

[54] REFRIGERATION SYSTEM AND PROCESS

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[56] References Cited

UNITED STATES PATENTS

1,565,795	12/1925	Coffey	62/115
2,639,594	5/1953	Watt	62/381 X
2,655,007	10/1953	Lazar	62/381 X
2,736,174	2/1956	Tice	62/64
3,195,547	7/1965	Rieutord	165/86 X
3,273,631	9/1966	Neuman	122/26 X

OTHER PUBLICATIONS

Nicol and McLean, "Boiling Heat Transfer From a Rotating Horizontal Cylinder," The Canadian Journal

of Chemical Engineering, Vol. 46, P. 304-308, October 1968.

Tang and McDonald, "A Study of Boiling Heat Transfer from a Rotating Horizontal Cylinder," Int. Journal of Heat and Mass Transfer, Vol 14, pp. 1643-1657, 1971.

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[57]

ABSTRACT

The evaporator of a refrigeration machine includes a hollow cylinder which rotates in a liquid refrigerant bath about a vertical axis. The rotation causes nucleate boiling along the surface of the cylinder, and this boiling in turn requires heat. The heat is derived from a fluid medium which is passed through the hollow interior of the cylinder. Hence, the temperature of the fluid medium decreases. The refrigerant which boils off is condensed and returned to the liquid bath.

18 Claims, 5 Drawing Figures

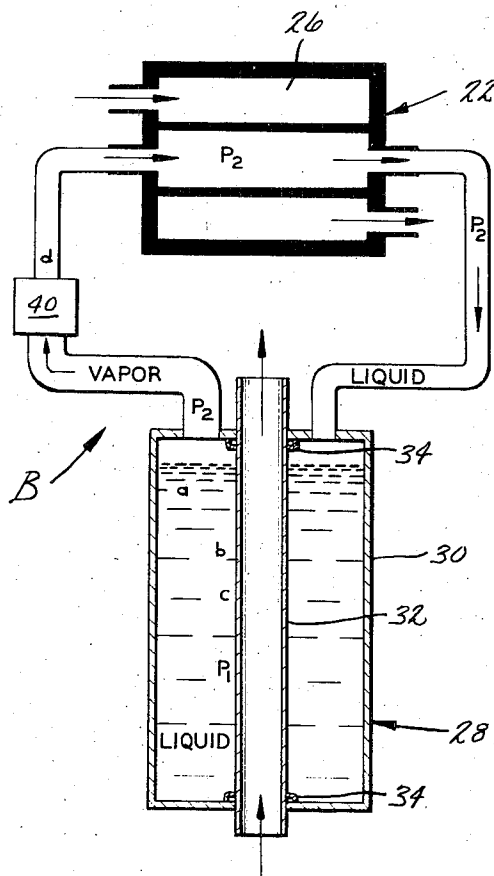


FIG. 1

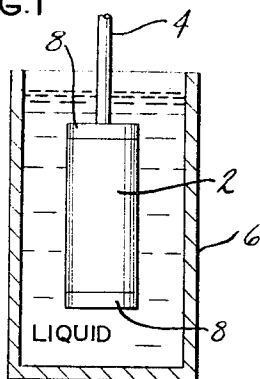


FIG. 2

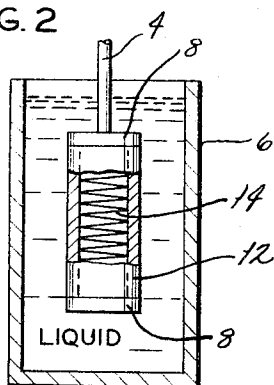


FIG. 3

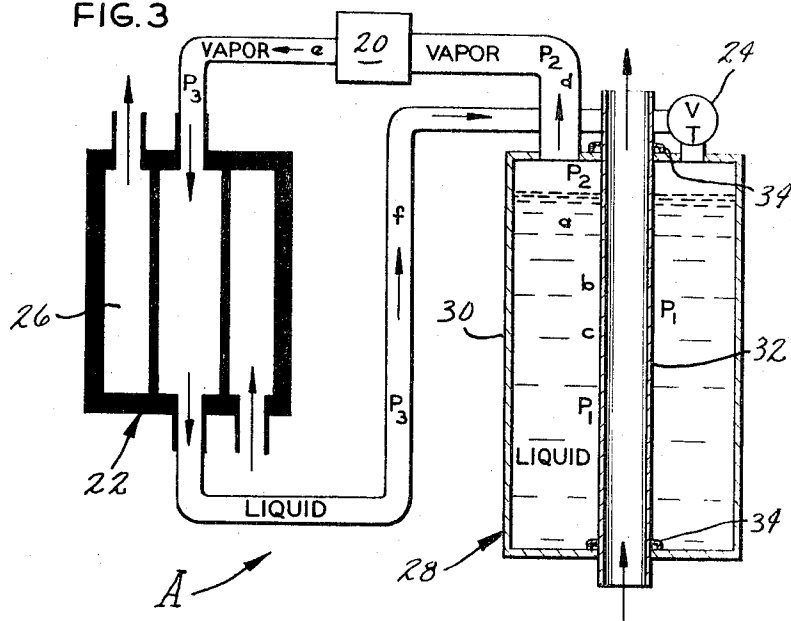


FIG. 5

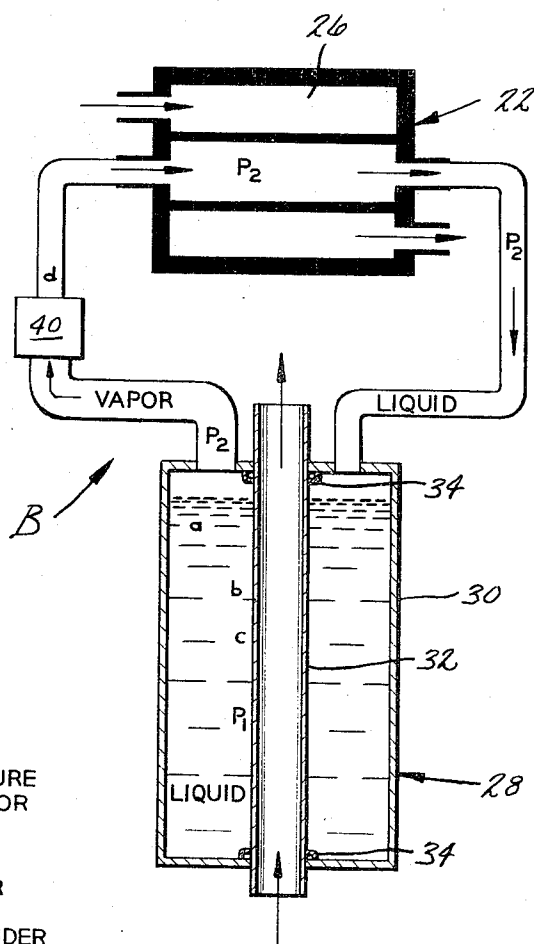
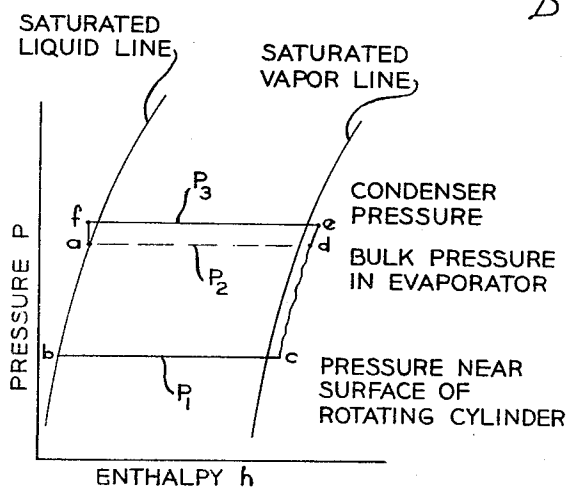


FIG. 4



REFRIGERATION SYSTEM AND PROCESS

BACKGROUND OF THE INVENTION

This invention relates in general to a heat extraction and more particularly to a heat extraction system and process which are extremely efficient.

The refrigeration cycle most commonly used today is the vapor compression cycle. In that cycle the refrigerant enters an evaporator as a mixture of saturated liquid and saturated vapor. In the evaporator, the refrigerant changes at constant pressure into a vapor and absorbs heat from the region to be refrigerated as it does. The vapor next enters a compressor where it is compressed, and thereafter it flows through a condenser at constant pressure where it rejects heat to the atmosphere or to cooling water, changing into a liquid as it does. Finally, the liquid at the condenser pressure is passed through an expansion valve, where its pressure decreases, and the low pressure refrigerant re-enters the evaporator to repeat the cycle.

Considerable energy is required to operate the compressor, and moreover the compressor develops friction which adds more heat to the refrigerant. Therefore, the conventional vapor compression cycle is somewhat inefficient.

SUMMARY OF THE INVENTION

One of the principal objects of the present invention is to provide a refrigeration system and process which is highly efficient. Another object is to provide a refrigeration system wherein a relatively large pressure differential in the refrigerant is derived with the expenditure of relatively little energy. A further object is to provide a refrigeration system which is simple in construction and operation and extremely durable. These and other objects and advantages will become apparent hereinafter.

The present invention is embodied in a heat extraction system and process wherein a member which is immersed in a liquid refrigerant bath moves relative to the liquid of the bath such that the temperature of the bath tends to decrease. The invention also consists in the parts and in the arrangements and combinations of parts hereinafter described and claimed.

DESCRIPTION OF THE DRAWINGS

In the accompanying drawings which form part of the specification and wherein like numerals and letters refer to like parts wherever they occur:

FIG. 1 is a schematic view showing an apparatus for demonstrating the principle on which the refrigeration system of the present invention is based;

FIG. 2 is a schematic view showing a refinement of the apparatus illustrated in FIG. 1;

FIG. 3 is a schematic view of a complete refrigeration system embodying the principles of the present invention;

FIG. 4 is a pressure-enthalpy diagram showing the thermodynamic cycle for the refrigeration system illustrated in FIG. 3; and

FIG. 5 is a schematic view of a modified refrigeration system.

DETAILED DESCRIPTION

The present invention is based on the discovery that a cylinder rotating in a suitable liquid bath will lower

the temperature of the cylinder and in many cases the temperature of the bath too. It is believed that the rotation causes a sharp reduction in the pressure of the liquid near the surface of the cylinder, and that this reduction in pressure results in nucleate boiling. The heat required for the nucleate boiling is derived from the cylinder and the liquid and consequently the temperature of the cylinder decreases, as does the temperature of the bath if the liquid thereof is subcooled.

For example, a 2 inch diameter cylinder 2 (FIG. 1) made of solid copper was mounted on a drive shaft 4 with the axis of the cylinder 2 and shaft 4 being colinear and oriented vertically. By way of the drive shaft 4, the cylinder 2 was suspended in an insulated vessel 6 containing liquid Freon 11. The top of the vessel 6 was vented to the atmosphere, thus placing the liquid Freon 11 at atmospheric pressure. The ends of the cylinder 2 were capped with an insulative material 8, and the cylinder 2 contained thermocouple junctions at its exterior cylindrical surface. The cylinder 2 and liquid Freon 11 were allowed to come to equilibrium at 68°F. Thereafter, the shaft 4 was rotated at 1,300 rev/min., causing the cylinder 2 to rotate in the liquid Freon at the same angular velocity. The temperature of the cylinder dropped rather quickly. The cylinder 2 reached an equilibrium condition with its bath in less than 2 hours, at which time the temperature of the cylinder 2 was 32°F. and the temperature of the liquid Freon was 42°F. The cylinder 2 and the liquid Freon remained at the lower temperatures as long as the cylinder 2 revolved.

Still lower temperatures can be derived by supplying energy in the form of heat to the cylinder. This additional energy increases the number of nucleation sites and hence enhances bubble production. By way of example, the solid copper cylinder 2 discussed in the previous example was replaced with a hollow cylinder 12 (FIG. 2) having a resistance-type electrical heater 14 in the hollow interior thereof. In lieu of Freon 11, the vessel 6 was filled with saturated liquid nitrogen at -320°F. The hollow cylinder 12 and liquid nitrogen were allowed to come to equilibrium, and thereafter the cylinder 12 was rotated at 800 rev/min. The temperature of the cylinder dropped 20°F. to about -340°F., at which time an equilibrium condition was reached and the cylinder 12 therefore remained at that temperature. With the cylinder 12 still rotating, electrical energy equivalent to 10,000 BTU/hr-ft.² was supplied to the heating element 14, and the temperature of the cylinder 12 decreased another 20° to 30°F. After a short period of time the temperature of the cylinder stabilized at the lower temperature, indicating an equilibrium condition had been reached, that is a condition in which energy was being removed from the cylinder 12 by boiling at the same rate as energy was supplied to that cylinder by the heating element 14. The liquid nitrogen bath absorbed heat through the wall of the vessel 6 also notwithstanding the insulation, and hence throughout the experiment it remained a saturated liquid at -320°F.

Similar results were derived using other liquids, such as water, for the bath.

The discovery may be utilized for refrigeration purposes by creating a channel through the cylinder and passing a fluid medium to be cooled through that channel. The fluid medium would supply the heat necessary to enhance nucleation at the cylinder surface. In so do-

ing, the fluid to be cooled would decrease in temperature. In other words, the fluid medium to be cooled would replace the electrical heating element 14 in the previous example.

A refrigeration system A (FIG. 3) incorporating the discovery heretofore discussed includes a compressor 20, a condenser 22, and an expansion valve 24 all connected together in the usual manner. In particular, the compressor 20 has its discharge side connected with the condenser 22, and the downstream side of the condenser 22 is in turn connected to the expansion valve 24. The condenser has a flow channel 26 through which a fluid cooling medium flows, and that cooling medium may be air, water, or some other suitable fluid. In addition to the foregoing components, the refrigeration system A includes an evaporator 28 to which the suction side of the compressor 20 is connected and into which the expansion valve 24 discharges.

The evaporator 28 comprises a container 30 having a tube or hollow cylinder 32 extending completely through it in the vertical direction. The exterior surface of the hollow cylinder 32 is embraced by seals 34 mounted on the upper and lower walls of the container 30 so that the interior of the container 30 is completely isolated from the surrounding atmosphere. The cylinder 32 is connected with a motor (not shown) for rotating it, and its interior serves as a conduit for the fluid to be cooled. The interior of the cylinder 32 may be fitted with vanes of a screw (not shown), in which case the cylinder 32 would further serve as an axial flow fan for moving the fluid to be cooled through it. The vanes or screw would further tend to effect better heat transfer between the fluid to be cooled and the walls of the cylinder 32. The container 30 is filled almost completely with a suitable refrigerant such as Freon 11, and this refrigerant also exists in the compressor 20, the condenser 22, and the expansion valve 24 as well as the refrigerant lines leading to and from them. The bulk refrigerant in the evaporator 28 is for the most part subcooled liquid although it may be saturated liquid if sufficient heat is supplied. Indeed, the liquid refrigerant almost completely fills the container 30. On the other hand, the refrigerant in the extreme upper portion of the container 30 and in the suction line to the compressor 20, is a vapor. In the line between the condenser 22 and the expansion valve 24 the refrigerant exists as a liquid.

To place the refrigeration system A in operation, the hollow cylinder 32 is revolved within the liquid refrigerant bath while the fluid medium to be cooled is passed through it. That fluid medium may be air. The compressor 20 is also energized to compress the vapor refrigerant to the condenser pressure P_3 , and a cooling medium, which may be air or water, is passed through the channel 26 of the condenser 22.

In operation, the refrigerant exists within the evaporator 28 primarily as a subcooled liquid at the evaporator pressure P_2 , although it may be saturated liquid if sufficient heat is supplied. As the cylinder 32 rotates a sharp reduction in the pressure of the liquid occurs near the cylindrical surface thereof. In other words, the pressure drops from pressure P_2 , which is the bulk evaporator pressure, to a significantly lower pressure P_1 , which exists only within the liquid along the cylindrical surface of the cylinder 32. At the reduced pressure P_1 the tendency to boil is much more pronounced and indeed nucleate boiling does occur along the sur-

face of the cylinder 32. This boiling is enhanced by heat derived from the cylinder 32 itself, and the cylinder 32 of course is heated by the fluid medium flowing through it. Hence, heat is extracted from the fluid medium to convert the liquid along the surface of the cylinder 32 into vapor. The end result is that the temperature of the fluid medium is reduced.

The refrigerant leaves the evaporator 28 as a vapor at the evaporator pressure P_2 and enters the suction line for the compressor 20. The compressor 20 elevates the pressure of the vapor refrigerant from the evaporator pressure P_2 to the condenser pressure P_3 and at the same time elevates its temperature. The high pressure vapor from the compressor 22 then flows into the condenser 22 where it loses heat to the fluid cooling medium flowing through the cooling channel 26. As a result, the refrigerant, while remaining at the condenser pressure P_3 , is cooled substantially and indeed is cooled enough to convert it to a liquid.

The liquid refrigerant thereafter flows through the expansion valve 24 where its pressure reverts back to the bulk evaporator pressure P_2 . The low pressure liquid refrigerant replaces the liquid which is lost through nucleate boiling along the surface of the cylinder 32.

The foregoing cycle is of course repeated.

The thermodynamic cycle for the refrigeration system A may be traced on a pressure-enthalpy diagram (FIG. 4). Beginning with the subcooled liquid in the evaporator (point *a*), the cycle traces as follows: an expansion along the saturated liquid line from the bulk evaporator pressure P_2 to pressure P_1 which exists only at the surface of the rotating cylinder 32 (*a* to *b*); an absorption of heat from the cylinder 32 at constant pressure P_1 (*b* to *c*); a rise in a pressure most likely within the superheated vapor region to the bulk evaporator pressure P_2 (*c* to *d*); a further rise in pressure effected by the compressor 20 to the condenser pressure P_3 ; a discharge of heat in the condenser 22 at constant pressure P_3 and concurrent transformation into a liquid (*e* to *f*); and an expansion through the expansion valve 24 at constant enthalpy back to the bulk evaporator pressure P_2 (*f* to *a*). The exact thermodynamic path for the compression or rise in pressure along the surface of the rotating cylinder 32 (*c* to *d*) is not known.

When the thermodynamic cycle is studied on the pressure-enthalpy diagram (FIG. 4), it may be observed that a large pressure differential ($P_2 - P_1$) is derived merely from the rotation of the cylinder 32 in the liquid refrigerant. This requires relatively little energy and certainly much less energy than a compressor would require to effect the same pressure differential. Hence, the refrigeration system is highly efficient. While the rotating cylinder creates a pressure differential which supplements that of the compressor 20, it does so by dropping the pressure of the liquid refrigerant P_2 existing along its surface which is quite different than compressing a vapor as does the compressor 20.

A modified refrigeration system B (FIG. 5) is similar to the system A, but does not have the compressor 20 and expansion valve 24. The modified system B does have the condenser 22 and evaporator 28, and in addition a blower 40 for moving the vapor discharged from the evaporator 28 to the condenser 22. The blower 40 consumes very little power. The condenser 22 should be located above the evaporator so that the condensed

refrigerant leaving it will flow into the evaporator 28 and become part of the bulk liquid therein.

Turning now to the operation of the modified refrigeration system B, the rotating cylinder 32 reduces the pressure of the liquid refrigerant at the surface of the cylinder to pressure P_1 , and at pressure P_1 nucleate boiling occurs. This boiling extracts heat from the cylinder 32 which in turn extracts heat from the fluid medium flowing through it, thus cooling the fluid medium. The vaporized refrigerant is withdrawn from the evaporator by the blower 40 which forces it into the condenser 22 where it is condensed back into a liquid. The liquid flows by gravity into the container 30 of the evaporator 28 where it joins the subcooled liquid therein.

The thermodynamic cycle for the modified system B may be followed on the pressure-enthalpy diagram (FIG. 4). Starting at the entrance to the evaporator 28, the thermodynamic path is as follows: an expansion along the saturated liquid line (*a* to *b*); absorption of heat at constant pressure P_1 (*b* to *c*); rise in pressure most likely as a superheated vapor (*c* to *d*) and then condensation at constant pressure P_2 (*d* to *a*).

In lieu of circulating the fluid to be cooled through the interior of the cylinder 32, it may be circulated through a coil or similar heat exchanger immersed in the subcooled liquid refrigerant confined in the insulated container 30 of the evaporator 28. Since heat is also absorbed from the subcooled liquid refrigerant as the cylinder 32 rotates, a reduction in the temperature of that liquid occurs.

It has been observed that better results are obtained when the surface of the cylinder 32 is smooth, than when it is roughened such as by glass bead peening.

This invention is intended to cover all changes and modifications of the example of the invention herein chosen for purposes of the disclosure which do not constitute departures from the spirit and scope of the invention.

What is claimed is:

1. A heat extraction system comprising: a container, the interior of which is isolated from the surrounding atmosphere; a refrigerant in the container, some of the refrigerant in the container being in the liquid phase and some being in the vapor phase; rotating means disposed within the container and extended into the liquid therein for causing the temperature at the exterior surface of the rotating means to drop below the temperature of the bulk of the liquid refrigerant when rotated about a substantially upright axis, the configuration of the rotating means being such that when the rotating means is rotated at sufficient speed a reduction in pressure and temperature occurs in the refrigerant along the surface of the rotating means while the pressure of the great bulk of the liquid refrigerant remains unchanged; and means for revolving the rotating means at a speed great enough to cause said reduction in pressure and temperature along the surface thereof.

2. A system according to claim 1 wherein the member is substantially circular in cross-section taken perpendicular to its axis of rotation.

3. A system according to claim 2 wherein the axis of rotation is substantially at the center of the rotating means.

4. A system according to claim 3 wherein the rotating member is hollow and a fluid medium to be refrigerated is passed through the hollow interior of the member.

5. A heat extraction system for cooling a fluid medium, said system comprising: a container; a refrigerant in the container, at least some of the refrigerant being in the liquid phase; rotating means within the container and extended into the liquid refrigerant therein to cause a reduction in temperature along the exterior side surface of the rotating means when the rotating means revolves at sufficient speed, the rotating means being hollow so that the fluid medium to be refrigerated can be passed through the hollow interior of the rotating means, the rotating means further being substantially circular in cross-section taken perpendicular to its axis of rotation, the axis of rotation being substantially vertical; means for rotating the rotating means at sufficient speed to cause said reduction in temperature along the side surface of the rotating means; a compressor having a suction side connected to the container and a discharge side, whereby the compressor will draw vaporized refrigerant from the container; a condenser connected with the discharge side of the compressor for receiving compressed vapor therefrom and for condensing the vapor into a liquid; and an expansion valve connected with the condenser for receiving the liquid refrigerant therefrom and to enable the refrigerant to expand to a lower pressure, the expansion valve being connected with the container so that the expanded refrigerant enters the container.

6. A heat extraction system comprising: a container, a refrigerant in the container, at least some of the refrigerant being in the liquid phase; a rotating member disposed within the container and extended into the liquid refrigerant therein, the rotating member revolving about a substantially upright axis and being configured such that when rotated at sufficient speed the refrigerant along the side surface of the member will boil and the temperature of the rotating member along the side surface thereof will drop below the temperature of the bulk of the liquid refrigerant; means for rotating the member at said sufficient speed; and a condenser connected with the container for condensing the vapor resulting from boiling of the refrigerant along the surface of the member.

7. A heat extraction process comprising: rotating a member about a substantially upright axis in a liquid refrigerant bath to cause boiling of the refrigerant along the surface of the member, the configuration of the member and the speed of rotation being such that the temperature along the side surface of the member drops below the temperature of the bulk of the liquid refrigerant; transferring heat from a fluid medium to the refrigerant of the bath, said heat transfer occurring through the member; extracting heat from the refrigerant after it boils along the surface of the member to cause the refrigerant to condense back to a liquid; and returning the condensate to the liquid refrigerant bath.

8. A process according to claim 7 and further comprising: compressing the refrigerant vapor derived from the boiling before it is condensed, and reducing the pressure of the refrigerant after it is condensed.

9. A process for extracting heat from a fluid medium, said process comprising: rotating a substantially rigid body about a substantially vertical axis in a liquid refrigerant bath to cause a reduction in pressure of the refrigerant along the surface of the body without altering the pressure of the great bulk of liquid refrigerant and to cause the temperature along the surface of the

body to drop below the temperature of the bulk of the refrigerant so that heat will be extracted from the body and the refrigerant; and causing the fluid medium to flow through the liquid bath while keeping it isolated from the bath, whereby heat is extracted from the fluid medium.

10. The process according to claim 9 wherein the substantially rigid body is hollow; and wherein the fluid medium flows through the refrigerant bath by passing it through the hollow interior of the rigid body.

11. The process according to claim 10 wherein the body is of substantially circular cross-section and the axis of rotation is at the center of the circular body.

12. A process according to claim 9 wherein the reduction in the pressure of the refrigerant along the side surface of the body causes the refrigerant to boil along the side surface of the body.

13. The process according to claim 12 and further characterized by collecting the refrigerant which boils, condensing the collected refrigerant, and returning the condensate to the liquid refrigerant bath.

14. A machine comprising: a container, a liquid refrigerant in the container, rotatable means rotatable about a substantially vertical axis and being located within the container and immersed in the liquid refrigerant therein for causing the temperature at the exterior of the rotatable means to drop below the temperature of the bulk of the liquid refrigerant when rotated, the rotatable means having a side surface which moves tangentially with respect to the refrigerant surrounding it when the rotatable means is rotated, the rotatable means further being configured such that when rotated it leaves the great bulk of the refrigerant remote from its side surface at substantially the same pressure, the rotatable means further being configured to cause a reduction in pressure of the refrigerant along its side surface when rotated at sufficient speed; and means for rotating the rotatable means at a speed great enough to cause said reduction in pressure of the refrigerant along

the side surface of the rotatable means accompanied by a corresponding reduction in temperature along the side surface, whereby the reduction in temperature along the side surface of the rotatable means will effect a transfer of heat.

15. A machine according to claim 14 wherein the body is of circular cross-section and the axis of rotation is coincident with the center of the circular cross-section.

16. A machine according to claim 14 wherein the means for rotating the rotatable means rotates the rotatable means at a speed great enough to cause nucleate boiling of the refrigerant along the side surface of the rotatable means.

17. A process for extracting heat from a substance, said process comprising rotating a body of generally circular cross-section about a substantially upright axis in a liquid refrigerant such that the circumferential side surface of the body moves tangentially with respect to the liquid refrigerant and such that the rotation leaves the great bulk of the liquid located remote from the side surface at substantially the same pressure, the speed of rotation being great enough to cause a reduction in the pressure in the refrigerant along the side surface of the body and to cause a reduction in temperature at the side surface of the body to a temperature below the temperature of the bulk of the refrigerant; and locating the substance from which heat is to be extracted such that heat is transferred from that substance to the refrigerant.

18. A process according to claim 17 wherein the speed of rotation for the body is great enough to cause nucleate boiling of the refrigerant along the side surface of the body; and wherein the substance from which heat is to be extracted is located such that the energy required for the nucleate boiling is derived at least in part from the substance as an extraction of heat therefrom.

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