Feb. 21, 1933. D. F. COMSTOCK 1,898,977

VACUUM INSULATION

Filed Sept. 7, 1928 3 Sheets-Sheet 1

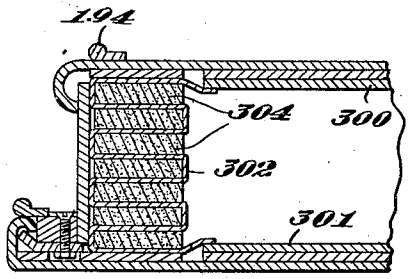

Fig. 9

Fig. 1

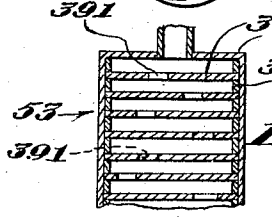

Fig. 11

Inventor
Daniel F. Comstock
by Roberts, Cushman & Woodbury.
Attys.

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VACUUM INSULATION

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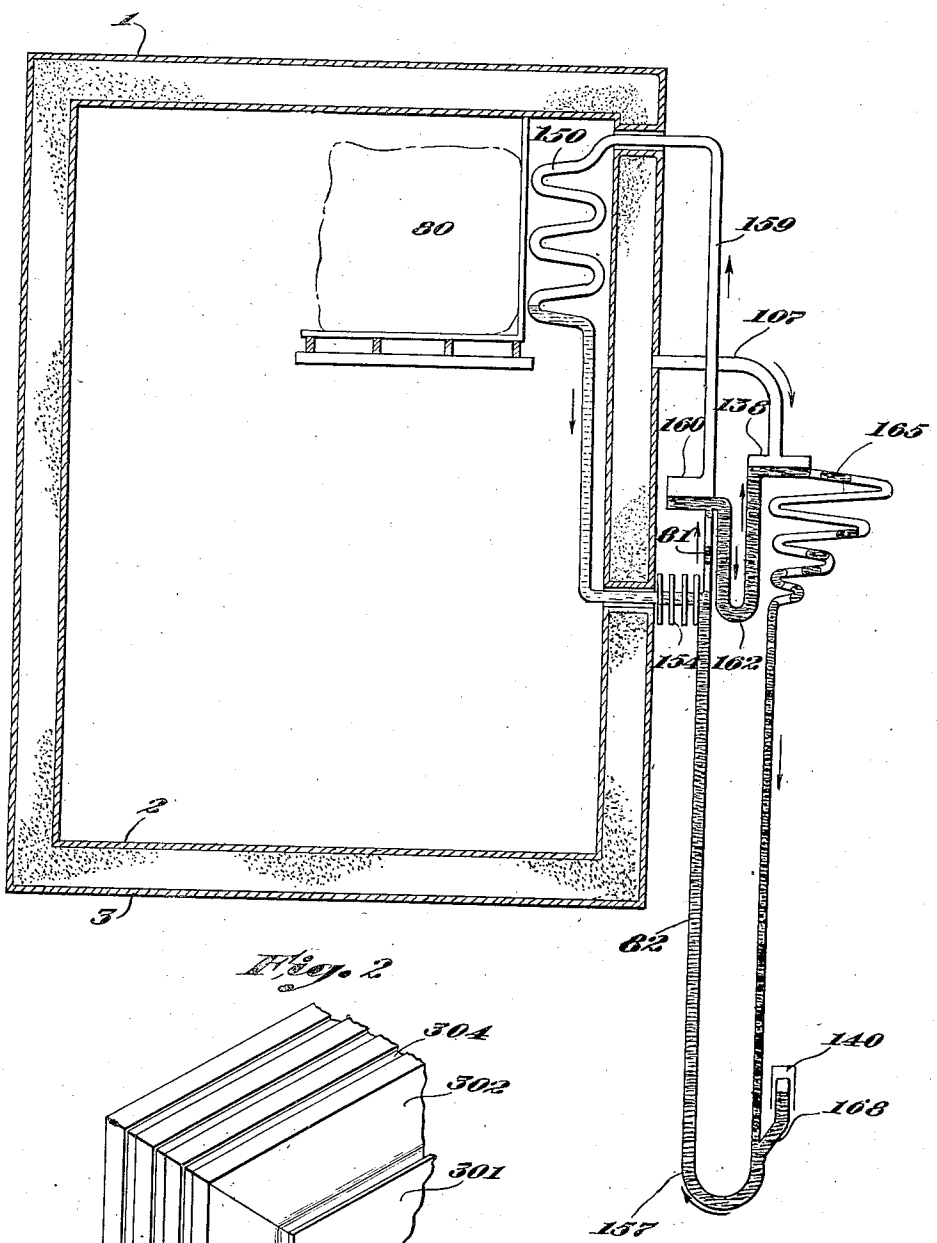

Fig. 2

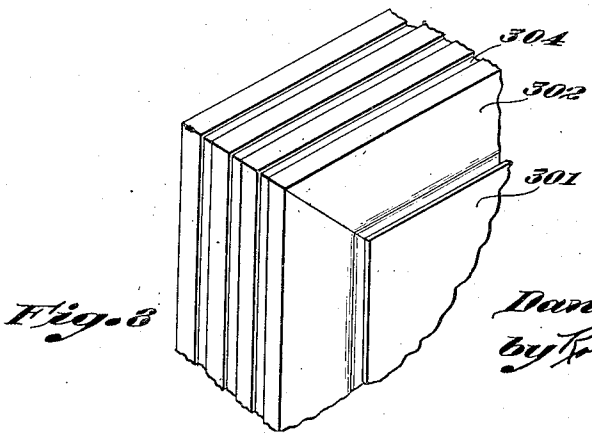

Fig. 8

Inventor
Daniel F. Comstock
by Roberts Cushman & Woodberry
Att'ys.

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VACUUM INSULATION

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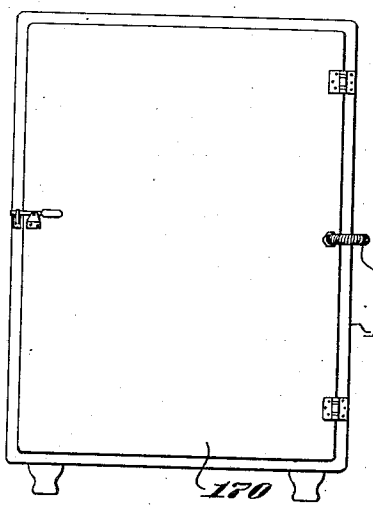

Fig. 3

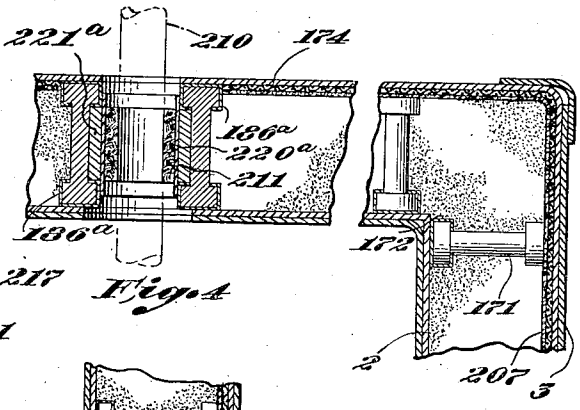

Fig. 4

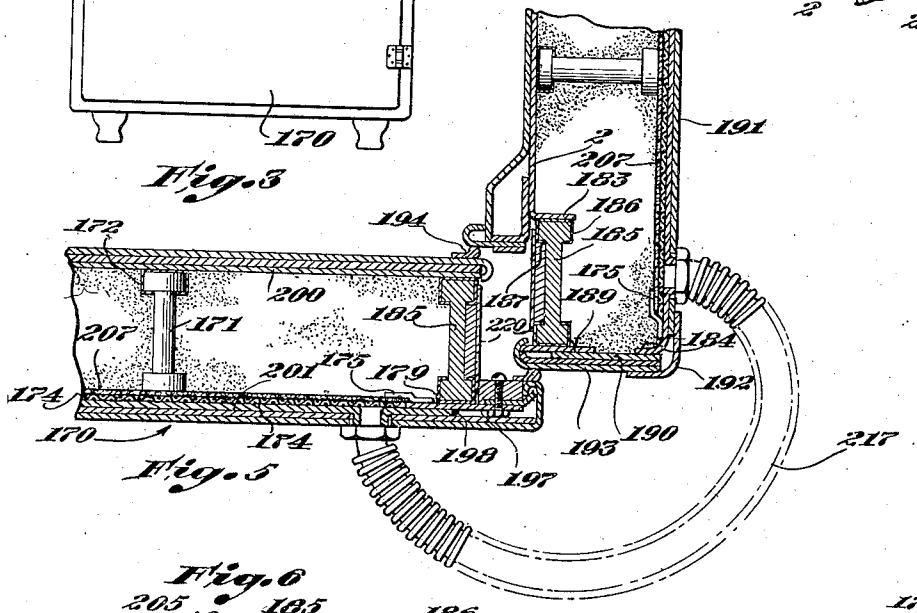

Fig. 5

Fig. 6

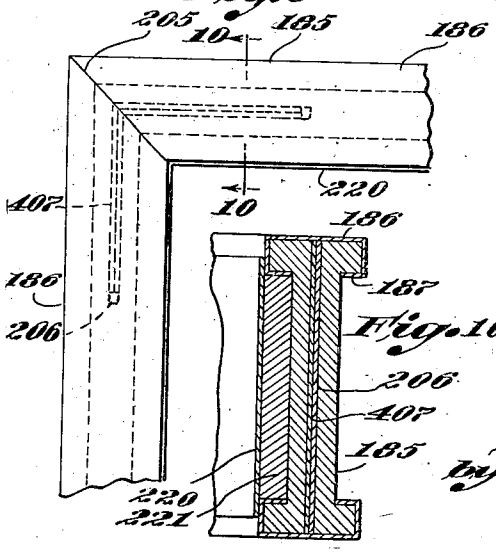

Fig. 10

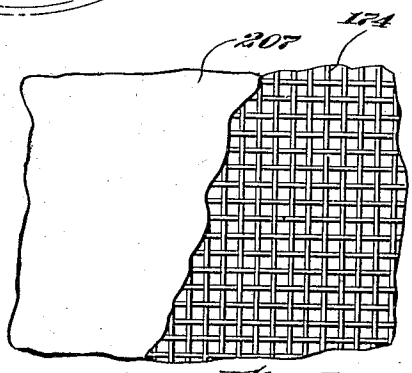

Fig. 7

Inventor
Daniel F. Comstock
by Roberts Cushman & Woodbury
Atty's.

Patented Feb. 21, 1933 1,898,977

UNITED STATES PATENT OFFICE

DANIEL F. COMSTOCK, OF BOSTON, MASSACHUSETTS, ASSIGNOR, BY MESNE ASSIGNMENTS, TO STATOR REFRIGERATION, INC., A CORPORATION OF DELAWARE

VACUUM INSULATION

Application filed September 7, 1926. Serial No. 304,589.

This invention relates to insulation as applied to or incorporated in refrigerators, refrigerator cars, refrigerant ducts, hot or cold fluid pipes or tanks, heaters, boilers, houses, or other installations, and more particularly as associated with the former.

While it has heretofore been proposed to utilize vacuum chambers for insulating refrigerators or the like, the difficulty of permanently maintaing a comparatively high vacuum in housings of this character has made the commercial provision of such insulating means impractical. The present invention provides vacuum insulation for purposes of this character, preferably utilizing a fairly high vacuum in conjunction with powdered or closely spaced filling material or other material having minute interconnected voids in the vacuum chamber.

The elements of this filler material may be so disposed in indifferent particle-to-particle contact that they afford a very poor path for direct heat conduction between opposite sides of the vacuum chamber, while preventing direct heat radiation between the same and providing only a low rate of reradiation. The voids in the filler material preferably have dimensions substantially less than the mean free path of the gas molecules. The filler is also preferably non-hygroscopic and not highly gas absorptive. When material of this character is located within a vacuum chamber, a considerably lower vacuum provides as good a heat insulating efficiency as does a high vacuum in chambers that are free from the separated or foraminous fillers.

One of the deficiencies of vacuum insulating walls or casings of the character heretofore proposed has been the freedom with which heat could pass from one wall of the vacuum chamber to the other by paths other than through the vacuum space itself; for example, the walls connecting hot and cold sides of the chamber have usually provided such a low resistance to the flow of heat that the effect of the vacuum insulation was substantially nullified. Thus, for example, in vacuum insulating walls of the character heretofore built or proposed it has been common to provide continuous metal connections between the opposite hot and cold walls of the chamber, the metal of these connections being of substantially the same thickness as the opposite hot and cold walls or face sheets of the vacuum chambers and consequently providing paths of high heat conductivity between the hot and cold sides of the insulating wall. The present invention preferably obviates these deficiencies by providing bridges or connections of low heat conducitvity between the face sheets or metal walls at opposite sides of the vacuum chamber. Thus, for example, I may provide non-metallic supporting elements between the margins of the inner and outer walls, which are adapted to support the same against the external atmospheric pressure and I may associate comparatively thin metal bridges with these non-metallic elements, the bridges preferably being formed of metal having comparatively high heat resistivity. Thus the thin metal is united with the opposite face sheets in order to provide a substantially gas-tight seal, while the thinness of the metal as well as its natural heat resistivity causes it to afford a comparatively poor heat conductive path. The non-metallic supporting material which permits the use of the thin metal bridges obviously may be a comparatively poor heat conductor.

It is thus evident that a housing having walls formed in accordance with this invention ordinarily will be characterized by parallel metal sheets which normally may be at quite different temperatures, having their edges connected by bridges of low conductivity whereby there is only a slight leakage from the high temperature to the low temperature sheet.

As a further adaptation of my invention, I preferably provide similar bridges or connective means not only between the edges or margins of the sheets, but at openings which are provided for the necessary pipes or the like that may pass through the wall to provide connections for refrigerant flow or the like and at other locations.

It is extremely difficult to provide absolutely air or gas-tight housings of considerable size in commercial quantities, especi-

ally when these vacuum containers are partially formed of metal sheets with soldered and/or welded joints or seams. It is feasible however to provide vacuum insulating chambers of this character which under ordinary conditions of use have only a low rate of gas leakage. I therefore propose to provide pumping means to maintain a comparatively high vacuum within the insulating chamber. Pumping means of this character may be arranged to be more or less continuously operable, for example being associated or combined with the means for maintaining a low temperature within a refrigerator. Thus, when utilized for a refrigerator provided with mechanically operable cooling means, the pumping means may be arranged to receive its energy from the same source as that which provides refrigeration. Furthermore, when used in conjunction with refrigerating apparatus characterized by comparatively low pressures, the pumping means may conveniently be multi-stage, the first stage of the same being arranged to exhaust gases from the vacuum chambered wall and to raise the pressure of the same to the pressure within the refrigerating apparatus and the second stage being associated with or inherent in that apparatus and being adapted to receive the gases from the first stage and to emit the same to the atmosphere or any suitable point of exhaustion. Thus, for example, in its preferred embodiment the pumping means may be associated with refrigerating apparatus of the character disclosed in the copending application of Eastman A. Weaver, Serial No. 733,699, filed August 23, 1924, now issued as Patent No. 1,761,551 and the copending application of Lyman F. Whitney, Serial No. 159,342, filed January 6, 1927, now issued as Patent No. 1,756,802, when this apparatus is provided with means for exhausting non-condensable gases, such as disclosed in my copending application Serial No. 198,715, filed June 14, 1927.

When the invention is thus associated with refrigerating apparatus of the mechanical type, it is evident that a portion of the energy imparted to the refrigerating apparatus is utilized to enhance the insulating qualities of the walls of the refrigerating chamber, so that the total amount of energy required to maintain a given temperature difference between the inside and the outside of that chamber may be greatly reduced.

In accordance with a further aspect of this invention, the pumping means which is adapted to maintain the vacuum in the insulating wall may be arranged to be automatically operable in response to a temperature difference existing at opposite sides of the insulating wall. Pumping means of this character may be associated with, and in its preferred aspect, have portions at opposite sides of the insulating chamber or wall, being automatically operable whenever a temperature difference exists at opposite sides of the wall. For this purpose, for example, pumping means may be utilized which is of the same general type as that which may be conveniently combined with the mechanical refrigerating apparatus, or the temperature difference existing at opposite sides of the insulating wall may be utilized in various other ways to maintain a vacuum in the wall and thus greatly enhance its efficiency. For example, thermal transpiration may be utilized for this purpose.

A specific pumping means provided by the present invention comprises a fluid circuit arranged so that a circulating fluid passes from a region of high pressure to a region of low pressure, during this movement entraining a second fluid, a portion of the circuit for which is arranged to entrain gas from the insulating wall and to exhaust the same to the low pressure refrigerating apparatus, to the atmosphere, or at any other suitable region.

When an insulating wall is filled with materials having minute interconnected voids, it may prove somewhat difficult to cause a continuous gas flow from all portions of the chamber thus filled to a single gas outlet. Therefore, in its preferred embodiment my invention provides the vacuum chamber with suitable air or gas passages arranged in conjunction with the filling material to permit the circulation or movement of gas from widely spaced regions within the insulating wall to the single gas outlet. Thus, for example, I may preferably provide air passageways which are substantially coextensive with a face of the wall itself. This novel insulating wall is disclosed and claimed in my copending application Serial No. 437,377 which is a division of this application.

In the accompanying drawings:

Fig. 1 illustrates a vacuum walled refrigerator provided with pumping means associated with a low pressure refrigerating apparatus, which in turn is preferably provided with means for exhausting non-condensable gases to the atmosphere;

Fig. 2 is a more or less diagrammatic view showing a somewhat similar form of automatically operable pumping means arranged in combination with a refrigerator adapted to utilize ice as the cooling means, the pumping means illustrated in this figure being arranged to operate in response to temperature differences at opposite sides of the vacuum wall, to receive the gases from the same and to exhaust them into the atmosphere;

Fig. 3 is a front view of a refrigerator casing;

Fig. 4 is a cross-sectional view through a rear corner of the same;

Fig. 5 is a similar view showing the construction of the front corner adjoining the door hinges;

Fig. 6 is an elevational detail of the non-conductive frame within the casing;

Fig. 7 is an elevational detail of the screen and fabric arrangement provided to maintain air passages within the casing;

Fig. 8 is a perspective view of an optional bridge arrangement;

Fig. 9 is a section through a door embodying the same;

Fig. 10 is a section on line 10—10 of Fig. 6; and

Fig. 11 is a sectional detail of a factor for stabilizing vapor flow.

Referring first to Fig. 1 of the accompanying drawings, it may be seen that the refrigerator housing 1 is provided with inner and outer shells 2 and 3 which afford a suitable space therebetween which may be exhausted of air, gases, and vapors, thus providing a comparatively high vacuum. This space is preferably filled with closely spaced, finely divided or foraminous material which is a poor transmitter of heat, such as silocel powder, closely spaced sheets of paper, attenuated fibrous material or the like, as well as silocel brick, cork or similar porous material, which not only prevents direct radiation from one wall of the vacuum chamber to the other, but which minimizes the effect of reradiation and which affords small voids which at a proper vacuum are substantially smaller than the mean free path of the gas molecules. Radiation is also minimized, because each particle can ordinarily radiate only to a juxtaposed particle or particles. Suitable gas-collecting passageways may be arranged within the vacuum chamber in a manner which will be described below, these passageways being connected to the air exhaust pipe 7. The latter is adapted to direct gases from the refrigerator wall to the first stage pumping means 8 which is operable concomitantly with the refrigerating apparatus. In the embodiment of the invention shown in Fig. 1, the pumping means 8 is arranged to emit the non-condensable gases into a portion of the low pressure refrigerating apparatus which maintains the cooler at a suitable low temperature.

For purposes of convenience in understanding a specific application of the invention, I will first describe a low-pressure refrigerating apparatus which has been in practical operation for a considerable period and which is described and claimed in the copending applications of Eastman A. Weaver and Lyman F. Whitney, identified above.

Refrigerating apparatus of the character disclosed herein may conveniently utilize a comparatively heavy propellant having a high boiling point, such as mercury or the like, and a refrigerant such as water or the like. A system of this character comprises a boiler 41 provided with a heating factor 42, such as an electrical resistance element. Mercury is vaporized in the boiler 41, rises in pipe 43, and flows outwardly through the aspirator jet 44, where there is a large increase in velocity and decrease in the pressure of the mercury vapor stream. Liquid refrigerant is contained in the cooler 5, and refrigerant vapor is drawn from the surface of this liquid through the duct 20, being entrained in the mercury stream which gives up its kinetic energy in the pumping of the refrigerant vapor.

The mixture of vapors passes into the inclined funnel 46 where the kinetic energy of the propellant is absorbed in compressing the vapor mixture. Funnel 46 is provided with cooling means 21 in order to cause condensation of the major portion of the mercury at a comparatively high temperature and the drainage of the same toward the lower end of the funnel. It is evident that the temperature of funnel 46 is normally below the condensation point of the mercury and above the condensation point of the refrigerant at the pressure conditions prevailing after compression within the system, so that the refrigerant vapor flows upwardly through passage 22 to refrigerant condenser 47 where condensation of the refrigerant occurs.

The condenser 47 comprises a pipe having a general downward inclination, being arranged to drain condensed refrigerant to the separating chamber 23, into the mid-portion of which the passage 22 vents. Liquid refrigerant flows to the bottom of chamber 23 and passes downwardly through pipe 48 to cooler 5, this pipe being provided with a suitable liquid trap 24 in order to permit different pressures in the cooler and the condenser. A drain 27 which comprises a liquid trap 28 is connected to the trap 24, being adapted to permit the flow of any heavier propellant which may have been carried into the cooler 5 back to the duct 11 of the propellant circuit.

In apparatus of this character which normally is operated at a low pressure so that the maximum pressure existing within the system may be of the order of atmospheric, and so that the lowest pressures within the system are of the order of a fairly small fraction of the maximum pressure, it is desirable to provide means to exhaust non-condensable gases from the system and to permit continued maintenance of a low pressure therein, since gas is likely to find its way slowly into the system from or through the metal walls or the joints of the same,

and thus cause the pressure within the system unduly to rise.

In order to permit exhaustion of non-condensable gases from the apparatus, a pipe 16 is connected to the upper end of the condenser and extends downwardly to join portion 10 of duct 19. This duct is arranged to drain propellant from the lower end of the funnel 46 and from the lower end of the upstanding passage 22, and comprises a U-shaped liquid trap 29, a continuation of which forms an upward bend 10^a of inverted U-formation, as shown. Pipe section 10 is of capillary size, i. e. this tube has a bore of such a diameter that mercury globules passing therethrough will act as liquid pistons, contacting on all sides with the inner surface of the tube. Pipe 16 joins the upper portion of duct section 10, this juncture being designated *a*. The capillary tube extends downwardly from this point to the U-shaped tube 11, the shorter leg of which comprises a vessel 31 into which the capillary is adapted to vent fluid. The upper end of this vessel is open to the atmosphere.

The other leg of tube 11 comprises an upstanding pipe which forms an outlet for the propellant from vessel 31 and holds a column 32 of propellant. The upper end of this leg of tube 11 terminates at 15 in a connection with a downwardly inclined pipe 12 which joins a substantially vertically disposed pipe 13, which is adapted to hold another column of the propellant, designated by numeral 34 proportioned to balance the vapor pressure in boiler 41, the juncture of pipes 12 and 13 being designated by the numeral 14. The lower portion of pipe 13 forms a liquid trap 45 through which the propellant may return to the boiler, the outlet of the trap being located below the liquid level in the same. Pipe 13 is continued upwardly beyond point 14 to provide a bypass 35 connecting with the drain 19 at point *b*, which is located near the juncture of pipe 22 with the funnel outlet and at a position designed to be always above the liquid level in trap 29 during normal operation.

In the operation of this system, propellant liquid is vaporized in boiler 41 and rises through upstanding pipe 43 to the aspirator jet 44 through which it passes, thereafter entraining refrigerant vapor at reduced pressure coming from the cooler 5 through duct 20. The vapor mixture passes into the funnel 46 where condensation of practically all of the propellant may occur, while the refrigerant, which is now compressed and has a higher temperature of condensation than formerly, passes upwardly through pipe 22 and chamber 23 to the refrigerant condenser 47 where it condenses. The liquid refrigerant flows down to the bottom of chamber 23 and through pipe 48 and trap 24 to cooler 5, its pressure being lowered as it bubbles through the mercury in trap 24. The condensed propellant passes down into the drain 19 and into the U-shaped trap 29 thereof. The pipe 16 normally collects any light non-condensable gas which may gather in the system, since such gas will fail to condense in the condenser 47 and will be swept to the end of the system.

When liquid propellant piles up in the leg of trap 29 adjoining point *b* to a sufficient height, it causes the propellant in the other leg of the trap to flow inwardly through capillary section 10 past the point *a* where pipe 16 joins tube 10. Since tube 10 is capillary, gases and vapor from pipe 16 will be entrained by the liquid as it flows by the point *a* towards the vessel 31, the liquid in trap 29 preventing flow of the fluid in the opposite direction. This gas and vapor will tend to be compressed as it passes downwardly to open vessel 31. The lighter fluid then rises to the top of the liquid in vessel 31 and is given up to the atmosphere. The height of the liquid in vessel 31 varies in response to variations in the barometric pressure, it being obvious that the head due to the weight of the liquid in this leg of tube 11, plus the atmospheric pressure, will balance the pressure of liquid column 32 in the other leg of tube 11 plus the pressure thereabove. This height is determined by the position of point 15 which defines the upper end of the liquid column, and propellant will flow from the top of the column through the drain 12 to the pipe 13 where it forms the liquid column 34 to balance the pressure in boiler 41.

It is obvious that instead of the vessel 11 venting to the atmosphere as shown in the drawings, it could vent into a closed vessel, the only condition being that said vessel must be large enough so that it will not become full of gas unduly soon or some means must be provided for the removal of the gas either continuously or intermittently.

It will be noted that point *a* is somewhat higher than point 15 and that the liquid head due to the weight of the propellent column in the capillary tube plus that in the adjoining portion of vessel 31 below the outlet of the tube must substantially balance the head due to the weight of the liquid column 32, the difference in height of these columns is effective in determining the amount of fluid that is entrained in the propellant as it passes point *a*. The various parts of the system are so arranged that a proper amount of fluid will be entrained at point *a* in order to exhaust the maximum quantity of non-condensable gas that may ordinarily appear in the system. However, even when no non-condensing gases appear in the system, the amount of refrigerant vapor exhausted will be so small as to have

a substantially negligible effect on the quantity of refrigerant liquid in the system even over long periods of time. In practice, the point *a* is preferably arranged near a hot part of the system, such as riser 43, so that the refrigerant in pipe 16 will remain vaporized and so that liquid refrigerant will not be pumped to vessel 31.

My improved vacuum pumping means may conveniently be combined with refrigerating apparatus of the character described above, which has been in practical use for a considerable length of time. In accordance with the present invention the vacuum pumping means 8 may be arranged to receive a portion of the compressed refrigerant vapor passing upwardly from the compression duct 46 to the condenser 47. For this purpose a pipe 9 is connected to the pipe 22 having a downward continuation 50 to which is connected an upwardly turned pipe 51. A suitable drain 52 is connected to the pipes 50 and 51 and is adapted to receive any stray mercury particles that may pass into this portion of the piping and return the same to the propellent column 32. Pipe 51 extends upwardly to a pressure stabilizing factor 53. The latter may be provided with a plurality of restricted passages or openings which tend to stabilize the pressure conditions of the vapor sweeping through the same; accordingly sudden irregularities or surges in the flow of fluid are substantially eliminated. Fig. 11 illustrates more in detail one specific arrangement of this factor which, for example, may be a porous plug or which, as shown, may comprise a series of parallel disks 390 spaced by suitable rings or the like 394 and provided with comparatively small openings 391 out of alignment with each other. Preferably the disks may be spaced from each other at distances substantially of the order of the diameter of the openings 391. It is accordingly evident that vapor passing through the factor 53 flows through a plurality of restricted and tortuous passages and accordingly sudden changes in the volume and/or pressure of the flowing vapor stream are opposed. Preferably the factor 53 and the adjoining piping are arranged close to a hot portion of the system, such as the hot riser 43. As a result of this arrangement condensation of the vapor passing to or through the stabilizing factor is prevented, and accordingly the pocketing of condensed fluid below the same is avoided.

A pipe 58 connected to the upper end of factor 53 is continued in a downwardly extending pipe portion 54, the lower end of which may be inclined diagonally to provide one leg of a mercury trap 57. Extending upwardly from the upper portion of this leg of the trap is a tube 59 of capillary size, i. e., of such a diameter that mercury globules flowing through the tube may contact upon all sides with the internal surface of the same to form liquid pistons. At the top of tube 59 is a separating chamber 60 from which a pipe 61 extends upwardly to the vapor duct 20 of the refrigerating apparatus. The chamber 60 is partially filled with mercury and is at the top of one leg of a mercury trap 62, the opposite leg of which joins pipe 7 that is adapted to receive gases from the vacuum chamber. At the juncture of pipes 62 and 7 is disposed the upper end of a tube 65 which may also be of restricted diameter, i. e., of substantially capillary size. This tube preferably follows a helical or sinuous downward path to a chamber 66, the upper portion of which is connected by a gas duct 68 with the low pressure vapor duct 20 and the lower portion of which vents into the leg of mercury trap 57 which is opposite tube 59.

In the operation of pumping means 8 in conjunction with the refrigerating system, compressed refrigerant vapor such as water vapor is received in the pipe 9 and passes through the stabilizing factor 53 to the pipe 54. Tube 59 joins the diagonal continuation of this pipe substantially at the top of the mercury contained in that leg of the trap 57 so that the vapor pressure in pipe 54 may depress the mercury and intermittently push globules of the same upwardly into pipe 59. The vapor still under pressure bubbles upwardly through the mercury contained in chamber 60, being released to the low pressure existing in pipes 61 and 20. Thus the vapor passing into the pipe 9 gives up its pressure in lifting mercury globules from trap 57 to chamber 60 and is received at low pressure in pipe 20 where it rejoins the main refrigerant circuit. Due to the induced circulation of mercury globules through pipe 59, the mercury level in chamber 60 tends to be raised and mercury flows downwardly through trap 62 and upwardly past the juncture with pipe 7.

The mercury thus being lifted to the mouth of pipe 7 tends to form intermittent globules which pass over into the upper end of the sinuous tube 65, trapping bodies of gas and vapor therebetween. It is evident that the trap 62 prevents refrigerant vapor from passing from chamber 60 to pipe 7. The sinuous arrangement of tube 65 and its average moderate downward inclination permits the passage of successive mercury globules which are spaced at a considerable distance from each other, and accordingly a comparatively large volume of gas may be entrained between successive globules, this being desirable due to the extremely low pressure prevailing in pipe 7 and accordingly the degree of compression which desirably occurs in pipe 65. As the mercury globules pass down through the latter the

gas pockets are compressed due to the weight of liquid thereabove so that they become comparatively small. The mercury globules join the body of mercury which is contained in chamber 66 which is located above the upper end of the corresponding leg of trap 57, while the trapped vapors and gases flow upwardly through pipe 68 to the low pressure duct 20. The increase in the weight of the mercury in chamber 66 causes the liquid in the corresponding leg of trap 57 to move downwardly and the mercury to flow upwardly in the opposite leg of the trap, thus replenishing the supply of mercury at the lower end of pipe 59.

It is evident that the pressure head, due to the weight of mercury in the leg of trap 57 which adjoins the chamber 66 as well as in that chamber and the vapor pressure thereabove substantially equals the head of the mercury in the opposite leg of the trap, and the pressure of the globules in pipe 59 plus the pressure thereabove. Since the mercury surface in chamber 60 is above that in chamber 66, the difference in mercury levels is effective in determining the volume of water vapor which passes upwardly through pipe 59 and causes the movement of mercury in the mercury circuit.

Obviously the weight of the liquid columns in trap 62 plus the pressures thereabove practically equalize each other. Since the pressure in vapor duct 20 may, for example, be of the order of three or four millimeters of mercury, while the pressure within pipe 7 may be a fairly small fraction of one millimeter of mercury the liquid level in the leg of trap 62 adjoining the pipe 7 will be slightly higher than the level in chamber 60. Since the latter has considerable volume, slight variations in pressure at either side of the trap tend to be equalized and do not seriously affect the operation of the system.

Obviously fluid vented from the pumping system 8 into the duct 20 of the refrigerating system, after passing through the aspirator funnel 46, will gather at the top of the refrigerant condenser where it will join the non-condensable gases to be exhausted through duct 10 and vessel 31. The trap 24 and the chamber 66 may be connected by a pipe 307 so that the mercury levels in the same may remain substantially equalized; thus accidental straying of mercury particles from the refrigerating apparatus to the pumping means 8 would not, even during a very long time, unduly increase the amount of mercury contained in the latter. In the accompanying drawings the size of the pumping means 8 is considerably exaggerated in order to permit a clear showing of the same. The mercury levels in chambers 60 and at the juncture of pipes 7 and 65 will normally differ by only a few millimeters, this distance being determined by the difference of pressures within duct 20 and pipe 7. In practice, the pumping means 8 may be quite compact and only needs to have a comparatively small pumping capacity to maintain the desired vacuum.

Fig. 2 illustrates pumping means of the general character disclosed in Fig. 1 as applied to a refrigerator utilizing a cake of ice, which is designated by numeral 80, as the cooling medium. The refrigerator housing itself may be of the same general character as described above. An arrangement of this character is more particularly claimed in my copending application Serial No. 602,008, filed March 30, 1932.

The pumping means disclosed in Fig. 2 is generally similar to that shown in Fig. 1, the pipe 107 of Fig. 2 being connected to the gas passages within the vacuum chamber of the refrigerator housing. In this form of the invention a condenser 150 is located within the refrigerator adjoining the cooling medium 80, the upper end of this condenser being connected by the duct 159 with the separating chamber 160. The lower portion of the condenser is connected to a vaporizer 154 that in turn joins the lower end of a capillary tube 81. This tube is continued downwardly in an extension 82, which may be non-capillary, if desired, while its upper end terminates in a separating chamber 160. The lower portion of pipe 82 is continued in a U-shaped extension or trap 157. To the opposite leg of this trap is connected a branch 168 which is protected by a cover 140, the liquid within the pipe 168 being exposed to the atmosphere.

A trap 162 is located between the bottom of separating chamber 160 and a chamber 138 at the juncture of the pipe 107 and the sinuous or coiled pipe 165 of small diameter, i. e., of substantially capillary dimensions. The latter is continued downwardly first in a generally sinuous or helical form and then straight down to join the vertical leg of trap 157 which is joined by the pipe 168. In this embodiment of the invention, vapor is liquefied in condenser coil 150 due to the low temperature existing within the refrigerator. The liquid thence passes downwardly to the vaporizer 154, where the temperature of the liquid is raised substantially to the temperature without the refrigerator. Vaporization of the liquid at this point tends to cause the same to rise upwardly through tube 81, where globules of mercury are entrained between bodies of vapor, the vapor passing through the mercury in chamber 160 and continuing upwardly in pipe 159 to the condenser where the circuit is completed.

The mercury overflows into trap 162, thence passes upwardly into chamber 138 where entrainment of non-condensable gases

from pipe 107 occurs. The pipe portion 165 preferably is so arranged that its upper part has a gradual inclination so that the comparatively large volume of non-condensable gas may be entrained between successive mercury globules. As the mercury continues downwardly the pipe eventually becomes vertical and the gaseous bodies between successive mercury globules become greatly compressed, in fact, tending to consolidate with one another. Thus the gas, when it reaches the pipe 168, is compressed to a pressure slightly above atmospheric and rises in pipe 168, being exhausted through the open end of the same to the atmosphere.

It is evident that the pressure conditions within the closed system comprising the pumping means of Fig. 2 are so determined in relation to the vapor pressure of the liquid in vaporizer 154, that the liquid will boil at ordinary room temperatures and will condense at temperatures ordinarily prevailing in a refrigerator. In this embodiment of the invention the distance from the junction of pipe 168 and the main mercury pipe to the other portions of the apparatus is sufficient to permit the liquid columns to balance atmospheric pressure. It is thus evident that in general the pumping apparatus shown in Fig. 2 resembles that disclosed in Fig. 1, but that the greater height of mercury columns permits the direct exhaustion to the atmosphere. It is further evident that apparatus of the type disclosed in Fig. 2 is particularly advantageous when a refrigerator using ice as a cooling medium is provided with vacuum insulated walls and further that apparatus of this type may be provided in a mechanically cooled refrigerator, particularly when the cooling apparatus is not of the low pressure type, although either specifically or broadly the arrangement shown in Fig. 1 may be advantageous, especially when the refrigerating system is operating at a comparatively low pressure and when the source of energy for the refrigerating apparatus is also conveniently usable for the pumping means to exhaust the refrigerator housing.

Obviously the pumping means disclosed in Fig. 2 may be utilized wherever a temperature difference exists between regions at opposite sides of a vacuum wall, the vapor pressure of the alternately vaporized and condensed liquid being determined in relation to pressure conditions within the system and the temperature ranges of the aforesaid regions.

Figs. 3, 4, 5, 6, 7 and 8 illustrate various structural details of one form of refrigerator housing provided with walls which include vacuum chambers. Fig. 3 shows a front view of a housing 1 of this character which may comprise inner and outer shells 2 and 3 which are nested in spaced relation to each other to provide a vacuum space therebetween, the box thus formed being provided with a suitable door or swinging closure 170 which also contains a vacuum chamber, this chamber being connected by a suitable duct with a chamber in the housing proper. The inner sheet metal casing 2 may carry a plurality of spacing elements or columns 171 of hard, non-conducting material, such as bakelite, asbestos wood, hard rubber, wood, or other material, which preferably is rendered impervious to moisture. Spacers 171 may be held to the inner shell 2 by means of metal clips 172 which are soldered, welded or otherwise secured to the shell.

Located along the inner face of the outer shell 3 are suitable means to provide fluid passages which may connect with the pipe 7. These passages preferably are arranged to permit the exhaustion of gas and vapor from widely spaced and distributed portions of the vacuum chamber. One mode of attaining this result consists of the provision of meshed wire screening 174 held against the face of the metal shell by clips 175. This screening preferably may be substantially coextensive with the outer face of the shell wall, and similar screening, similarly designated, may be arranged within the door 170. A suitable fabric 207, such for example as felt, may be arranged against the wire screen 174, this fabric preferably being sufficiently impervious to prevent the finely divided filling material from penetrating into the air spaces between the wires of the meshed screen, while readily permitting the flow of gas.

As previously stated, the finely divided or foraminous filler material preferably is packed between the inner and outer walls of the vacuum chamber. Such material, for example, may be silocel, closely spaced sheets of paper, closely packed fibrous material, or similar substances, which are adapted to prevent the movement of heat by radiation between opposite walls of the vacuum chamber and which may provide interconnected voids having dimensions substantially less than the mean free path of the gas molecules.

The outer ends of spacers or struts 171 engage the sheet 207, aiding in holding the same in place. The filling material packed between the fabric and the inner shell and about each of the spacers also aids in supporting the walls against the external atmospheric pressure, and with properly reinforced walls the internal reinforcements or spacers 171 may be omitted and dependence placed upon the filling material alone for this purpose, if desired.

If porous solid material such as silocel blocks is used for a filler, the internal reinforcements can ordinarily be omitted and the filler material itself be depended upon to

support the outer walls against the external pressure.

Special means are provided between the edges of the inner and outer shell to prevent heat conduction therebetween, thus materially raising the heat insulating efficiency of the housing. For this purpose, I preferably arrange the edges of the inner and outer shells in spaced parallel relation and provide especially constructed non-conductive bridges therebetween. In the specific arrangement illustrated herewith, for example, the edge of the inner casing 2 may be turned outwardly to provide a perimetric flange 183 while the edge of the outer casing is inturned to provide a flange 184. The form of non-conducting bridge which is illustrated therewith may comprise strips 185 of heat insulating material such, for example, as bakelite, asbestos wood, hard rubber, or various other synthetic compositions, or natural wood impregnated with suitable moisture-resistant material, such for example as high boiling point paraffin. The inner and outer edges of these bridge elements preferably may be enlarged and may receive sheet metal channels 186, the outer edges of the legs of which are firmly flanged about the enlarged portions of the non-metallic elements as designated by the numeral 187. A suitable filler strip 221 may be arranged between the inturned metal portions 187 to provide a surface substantially aligned with the aligned surfaces of metal strips 186. A thin metal plate 220 may then be secured by soldering or the like to these aligned surfaces of the strips 186, this metal plate being supported by the filler 221 and serving to provide a substantially gas-tight seal between the two strips 186. The sealing strip 220 preferably is formed of metal having high heat resistivity such, for example, constantan, nichrome, or the like, and preferably is of thin gage in order to provide low heat conductivity. The non-metallic element 185 supports the opposite edge portions of the metal walls against external pressure so that the metal sealing strip 220 does not need to have great structural strength and accordingly may be made quite thin.

One of the strips 186 upon each of the bridges 185 is secured by soldering or welding to the flange 183, while the opposite metal portion 186 is secured to a rectangular frame 189 of sheet metal. Preferably flange 184 and frame 189 lie in the same plane and are spaced from each other. A suitable cover frame 190, which also preferably is rectangular, may then be soldered or welded upon the outer faces of frame 189 and flange 184, thereby closing the space between casings 2 and 3. Thereafter any conventional outer sheathing or covering means may be provided as, for example, the outer sheets of veneer or decorative metal 191 and the corner trim 192 and the edge strips 193.

The door preferably is formed of inner and outer metal sheets 200 and 201, the screen 174 being arranged adjoining the inner face of the latter. Suitable spacers 171 may be arranged between the inner and outer sheets after the manner described above with reference to the main vacuum chamber. The bridge elements 185, which are arranged within the door, may correspond to the similar strips similarly designated and described above, and similarly may be associated with non-metallic fillers 221 and thin metal sealing plates 220. The inner metal portion of the bridge strip within the door may be welded to a marginal face of the inner sheet 200, while the outer metal element may be secured to the rectangular frame 197, this frame being secured by soldering, welding or the like, as designated by numeral 198 to the edge of sheet 201. The door may be provided with suitable covering means and flanges in any desired manner, as shown.

The bridge members may conveniently be assembled to compose rectangular frames before they are disposed between the inner and outer shells or between the face sheets of the door. For this purpose the strips 185 and the channels 186 are provided with mitered joints, Fig. 6, and slots 206 are cut in the mitered ends of the non-metallic elements 185, these slots preferably extending the full depth of these elements, as indicated in Fig. 8. A comparatively stiff, impervious sheet material, which may be impregnated by a high melting point paraffin or the like, may be folded to provide an angle element 407 which is engaged in the slots at the ends of strips 185, pressphan or fishpaper or similar material being suitable for this purpose, since it is comparatively stiff and sturdy and yet has sufficient yieldability to permit its introduction into the slots 206. When the bridge strips are thus assembled in this manner, the adjoining portions of the metallic channels 186 may be secured to each other by soldering or welding, as designated by numeral 205, Fig. 6. The sealing strips 220 which meet at the corners may then also be welded or otherwise secured to each other to provide a substantially continuous metallic seal. It is evident that the rectangular bridge frame utilized in the door is similar to that provided for the casing, but that the sealing strips 220 are located about the bridge frame in the former case rather than inside the same as shown in Fig. 6.

Bridges similar in general construction to those utilized between the inner and outer shells of the housing may also be arranged adjoining each of the openings for the pipes which are adapted to permit refrigerant to

circulate from the refrigerating apparatus into the refrigerator, to permit drainage from the same, or for any other purpose. Such a construction is illustrated at the left of Fig. 4, the numeral 210 designating a typical pipe which necessarily passes through the vacuum wall.

Suitable circular openings are cut in the inner and outer sheets adjoining such a pipe. An annular or spool-like bridge of any desired composition, such as hard rubber, wood bakelite, asbestos wood, or the like is arranged between the inner and outer sheets at this point, suitable metal channels having their legs clinched about enlarged portions of the annular member in the same general manner, as described in reference to the bridges at the edges of the box with the exception that these members are curved rather than straight. Thus the outer metal member 186^a may be soldered or welded to the face of sheet 3 adjoining the pipe opening therein, while the corresponding opening in the inner sheet may be somewhat larger so that the edge thereof registers with the face of the adjoining metal channel 186^a, thus permitting these parts to be joined by soldering or welding after the inner and outer housings are assembled.

Similarly in this case a non-metallic filler element 221^a may be arranged between the inturned portions of the channels 186^a inside of the annular bridge member, and a metallic sealing strip 220^a may be soldered or otherwise secured to the aligned surfaces of the channels 186^a, this strip being supported by the filler 221^a.

A suitable ring of heat insulating material 211 is arranged within the annular member and is adapted to hold the pipe 110 in spaced relation thereto and spaced from the inner and outer walls of the vacuum chamber. If desired, this portion of the pipe may be made of material having low heat conductivity, such as German silver or nichrome and/or may have thin walls.

In order to permit the flow of gas from the air passages provided by the meshed screen in the door to the corresponding passages within the chamber, I provide a suitable flexible duct 217 which is connected to the interior of the door and the interior of the chamber. This duct may be formed of a single metal tube with an undulatory wall of the type commonly utilized for metal bellows or the like, the ends of this tube being welded, brazed, soldered or otherwise secured to the outer walls 3 and 201 of the housing and door respectively and the ends of this tube being arranged in somewhat spaced relation from the edges so that each local portion of the same is only moderately flexed when the door is opened.

Figs. 8 and 9 illustrate a modified form of bridge construction. As in the case of the construction shown in Fig. 5 these connecting bridges may be utilized both between the inner and outer shells of the casing and the inner and outer walls of the closure, Figs. 8 and 9 illustrating the latter specifically.

In order to minimize heat conduction between the inner sheets 300 and the outer sheets 301, it is desirable to use material having low heat conductivity, to make the path to be traversed by the heat comparatively long, and to minimize the cross-sectional area of the conductive path. Accordingly when metal is utilized for this purpose I preferably provide a bridge sheet 302 which may be of a gauge considerably thinner than that of the outer and inner sheets 300 and 301. This sheet preferably has portions welded or otherwise secured to the edges of the sheets 300 and 301 and is preferably formed of metal having low heat conductivity, such for example as constantan or nichrome. Furthermore this metallic bridge may be arranged to follow an indirect course between the inner and outer sheets 300 and 301. For this purpose I may arrange a plurality of filler elements 304 in channels formed in the sheet, the adjoining channels facing in opposite directions and being reinforced by the filler elements 304 that fit tightly within the same. These elements may be of any suitable material having low heat conductivity, and may conveniently be formed of material adapted to withstand considerable heat so that they may be heated when the chamber is initially evacuated. Asbestos wood is therefore suitable for this purpose.

Suitable non-conductive finishing material may be arranged about the bridge strip 302, as shown in Fig. 9.

Fig. 8 illustrates a typical corner construction in a door having a metallic bridge of the type shown in Fig. 9, it being understood that the channels may be built up and welded together at the corners in order to make the same substantially continuous about the perimeter of the bridge frame. It is evident that the construction shown in Figs. 8 and 9 permits the provision of a metallic bridge between an inner and outer wall of the vacuum casing which may remain at different temperatures. The heat resistivity of the bridge metal as well as the length of the same, and the thinness thereof thus may cooperate in permitting only a slight heat flow between the inner and outer sheets.

From the foregoing it will be evident that this invention provides an insulating wall or housing which may contain one or more vacuum chambers that preferably are filled with closely spaced, or foraminous non-heat transmitting material and which are exhausted to a fairly high vacuum; that this invention is particularly intended to pro-

vide a commercially feasible type of wall that is not absolutely free from atmospheric leakage but which is adapted to receive a small amount of gas either from the atmosphere or from the metal of the walls, the vacuum chamber being combined with pumping means continuously to maintain the vacuum within the chamber.

According to this invention pumping means of this character would be in substantially continuous operation when the vacuum wall is in use as an insulating factor. Thus this pumping means may be operated from the same source of energy as the refrigerating apparatus, so that the refrigerator wall is being evacuated while the refrigerating apparatus is operating, or it may be arranged to be partially or wholly responsive to a difference in temperature between opposite sides of the insulating wall so that once such a temperature difference is established, it will be maintained for a long period of time. It is further evident that my invention permits the ready removal of gas from all portions of the evacuated chamber despite the packing of the same with a filler providing minute voids, since air passages are provided which are substantially coextensive with the wall and are adapted to remove gas which might otherwise tend to become trapped in local portions of the filler. The bridges between the inner and outer metal wall portions are very effective in enhancing the insulating efficiency of the vacuum wall, since otherwise a comparatively large flow of heat would occur if the conventional metal sheets of the inner and outer walls were directly joined to each other. When insulating means of this character is utilized in conjunction with refrigerating apparatus characterized by comparatively low pressures and adapted to receive non-condensable gases and to exhaust the same to the atmosphere or to make use of them in any other suitable way, the first stage pumping means may serve merely to raise the pressure of the gas drawn from the vacuum chamber to the minimum pressure existing within the refrigerating apparatus. On the other hand, pumping means of the same general type may be arranged as shown in Fig. 2 to raise the pressure of the gas directly to atmospheric pressure and to exhaust the same directly to the air.

From the foregoing it will be evident that an important feature of the invention consists in the unique construction of the bridges which interconnect the inner and outer walls around the boundary of the vacuum spaces, whereby heat conduction is minimized not only through the insulation walls but also along the boundary bridges; that low bridge conduction may be attained by making the bridges of low conductivity, thin, or long, or with any two of these three characteristics, or with all three characteristics; and that a long bridge may be provided without increasing the spacing between the walls by turning the bridge back and forth in suitable contour as illustrated in Figs. 8 and 9.

While I have disclosed this invention particularly as applied to a refrigerator housing and specifically as combined with refrigerating apparatus, it is evident that the principles thereof are widely applicable to various installations where a heat insulating wall or jacket has proven or may prove desirable. Thus, for example, a vacuum chambered housing of this general type may be utilized in conjunction with heaters, ovens or boilers, while the walls of houses may similarly be provided with hollow evacuated panels that are provided with pumping means arranged as disclosed and described herein.

I claim:

1. In combination a refrigerator, an insulating housing associated therewith, the walls of said housing including a vacuum chamber, a cooler within the housing, pumping means to circulate refrigerant through a cycle to maintain the cooler at low temperature, a refrigerant duct connecting the cooler with the pumping means, said duct normally containing rarefied refrigerant, and a connection between the vacuum chamber and duct whereby the pressure within the former may be maintained at least substantially as low as that in the duct.

2. In combination a refrigerator, an insulating housing associated therewith, the walls of said housing including a vacuum chamber, a cooler within the housing, pumping means to circulate refrigerant through a cycle to maintain the cooler at low temperature, and pumping means to maintain a comparatively high vacuum in the chamber of the insulating wall, said last-named pumping means being multi-stage, one of the stages thereof being associated with said refrigerant pumping means.

3. In combination a refrigerator, an insulating housing associated therewith, the walls of said housing including a vacuum chamber, a cooler within the housing, pumping means to circulate refrigerant through a cycle to maintain the cooler at low temperature, a refrigerant duct connecting the cooler with the pumping means, said duct normally containing rarefied refrigerant, and pumping means to maintain a vacuum in the chamber of the insulating wall, said last-named pumping means being adapted to emit gas into the refrigerant duct.

4. In combination a refrigerator, an insulating housing associated therewith, the walls of said housing including a vacuum chamber, a cooler within the housing, pumping means to circulate refrigerant through a

cycle to maintain the cooler at low temperature, a refrigerant duct connecting the cooler with the pumping means, said duct normally containing a rarefied refrigerant, and pumping means to maintain a vacuum in the chamber of the insulating wall, said last-named pumping means being adapted to emit gas into the refrigerant duct, and means to eliminate non-condensing gases from the refrigerant circuit.

5. The method of maintaining a vacuum in a chamber of an insulating wall and of compensating for leaks in the same, which comprises establishing a temperature differential at opposite sides of the wall, circulating fluid from one side of the wall to the other, the pressure in the fluid circuit permitting vaporization of the fluid at one side of the wall and condensation at the other, pumping a second fluid through a second circuit having a portion in common with the first circuit by means of entrainment in the common part of the circuits, and entraining gas from the chamber in a portion of the second circuit between bodies of the fluid circulating therein, there compressing said gas and exhausting the gas from said circuit.

6. The method of maintaining a temperature difference at opposite sides of an insulating wall which comprises creating a temperature difference with a source of energy, circulating fluid in response to the temperature difference at opposite sides of the wall to pump gases from the wall and maintain a vacuum in the wall, whereby heat leakage through the wall is reduced and the total effect of the energy supply in providing a temperature difference is enhanced.

7. The method herein described which comprises maintaining a difference in temperature between two regions separated by a vacuum and maintaining the vacuum by the energy of the difference in temperature between the regions.

8. In combination, refrigerating apparatus including a cooler, an insulating wall impeding undesirable heat flow to the cooler, said wall providing a vacuum chamber, and pumping means to remove non-condensable gases from the chamber, said pumping means including a liquid circuit, a capillary tube in said circuit, wherein circulating liquid entrains gases from the chamber, and a common source of energy for said refrigerating apparatus and pumping means.

9. In combination, refrigerating apparatus including a cooler, an insulating wall impeding undesirable heat flow to the cooler, said wall providing a vacuum chamber, and pumping means to remove non-condensable gases from the chamber, said pumping means including a liquid circuit, a capillary tube in said circuit, wherein circulating liquid entrains gases from the chamber, said refrigerating apparatus having high and low pressure portions with fluid flowing between said portions during operation of the apparatus, the circulation of liquid in said pumping means occurring in response to the differences of pressure in said apparatus.

10. In combination, refrigerating apparatus including a cooler, an insulating wall impeding undesirable heat flow to the cooler, said wall providing a vacuum chamber, and multi-stage pumping means to remove non-condensable gases from the chamber, said pumping means including a liquid circuit for the first stage pumping means, a capillary tube in said circuit, wherein circulating liquid entrains gases from the chamber, and a common source of energy for said refrigerating apparatus and at least two stages of the pumping means including said first stage pumping means.

11. In combination, a refrigerating apparatus including a cooler, an insulating wall impeding undesirable heat flow to the cooler, said wall providing a vacuum chamber, and multi-stage pumping means to remove non-condensable gases from the chamber, said pumping means including a liquid circuit for the first stage pumping means, a capillary tube in said circuit, wherein the circulating liquid entrains gases from the chamber, and a common source of energy for said refrigerating apparatus and at least two stages of the pumping means, including said first stage pumping means, said refrigerating apparatus having high and low pressure portions and fluid flow between said portions during operation of the apparatus, the circulation of liquid in the first stage pumping means occurring in response to the differences of pressure in said apparatus.

12. In combination, a refrigerating apparatus including a cooler, an insulating wall impeding undesirable heat flow to the cooler, said wall providing a vacuum chamber, and multi-stage pumping means to remove non-condensable gases from the chamber, said pumping means including capillary tubes, wherein the circulating liquid entrains gases from the chamber, said refrigerating apparatus having high and low pressure portions and fluid flow between said portions during operation of the apparatus, the circulation of liquid through said capillary tubes of said pumping means occurring in response to the differences of pressure in said apparatus.

13. In combination, refrigerating apparatus including a cooler, a heat insulating wall associated with the cooler and including a vacuum chamber, pumping means for maintaining a vacuum in the chamber, said means including a fluid circuit having a portion wherein falling liquid globules entrain gases from the chamber, the apparatus having high and low pressure portions between which fluid normally circulates, a

part of the liquid circuit receiving fluid flowing between the high and low pressure portions, the fluid being effective in this part in lifting slugs of the liquid to cause its circulation through the liquid circuit of the pumping means, whereby gases are automatically pumped from the vacuum chamber in response to normal operation of the refrigerating apparatus.

14. In combination, refrigerating apparatus including a cooler, a heat insulating wall associated with the cooler and including a vacuum chamber, pumping means for maintaining a vacuum in the chamber, said means including a fluid circuit having a portion wherein falling liquid globules entrain gases from the chamber, the apparatus having high and low pressure portions between which refrigerant vapor normally circulates, a part of the liquid circuit being connected to the apparatus and receiving the vapor flowing between the high and low pressure portions, the vapor being effective in this part in lifting slugs of liquid to cause its circulation through the liquid circuit of the pumping means, whereby gases are automatically pumped from the vacuum chamber in response to normal operation of the refrigerating apparatus.

15. In combination, low pressure refrigerating apparatus including a cooler, an insulating wall including a vacuum chamber, means operable to maintain low pressure in the apparatus comprising a downwardly extending capillary tube wherein liquid globules entrain non-condensable gases, separating means at the lower end of the tube exhausting the gases to a region of higher pressure, the capillary tube also receiving gases from the vacuum chamber, whereby low pressures are concomitantly maintained in the apparatus and the chamber.

16. In combination, low pressure refrigerating apparatus including a cooler, an insulating wall including a vacuum chamber, means operable to maintain low pressure in the apparatus comprising a downwardly extending capillary tube wherein liquid globules entrain non-condensable gases, separating means at the lower end of the tube exhausing the gases to a region of higher pressure, pumping means connected to the chamber, said pumping means comprising a portion wherein falling liquid globules entrain and compress gases from the chamber, and a connection directing the gases from said portion to the first-named tube, whereby both gases from the system and from the chamber are exhausted.

17. In combination, low pressure refrigerating apparatus including a cooler, an insulating wall including a vacuum chamber, means operable to maintain low pressure in the apparatus comprising a downwardly extending capillary tube wherein liquid globules entrain non-condensable gases, separating means at the lower end of the tube exhausting the gases to a region of higher pressure, pumping means connected to the chamber, said pumping means comprising a fluid circuit, a duct between high and low pressure portions of the apparatus, said duct having a part in common with the fluid circuit wherein liquid globules are lifted by fluid flowing through the duct, thereby causing circulation of liquid through the circuit, the circuit also having a portion wherein falling liquid globules entrain and compress gases from the chamber, a connection directing the gases from said portion to the first-named tube, whereby both gases from the system and from the chamber may be exhausted.

Signed by me at 80 Federal Street, Boston, Mass., this 1st day of September, 1928.

DANIEL F. COMSTOCK.