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METHOD AND APPARATUS FOR MAINTAINING A CONSTANT TEMPERATURE WITHIN AN INCLOSURE

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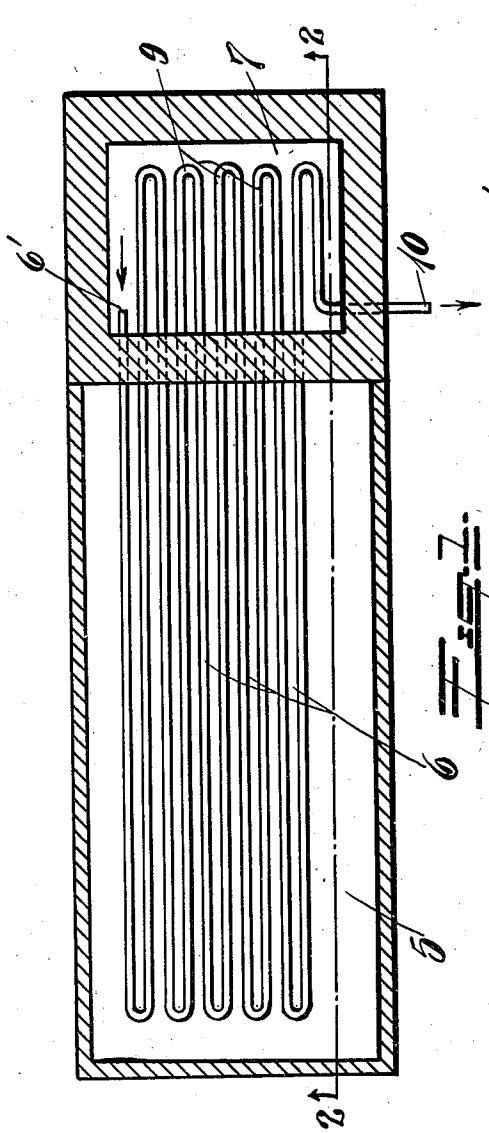



Fig. 1.

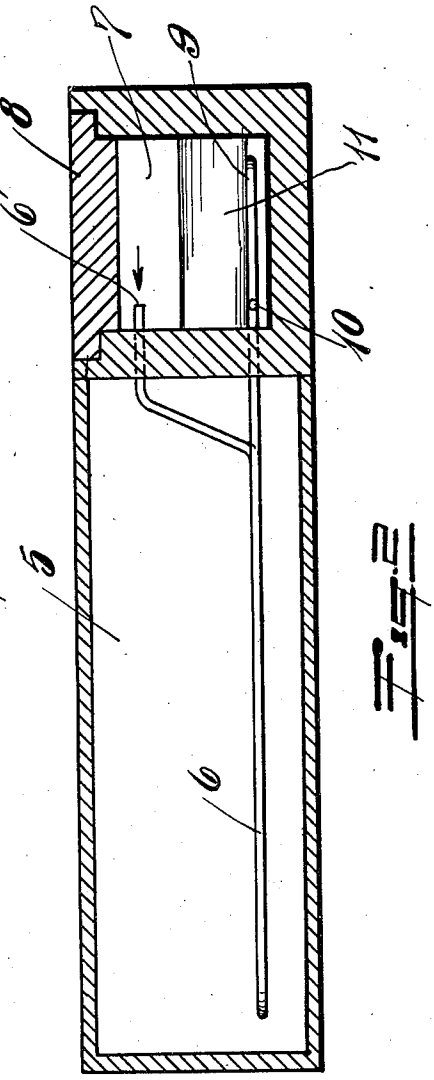



Fig. 2.

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## METHOD AND APPARATUS FOR MAINTAINING A CONSTANT TEMPERATURE WITHIN AN INCLOSURE

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8 Claims. (Cl. 62—91.5)

My invention relates to a method and means for maintaining approximately a constant temperature within an inclosure, when the rate of heat flowing into or developing within the inclosure varies over a large range.

This action is accomplished by absorbing all of the heat flowing into or generated within the inclosure, in excess of that required to maintain the temperature within the inclosure, approximately constant.

It is to be understood that the means embodying the invention will operate, using a gas or vapor as the circulating phase and either a liquid or a solid as the static phase, and we shall hereinafter designate the circulating gas or vapor as the circulating phase and the stationary liquid or solid as the case may be, as the static phase. An example of a liquid which might be used as the static phase is liquid ammonia, and the concomitant circulating phase in this case would be gaseous ammonia. An example of a solid that might be used as a static phase is solid carbon dioxide, and the concomitant circulating phase in this case would be gaseous carbon dioxide. It is understood, however, that the apparatus is not restricted to the use of these above mentioned examples.

The apparatus embodying the invention may be divided into two parts, which I shall term a high temperature side and a low temperature side.

In the accompanying drawing, forming a part of this specification, and in which like numerals are employed to designate corresponding parts throughout the same,

Fig. 1 is a sectional plan view, generally schematic, of apparatus embodying the invention, and

Fig. 2 is a longitudinal sectional view taken on line 2—2 of Fig. 1.

The high temperature side of the apparatus comprises an inclosure or chamber 5, and the rate of heat flowing into or generated within the same, may vary over a large range. It is the function of the invention to maintain the temperature within this inclosure, approximately constant, notwithstanding the variation above referred to. Arranged within the inclosure 5 is a number of separate heat absorbing units 6, in the form of coiled pipes, or other hollow heat absorbing surfaces, through which the circulating phase may pass, and thereby become warmed by the heat flowing from within the inclosure 5, through the walls of the heat absorbing units 6 and into the circulating phase. These are the ordinary heat absorbing units well known and used by those versed in the art of refrigeration, and the number of them used will be determined by a mathematical equation given in the theoretical discussion of this specification.

The low temperature side of the apparatus comprises an inclosure or casing 7 which holds the static phase 11. This inclosure 7 may be located within or exterior to the inclosure 5.

This inclosure 7 has a removable cover 8 which forms a gas tight joint when closed. Any suitable means may be employed to hold this cover 8 closed. The entire inclosure 7 is thoroughly heat insulated upon all sides, by any of the usual methods. The inclosure 7 has an opening formed through one wall thereof, for receiving an outlet pipe 6', and the entire inclosure 7 is so constructed that any circulating phase originating within it, even under considerable pressure, can pass from this inclosure only by way of the outlet pipe 6'. Arranged within the inclosure 7 so as to be continually in intimate thermal contact with the static phase 11 is a number of separate compact heat radiating units 9, in the form of coiled pipes or other hollow heat radiating surfaces, through which the circulating phase may pass, and thereby become cooled by discharging its heat through the heat radiating units 9 and directly into the static phase 11.

The units 9 correspond in number to the units 6, and pipes connect the outlet ends of the units 6 with the intake ends of the units 9, and pipes also connect the outlet ends of the units 9 with the intake ends of the units 6, excepting the intake end of the first unit 6 which is connected with the outlet pipe 6', and the outlet end of the last unit 9 which is connected with the pipe 10. In other words the above system is so connected that any circulating phase originating within the low temperature inclosure 7 will be forced to flow out of the inclosure through the outlet pipe 6' into successively a heat absorbing unit and then a heat radiating unit, and so on until it is finally discharged through the pipe 10.

In considering the operation of the apparatus, assume a quantity of the static phase 11 to be placed within the inclosure 7, and to be in intimate thermal contact with the heat radiating units 9, and to be at the temperature which such static phase transforms, under the existing pressure, into the circulating phase, when such static phase absorbs heat. The heat absorbing units 6, the heat radiating units 9, and the space within the inclosure 7 not occupied by the static phase 11, is filled with the circulating phase. Now, if

the temperature of the inclosure 5 is sufficiently higher than the transformation temperature of the static phase 11, and a very small initial amount of heat is imparted to the static phase 11, by any means whatsoever, and since the static phase 11 is at its transformation temperature, this heat will then generate a quantity of the circulating phase from the static phase 11, which circulating phase, flowing out of the inclosure 7, through the pipe 6' will, obviously, cause the warm circulating phase in the several heat absorbing units 6, to be displaced, and pass into the heat radiating units 9, and the cold circulating phase in the several heat radiating units 9, to be displaced, and pass into the several heat absorbing units 6, except, of course, the circulating phase in the last heat radiating unit, which will be displaced or discharged through the pipe 10.

The cold circulating phase passing into the heat absorbing units 6, will absorb heat through the walls of the units 6, thereby cooling the inclosure 5, and the heat carried by means of the circulating phase into the heat radiating units 9, will be absorbed through the walls of the units 9 by the static phase 11, thereby generating from the static phase 11 a further quantity of the circulating phase, which, flowing out through the pipe 6', will cause the circulation to continue at an accelerated rate, until thermal equilibrium is established. When this occurs, the quantity of heat per unit time being absorbed from the circulating phase by the static phase 11, is just sufficient to generate enough new circulating phase to maintain the thermal equilibrium.

It will be shown in the theoretical discussion of the invention, and it has been verified by actual practice, that when this thermal equilibrium condition is reached, the positive difference between the temperature of the circulating phase flowing out of any heat absorbing unit, and the temperature of the circulating phase flowing into any heat absorbing unit, is approximately constant, no matter how fast heat is being absorbed from within the inclosure 5. Also it will be shown in the theoretical discussion, and it has been verified by actual practice, that if the areas and the thermal conductivity of the heat absorbing units 6 and the heat radiating units 9, are large enough, the positive difference between the temperature within the inclosure 5 and the transformation temperature of the static phase 11, will be approximately constant, no matter how fast heat is flowing into or generated within the inclosure 5. The transformation temperature of the static phase 11, under the existing approximately constant pressure, will be approximately constant, and therefore, the temperature within the inclosure 5 will be approximately constant, and any increase in the rate of heat flowing into or generated within the inclosure 5, will only serve to increase the rate of circulation of the circulating phase and to decrease the all over temperature of the heat absorbing units 6, and will not appreciably raise the temperature within the inclosure 5.

If the transformation temperature of the static phase 11 is below the temperature of the media surrounding the inclosure 7, the above circulation will start automatically because of the small amount of heat flowing into the inclosure 7, through its walls. However, if the transformation temperature of the static phase 11 is above the temperature of the media surrounding the inclosure 7, then a small amount of heat must be imparted to the static phase 11, in order to start the circulation of the circulating phase. This starting of the circulation may be accomplished by the use of any small heating unit, arranged interiorly or exteriorly of the inclosure 7.

The following theoretical discussion is presented as a further explanation of the invention. In this discussion we will use these symbols:—

$\theta_1$—Temperature within the inclosure (5).

$\theta_2$—Temperature of the circulating phase flowing out of the heat absorbing units.

$\theta_3$—Temperature of the circulating phase flowing into the heat absorbing units.

$\theta_4$—Transformation temperature of the static phase.

$v$—Velocity of the circulating phase.

$s$—Specific heat of the circulating phase.

$\rho$—Density of the circulating phase.

$h$—Heat of transformation of the static phase per unit mass.

$q$—Rate of heat flowing into the inclosure (5).

$k$—Thermal conductivity of the heat radiating and heat absorbing surfaces.

$n$—Number of heat absorbing units and also number of heat radiating units.

When thermal equilibrium as explained above is established, it is evident that the heat absorbed from a unit mass of the circulating phase by the static phase must be equal to the heat required to generate a further unit mass of circulating phase, therefore:—

$$ns(\theta_2-\theta_3)=h$$

$$(\theta_2-\theta_3)=\frac{h}{ns}=\text{constant} \qquad (1)$$

This shows that the difference between the temperature of the circulating phase flowing out and the temperature of the circulating phase flowing in any heat absorbing unit is approximately constant and independent of the rate of heat flowing into inclosure (5).

For purposes of theory it will be reasonable to assume the heat absorbing units and the heat radiating units to be pipes each of length $l$ radius $r$ and surface area $a$. We will consider an infinitesimal volume $\pi r^2 dx$ of the circulating phase and derive an equation which will determine its temperature $\theta$ at any point $x$ along the length of the heat absorbing pipe. The infinitesimal amount of heat flowing through the surface element $2\pi r dx$ in time $dt$ will be:

$$2\pi r k(\theta_1-\theta)\,dx dt$$

The infinitesimal amount of heat absorbed by the volume element $\pi r^2 dx$ in time $dt$ will be:

$$\pi r^2 \rho s dx d\theta$$

These two expressions must be equal, consequently:

$$2k(\theta_1-\theta)\,dt=r\rho s d\theta$$

$$\frac{2k}{r\rho s}\int_0^t dt=\int_{\theta_3}^{\theta}\frac{d\theta}{\theta_1-\theta}$$

$$\frac{2kt}{r\rho s}=\log_\epsilon\frac{\theta_1-\theta_3}{\theta_1-\theta}$$

$$\theta_1-\theta=(\theta_1-\theta_3)\epsilon^{-\frac{2kt}{r\rho s}}$$

but

$$t=\frac{x}{v}$$

therefore

$$\theta_1-\theta=(\theta_1-\theta_3)\epsilon^{\frac{-2kx}{r\rho sv}} \qquad (2)$$

This equation determines the temperature of the circulating phase at any point along the length of the pipe. Now applying this equation to the full length of the pipe we obtain:—

$$\theta_1-\theta_2=(\theta_1-\theta_3)\epsilon^{\frac{-2kl'}{r\rho sv}}$$

and since it is evident that

$$q=\pi r^2 v h\rho \text{ and } v=\frac{q}{\pi r^2 h\rho} \text{ and } 2\pi rl=a$$

the above exponential equation will take the form

$$\theta_1-\theta_2=(\theta_1-\theta_3)\epsilon^{\frac{-kah}{sq}} \quad (3)$$

An expression similar to the above equation but applying to the circulating phase flowing in the heat radiating pipes may be immediately written

$$\theta_3-\theta_4=(\theta_2-\theta_4)\epsilon^{\frac{-kah}{sq}} \quad (4)$$

Adding Equations three (3) and four (4) we obtain

$$\theta_1-\theta_2+\theta_3-\theta_4=(\theta_1+\theta_2-\theta_3-\theta_4)\epsilon^{\frac{-kah}{sq}}$$

but from Equation one (1) we have

$$\theta_2-\theta_3=\frac{h}{sn}$$

substituting this in the above equation and solving for $\theta_1-\theta_4$ we obtain

$$\theta_1-\theta_4=\frac{h}{sn}\left\{\frac{1+\epsilon^{\frac{-kah}{sq}}}{1-\epsilon^{\frac{-kah}{sq}}}\right\} \quad (5)$$

Now if $kah$ is large compared to $sq$ then

$$\epsilon^{\frac{-kah}{sq}}$$

will be very small and we obtain to a high degree of approximation the relation

$$\theta_1-\theta_4=\frac{h}{sn}=\text{constant} \quad (6)$$

This shows that if the areas and the thermal conductivity of the heat absorbing units and the heat radiating units are large enough, the difference between the temperature within the inclosure (5) and the transformation temperature of the static phase will be approximately constant. Since the transformation temperature of the static phase under the existing approximately constant pressure will be approximately constant, therefore the temperature within the inclosure (5) will be approximately constant and independent of the rate of heat flowing into the inclosure (5).

Solving Equation six (6) for $n$ we obtain

$$n=\frac{h}{s(\theta_1-\theta_4)}$$

which shows that the number of heat radiating units and the number of heat absorbing units necessary to maintain any desired constant temperature within the inclosure (5) may be determined by dividing the heat of transformation of the static phase by the product of the specific heat of the circulating phase and the difference between the desired temperature and the transformation temperature of the static phase.

It is to be understood that the form of my invention herewith shown and described, is to be taken as a preferred example of the same, and that various changes in the shape, size and arrangement of parts, may be resorted to without departing from the spirit of the invention or the scope of the subjoined claims.

What I claim is:—

1. In a refrigerating apparatus of the character described, a refrigerating compartment, a heat insulated refrigerant containing compartment adapted to contain a refrigerant which forms a cold gas upon the absorption of heat, a tubular conduit communicating at one end with the refrigerant containing compartment and adapted to convey the cold gas therefrom, said tubular conduit thereafter passing alternately and repeatedly in heat exchanging relation with the refrigerating compartment and the refrigerant and having a discharge end communicating with the atmosphere whereby gas evolved from the refrigerant will pass alternately and repeatedly in heat exchanging relation with the refrigerating compartment and the refrigerant.

2. In a refrigerating or cooling system, a refrigerant chamber, a region to be cooled, heat insulating means between said chamber and said region, a substantially fluid-tight sealing member for closing said chamber, thereby to maintain a pressure upon a fluid generated by the refrigerant in said chamber, and means for passing fluid generated by the refrigerant successively and repeatedly through said region and said chamber, said last-named means comprising a conduit passing in successive loops through said region and said chamber.

3. In a refrigerating or cooling system, a refrigerant chamber having a door opening communicating with the interior thereof and a substantially fluid-tight closure therefor, a region to be cooled, heat insulating means between said chamber and said region, and means for passing a fluid generated by the refrigerant in successive different paths through said region and said chamber, said last-named means comprising a conduit passing in successive loops in heat absorbing relation to said region and in heat radiating relation to said chamber.

4. In an apparatus of the character described, a refrigerant chamber, a region to be cooled, heat insulating means separating said chamber from said region, a heat exchange member connecting said chamber and said region and comprising a conduit having an open end communicating with the interior of said chamber and adapted to conduct from said chamber a heat transferring fluid generated by a refrigerant therein and to convey said fluid through successive loops alternately passing through said region in heat absorbing relation thereto and through said chamber in heat radiating relation thereto after each passage through said region.

5. A method of maintaining an approximate thermodynamic balance between a plurality of insulated chambers having different temperatures in the interiors thereof, said method comprising converting a heat transferring medium from its static to its circulating phase in a refrigerant chamber, conveying the circulating phase of the heat transferring medium into a chamber to be cooled, and thereafter conveying said circulating phase of said heat transferring medium alternately and successively in heat radiating relation with the heat transferring medium in its static phase in said refrigerant chamber and in heat absorbing relation to said chamber to be cooled, thereby to control the rate of conversion of the heat transferring medium from its static to its circulating phase substantially by tempera-

ture changes occurring in said chamber to be cooled.

6. A method of refrigeration or cooling, which consists in passing fluid generated by a refrigerant in successive different paths through one or more regions to be cooled and a chamber containing the refrigerant, while varying the rate of flow of the fluid in accordance with changes in the temperature of a region to be cooled.

7. In a refrigerating apparatus of the character described, a relatively high temperature inclosure, a relatively low temperature heat insulated inclosure for receiving a static phase of the refrigerant and holding the same under suitable pressure, circulating apparatus comprising a conduit adapted to receive a refrigerant in its circulating phase, said conduit having its intake end in communication with the interior of the heat insulated inclosure and formed with a series of loops leading to said relatively high temperature inclosure and alternately and successively returning to said relatively low temperature inclosure and having its outlet end discharging outside of the apparatus.

8. A method of refrigeration or cooling which consists in passing a heat transferring fluid generated by a refrigerant in successive paths through one or more regions to be cooled and a chamber containing the refrigerant, thereby to control the rate of generating the refrigerant in response to relatively small variations of temperature within said regions to be cooled.

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