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3,416,693

REFRIGERATION SHIELDED DEWAR VESSEL

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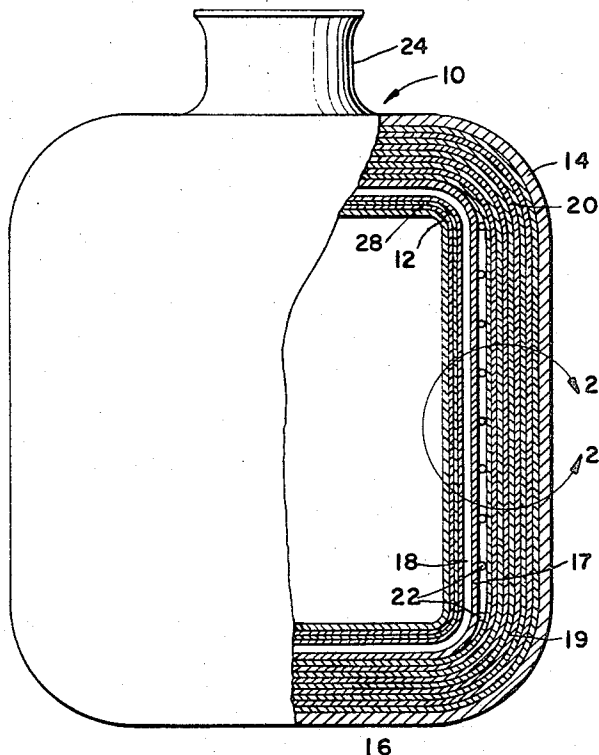
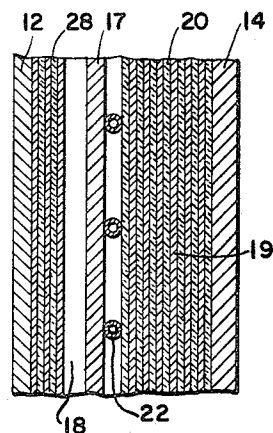


FIG. 2.

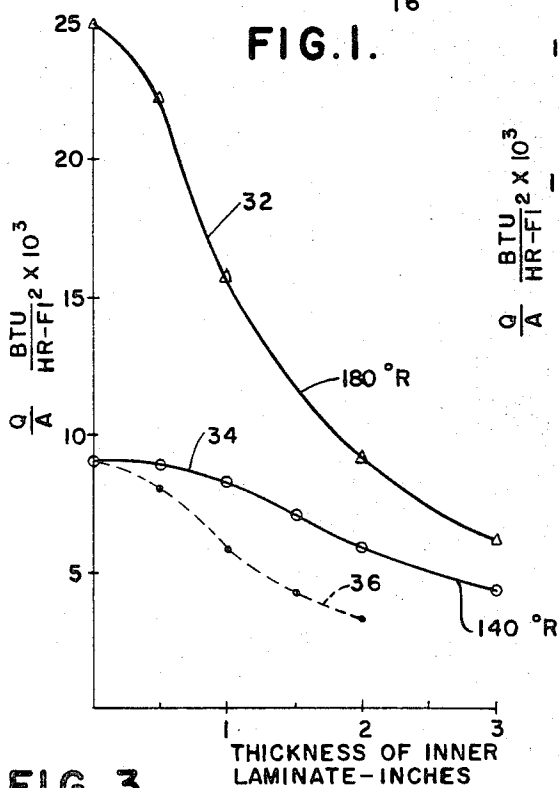


FIG. 3.

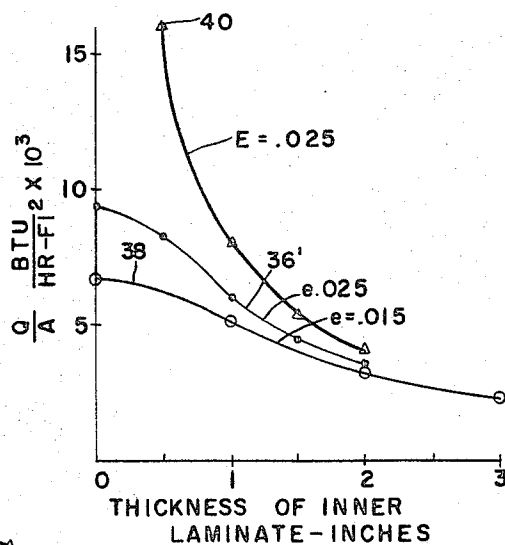


FIG. 4.

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REFRIGERATION SHIELDED DEWAR VESSEL
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ABSTRACT OF THE DISCLOSURE

The disclosure describes an improved refrigeration-shielded Dewar type of storage container. That is a container having an inner wall separated from an outer wall by an evacuated chamber and including a refrigeration shield located between the inner and outer walls. The improvement resides in the placement of a laminated insulation about the vessel's inner wall so that it does not touch the refrigeration shield. A structure which yields particularly good results is described as having an inner wall emissivity of greater than about 0.015; an inner laminate comprised of nylon or terephthalic ester polymer fibers having diameters greater than about 10 microns; and an effective thermal conductivity across the inner laminate of less than about 10×10^{-6} B.t.u./hr.-ft. ° R.

This invention relates to fluid storage containers and, more particularly, to an improved insulation system for such containers.

Cryogenic fluids and other fluids that must be maintained at extremely low temperatures are frequently stored in Dewar-type containers. That is, double-walled containers having a gas-evacuated space between an inner wall and an outer wall. In this manner, because there are relatively few gas molecules between the vessel's walls, there is relatively little convective heat transfer therebetween. By minimizing the contact between the inner and outer walls of a Dewar-type vessel, the conductive heat transport is also substantially decreased; and by placing a plurality of radiation barriers between the two walls the vessel's radiation heat transfer is also substantially reduced. As a practical matter, however, when radiation barriers are employed, they must be so situated with respect to one another and the vessel's walls that their abilities to impede radiation heat transfer are not offset by an increase of solid conduction. Hence, a wide variety of low-conductive radiation-resistant insulation materials have been utilized in the gas evacuated space of Dewar-type containers.

It has also been a practice in the past to substantially surround a Dewar vessel's inner wall with a refrigerated shield where boil-off gases from the inner vessel are directed about the refrigerated shield through a suitable vent-line. In this manner, the gas-evacuated space is divided into two portions and some of the refrigeration value of the boil-off gases is transmitted to the shield. In addition, in those of the Dewar vessels that use a refrigerated shield type of construction, it has also been quite common to apply one or another of a variety of bulk insulation materials in the outer portion of the gas-evacuated space that is located between the refrigerated shield and the vessel's warm outer wall. One of the more satisfactory types of bulk insulation that have been employed in this respect is comprised of a laminate of radiation barriers which are separated from each other by a suitable low conductive material. A multilayer insulation of this type is described, for example, in an article by Dr. Richard H. Kropschot of the National Bureau of Standards. This article appears in the March 1961 issued of Cryogenics, vol. I, No. 3, and is entitled "Multiple Layered Insulation for Cryogenic Application."

In the past, these multilayer insulations have not been employed in the inner evacuated portion of a refrigeration shielded Dewar vessel. This has been because of two related factors. Firstly, the main function of the laminated insulations is to reduce radiation heat transport; and, secondly, although conductive heat transport between two connected bodies merely varies with the temperature differential between those bodies, the radiation heat transport between two bodies varies as the difference between the fourth powers of the bodies' temperatures. Hence, in refrigeration shielded Dewar vessels where the temperature differential between the vessel's inner wall and the shield is relatively small, laminated insulations have not been used in the inner evacuated space because the reduction in radiation heat transfer has been offset by an even greater resulting increase in solid conduction.

An example of a prior art type of refrigeration shielded Dewar vessel may be found, for example, in U.S. Patent 3,134,237, on a "Container for Low-Boiling Liquefied Gases," which issued to J. M. Canty et al. on May 26, 1964, on an application filed Dec. 21, 1960. A more theoretical discussion of this type of container is to be found in a paper by P. J. Murto entitled "A Gas-Shielded Storage and Transport Vessel for Liquid Helium," which appears in vol. 7 of Advances in Cryogenic Engineering, pp. 291-295, Plenum Press, New York, 1962. In both of these references it is suggested that the evacuated space between the refrigeration shield and the vessel's outer wall be filled with some type of multilayer insulation. In accordance with the above described conventional theory, however, the inner portion of these vessels' evacuated space has either been left void, so as to prevent solid conduction between the refrigeration shield and the inner wall, or in some cases, filled with a low conductive powder type of insulation. Where a refrigeration-shielded Dewar vessel's inner evacuated space has been left void, the outer surface of the vessel's inner wall and the inner surface of the refrigeration shield are provided with low emissivity surfaces. Such surfaces may be obtained, for example, by silvering to thereby reduce radiation heat transport to an acceptable amount. Particularly when used in connection with large containers, however, this silvering or other suitable preparation of the surfaces is quite expensive and difficult to satisfactorily accomplish. Moreover, this silvering tends to deteriorate with age whereby the vessel's operational life is reduced. Hence, it is an object of this invention to obtain the benefits of a refrigeration shielded construction without the requirement for the above noted highly-silvered surfaces.

It is a further object of this invention to provide a refrigeration shielded Dewar vessel having an insulation structure that not only eliminates the requirement for highly reflective surfaces, but additionally results in an improved overall insulation quality.

As suggested above, a principle of the refrigeration shielded Dewar lies in the vessel's boil-off gas being passed over the shield as it is vented to atmosphere, so that it gives up its otherwise wasted refrigeration value to the shield. In this respect, therefore, more of the refrigeration value of the boil-off gas is recovered if the shield is maintained at a relatively higher temperature. In the past however, the refrigeration shield has been kept at quite a low temperature in order to minimize heat flux to the inner shell by radiation. This has resulted in a less effective utilization of the refrigeration value of the boil-off gases. Consequently, it is another object of this invention to provide a structure whereby a Dewar vessel's boil-off gases are more effectively utilized.

It is in accordance with the principle of the instant invention that a refrigeration shielded Dewar vessel have its inner wall wrapped with a conventional multilayer insulation which, although contacting the vessel's inner

wall is not permitted to actually contact the refrigerated shield. As will be discussed more fully shortly, it has been found that by thusly wrapping the vessel's inner wall, not only is the combination of the radiation and conductive heat transfer between the refrigeration shield and the inner wall surprisingly reduced, but this, in further combination with a more effective utilization of the vessel's boil-off gases, has resulted in an even larger increase in the structure's overall insulation qualities.

In addition to the above discussed aspects of the invention, it should be noted that conventional multilayer insulations, such as those described in the Kropschot article, for example, have generally used a glass fiber type of low conductive material between the various radiation barriers. This, very simply, has been because very thin glass fibers have been available; and for a given composition, thinner fibers tend to be less conductive than thicker ones. It is in accordance with another aspect of this invention, however, that the inner laminate be comprised of thicker fibers such as nylon or terephthalic ester polymers, one type of which is identified by the trademark Dacron. In this respect, it has been found that at the low temperatures involved, a laminate having fibers comprised of nylon or terephthalic ester polymers results in a lower heat flux than if a glass fiber laminate is employed; and this notwithstanding that nylon and Dacron fibers are generally larger than conventionally employed glass fibers.

The foregoing other objects, features, and advantages of the invention will be apparent from the following more particular description of the preferred embodiments thereof, as illustrated in the accompanying drawings wherein the same reference numerals refer to the same parts throughout the various views. The drawings are not necessarily intended to be to scale, but rather are presented so as to illustrate the principles of the invention in clear form.

In the drawings:

FIG. 1 is an elevational view, partially in section, of a Dewar type cryogenic storage vessel, which incorporates a preferred embodiment of the invention;

FIG. 2 is a developed section of FIG. 1 along the arc 2-2 in FIG. 1;

FIG. 3 is a graph of the heat flux across a helium storage vessel's inner laminate for various refrigeration shield temperatures;

FIG. 4 is a graph of the heat flux across a helium storage vessel's inner laminate for various inner emissivities.

Referring now to the drawings, a preferred embodiment of the invention will be described in connection with FIGS. 1 and 2, wherein a Dewar type vessel, referred to generally as 10, is comprised of an inner shell 12 and an outer shell 14 having an evacuated space 16 therebetween. A refrigeration shield 17 is located between the vessel's inner and outer walls 12 and 14 respectively, as shown. In this manner, the gas-evacuated space 16 is divided into an inner portion 18 and an outer portion 19.

The outer portion 19 of the gas evacuated space 16 is filled with a bulk insulation 20. In this respect, although any suitable type of a bulk insulation might be used, it is generally preferred to employ one of the multilayer types. Multiple layered insulations of the type contemplated are more fully described in the above noted Kropschot article from Cryogenics magazine.

In a preferred embodiment of the invention, the inner container 12 was fabricated of a low-heat conductive material such as type 304 stainless steel while the outer casing 14 was constructed of simple carbon steel. The radiation shield 17, on the other hand, was constructed out of copper, which is highly conductive and supported between the two walls 12 and 14 by any suitable means, which, for purposes of simplicity, have not been shown herein.

A generally spiral tube 22 is coiled along the outer surface of the refrigeration shield 17 and directs boil-off gases from the inner vessel's interior, past the refrigeration shield and out of a storage vessel's neck 24 by means of a suitable vent tube. In this manner, the refrigeration value of the vessel's boil-off gases is given up to the refrigeration shield rather than being passed to the atmosphere. A structure of this general type is more fully described in the above noted U.S. Patent No. 3,134,237.

The vessel's inner wall 12 is wrapped with a suitable multilayer insulation 28. This layer, however, is not permitted to touch the refrigeration shield because, as will be discussed more fully shortly, if contact is permitted between this inner laminate and the refrigeration shield, the heat flux between the shield and the inner wall increases significantly, particularly when the shield is at a relatively high temperature or when the thickness of the laminate 28 is relatively small. In this respect, it should be noted that a desired thickness for the laminate 28 is about one-half inch or more and, even more preferably, about one inch thick.

It should be noted that in the above described structure, no mention was made of the inner walls' emissivity e which is the characteristic of the wall relating to its ability to emit energy. Although not quite technically correct, emissivity can be thought of generally as being a measure of a surface's reflectivity. That is, a surface having a low emissivity is also usually highly reflective. In these respects, as will be described more fully shortly, for a given heat flux across the inner laminate, the above described structure does not require the low emissive (highly reflective) inner vessel surfaces of the prior art. Additionally, because the inventive structure reduces the radiation heat transfer between the shield and the inner wall, the refrigeration shield is permitted to be at a higher temperature whereby more of the refrigeration value of the boil-off gases may be utilized and, furthermore, by using nylon or Dacron types of fibrous material in the multiple layered insulation, the conductive heat transfer across the inner laminate is still further reduced from that of a laminate having glass fibers of a similar size. In this respect, it should also be noted that the fibers of the nylon material employed in the inner laminate of a preferred embodiment of this invention were greater than about 10 microns in diameter while the fiber diameters of the conventionally employed glass fibers are less than about 10 microns and commonly more on the order of about .5 micron in diameter.

By way of summary of the invention's principle, applicants have discovered that a given refrigeration shielded Dewar vessel's heat flux is decreased when multiple layered insulation is inserted between the inner wall and the refrigeration shield in such a manner that the insulation does not touch the shield itself. Further it is noted that even though the inner wall is of relatively high emissivity, and so long as the inner laminate is greater than about one-half to one inch thick, a substantially lower heat flux is obtained as compared with conventional Dewars having surfaces of low emissivity.

Having described the general structure of the invention, several typical results will now be described. These results indicate the magnitude of improvement that is obtained by employing the structure of the invention. In this respect, however, it should be understood that although the following examples are described in terms of a system for storing helium in a liquified state, that the invention is also suitable for storing other low-boiling fluids, such as hydrogen and nitrogen, which also have boiling points below 100 degrees K., at atmospheric pressure.

The graph of FIG. 3 illustrates the inventive structure's ability to reduce the heat flux across a conventionally shielded Dewar's inner evacuated portion. FIG. 3 also illustrates the inventive structure's ability to per-

mit a substantially increased refrigeration shield temperature and therefore a lower overall heat flux between maintaining a comparable heat flux between the refrigeration shield and the inner vessel. In these respects, the graph's ordinate axis represents the heat flux between the test vessel's refrigeration shield and its inner wall; while the abscissa of the graph represents the thickness of the inner laminate corresponding to 28 in FIGS. 1 and 2.

Three curves are illustrated in FIG. 3. The upper curve 32 represents the heat flux for various inner laminate thicknesses with the refrigeration shield at a temperature of 180° Rankine. The middle curve 34 represents a similar heat flux for a refrigeration shield maintained at 140° Rankine. In both of these cases the "effective thermal conductivity" (k) of the multilayer insulation was 10.0×10^{-6} B.t.u./hr.ft. ° R. The lower dashed curve 36 represents a similar heat flux for a 140° R. shield, but for a higher quality multilayer insulation having an "effective thermal conductivity" of 5.0×10^{-6} B.t.u./hr.ft. ° R. Each of the curves 32, 34 and 36 is derived from a vessel having an inner wall surface emissivity of 0.025.

In connection with the above described curve, it should first be observed that the heat flux across the inner portion of the conventional refrigeration shielded Dewar is represented by the point where each of the curves touches the ordinate axis. For a particular refrigeration shielded Dewar represented by curve 34, therefore, the heat flux is about 9.5×10^{-3} B.t.u./hr.ft.² for a conventional structure having no inner laminate. When a 180° refrigeration shield is employed, on the other hand, a conventional Dewar vessel's heat flux across the inner evacuated portion is about 25×10^{-3} B.t.u./hr.ft.².

As shown in FIG. 3, the vessel having the 180° refrigeration shield has its heat flux reduced to about 65% of the conventional refrigeration shielded vessel when only one inch of inner laminate is added. When two inches of inner laminate are employed, the results are even more dramatic because the heat flux is reduced to about 40% of the conventional vessel's value. When the vessel having the 140° refrigeration shield is supplied with an inner laminate as described above, the heat flux across the vessel's inner portion is similarly reduced, although somewhat less dramatically. This is because of the lower refrigeration shield temperature whereby the radiation heat transfer is lower to begin with.

It should also be observed when no inner laminate is employed, the heat flux between curve 32's 180° refrigeration shield and the inner vessel is about 250% greater than the corresponding heat flux for curve 34's 140° refrigeration shield. It is for this reason that the conventional refrigeration-shielded Dewar must have its shield maintained at a relatively low temperature. When using the structure of the invention, however, with only two inches of inner laminate, the heat flux for the 180° refrigeration shield is about the same as that of the 140° vessel having no inner laminate. Consequently, it will be appreciated that for a comparable heat flux between the container's refrigeration shield and its inner wall, the structure of the invention permits the shield to be maintained at a considerably higher temperature whereby more of the refrigeration value of the boil-off gas can be utilized.

The two curves 32 and 34 are based upon a multilayer insulation having an effective thermal conductivity (k) of 10×10^{-6} B.t.u./hr.ft. ° R. In the event that a higher quality multilayer insulation is employed the structure of the invention provides even better results. This is illustrated by dashed curve 36 in FIG. 3 where a mere 2 inches of inner laminate reduces the heat flux across the evacuated vessel's inner portion to only about 37% of a conventional vessel's heat flux across the inner portion.

The ordinates and abscissas of FIG. 4 correspond to those of FIG. 3. Curves 36' and 38 of that figure are used to illustrate another major advantage of the in-

vention which permits the inner vessel's outer wall to have a considerably higher emissivity as well as a reduced heat flux between the container's refrigeration shield and the inner vessel. Both of the curves 36' and 38 represent heat fluxes for various inner laminate thicknesses wherein the thermal conductivity of the multilayer insulation was 5×10^{-6} B.t.u./hr.ft. ° R. In this respect it should be noted that the curve 36' represents the same data as curve 36 in FIG. 3. Additionally, curve 36' illustrates the heat flux when the emissivity of the inner vessel's outer wall is 0.025 while curve 28 illustrates the heat flux when the emissivity of the inner vessel's outer wall is at the higher quality of 0.015. In both cases, all other factors (such as the emissivity of the refrigeration shield's inner surface) were maintained substantially equal.

It should be particularly noted in the case of curve 36', that when as little as about one inch of inner laminate is used, the heat flux between the radiation shield and the inner vessel is less than the heat flux of a conventional vessel having no inner laminate (curve 38 at the ordinate axis) and this even though the inventive structure's inner vessel wall is considerably less reflective ($e=0.025$) than that of the conventional vessel ($e=0.015$). It will be appreciated by those skilled in the art that this results in a lower manufacturing cost while nevertheless maintaining or increasing the effectiveness of the vessel's overall insulation system. It will also be appreciated that even a conventional vessel with a highly silvered outer surface on its inner vessel can have its overall insulation properties improved merely by adding an inner laminate thereto. For example, as illustrated by curve 38, the addition of two inches of inner laminate to the vessel's inner wall results in a reduction of heat flux from the radiation shield to the inner wall of over 50 percent.

In all cases discussed above, it should be carefully noted that in no case does the inner laminate touch the refrigeration shield. If this is permitted, the system's effectiveness is sharply reduced. For example, as illustrated by curve 40 in FIG. 4, even when using a highly effective multilayer insulation having an effective thermal conductivity (k) of 5.0×10^{-6} B.t.u./hr.ft. ° R. the resulting heat flux is higher than that of a conventional vessel having no inner laminate. In this respect, however, it should also be noted that curve 40 results from a less specular outer surface on the container's inner vessel wall without increasing the heat flux between the container's radiation shield and the inner vessel. Moreover, quite contrary to currently accepted practice, the overall insulation of a given refrigeration shielded container is surprisingly improved merely by including an inner laminate of multilayer insulation about the container's inner wall so long as the inner laminate does not touch the refrigeration shield.

While the invention has been particularly shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that various changes in form and detail may be made therein without departing from the spirit and scope of the invention. For example, although it is presently conventional to use a multilayer insulation comprised of alternate radiation barriers and glass fiber paper, the invention is equally applicable when the radiation barriers are separated by materials such as nylon or terephthalic ester polymers, for example. In fact, as was noted above, because of the extremely low temperatures involved whereby the dominant mode of heat transfer is by conduction, and because the conductivity of nylon, for example, at liquid helium temperatures is only about $\frac{1}{8}$ that of glass fibers, even better results are obtained when these materials are used.

The embodiments of the invention in which an exclusive property is claimed are defined as follows.

What is claimed is:

1. An improved Dewar type of cryogenic storage container of the type in which an inner vessel wall is sepa-

rated from an outer wall by an evacuated chamber and a refrigeration shield is located in the evacuated chamber between the inner and outer walls wherein the improvement comprises:

an inner laminate of multilayer insulation wrapped about said inner wall so that said inner laminate is spaced from said refrigeration shield.

2. The apparatus of claim 1 wherein said inner laminate is at least about one-half inch thick.

3. The apparatus of claim 2 wherein said inner laminate is comprised of alternate layers of radiation barrier material and a material having thermal conductivity of about that of nylon or terephthalic ester polymer fibers.

4. The apparatus of claim 1 wherein said inner laminate is over about one inch thick.

5. The apparatus of claim 4 wherein said inner laminate is comprised of alternate layers of radiation barrier material and a material having an effective thermal conductivity of about that of nylon or terephthalic ester polymer fibers.

6. The apparatus of claim 1 wherein said inner laminate is comprised of alternate layers of radiation barrier material and a material having an effective thermal conductivity of about that of nylon or terephthalic ester polymer fibers.

7. The apparatus of claim 1 including an outer laminate comprised of a plurality of radiant heat barrier layers separated by low conductive fibrous material wherein said outer laminate is wrapped about said refrigeration shield.

8. The apparatus of claim 7 wherein said inner lami-

nate is comprised of alternate layers of radiation barrier material and a material having thermal conductivity of about that of nylon or terephthalic ester polymer fibers.

9. The apparatus of claim 1 wherein said inner laminate is comprised of alternate layers of radiation barrier material and a fibrous material having fiber diameters of more than about 10 microns and wherein the effective thermal conductivity of said inner laminate is less than about 10×10^{-6} B.t.u./hr.ft.²°R.

10. The apparatus of claim 9 wherein the emissivity of said inner vessel wall is greater than about 0.015.

11. The apparatus of claim 9 including an outer laminate comprised of a plurality of radiant heat barrier layers separated by a low conductive fibrous material having fiber diameters less than about 10 microns wherein said outer laminate is wrapped about said refrigeration shield.

12. The apparatus of claim 11 wherein the emissivity of said inner wall is greater than about 0.015.

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