

Sept. 12, 1967

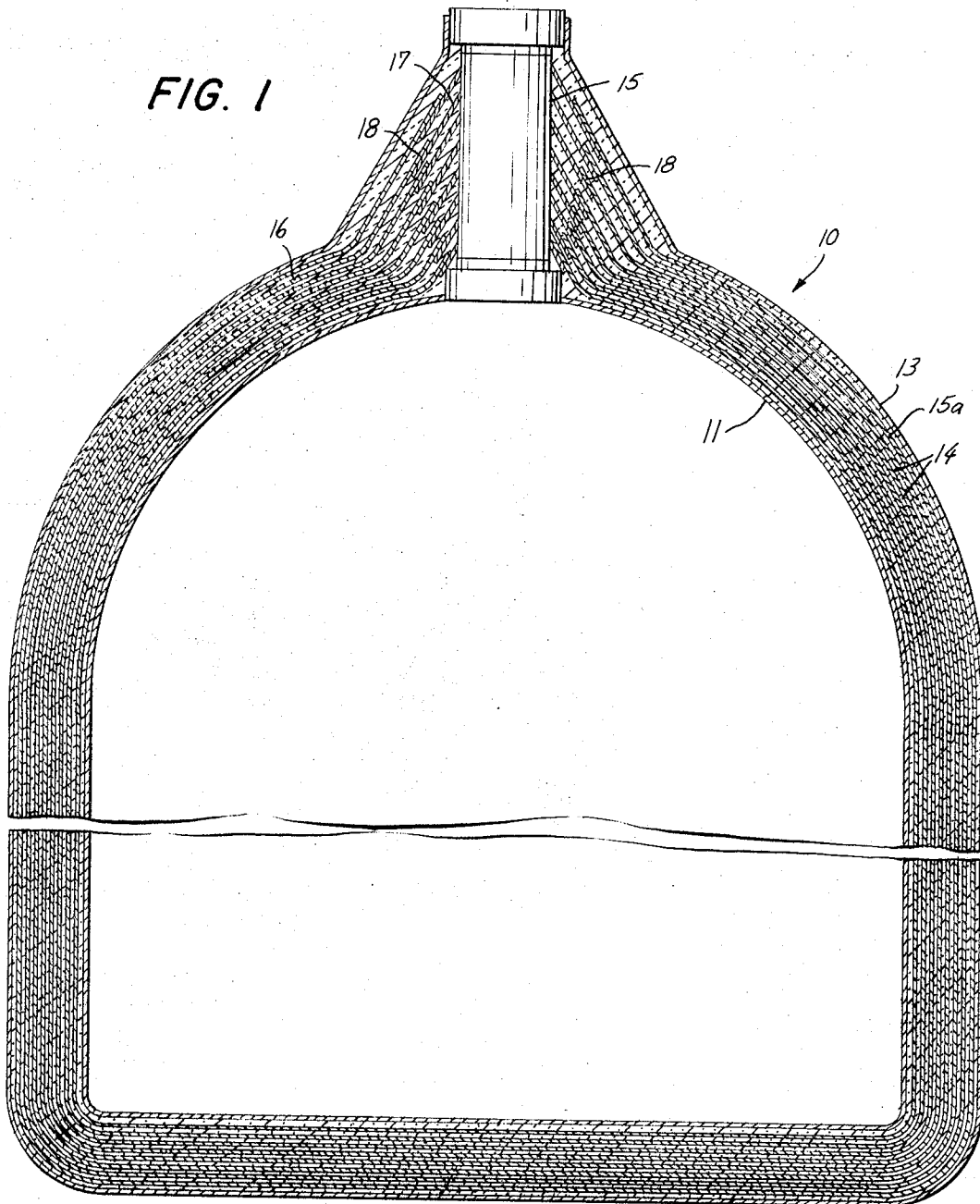
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3,341,052

DOUBLE-WALLED CONTAINER

Filed Sept. 12, 1963

6 Sheets-Sheet 1



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DOUBLE-WALLED CONTAINER

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FIG. 2

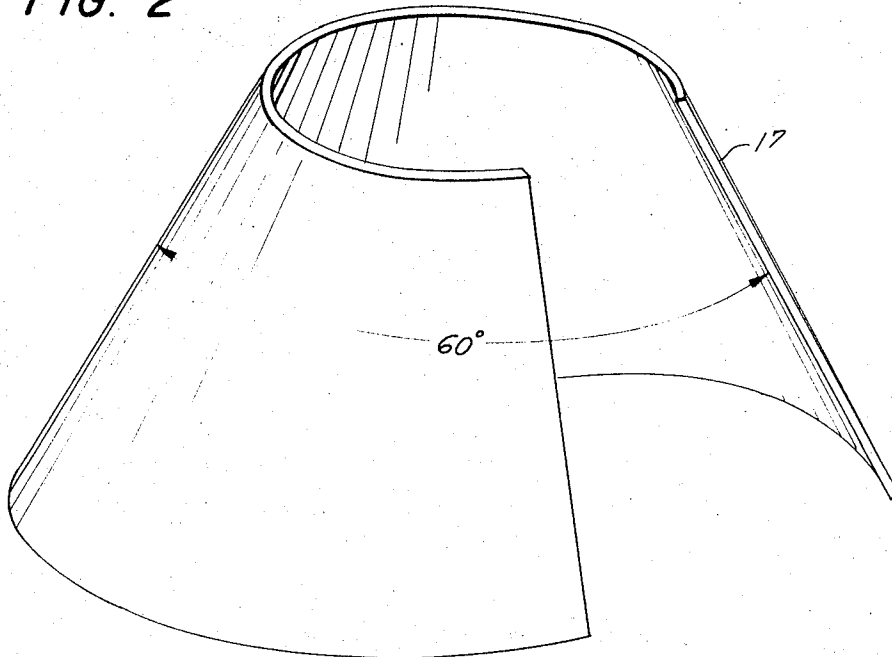
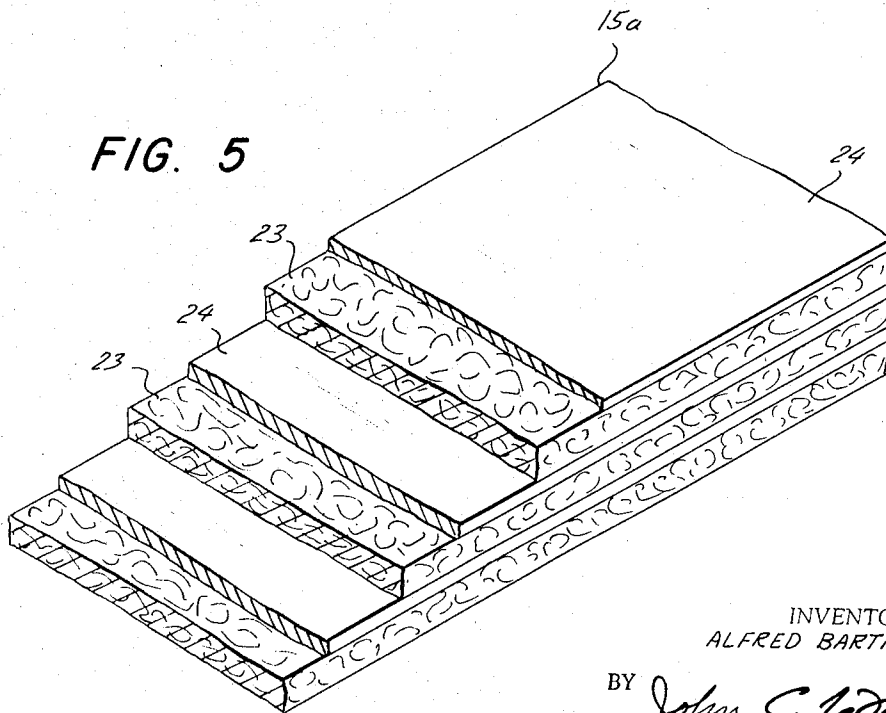


FIG. 5



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FIG. 3

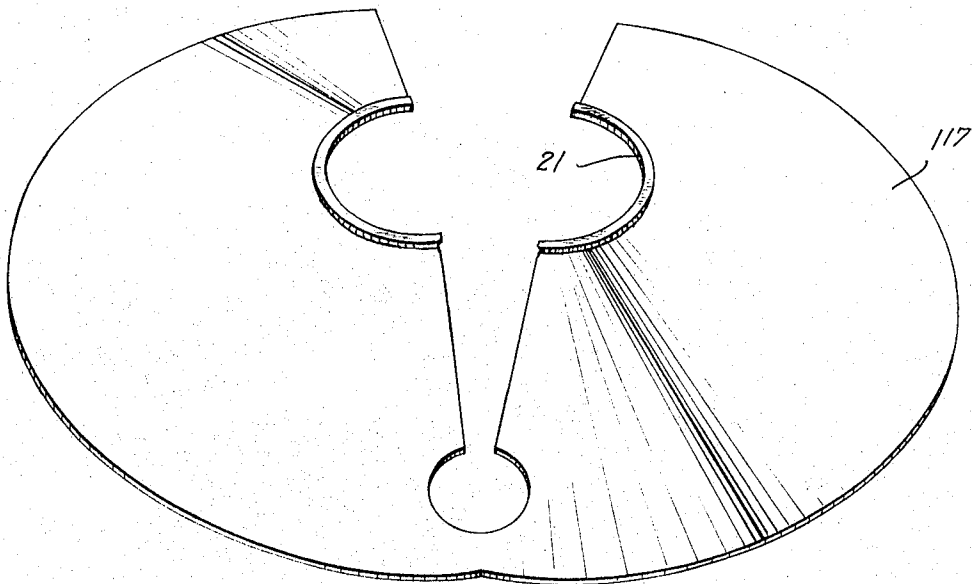
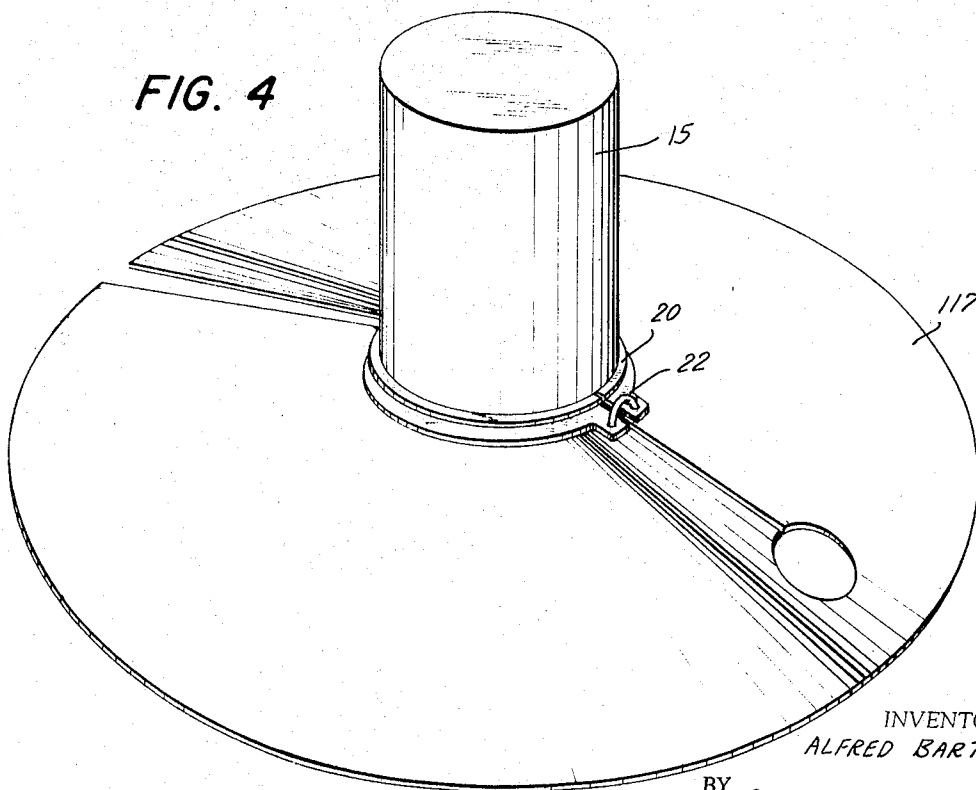


FIG. 4



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DOUBLE-WALLED CONTAINER

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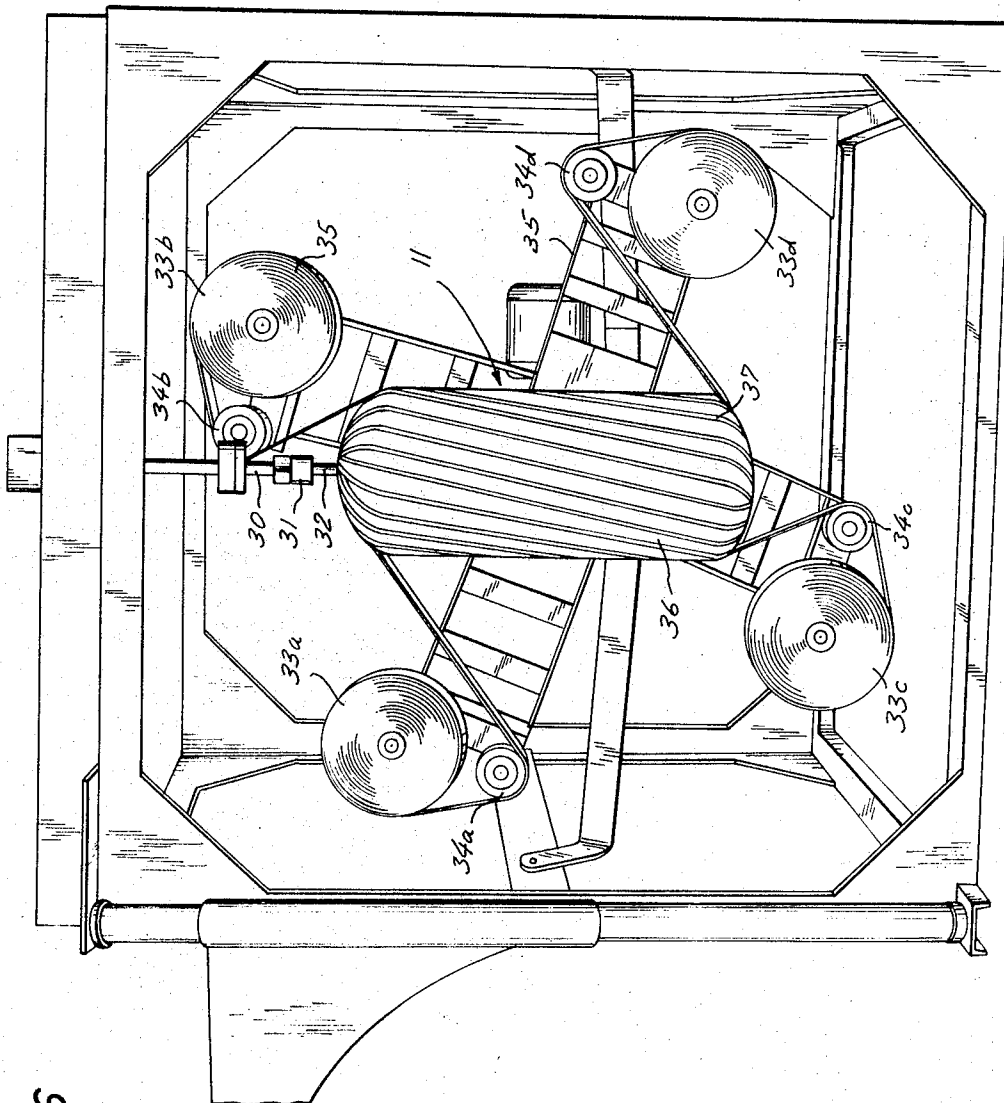


FIG. 6

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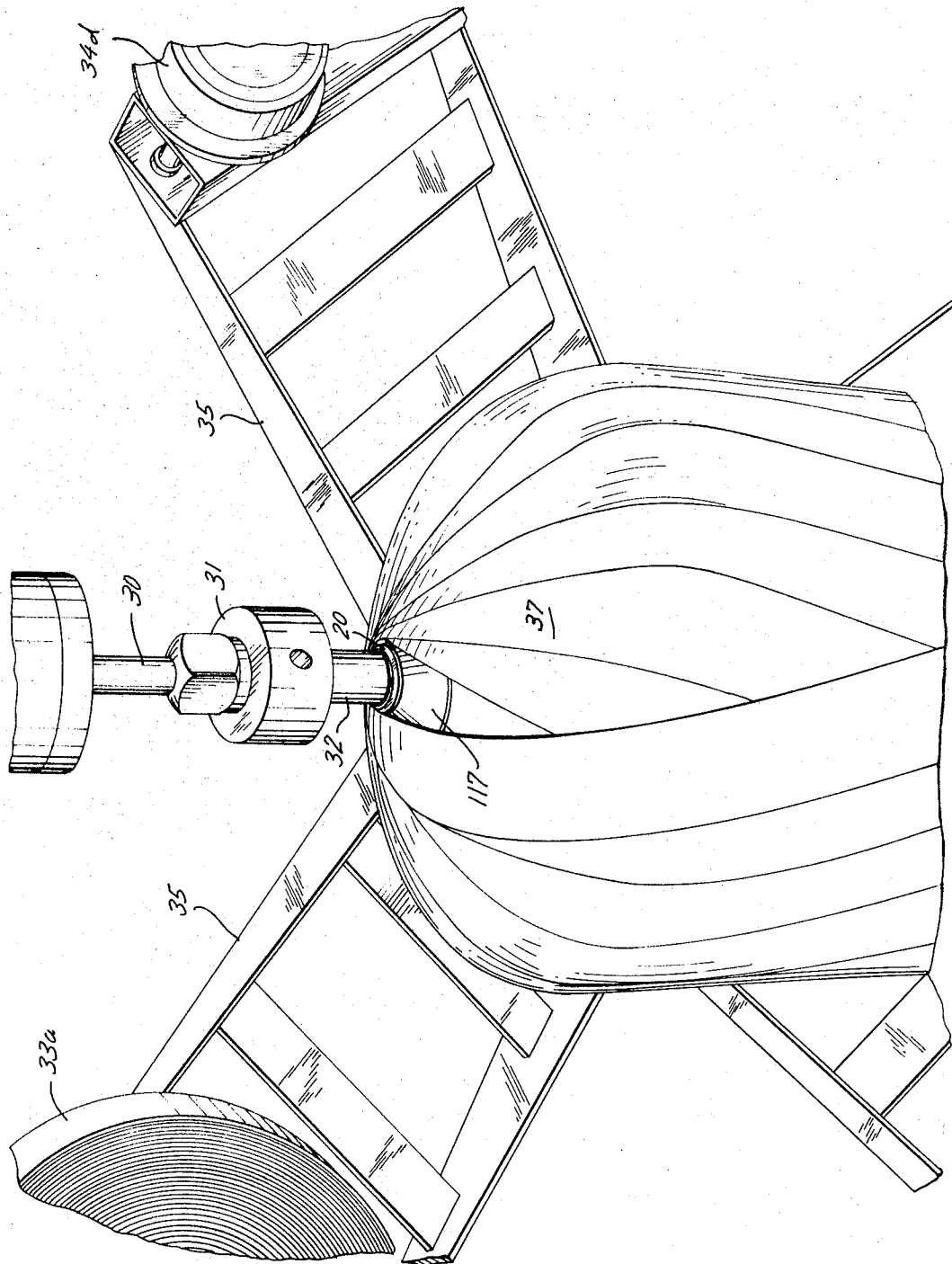


FIG. 7

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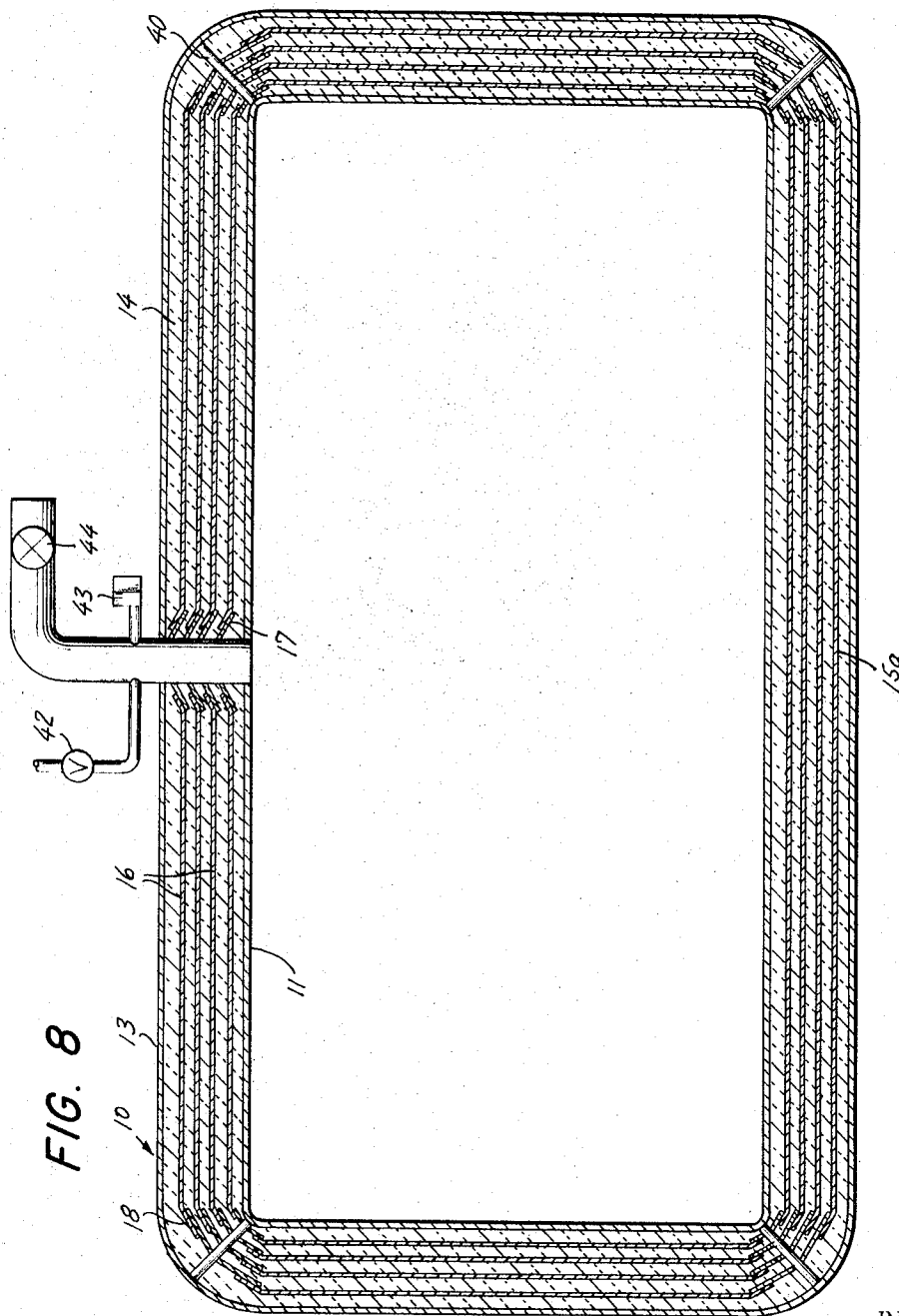


FIG. 8

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3,341,052

DOUBLE-WALLED CONTAINER

Alfred Barthel, Indianapolis, Ind., assignor to Union Carbide Corporation, a corporation of New York
Filed Sept. 12, 1963, Ser. No. 308,541
5 Claims. (Cl. 220—14)

This invention relates to an improved double-walled liquefied gas container for storing and transporting low boiling liquids as, for example, liquid helium, hydrogen and oxygen.

In copending application Serial No. 198,987, filed May 31, 1962, to John A. Paivanas et al., now Patent No. 3,133,422, there is described and claimed an improved low boiling liquefied gas container comprising an inner vessel for holding the liquefied gas and an outer shell surrounding the inner vessel and spaced therefrom so as to form an intervening vacuum space with a temperature gradient thereacross. An evaporation gas conduit is provided between the inner vessel and the outer shell for transporting such gas from the container. A composite multi-layered insulation is disposed within the vacuum space and comprises low conductive material and radiant heat barrier material, the layers being disposed generally parallel to the container walls and normal to the flow of heat. Multiple parallel spaced highly conductive metal shields are also disposed in the vacuum space in heat exchange relation with insulation. These shields are respectively joined by low thermal resistance means to the evaporation conduit at regions where the temperature, when the container is filled with low boiling liquefied gas, is lower than the temperature assumed by the individual shield absent the joining.

The refrigeration of the evaporating liquefied gas discharging from the inner vessel is transferred to the conduit walls and thence through the low thermal resistance means to the conductive shields. Stated in another way, of the total heat entering a conductive shield from the atmosphere through the outer shell and the contiguously associated insulation, a portion is intercepted and conducted to the discharging evaporation vapor. Only the remainder of the total heat is allowed to pass further towards the cold inner vessel. Thus, with a succession of such "interceptions" (i.e. multiple conductive shields), the net heat influx to the cold inner vessel is greatly reduced.

Although the conductive metal shields have been found highly effective in improving the thermal performance of the composite multi-layer insulation, their juncture with the evaporation conduit has introduced substantial problems. For example, the inner vessel is preferably wrapped mechanically with the composite multi-layered insulation and the wrapping sequence must be suspended each time a metal shield is to be introduced and joined to the evaporation gas conduit. One suitable juncture means is a metal disk fitting concentrically around the evaporation conduit. The disks must be spaced longitudinally along the conduit and heat bonded thereto, as by silver soldering. This means that if ten thermal shields are to be employed within the insulation, the wrapping operation must be interrupted ten times. Such an assembly procedure greatly increases the labor costs of construction and consequently the overall cost of the container. While the improvement in thermal insulating quality resulting from the multiple conductive shields more than justifies the additional cost in the case of extremely valuable and cold liquids such as liquid helium and hydrogen, the performance improvement does not justify the use of metal bonded disks and shields in the construction of double-walled containers for less valuable liquefied gases as, for example, liquid oxygen and nitrogen.

Another limitation of the disk-type construction is the difficulty encountered in establishing and maintaining a

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thermal association between the disks and the radiation heat barrier component of the composite layered insulation and/or the conductive shields. Either or both the radiation heat barriers and the conductive shields may be in the form of metal foil strips or ribbons, and they tend to tear when pressed against the sharp edges of the disk during the wrapping operation. If the foil is completely severed, the heat transfer path between the evaporation conduit walls and the insulation is eliminated and the shields become ineffective.

It is an object of this invention to provide an improved double-walled liquefied gas container having composite multi-layered insulation, and conductive metal shields in the intervening evacuable space.

Another object is to provide such a container that does not require a metal bond to thermally join the conductive metal shields to the evaporation gas conduit.

A further object is to provide an improved, less time consuming and tedious method for assembling the container, which method avoids the tendency to sever the radiation heat barrier and/or the conductive shields.

Other objects and advantages of this invention will be apparent from the ensuing disclosure and the appended claims.

In the drawings:

FIG. 1 is a view of a longitudinal cross-section through a liquefied gas storage container illustrating one embodiment of the invention;

FIG. 2 is an isometric view looking downwardly on a frusto-conical section suitable for use in the FIG. 1 container;

FIG. 3 is an isometric view looking downwardly on an alternative frusto-conical section suitable for use in the FIG. 1 container;

FIG. 4 is an isometric view looking downwardly on the FIG. 3 frusto-conical section clamped around the evaporation gas conduit;

FIG. 5 is an isometric view looking downwardly on a composite multi-layered thermal insulation suitable for use in the FIG. 1 container;

FIG. 6 is a longitudinal elevation view of apparatus suitable for orbital wrapping the FIG. 5 multilayered insulation around the FIG. 1 container;

FIG. 7 is an isometric view looking downwardly on a frusto-conical section-conductive shield assembly suitable for use in the FIG. 1 container; and

FIG. 8 is a view of a longitudinal cross-section through a liquefied gas storage container illustrating another embodiment of the invention.

One embodiment of this invention takes the form of a double-walled container comprising an inner storage vessel and an outer shell being arranged and constructed with a vacuum space therebetween. An evaporation gas conduit is provided between the inner vessel and outer shell for transporting evaporated liquefied gas from the container the conduit having a temperature gradient across the vacuum space. A composite multi-layer insulation is disposed within the space and comprises low conductive material and radiant heat barrier material. At least one and preferably multiple highly conductive metal shields are disposed in the vacuum space and surround the inner vessel. The conductive shields are also contiguously associated on both sides with the composite insulation.

At least one frusto-conical section formed of heat conductive metal is concentrically aligned around the evaporation gas conduit within the vacuum space and positioned with its small end frictionally bearing against the outer surface of the conduit for thermal contact therebetween, one edge of the conductive shield contiguously contacting the large end of the frusto-conical section. This shield edge and the frusto-conical section large end, as well as the section small end and evaporation gas conduit are

aligned with respect to the vacuum space width and thermally contacted so that the shield edge and frusto-conical section are at temperatures lower than they would assume absent the thermal contacts.

In this manner, the refrigeration of the evaporation gas emerging from the inner vessel through the evaporation gas conduit is transferred consecutively through the conduit walls, the frusto-conical section and the heat conductive shield to the composite layered insulation. Stated in another manner, the heat inleak to the insulation is transferred consecutively through the shield, frusto-conical section, and conduit walls to the emerging evaporation gas.

In a preferred embodiment, a multiplicity of highly conductive metal shields are positioned in parallel spaced relationship across the width of the vacuum space and a multiplicity of frusto-conical sections are also positioned in parallel spaced relationship across the vacuum space width. The previously mentioned one edge of consecutive conductive metal shields contiguously thermally contacts the large end of consecutive frusto-conical sections with the coldest metal shield edge contacting the coldest section large end and the warmest metal shield edge contacting the warmest section large end.

As used herein, the expression "frusto-conical section" refers to a general shape which is substantially the frustum of a right circular cone, the latter being a solid generated by the rotation of a right triangle about one of its legs as the axis. For the purposes of this invention, the cross-section of this section may depart slightly from a true circle.

As previously indicated, the composite multi-layered insulation disposed between the warm and cold walls comprises low conductive material and radiant heat barrier material, thereby substantially reducing the amount of heat inleak due to conduction and radiation. The low conductive material is preferably fibrous and composed of many elements of small cross-sectional dimension having a solid volume not exceeding 10 percent of its gross volume (at least 90 percent voids). A particularly suitable composite insulation consists of alternating layers of a thin flexible metal foil such as aluminum or copper of less than about 0.0008 inch thick and usually about 0.00025 inch thick, and an elastically compressible web or mat of glass fiber. This insulation is described and claimed in U.S. Patent No. 3,009,601 issued Nov. 21, 1961 to L. C. Matsch, the disclosure being incorporated herein to the extent pertinent. Another widely employed low conductive material is permanently precompacted paper composed of unbonded fibers, as more fully described and claimed in U.S. Patent No. 2,009,600 also issued Nov. 21, 1961 to L. C. Matsch.

Another suitable composite multi-layer insulation is the metal-coated, flexible plastic material described in U.S. Patent No. 3,018,016 issued Jan. 23, 1962 to M. P. Hnilicka, Jr. The metal coating should have a thickness less than about 0.25 micron and yet be sufficiently thick to have an emissivity less than 0.06. The individual layers of metal-coated plastic are preferably permanently deformed, as by crumpling, so as to be free of extensive areas of planar contact. A suggested composite is aluminum-coated polyethylene terephthalate film. Another satisfactory metal-coated substrate is thin metallized paper such as metallized glassine.

Still another composite multi-layered insulation for use in the vacuum space consists of the paper layers and finely-divided radiant heat reflecting bodies of less than about 500 microns in size, being incorporated in and uniformly dispersed through the layers, as well as a binder for cementing the heat reflecting bodies to the fibers. The finely-divided radiant heat reflecting bodies may, for example, be formed of aluminum, copper, nickel and molybdenum. Best results are obtained when the radiant heat reflecting bodies are relatively small, with particle sizes of less than 50 microns as the major dimension. Aluminum and copper paint pigment flakes of less than 0.5 micron

thickness are especially suitable. The fibers may, for example, be formed of glass, ceramic, quartz, or potassium titanate. When glass fibers are used, they are preferably of less than 5 microns diameter, while a fiber diameter range of 0.2 to 3.8 microns gives best results. The reflecting body-containing paper may, for example, be formed on standard paper-making machines using colloidal silica as a binder.

The highly conductive metal shields may, for example, be thin, flexible and light in weight, and thus essentially self-conforming to the contour of the composite insulation layers, e.g. 0.001-0.030 inch thick. Shields of such thinness, however, are limited in the quantity of conductive heat they can transport along their length to the area of contact with the frusto-conical sections. The heat load or duty imposed on such thin shields must be kept low, and this is accomplished by employing the highly effective composite multi-layered insulation on the warm side of the shield.

While each conductive shield may be a single thickness of metal, it may be alternatively applied as a multiple thickness of very thin foil by, for example, spiral winding such foil around the multi-layer composite insulation at the appropriate locations. Spiral winding is a particularly advantageous technique for obtaining maximum flexibility with very low temperature gradient along the shield. The total thickness of each conductive shield is related to its thermal conductivity and the length through which heat is conducted. The total thickness, while relatively thin and non-self-supporting as previously discussed, must be sufficient to limit the maximum temperature difference across the conductive shield to a low value which is less than the temperature difference between immediately adjacent shields at a particular cross-sectional plane through the insulation construction.

It is important to clearly differentiate the heat conductive shields of this invention from radiation shields, employed by certain prior art insulations. The conductive shields are formed of highly conductive material having a thermal conductivity k of at least 5 B.t.u./hr.-ft. °R. at 100° K. and preferably 40-400 B.t.u./hr.-ft. °R. Lower values do not permit sufficiently rapid heat transfer to the cold evaporation gas as it flows through the conduit between the cold inner vessel and the relatively warm outer casing. Also, such heat conductive shields need not be highly reflective. Suitable heat conductive shield materials include aluminum, copper, silver and gold. In contrast, the prior art radiation shields need not be highly conductive and, if desired, may be composed of metal-coated plastic films, most plastics having relatively low thermal conductivity values.

The heat conductive metal shields may alternatively be sufficiently thick to be substantially rigid so as to support its own weight, that is, for example, 1/32-inch aluminum sheeting. Whether the conductive shields be relatively thin and non-self-supporting or sufficiently thick to support their own weight, it is necessary that they be contiguously associated with and in thermal association to the insulation for effective cooling. This may be accomplished during assembly by wrapping composite insulation layers between adjacent shields. Alternatively, the shields may be thermally bonded to the radiation barrier sheet component of the composite insulation.

The frusto-conical section is also formed of highly conductive but not necessarily highly reflective metal as, for example, the same material used for the conductive shields. This section must be of sufficient thickness, on one hand, to retain its substantially conical shape when so formed, and is characterized by a resilient or spring action which provides sufficient frictional bearing or "grip" against the outer wall of the evaporation gas conduit to insure a good mechanical and thermal contact. On the other hand, the frusto-conical section must not be so thick as to prevent easy shaping and preclude this desired spring action which permits the frictional and

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thermal contact against the conduit wall. The frusto-conical section is preferably between 0.02 and 0.04 inch thick. A particularly suitable and inexpensive material was found to be $\frac{1}{32}$ -inch thick aluminum sheeting for the 25-liter capacity vessel.

It has been indicated that one edge of the conductive shield must contiguously contact the large end of the frusto-conical section. This is necessary to insure a continuous path for heat transfer by solid conduction to the evaporation conduit from the composite insulation. Such contact may be achieved by simply extending the shield edge over the frusto-conical section in an overlapping relation during assembly. A satisfactory contact results by virtue of the compressive effect inherent in most wrapping techniques. If a more positive physical contact is necessary or desirable in a particular construction, a simple compression medium, e.g. an elastic band, may be slipped around the overlapping section of the shield. In the event that a rigid contact is necessary, the overlapping shield section may be metal-bonded to the frusto-conical section.

Up to this point, the radiant heat barrier component of the composite multi-layered insulation and the highly conductive metal shields have been described as two separate elements of the instant container. In one embodiment, they may be the same element, as for example when aluminum or copper ribbon is wrapped in an orbital manner around the inner vessel. In this construction, at least some of the ribbons overlap the large lower end of the frusto-conical section to achieve the necessary solid path for heat conduction.

Referring now to the drawings and FIG. 1, a double-walled, low boiling liquefied gas container 10 is illustrated. Inner vessel 11 storing the low boiling liquefied gas, e.g. liquid helium, is surrounded by outer shell 13 with vacuum space 14 therebetween. The inner vessel 11 is supported by neck tube 15 also serving as the previously defined evaporation gas conduit. Disposed within the vacuum space 14 is the composite multi-layered insulation 15a, which may also serve to stabilize inner vessel 11 against lateral movement or side-sway. Multiple heat conductive shields 16 extend concentrically around inner vessel 11 at intervals across the vacuum space 14 and are separated by layers of composite-layered insulation 15a.

Frusto-conical sections 17 are concentrically aligned around conduit 15, spaced along the conduit length, and positioned with their small ends frictionally bearing against the outer surface of conduit 15. Shield edge 18 overlaps and is supported by the large end of section 17 for solid conduction.

It has been found that the frusto-conical sections 17 may be intermittently snapped around evaporation gas conduit 15 during the insulation wrapping operation without stopping the wrapping machine. This eliminates one important limitation of the previously described metal bonded disk construction.

In one series of tests, double-walled liquefied gas containers of 25 liter liquid capacity were orbital wrapped with a composite insulation of aluminum foil ribbon and glass fiber strips, with and without the frusto-conical sections. These sections were of the type illustrated in FIGS. 1 and 2, formed from $\frac{1}{32}$ -inch aluminum sheeting with a 60-degree vertex angle and snapped on at equal intervals between 80 turns of the composite insulation. To bring the aluminum ribbons in intimate physical contact with the frusto-conical sections, the former was aligned under the glass ribbon and over substantially the entire outer surface of the sections. It should be noted that in these containers, the same aluminum ribbon served as the radiation barrier component of the insulation, and the heat conductive shields. The width of the vacuum space was 0.75 inch, and one container had only a single frusto-conical section placed midway through the composite insulation.

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The normal evaporation rates of these containers were tested with both liquid nitrogen and liquid hydrogen, and the following results were obtained:

Liquid	No Cones	1 Cone	5 Cones	8 Cones
Nitrogen, lbs./day.....	1.23	1.01	0.94	0.80
Hydrogen, c.f.h. NTP.....	4.07	1.57	1.48	-----

It is apparent from these tests that the insulation performance of the containers was improved at least 25% by the use of frusto-conical sections to provide multi-shielded construction at the negligible expense of a few simple aluminum stampings and no increase in labor time.

The invention was also successfully demonstrated in the construction of a substantially larger container having 150 liter liquid capacity. Whereas the previously described 25 liter container is 18 inches long and has a 13.8 inch diameter (L/D ratio of 1.3), the larger 150 liter container is 44 inches long, 17 inches in diameter and has an L/D ratio of 2.59. The cone section used in the larger containers is shown in FIG. 3, and is formed from 0.022-inch thick (16 oz./sq. ft.) electrolytic tough pitch copper. The geometry of the container required a rather "flat" cone having a vertex angle of 140 degrees. Due to the large vertex angle, the frusto-conical section 117 did not inherently possess the necessary elasticity to be snapped over the conduit. The arc of contact between the section and the conduit would have been 270 degrees, the same as the successful FIG. 2 frusto-conical section. To remedy this situation, the section 117 was cut across most of its diameter leaving only a small segment to hold the two semi-circular portions together (see FIG. 3). This feature provided an arc of contact of nearly 360 degrees and a firm grip on the conduit. It required, however, the use of a retaining ring 20 which is pressed into groove 21 around the small end of frusto-conical section 117 by means of clamp 22 (see FIG. 4). In this manner, an excellent frictional contact is maintained between evaporation conduit 15 and frusto-conical section 117, thereby insuring effective heat transfer by solid conduction.

The large 150 liter container was orbital wrapped with a composite insulation of 3-inch wide aluminum foil ribbons and $3\frac{1}{2}$ -inch wide glass fiber paper ribbons to a density of 64 layers/inch vacuum space cross section. Four conductive metal shields were wrapped at intervals during the composite insulation wrapping, the shield material being tough pitch copper ribbon 3 inches wide and 0.0007 inch thick ($\frac{1}{2}$ oz. per sq. ft.). Each shield consisted of four turns of the orbital machine area which corresponds to 1.6 layers.

The assembly of a 150 liter liquid helium container using the previously described disks and a soft-solder joint to the evaporation conduit required about 15 man-hours. Part of this time may be attributed to a spiral wrapping procedure whereby sheets of aluminum foil and glass fiber paper were employed and the composite insulation ends were laboriously folded over each other one-by-one. However, use of the previously described frusto-conical sections along with orbital wrapping reduced the required labor time by 80% to 3 man-hours. Again, it was not necessary to stop the wrapping machine to snap on the frusto-conical sections. This remarkable savings in labor was obtained without loss in insulating efficiency, as the normal evaporation loss rate was substantially the same for the soft solder-disk arrangement and the clamped frusto-conical section construction.

In the interest of simplicity, the composite multilayered insulation 15a has been shown schematically in FIG. 1. FIG. 5 illustrates one suitable form of this insulation in greater detail, and comprises a low heat conductive fibrous material 23 such as glass paper arranged in alternating layers with thin reflecting shields 24 for diminishing the transfer of heat by radiation. The individual fibers

of the glass paper layers are preferably oriented substantially parallel to the reflecting shields 24 and substantially perpendicular to the direction of heat inleak across the vacuum space between the outer casing and inner vessel.

It has been previously stated that the composite multi-layered insulation and highly conductive metal shield may be wrapped around the inner vessel either in a spiral fashion or in an orbital manner. In either case the frusto-conical sections are snapped onto the evaporation conduit and over the insulation layers after a desired number of insulation layers have been formed. If the conductive shield is a separate element, it may then be wrapped around the vessel so as to overlap and lie against the installed frusto-conical section. Additional layers of the composite insulation are then wrapped around the inner vessel, over the frusto-conical section and the metal shield (if separate), and the sequence is repeated until the desired number of composite insulation layers—frusto-conical sections—metal conductive shields have been installed.

The orbital wrapping method is preferred for containers small enough to be rotated about a vertical axis, i.e. up to about 12 feet long, and will be briefly described hereinafter. A detailed description of orbital wrapping is found in copending application S.N. 128,166 filed July 31, 1961, now abandoned, of which the present application is a continuation-in-part. In a broad sense, orbital wrapping comprises the steps of providing at least two composite strips of the insulation, e.g. fibrous sheeting underlayer and metal foil, on opposite sides of the vessel and securing an end of each composite strip to the vessel surface. The vessel is suspended vertically and rotated around its axis. The composite insulation strips are simultaneously orbited around the rotating vessel in a plane which cuts the axis of the vessel at an angle θ . In this manner, the strips are continuously delivered to the vessel from the top to the bottom thereof forming a continuous insulation mat of crisscrossing strips.

The orbital wrapping sequence is illustrated in FIGS. 6 and 7 and will be described in conjunction with the previously discussed 150-liter helium container.

Inner vessel 11 is attached to the vertically aligned shaft 30 by means of expansion mandrel (not shown) inserted into the evaporation conduit-neck tube 32 of vessel 11, and secured by a lock nut 31. Shaft 30 in turn is connected to a suitable drive (not shown) so as to rotate the vessel 11 about its axis. The drive may consist of any type of motor and speed reducing gears necessary to obtain the desired rotating speed of the vessel.

To orbital wrap the 150-liter vessel 11 having a length/diameter ratio of 2.5:1, it was found necessary to orbit four systems of composite insulation ribbons (8 rolls altogether). The four rotatable fibrous sheeting rolls 33a-33d, and the corresponding four rotatable metal foil rolls 34a-34d are attached to four arms of the planetary support 35 through respective shafts so as to be orbitable about the vertically rotatable vessel 11. The roll rotation speed is determined by the speed of rotation of support 35. This speed was about 10 r.p.m. in the case of relatively long vessel 11, whereas in the case of the small spherical 25 liter containers a higher rotational speed of about 30 r.p.m. was found satisfactory. Each pair of fibrous sheeting rolls 33a-33d and metal foil rolls 34a-34d are adjacently positioned at 90-degree intervals so that composite layers of fibrous sheeting underlayer and metal foils from the four pairs of rolls are simultaneously applied on opposite sides of the rotating container.

In a manner similar to the vessel 11 rotating means, planetary support 35 having four motions arms is driven through a shaft by drive means which, for example, may consist of a suitable motor and speed reducing means. The speed of planetary support 35 has a maximum value which is determined experimentally by the breaking load of the metal foil strip.

Having once determined the speed of planetary support

35, the speed of the vessel 11 is synchronized in a certain relationship to the speed of support 35. This relationship depends upon the angle θ between the plane of the orbiting rolls and the vertical axis of the vessel, the angle ϕ between the wrapping strip and the axis of the vessel, and the diameter of the vessel D_c . If these factors are not properly determined, the insulation strips form excessive wrinkles in those areas where there is a transition from one surface to another. These wrinkles will "pile up" thus forming a loose insulation mat with improper density.

For non-spherical vessels, e.g. cylindrical, the angle θ between the plane of the orbit and the axis of the vessel is dependent upon the length of the vessel, the diameter of the vessel neck tube-evaporation conduit, and the width of the strip. The relationship may be expressed mathematically as follows:

$$\tan \theta = \frac{D_n + w}{L} \quad (1)$$

wherein D_n =diameter of the vessel neck tube, L =length of the vessel, and w =width of the metal foil strip.

The angle ϕ that the applied composite wrapping strip makes with the vertical axis of the vessel results from the change of one surface to another and is dependent upon the diameter of the vessel, the diameter of the vessel neck tube, and the width of the strip. Expressed mathematically:

$$\sin \phi = \frac{D_n + w}{D_c} \quad (2)$$

wherein D_c =diameter of the vessel, D_n =diameter of the vessel neck tube, and w =width of the metal foil strip.

For a spherical vessel, these angles are equal since the surface of a sphere is uniform. The magnitude of the orbiting angle for a spherical vessel in degrees is expressed by the formula:

$$\theta = \frac{D_n + w}{D_c} \times 180 \quad (3)$$

where D_n =diameter of the vessel neck tube, w =width of the metal foil strip and D_c =diameter of the vessel. In most cases these angles will vary between 6 and 30 degrees. Having determined these angles, the speed of the container can be determined.

For a non-spherical, e.g. cylindrical container, during the period of time in which the planetary support 35 winds the foil and fibrous strips onto one of the vessel's lateral sections, the vessel must rotate through a central angle α , whose magnitude in degrees is expressed by the mathematical formula:

$$\alpha = \frac{L (\tan \phi - \tan \theta)}{D_c} \times 360$$

in which L =length of the vessel, D_c =diameter of the vessel, and the angles ϕ and θ are the wrapping and orbital angles respectively. This displacement is necessary in order that the wrapped composite strips of insulation be wound adjacent to each other onto the vessel and as wrinkle-free as possible to minimize the insulation "pile up."

In wrapping the 150-liter cylindrical vessel, the above-defined angles were as follows:

$$\begin{aligned} \theta &= 6 \text{ degrees (approximately)} \\ \phi &= 16 \text{ degrees (approximately)} \\ \alpha &= 54 \text{ degrees (approximately)} \end{aligned}$$

The wrapping of vessel 11 was initiated by insulating ribbons of 3-inch wide aluminum foil 36 and 3½-inch wide glass paper 37 from the rolls to form a first section of 28 turns, corresponding to 12 layers.

Since the radial force component of a ribbon wrapped in an almost axial plane around a long cylindrical vessel is extremely small, the composite insulation cannot be wrapped to the desired density at the cylindrical portion,

but remains rather loose. In order to overcome this problem and have the insulation compressed to the desired density of 60-70 layers per inch, a 2½-inch wide woven glass fiber ribbon (not illustrated) was hand-wrapped helically around the cylindrical portion of the vessel. This procedure was repeated at the end of each of the five sections.

On completion of each of the composite-layered insulating sections, a copper conductive shield was orbital wrapped. The 3-inch wide, 0.0007-inch thick copper ribbon was positioned as rolls on the spindles previously used for the metal foil rolls 34a-34d. The rolls were orbited in the previously described manner, each complete shield consisting of four strips 37 applied by four turns of the rotatable frame 35, which corresponds to 1.6 layers. The sequence of shield wrapping is illustrated in FIG. 7. After two turns of planetary support 35, the machine was stopped and a frusto-conical section 117 (see FIG. 3) was attached to neck tube 32 by retaining ring 20. By this procedure, the composite insulation was slightly compressed by the inner, under surface of the frusto-conical section 117, since there is a natural build-up of the insulation at the polar area of the vessel. This slight compression of the composite insulation provided a good thermal contact with the thermal shield 37. Without breaking the copper ribbons, the remainder of the copper ribbons (two turns of the orbital frame) was wrapped on top of the frusto-conical section 117, thus providing an excellent heat transfer path across the section's outer surface to the shield 37. For example, the total contact area between the shield 37 and frusto-conical section 117 is on the order of 35 square inches. In marked contrast, the soft soldered contact area of a spiral wrapped shield to a copper disk concentrically positioned around the neck tube of a 150-liter cylindrical vessel as described in the previously described copending application to Paivanas et al. is only about 3.5 sq. in.

The following table is a summary of the complete insulation construction using the orbital wrap method:

Section Number	Turns Per Section	Number of Layers	Finished O.D., inches
I.....	28 insulation.....	12	18.25
	4 conductive metal shield.....	1.6	
II.....	30 insulation.....	12.4	18.80
	4 conductive metal shield.....	1.6	
III.....	32 insulation.....	12.8	19.35
	4 conductive metal shield.....	1.6	
IV.....	34 insulation.....	13.2	19.75
	4 conductive metal shield.....	1.6	
V.....	36 insulation.....	13.8	
Total...	160	64	20.05

Although preferred embodiments of the invention have been described in detail, it is contemplated that modifications may be made by the art, all within the spirit and scope of the invention.

For example, the invention has been specifically described with reference to double-walled liquefied gas containers having vertically aligned longitudinal axes. The longitudinal axis may also be horizontal—often a more desirable orientation for very large containers. Such large containers may need load rod support members in addition to the previously described neck tube-gas evaporation conduit support member. One embodiment of this invention illustrated in FIG. 8 contemplates the use of frusto-conical sections concentrically aligned around these load-rod members with the large end of these sections thermally connected to the edge of a heat conductive shield.

Referring more specifically to FIG. 8, inner vessel 11 is supported and stabilized within outer casing 13 by load rod members 40 constructed of relatively low heat conductive material, e.g. stainless steel. Load rods 40 may be positioned at opposite ends of the container 10, one end of each rod bearing against and attached to inner vessel 11 while the other end bears against outer casing 13. Frusto-conical sections 41 formed of heat conductive

metal are concentrically aligned around each load rod within vacuum space 14 filled with composite multi-layered insulation 15a. The small end of each frusto-conical section 41 is positioned with its small end frictionally bearing against the outer surface of the load rod 40. If multiple frusto-conical sections are employed, they are spaced along the length of load rod 40.

At least one and preferably multiple highly conductive metal shields 16 are disposed in the vacuum space 14 and surround inner vessel 11. Shields 16 are also contiguously associated on both sides with composite multi-layered insulation 15a. The edge 18 of each shield adjacent to a particular frusto-conical section 41 surrounding load rod 40 is positioned in thermal contact with the section large end, and the small end of the same section is aligned and positioned in thermal contact with load rod 40 so that the shield edge and conical section temperatures are higher than the temperatures they would assume absent the thermal contact. In this manner, the heat inleak conducted along the length of load rods 40 is diverted through conical sections 41 and thermally associated shields 16 to the evaporation gas discharged through conduit 15. That is, another edge of certain heat conductive shields 16 is thermally associated with a selected frusto-conical section surrounding and frictionally bearing against evaporation gas conduit 15 in the previously described manner.

The outer end of evaporation gas conduit 15 preferably is associated with conventional pressure relief devices, i.e. relief valve 42 and bursting disk 43, if it is desired to maintain the liquefied gas in inner vessel 11 at above atmospheric pressure. Control valve 44 is also provided in evaporation conduit 15.

What is claimed is:

1. A double-walled liquefied gas container comprising an inner storage vessel and an outer shell being arranged and constructed with a vacuum space therebetween; an evaporation gas conduit between said inner vessel and said outer shell for transporting such gas from the container and having a temperature gradient across said vacuum space; a composite multi-layered insulation disposed within such space comprising multiple layers of precompacted paper ribbon and aluminum foil ribbon being orbital wrapped crisscrossly in overlaying relation around said inner vessel; multiple frusto-conical sections formed of aluminium sheeting of 0.02 to 0.04 inch thickness being concentrically aligned around said evaporation conduit within said vacuum space, positioned with their small ends frictionally bearing against the outer surface of the conduit for thermal contact therebetween and longitudinally spaced along the conduit outer surface, at least some of the orbital wrapped aluminum ribbons overlapping and contiguously thermally contacting the large ends of respective frusto-conical sections as heat conductive shields, the shields and frusto-conical section large ends as well as the section small ends and conduit outer surface being aligned with respect to the vacuum space width and thermally contacted so that the shield and frusto-conical sections are at temperatures lower than the temperatures they would assume absent the contacts.

2. A double-walled liquefied gas container comprising an inner storage vessel and an outer shell being arranged and constructed with a vacuum space therebetween; an evaporation gas conduit between said inner vessel and said outer shell for transporting such gas from the container and having a temperature gradient across said vacuum space; a composite multi-layered insulation disposed within such space comprising multiple layers of precompacted paper ribbon and aluminum foil ribbon being orbital wrapped crisscrossly in overlaying relation around said inner vessel; multiple frusto-conical sections formed of aluminium sheeting of 0.02 to 0.04 inch thickness being concentrically aligned around said evaporation gas conduit within said vacuum space, positioned with their small ends frictionally bearing against the outer surface of the conduit for thermal contact therebetween and longitudinally

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nally spaced along the conduit outer surface and copper foil ribbon orbital wrapped around said inner vessel between and contiguously associated with adjacent layers of said composite multi-layered insulation, said copper foil ribbon being positioned so as to overlap and contiguously thermally contact the large ends of respective frusto-conical sections as heat conductive shields, the shields and frusto-conical section large ends as well as the section small ends and outer surface being aligned with respect to the vacuum space width and thermally contacted so that the shield and frusto-conical sections are at temperatures lower than the temperatures they would assume absent the contacts.

3. A double-walled liquefied gas container comprising an inner storage vessel and an outer shell being arranged and constructed with a vacuum space therebetween; an evaporation conduit between said inner vessel and said outer shell for transporting such gas from the container and having a temperature gradient across said vacuum space; a frusto-conical section formed of heat conductive metal being concentrically aligned around said evaporation conduit within said vacuum space and positioned with its small end frictionally bearing against the outer surface of the conduit for thermal contact therebetween; a composite multilayered insulation disposed within such space comprising ribbons of a low heat conductive non-metallic component and a metallic reflective component being wrapped criss-crossly in overlaying relation around said inner vessel, at least some of said ribbons being positioned with edges overlapping the outer surface of the large end of said frusto-conical section as a highly conductive metal shield, the shield edge and frusto-conical section large end as well as the section small end and the conduit outer surface being aligned with respect to the vacuum space width and thermally contacted so that the shield edge and frusto-conical section are at temperatures lower than the temperatures they would assume absent the contacts.

4. A double walled container as claimed in claim 3 wherein said composite multilayered insulation is orbital wrapped criss-crossly in overlaying relation around said inner vessel.

5. A double walled liquefied gas container as claimed in claim 3 including load-rod members provided in said vacuum space and positioned with opposite ends bearing

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against said inner vessel and said outer casing so as to support and stabilize said inner vessel; multiple frusto-conical sections formed of heat conductive metal being concentrically aligned around said load-rod members and positioned with their small ends frictionally bearing against the surface of said members for thermal contact therebetween and longitudinally spaced along said surface; multiple conductive shields disposed in said vacuum space and surrounding said inner vessel in spaced relation to each other, another edge of said shield contiguously thermally contacting the large ends of respective frusto-conical sections, said another shield edge and matching frusto-conical section large ends as well as the section small end and load-rod members surface being aligned with respect to the vacuum space width and thermally contacted so that the shield edge and conical section temperatures are lower than the temperatures they would assume absent the thermal contact.

References Cited

UNITED STATES PATENTS

673,073	4/1901	Bebrick.	
2,643,022	6/1953	Cornell	220—15
3,009,600	11/1961	Matsch.	
3,047,191	7/1962	Young	220—3
3,097,084	7/1963	Putman	220—14
3,102,655	9/1963	Adkins et al.	220—15
3,133,422	5/1964	Paivanas et al.	220—15
3,133,659	5/1964	Debell et al.	220—83

FOREIGN PATENTS

143,219 12/1920 Great Britain.

OTHER REFERENCES

Swedish Specification, Petersen, P.: "Some Means to Improve the Vacuum Insulation of the Dewar Flask," TVF, vol. 29, 1958, p. 151—160 (Teknisk-Vetenskaplig Forsknng).

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