Sept. 8, 1964 — I. L. WISSMILLER — 3,147,878

CRYOGENIC STORAGE TANK

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Fig. 1

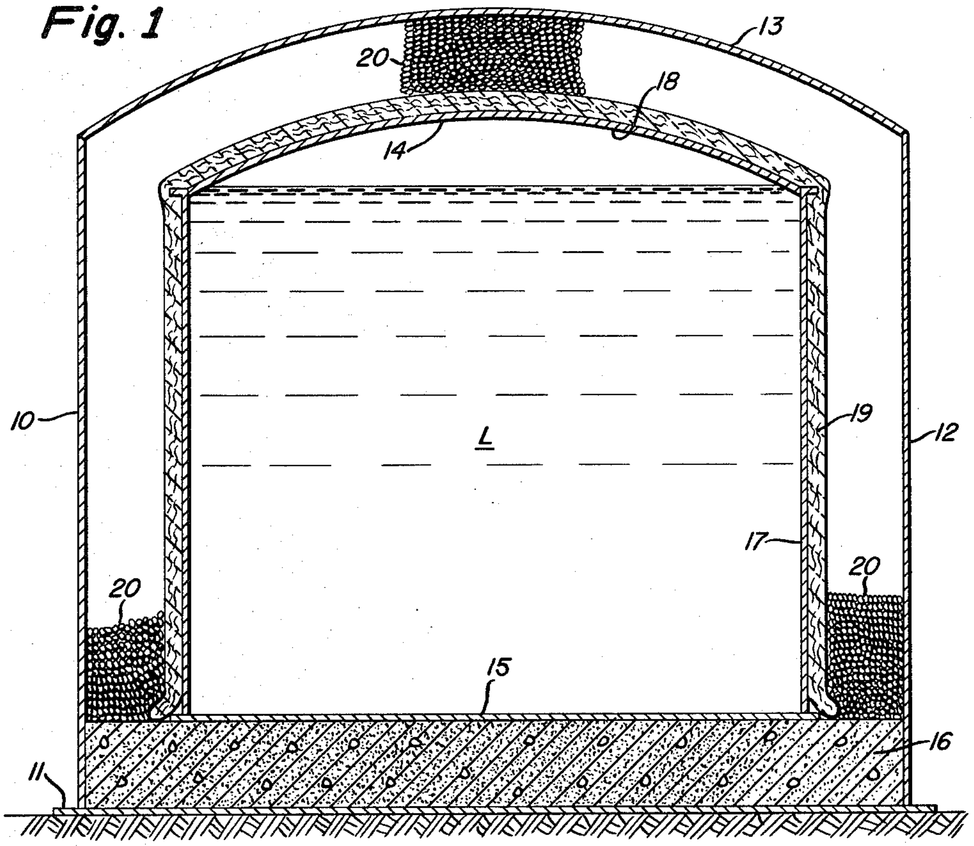

Fig. 3

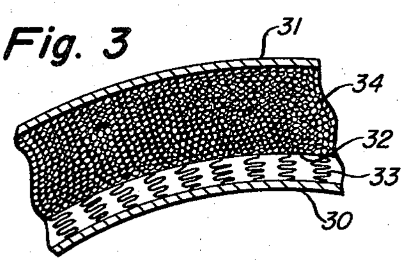

Fig. 4

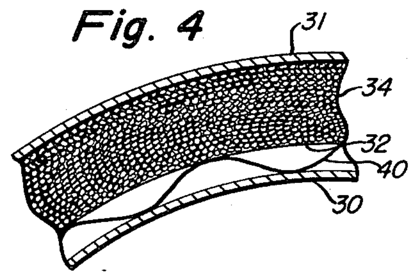

Fig. 5

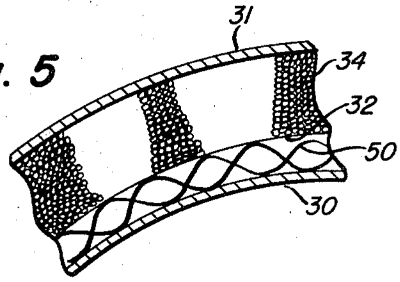

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Fig. 2

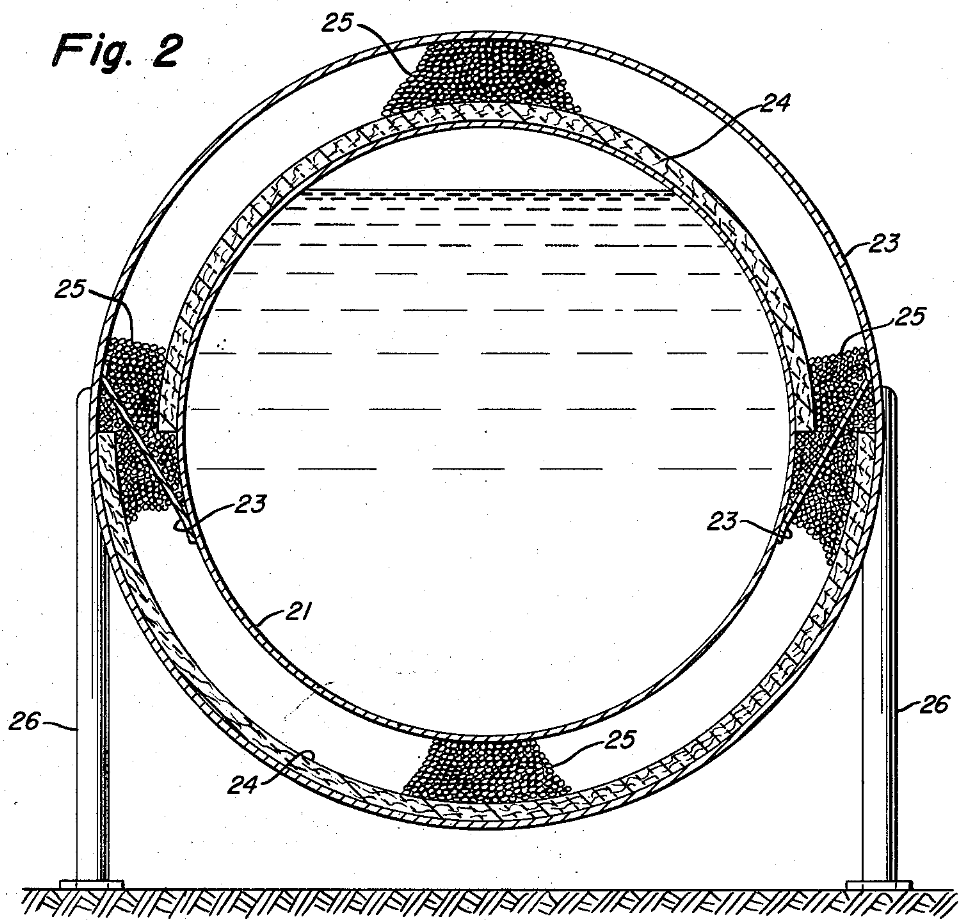
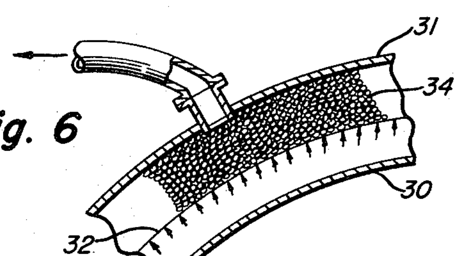


Fig. 6



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CRYOGENIC STORAGE TANK

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7 Claims. (Cl. 220—9)

This invention relates to a tank for the cryogenic storage of liquids. It is more particularly concerned with providing an insulation for the tank which will effectively function within the extreme temperature ranges encountered during the use of the tank.

It is sometimes desired to store normally gaseous elements, hydrocarbons, and other such material in the liquified state at pressures near atmospheric pressure and temperatures near the boiling point of the liquid. By storing such gases in the liquid phase, the volume is greatly reduced, thus making it practicable and economical to store large quantities of such gases, the storage of which, employing conventional storage techniques, had been prohibitively expensive and sometimes quite dangerous. Normally gaseous materials for which it is desired to provide storage in the liquid phase include hydrogen, oxygen, methane and ethylene. When hydrogen is stored at its liquid boiling point of —423° F., it has a gas to liquid volume ratio of 824 to 1. Oxygen stored at its boiling point of —297° F. has a ratio of 845 to 1; methane at —258° F. has a ratio of 625 to 1; and ethylene at —155° F. has a ratio of 480 to 1.

In order to take advantage of the large volume reduction demonstrated by the foregoing figures, it is necessary to store the very cold liquid in a heavily insulated tank. Ordinary insulation materials are unduly expensive, and some of them fail to maintain the desirable properties at the extremely low temperatures which are reached. According to this invention a double-walled tank having an inner vessel designed to contain the liquified gas to be stored and also designed to withstand the lateral pressure of insulating material acting against the outer surface of the inner vessel and an outer vessel serving as a vapor barrier designed to withstand the lateral forces of insulating material acting against the inner surface of this vessel, is employed as a cryogenic storage tank. Within the space formed between the inner vessel and the outer vessel an inexpensive non-cohesive insulating material which exerts an active lateral pressure arising from the weight of the material and its tendency to flow is placed.

In a tank construction of this type effective use of such insulating material presents a problem because the extensive thermally induced lateral movement of the inner vessel wall effected by the extreme temperature range occurring during use results in a passive lateral pressure being developed by the insulation. The extremely low temperatures to which the inner vessel is subjected cause a thermal contraction when the cold liquid is placed inside the vessel and a thermal expansion when the liquid has been withdrawn and the vessel is permitted to warm up to ambient temperature. Furthermore, when the liquid level in the inner vessel is low, a temperature gradient exists between the lower portion of the inner vessel in contact with the liquid and the upper portions of the vessel which are some distance removed from the cold liquid. Here, again, thermal expansion takes place.

Because of the variations in the dimensions of the annular space between the inner vessel and the outer vessel which occur during the thermally induced movement of the inner vessel wall insulating material particles placed within that space have a tendency to settle or move vertically down when the inner vessel has thermally contracted. However, when thermal expansion takes place,

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there is no vertical upward movement of the particles but instead a compacting and crushing effect results from the passive lateral pressure developed in the insulation by the outward movement of the inner vessel wall. As this cycle is repeated, the amount of compaction, crushing and trituration becomes significant, the insulating material continues to drop down, and portions of the space near the top of the vessel become completely devoid of insulating material. In the area in which compaction and crushing have been most severe, the accumulated triturated particles lack the resiliency of the original loosely packed particles and continued cyclic thermal expansion and contraction results in an increased passive lateral pressure of the insulating material acting against the outer surface of the inner vessel which could cause buckling or rupturing of the shell with disastrous consequences.

The amount of thermal expansion and contraction which may take place in the inner vessel depends upon such factors as the range of temperatures in a cycle, the size of the inner vessel and the coefficient of thermal expansion of the material of which the inner vessel is constructed. For example, in a tank having an inner cylindrical vessel 100 feet in diameter, constructed of aluminum, where maximum ambient temperature is +100° F., used in storing liquid methane at —258° F., the diameter of the inner vessel will be reduced by 4.36 inches during that portion of the storage cycle in which the tank is filled with liquid methane.

According to this invention there is provided a means for preventing the compaction, crushing and trituration of insulating material particles in the annular space between the inner and outer vessels of a double walled cryogenic storage tank which permits the utilization of inexpensive, easily handled insulating materials in the aforesaid space.

The invention will be described in conjunction with the attached drawings, in which:

FIGURE 1 is a vertical cross-sectional view of a double walled cylindrical storage tank;

FIGURE 2 is a vertical cross-sectional view of a double walled spherical storage tank; and

FIGURES 3, 4, 5, and 6 are fragmentary vertical cross-sectional views of alternate expedients for compensating for the lateral forces exerted during the thermal expansion and contraction of the inner vessel.

In the embodiment shown in FIGURE 1, the cylindrical cryogenic storage tank consists of (*a*) a cylindrical outer vessel **10** having a flat bottom **11** resting on a prepared grade, enclosed by side wall **12** and roof **13**; and (*b*) a concentric cylindrical inner vessel **14** consisting of a flat bottom **15** resting upon a load bearing insulating material **16**, such as light weight concrete or foamglass, side wall **17** and roof **18**. A resilient blanket **19** is placed about the outside of side wall **17** and roof **18** of the inner vessel and held in position by suitable fasteners such as welded studs laterally depending outwardly from side wall **17** which penetrate blanket **19**. The terminal end of the stud is fitted with flat bearing member which frictionally engages the stud and holds the blanket in position. The remainder of the space between the side walls and the roofs of the inner and outer vessels is filled with granular insulating material particles **20**, such as expanded perlite. The liquefied material L to be stored is located within the inner vessel, and can be withdrawn and replenished by means of a suitable loading and unloading system employing nozzles, valves and pipes which are not shown for the purposes of simplicity.

Resilient blanket **19** is selected so as to resist the active lateral pressure of granular, insulation material **20** without substantial deflection, but to deflect or compress elastically without permanent set when the active lateral pressure of the insulation is supplemented by a passive lateral pressure resulting from the thermally induced lateral movement of the sidewall of the inner vessel during operational use. For example, in the case of expanded perlite the active lateral pressure is about 10 to 30 pounds per square foot at depths lower than about 10 feet from the top. The resilient blanket must therefore be capable of resisting a force of at least 10 pounds per square foot and preferably about 30 pounds per square foot without substantial deflection or compression. There is no established specific lateral force which will cause crushing or compaction of perlite, but it has been established that lateral forces not in excess of 100 pounds per square foot will not cause significant crushing or compaction of the expanded perlite. Furthermore it is expedient to design the inner vessel to withstand externally applied forces of 100 pounds per square foot without buckling. The resilient blanket selected for use with expanded perlite as the insulation must also deflect or compress substantially when a combination of active and passive lateral pressures developed by the insulation produces loads greater than about 30 pounds per square foot and not in excess of 100 pounds per square foot and return to substantially its original thickness without taking a permanent set when the load is released.

Care must be exercised in the selection of a resilient blanket, primarily on account of the extremely low temperature at which such resilient blanket must function. Many materials which have the desired characteristics at ambient temperatures, such as natural and synthetic rubber materials, become embrittled at extremely low temperatures and are completely worthless for this purpose. Accordingly, the preferred resilient blanket is prepared from sheets of matted glass fibers which are formed into a resilient mass and held in place by means of a suitable binder. For example, a satisfactory, low density, resilient insulating blanket formed of fine glass fibers, bonded together by a suitable binder such as a thin film of phenol-formaldehyde resin binder, can be successfully used. It is desirable to select a blanket made of glass fibers having nominal diameters less than 0.00015 inch. One type of fiberglass blanket which has been used is a type manufactured and marketed by the L-O-F Glass Fibers Company under the name "Microlite" having a phenolic binder and a density of 2 pounds per cubic foot.

In testing the useful resilience of the illustrative glass fiber blanket a sample 2 inches thick was used. Lateral forces were applied and the deflection for the material both at normal ambient room temperature and at −320° F. were noted. Under these test conditions the blanket had almost exactly the same resilience at −320° F. as it had at normal room temperature. It was also observed that substantial deflection without permanent set took place in the range of 30 pounds per square foot to 100 pounds per square foot of lateral force. In the sample, the amount of deflection within that range was $^{17}/_{32}$ inch, which measurement is considered to be the "useful resilience" of the 2 inch thick material.

The thickness of the resilient blanket must be selected so as to make available as much "useful resilience" as there is variation in thickness of the annular space of the tank between ambient temperature and the lowest operating temperature. For example, a resilient blanket made of the glass fiber material described above, placed in the four feet thick insulating space produced in the 100 foot diameter tank described above, where expanded perlite is employed as the insulating material, the inner vessel is made of aluminum and liquid methane is to be stored, must be 8.2 inches in thickness so as to have a useful resilience of 2.18 inches.

Resilient blankets made of other types of natural or synthetic fibers which maintain their resilience at the low operating temperature can also be utilized. For example, blankets made of acetate synthetic fibers if properly bonded and if selected of a thickness to afford the proper amount of "useful resilience" are satisfactory.

FIGURE 1 shows a resilient blanket made of fine fibrous material, such as glass fiber, placed around the cylinder and over the roof portions of the inner vessel. Suitable provision must be made, of course, to hold the resilient blanket in proper position after it has been placed. When so placed, it can be seen that, as the inner vessel contracts and expands during different portions of the cooling and warming cycle, the resilient blanket will expand and compress commensurately, maintaining the insulating material in place and preventing the compaction or crushing of the insulating material. In practice, both the resilient blanket and the insulating material are placed in the annular space when the tank is at ambient temperature. The insulation, when placed at ambient temperature, causes the resilient blanket to be compressed slightly on account of the active lateral pressure exerted by the insulation material, ranging, as stated above, from about 10 to about 30 pounds per square foot. When liquefied methane or other liquefied gas is introduced into the inner vessel, the inner vessel contracts, causing the total thickness of the annular space to increase, but the resilient blanket expands on account of the reduction in lateral force of the insulating material as the contraction of the inner vessel takes place. When the liquefied gas is withdrawn from the inner vessel, and that vessel commences to warm up its diameter increases due to thermal expansion, the total thickness of the annular space decreases commensurately, but the resilient blanket commences to compress as the supplementary passive pressure exerted by the insulating material increases, and the lateral pressure of the insulating material therefore never becomes so great as to cause significant crushing or compaction. During the first cycle there will be some consolidation of insulating material, requiring replenishment in the upper portion of the insulating space, but thereafter, only insignificant amounts of compaction and crushing take place. The deflection of the resilient blanket which takes place even upon slight increases in passive lateral pressure prevents such crushing and compaction from becoming critical.

FIGURE 2 shows the use of a similar resilient blanket in a spherical storage tank. The inner spherical vessel **21** is concentrically cradled within outer spherical vessel **22** by means of bars **23** or similar supports which depend downwardly from spaced positions on the inner periphery of outer vessel **22**. The resilient blanket **24** is placed so as to surround the inner vessel **21** completely. To facilitate installation the upper half of the inner vessel is provided with one portion of the resilient blanket and the remaining portion is laid upon the lower half of the outer vessel. Filling the remainder of the annular space is a suitable granular insulating material **25**. The entire tank is supported by means of columns **26** attached to the outer spherical vessel **22**. The resilient blanket **24** functions in a spherical tank in exactly the same way that it functions in a cylindrical tank such as that shown in FIGURE 1.

It should be understood that, while in most of the drawings the blanket is shown in position against the outer surface of the inner vessel, it will also function effectively if placed against the inner surface of the outer vessel, partly against one and partly against the other as in FIGURE 2, or appropriately draped within the annular space and surrounded by granular insulation.

In addition to the matted fibrous resilient blanket other means can be utilized for absorbing the lateral forces produced in the cryogenic storage tank of this invention. For example, FIGURE 3 shows in fragmentary form an inner vessel wall **30**, an outer vessel wall **31**, a thin membrane **32** spaced apart from the inner vessel wall **30** by means of helical compression springs **33** having axes normal to the wall surface, with granular insulating material **34** placed between thin membrane **32** and the outer vessel wall **31**. In this embodiment, it is, of course, necessary to select compression springs of such strength and to space them in such manner that the thin membrane 32 will be depressed substantially evenly upon any increase in lateral pressure of the granular insulating material acting against it. Moreover, the membrane and the springs must be selected of material possessing the necessary low temperature resilience characteristics.

FIGURE 4 illustrates another embodiment, in which a sinuous or corrugated type of resilient spring strip material 40 is substituted for coil springs 33. In this embodiment, inner wall 30, outer wall 31, membrane 32 and granular insulating material 34 are the same as shown in FIGURE 3. Here again, corrugated spring 40 which separates membrane 32 from vessel wall 30 must be so selected as to have the desired characteristics at the extremely low temperatures at which the tank must function. The spacing between vessel wall 30 and membrane 32 and the spring strength must likewise be so selected as to permit the proper deflection of membrane during the warming and cooling cycle.

FIGURE 5 illustrates still another embodiment of the invention, in which gas inflatable cells 50 are placed between membrane 32 and inner vessel wall 30. In this embodiment, however, it is necessary to provide a means for controlling the pressure of the air or gas in the inflatable cells so as to be maintained at a proper pressure regardless of temperature variations, to insure the proper amount of deflection during the warming and cooling cycle. Such means can include a constant pressure gas holder, not shown, to maintain about 30 pounds per square foot gas pressure in the cellular structure, thus controlling the lateral insulation pressure to that same amount. The gas holder should have enough volume to accommodate all volume variations of the mattress caused by temperature changes resulting from varying depth of the cold stored liquid. To accommodate the extreme volume variation which occurs when the inner tank is cooled from ambient temperature an automatic repressuring system should be provided to maintain the constant gas holder pressure. An automatic vent should be provided to release excess gas from the holder during a complete warm-up to ambient temperature.

FIGURE 6 illustrates one other embodiment of the invention in which fluid-impermeable membrane 32 is resiliently held against granular insulating material 34 by means of a subatmospheric pressure induced in the space in which the granular insulating material is located by means of a suitable vacuum pump, not shown. The vacuum producing means is located at a convenient external location and is connected by means of piping to the space in which the granular insulating material is placed. It is necessary to maintain only a very slight vacuum in the space between the outer tank wall 31 and the membrane 32. For example, in order to maintain a lateral pressure against the insulating material of 30 pounds per square foot, an amount sufficient to hold perlite material in place at all points, a vacuum of only approximately 0.2 p.s.i. is required.

In the embodiments shown in FIGURES 3, 4, 5, and 6, fabricated sheets which can be used to construct the flexible diaphragms include thin metal plates if provided with suitable expansion joints, or sheets of nylon, polychlorotrifluoroethylene, polyethylene terephthalate, etc. Woven fabrics of fiber glass, cotton, nylon or the like can be used and made fluid impermeable, if necessary, by coating with thin films of suitable natural or synthetic elastomers. The spring elements used in these embodiments can be made from stainless steel or the like. It should be understood that the lateral force compensators employed in this invention can be placed adjacent to the inner surface of the outer vessel instead of adjacent to the outer surface of the inner vessel, as shown, without departing from the spirit or scope of this invention.

The insulating materials which are preferably employed are non-cohesive or substantially free-flowing, lightweight, thermal insulators having a particle size sufficiently small so as to prevent convection losses through circulation of air through the packed mass. Preferably, granular insulation having a particle size of less than about ⅛ inch is used. The particulate insulation should be substantially non-friable and have a *k* factor of less than about 0.4 B.t.u./sq. ft./hr./inch. To avoid combustion problems encountered in the storage of liquid oxygen, inorganic substances such as expanded perlite, expanded vermiculite, inorganic aerogels such as silica aerogel, and the like can be used. Other insulation which can be used includes granulated cork, shredded foamed polystyrene, etc. Although granular insulation is used in the illustrative embodiments other types of insulation, such as fibrous materials, including shredded wood or bark, fiber glass waste or mineral wool can be used which can consolidate and cause excessive passive lateral pressure.

In fabricating the inner and outer vessel conventional materials of construction, preferably low carbon steel, are used for the latter. The inner vessel, however, must be constructed from materials which do not become brittle in the low temperature service to which they are exposed. Metals such as aluminum, cupro-nickel, and others have desirable properties over substantially the entire temperature range. Steel alloys, however, have to be "notch tough" (Charpy Impact Test of about not less than 15 foot-pounds keyhole at the lowest expected operating temperature of the material), e.g. 18–8 stainless steel, 9% nickel alloy steel, and others.

Other embodiments which have not been shown may still come within the spirit and scope of this invention. The embodiments shown have been presented for the purpose of clarity of explanation only, and no undue limitations in the breadth of the appended claims should be implied therefrom.

What is claimed is:

1. A tank for storing liquids comprising a closed inner storage vessel for receiving the liquid fabricated from a material remaining ductile at storage temperatures, an outer vessel spaced apart from said inner vessel defining an insulating space about the inner vessel, said insulating space being subject to substantial changes in transverse width caused by thermally-induced expansions and contractions produced in said inner vessel during the loading and emptying cycle of said tank, a resilient blanket having low temperature compressive resiliency disposed in the insulating space and freely exposed to the ambient atmosphere therein to form a layer between the inner vessel and the outer vessel, and a free mass of substantially free-flowing light-weight thermal insulating material exposed to the atmosphere within and filling the remainder of the insulating space, said mass exerting a lateral pressure against said blanket and being confined within said insulating space only by direct contact with said blanket and direct contact with at least one vessel surface, the compressive resiliency of the blanket being such that variation in the thickness of the insulating space between the inner vessel and the outer vessel, due to the expansion or contraction of one vessel relative to the other, causes the blanket to expand or contract correspondingly to prevent displacement of the mass of insulating material.

2. A tank for storing liquids comprising a closed inner storage vessel for receiving the liquid fabricated from a material remaining ductile at storage temperatures, an outer vessel spaced apart from said inner vessel defining an insulating space about the inner vessel, said insulating space being subject to substantial changes in transverse width caused by thermally-induced expansions and contractions produced in said inner vessel during the loading and emptying cycle of said tank, a resilient blanket fabricated from a unitary mass of matted glass fibers and having low temperature compressive resiliency disposed in the insulating space and freely exposed to the ambient atmosphere therein to form a layer between the inner

vessel and the outer vessel, and a free mass of substantially free-flowing light-weight thermal insulating material exposed to the atmosphere within and filling the remainder of the insulating space, said mass exerting a lateral pressure against said blanket and being confined within said insulating space only by direct contact with said blanket and direct contact with at least one vessel surface, and exerting a compressive force on said blanket under all service conditions of the insulating space, the compressive resiliency of the blanket being such that variation in the thickness of the insulating space between the inner vessel and the outer vessel, due to the expansion or contraction of one vessel relative to the other, causes the blanket to expand or contract correspondingly to prevent displacement of the mass of insulating material.

3. A tank in accordance with claim 2 in which said glass fibers have nominal diameters less than about 0.00015 inch.

4. A tank in accordance with claim 2 in which said glass fiber blanket has a density not greater than about 2 pounds per cubic foot.

5. A tank for storing liquids comprising a closed inner storage vessel for receiving the liquid fabricated from a material remaining ductile at storage temperatures, an outer vessel spaced apart from said inner vessel defining an insulating space about the inner vessel, said insulating space being subject to substantial changes in transverse width caused by thermally-induced expansions and contractions produced in said inner vessel during the loading and emptying cycle of said tank, a resilient blanket fabricated from a unitary mass of matted glass fibers and having low temperature compressive resiliency disposed in the insulating space and freely exposed to the ambient

atmosphere therein to form a layer between the inner vessel and the outer vessel, and a free mass of substantially free-flowing light-weight thermal expanded perlite material exposed to the atmosphere within and filling the remainder of the insulating space, said mass exerting a lateral pressure against said blanket and being confined within said insulating space only by direct contact with said blanket and direct contact with at least one vessel surface, and exerting a compressive force on said blanket under all service conditions of the insulating space, the compressive resiliency of the blanket being such that variation in the thickness of the insulating space between the inner vessel and the outer vessel, due to the expansion or contraction of one vessel relative to the other, causes the blanket to expand or contract correspondingly to prevent displacement of the mass of insulating material.

6. A tank in accordance with claim 5 in which said glass fibers have a nominal diameter of less than about 0.00015 inch and said blanket has a density of less than about 2 pounds per cubic foot.

7. A tank for storing liquids in accordance with claim 6 in which said inner storage vessel is fabricated from aluminum.

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