that when substantially filled with a normal liquid and containing a normal internal or vapor pressure, the radius of curvature at each point on the shell above the supported bottom in a vertical plane, through a line normal to the shell at that point, equals the vertical tension at such point times the square of the radius of curvature in a plane at right angles to the first mentioned plane and also passing through said normal line, divided by the pressure at such point times the square of said second mentioned radius minus said vertical tension times said first mentioned radius.

2. A closed container substantially in the shape of a solid of revolution about a vertical axis, so shaped that at each point on the curved portion of the shell the radius of curvature in a vertical plane, through a line normal to the shell at that point, is less than the radius of curvature in a plane at right angles to the first mentioned plane and also passing through said normal line.

3. A closed container substantially in the shape of a solid of revolution about a vertical axis, so shaped that at each point on the curved portion of the shell, the radius of curvature in a vertical plane, through a line normal to the shell at that point, is less than the radius of curvature in a plane at right angles to the first mentioned plane and also passing through said normal line; and in which the radii of curvature at successive points from the top of the shell toward the bottom on the curved portion of said shell in a vertical plane, through lines normal to the shell at such points, are successively shorter.

4. A closed container substantially in the shape of a solid of revolution about a vertical axis and having a supported bottom, said container so shaped that at each point on the shell above the supported bottom the radius of curvature in a vertical plane, through a line normal to the shell at that point, is less than the radius of curvature in a plane at right angles to the first mentioned plane and also passing through said normal line.

5. A closed container substantially in the

shape of a solid of revolution about a vertical axis and having a supported bottom, said container being so shaped that at each point on the shell above the supported bottom the radius of curvature in a vertical plane, through a line normal to the shell at that point, is less than the radius of curvature in a plane at right angles to the first mentioned plane and also passing through said normal line; said container also being so shaped that the radii of curvature at successive points on the shell from the top thereof down to the supported bottom in a vertical plane, through lines normal to the shell at such points, are successively shorter.

6. A closed container substantially in the shape of a solid of revolution about a vertical axis and having a supported bottom, said container so shaped that at each point on the shell above the supported bottom the radius of curvature in a vertical plane, through a line normal to the shell at that point, is less than the radius of curvature in a plane at right angles to the first mentioned plane and also passing through said normal line; said container also being so shaped that the radii of curvature at successive points on the shell from the top thereof down to the supported bottom in a vertical plane, through lines normal to the shell at such points, are successively shorter; and said container also being so shaped that the radii of curvature at successive points on the shell from the top thereof down to the supported bottom, in planes at right angles to said vertical plane, and also passing through lines normal to the shell at such points, are successively shorter from the top of said shell down to the point of its greatest horizontal diameter, and successively longer from said point down to the supported bottom.

7. A closed container substantially in the shape of a solid of revolution about a vertical axis and having a supported bottom, said container being so shaped that the radii of curvature at successive points on the shell from the top thereof down to the supported bottom in a vertical plane, through lines normal to the shell at such points, are successively shorter; said container also being so shaped that the radii of curvature at successive points on the shell from the top thereof down to the supported bottom in planes at right angles to said vertical plane, and also passing through lines normal to the shell at such points, are successively shorter from the top of said shell down to the point of its greatest horizontal diameter and from such point are successively longer down to the supported bottom.

8. A closed container substantially in the shape of a solid of revolution about a vertical axis and having a supported bottom, said container being so shaped that the radii of

curvature at successive points on the shell from the top thereof down to the supported bottom in planes at right angles to a vertical plane, and passing through lines normal to the shell at such points, are successively shorter from the top of the shell down to the point of its greatest horizontal diameter and from such point are successively longer down to the supported bottom.

- 10 9. A closed container for a volatile liquid substantially in the shape of a solid of revolution about a vertical central axis, every vertical central cross-section of which is an area bounded by a curve the bottom portion of which is flattened and of which the arcs from the flattened portion to the top central point have successively longer radii, the whole curve being a function of the weight and pressure of a liquid for which the container is designed substantially as set forth.

- 20 10. A closed container for a volatile liquid substantially in the shape of a solid of revolution about a vertical central axis, every vertical central cross-section of which is an

area bounded by a curve the bottom portion of which is flattened and of which the arcs from the flattened portion to the top central point have different radii, the whole curve being a function of the weight and pressure of a liquid for which the container is designed substantially as set forth.

11. A closed container for a volatile liquid substantially in the shape of a solid of revolution about a vertical central axis, every vertical central cross-section of which is an area bounded by a curve the bottom portion of which is flattened and of which the arcs from the flattened portion to the top central point have different radii, those of the upper arcs being substantially longer than those of the lower arcs, the whole curve being a function of the weight and pressure of a liquid for which the container is designed substantially as set forth.

In testimony whereof, I have hereunto set my hand this 2 day of November, A. D., 1925.

GEORGE T. HORTON.