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(54) Heat Pump.

(57) A heat pump system has a refrigerant circulation system that is cooled by passing through a thermal storage heat exchanger. The heat exchanger is supplied by ice from an ice maker and can store heat energy by accumulation of ice in the heat exchanger. The ice is generated by cooling a secondary refrigerant, typically brine, at the wall of a ice making machine and scouring the wall prior to crystallisation of the brine mixture to disperse the super cooled liquid adjacent the wall into the body of the secondary refrigerant. Crystallisation is then promoted in the body of the liquid. The ice generator in a preferred form comprises a series of flat plates having primary refrigerant passing between the flat plates and secondary refrigerant passing over the surface of the flat plates. A series of scrapers rotate about an axis normal to the plane of the plates to disperse super cooled secondary refrigerants throughout the body of the secondary refrigerant in the ice generator.

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ICE MAKING MACHINE

This invention relates to an apparatus and method for the continuous manufacture of ice and to thermal storage systems utilising ice as a storage medium.

In today's society vast quantities of ice are used in the preservation and processing of food products. By way of example it is considered that two pounds of ice are required for each pcund of fresh poultry that is retailed. The fishing industry, the dairy industry and the fruit and vegetable industry are also large consumers of ice. Service industries such as hotel, restaurant and hospital also use large quantities. Further, ice is consumed in large amounts in many manufacturing industries.

The manufacture of ice is, therefore, of itself, an important industry. A good portion of ice manufactured today is manufactured in block on a batch basis. This is a relatively inefficient method. It is labour oriented and time consuming because the large blocks of ice produced take up to 48 hours to form. Inefficiency is increased by the requirement to use heat to melt the bond between the ice and the evaporator. The cost of providing this heat in the harvesting step alone contributes substantially to the inefficiency of the process. Notwithstanding these inefficiencies, however, the method continues to be used.

There are also continuous methods of making ice in current use with mixed success. In the continuous methods of making ice presently used, ice is formed from water on the walls of an evaporator from which it must be broken away by a rotating auger. Variations of bond strength and irregular pattern of ice formation have caused an irregular torgue requirement for the auger shaft drive. The irregularity of this torgue requirement has been such that many attempts at evaporator designs for continuous ice making machines have failed.

A further use for ice is in thermal storage heat exchangers which are commonly used in heat pump systems such as air conditioning systems in order to shift the loads which are applied to the system to achieve load leveling and avoid the need to provide a pump which is designed to meet the requirements when maximum load requirements are only required for a limited period of its day-to-day operation.

Heat pump systems which incorporate heat source, heat sink and a thermal storage heat exchanger are well known. In United States Patent 433,412 dated June 15, 1982, a cooling system is disclosed in which an ice slurry is circulated as the secondary refrigerant. A motor driven agitator is provided in the collection means for maintaining the ice in a slurry and this slurry is circulated through the system.

To maintain the ice in a slurry form, it is be necessary to prevent a high concentration of ice in the collection device and as a result, the efficiency of the collection device is somewhat limited.

It is known to take a mixture that is at less than eutectic concentration, contain it in a container, agitate the mixture, and cool the sidewall of the container to crystallize water in the solution and concentrate the remainder. Such a general method is the basis for making ice cream. The method has also been proposed to be used for the concentration of the eutectic solution in the case where the solution is, for example, brewed coffee or orange juice. Such a proposal is found in U.S. Patents 3,328,972 and 3,328,058 to Svanoe.

One object of this invention is to provide a novel method for producing ice on a continuous basis.

A continuous method for making ice according to one aspect of the invention comprises the steps of making a mixture wherein the solvent is water, the solute is non toxic and the initial concentration is less than the eutectic concentration; containing the mixture within a container, the mixture being in heat exchange relation with a wall of the container; continuously cooling the wall of the container to cool the layer of mixture immediately adjacent the wall no more than 1° below its freezing point with a refrigerant at a rate of at least 4000 BTU's per square foot of cooled container wall per hour; continuously mechanically scouring the wall of the container to remove continuously the cooled layer of mixture from the wall of the container; as aforesaid before the cooled layer is crystallized into a layer of ice whereby to lower the temperature of the mixture substantially uniformly throughout the container below its freezing point and form ice crystals of harvestable size suspended throughout the body of the mixture in the chamber; harvesting formed ice crystals from suspension in said mixture; and continuously replenishing said mixture in said chamber as said ice crystals are removed.

This process produces ice in a very efficient manner on a continuous basis and in a form that this suitable for most of its subsequent uses.

One apparatus that is conventional but may be utilised in a novel manner for this process has a generally cylindrical heat exchanger surface which is scoured by an agitator rotating about an axis generally parallel to the heat exchanger surface. Whilst such an apparatus operating under the above process has proven successful when compared with previous attempts to produce ice, the expansion of the apparatus

onto a larger scale does present certain problems. Firstly, the surface area presented by the cylindrical wall is limited as the volume of the apparatus increases as the square of the radius, whereas the surface area only increases in proportion to the radius. Further, the cylindrical wall must be of relatively thin gauge for maximum heat transfer efficiency which is inconsistent with the structural requirements of the apparatus. The apparatus is not susceptible to a modular expansion to suit differing requirements which detracts from its commercial viability.

According therefore to a further aspect of the present invention there is provided an ice making machine comprising a housing to receive a fluid from which ice is to be made and having an outlet to permit egress of ice from said housing,

a heat exchanger located within said housing and having an inlet and an outlet to permit the flow of coolant to extract heat from said fluid, and

agitator means moveable about an axis to inhibit deposition of ice on said heat exchanger said heat exchanger including at least one heat exchange surface extending generally transverse to said axis.

By providing the heat exchange surfaces normal to the axis of rotation of the agitators it is possible to stack heat exchangers one above the other and thereby increase the capacity of the ice making machinery. Further upon an increase in the diameter of the apparatus, both the volume and surface area available for heat exchange will increase in proportion and the structural requirements of the heat exchanger are more readily accommodated by use of a pair of parallel interconnected plates than a cylindrical shell.

According to one further aspect of the present invention, there is provided in a heat pump having a source, a heat sink and a thermal storage heat exchanger in which heat energy is cyclically accumulated and discharged by circulation of a secondary refrigeration therethrough, characterized in that: the secondary refrigerant is an aqueous solution having a concentration which is below its eutectic concentration; the heat sink is adapted to super cool the aqueous solution to partially freeze it to generate a partially frozen solution in which fine ice particles are retained in suspension; and the thermal storage heat exchanger has a storage chamber adapted to receive said partially frozen solution from the heat sink and to separate the ice particles from the liquid phase refigerant to form a porous ice bed and a substantially ice free liquid bath, and wherein the thermal storage heat exchanger is adapted to receive heated refrigerant and to discharge the heated refrigerant into said chamber such that it is placed in intimate contact with the ice bed in a manner such that it may pass through the pores of the porous ice bed prior to its return to the bath.

A thermal storage heat exchanger of high efficiency is provided by separating ice from the liquid phase refrigerant in the thermal storage heat exchanger so as to form a porous ice bed and a bath of secondary refrigerant within the thermal storage heat exchanger. This enables the accumulation of a dense porous ice bath during the cooling stage and through which the heated refrigerant can be passed in order to recover the stored energy during the peak cooling demand condition.

A refrigerant which is suitable for use in the system is a secondary refrigerant in the form of a binary solution having a concentration which is below its eutectic concentration.

A continuous supply of a partially frozen refrigerant solution in which fine ice particles are retained in suspension, may be generated by utilising an ice making method and apparatus and an ice making machine of the type described above.

Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings in which:

Figure 1 is a schematic representation of a heat pump system.

Figure 2 is a schematic illustration of a heat sink suitable for use in super cooling a binary soltuion.

Figure 3 is a diagram illustrating a temperature concentration curve of an aqueous solution suitable for use as a secondary refrigerant.

Figure 4 is a sectional view of an alternative embodiment of an ice making machine.

Figure 5 is a view on the line 5-5 of an ice making machine shown in Figure 4.

Figure 6 is an exploded perspective view showing schematically the arrangement of heat exchangers and agitators shown in the machine of Figure 6.

Figure 7 is a schematic view of a further alternate embodiment of an ice making machine.

With reference to Figure 1 of the drawings a heat pump 50 consists of an ice generator generally identified by the reference numeral 52, a heat source generally identified by reference numeral 55 and a thermal storage heat exchanger generally identified by the reference numeral 53. Output from the ice generator 52 is conveyed through output line 18 to a heat exchanger tank 53.

In the embodiment illustrated, the heat source 55 is in the form of a heat load device 58 which may be a heat exchanger in the form of a cooling coil, chiller or the like.

The thermal storage heat exchanger 53 comprises a storage tank 54 within which a storage chamber 56

is formed. A barrier wall 58 serves to divide the storage chamber 56 into a first compartment 60 and a second compartment 62. The barrier wall 58 is porous and serves to permit liquid phase secondary refrigerant to pass from the compartment 60 into the compartment 62 while preventing the passage of ice particles therebetween.

During the thermal storage phase of operation, a circulating pump 14 withdraws liquid phase secondary refrigerant from the second compartment 62 through a line 64 and discharges it under pressure through line 66 into a freezing cylinder 10 of the ice generator 52. The partially frozen solution containing the ice particles is discharged from the ice generator 52 through line 18 and enters the first compartment 60 through a return header 68 which is disposed in the lower end of the first compartment 60. The ice particles will float toward the surface 70 of the body of secondary refrigerant which is stored within the storage chamber 56 where they will accumulate to form a porous ice bed 74.

By reason of the fact that the secondary refrigerant is an aqueous solution, the ice particles will not bridge to form a solid ice mask and consequently the ice bed which is formed, will be porous. This condition will remain even when the ice bed is compacted as a result of its buoyancy to form a compact ice bed which may substantially fill the chamber 60.

In order to avoid a situation where an excessive amount of ice is accumulated in the storage chamber 60, a liquid level sensing device 78 is provided which has a probe 72 extending into the compartment 62. When the level of liquid in the compartment 62 drops below a predetermined level such as that indicated by the broken line 75, the sensor 70 will operate to deactivate the ice generator 52.

Liquid phase refrigerant is withdrawn from the second compartment 62 by means of a circulating pump 80 of the heat source and it is circulated through the heat exchanger 58. A valve 71 is provided in the output line 82 of the heat exchanger 58 to control flow of the heated refrigerant to the return header 76 of the thermal storage heat exchanger. A bypass line 79 is connected between the return line 82 and the circulating pump 14 of the ice generator with a valve 69 to control flow. This circuit is made operational during high load demand periods and may be used to moderate the cooling effect.

The return header 76 is arranged to discharge the heated liquid phase refrigerant into contact with the ice bed such that the heated refrigerant must pass through at least a major portion of the ice bed before it can be withdrawn from the first compartment 62, thus ensuring that it is cooled by contact with the ice bed. The porous nature of the ice bed is such that the heated refrigerant will permiate the ice bed to thereby achieve an efficient heat exchange between the ice bed and the refrigerant.

A secondary refrigerant suitable for use in the system may be a brine solution having a 5% to 10% concentration. Solutions other than brine could be used. The solvent should, of course, be water based to make ice but the solute could by any nontoxic material that has a suitable eutectic characteristic. Substitutes for salt might be glycerine, propylene glycol, ethanol or calcium chloride. Alternatively, the thermal storage medium is an aqueous solution having a glycol concentration in the rang of 3% to 10% by weight. A suitable 10% glycol thermal storage medium may have the following properties:

SPECIFIC HEAT	0.982 BTU/LB/° F
FREEZING POINT	APPROX 27° F
THERMAL CONDUCTIVITY (27°)	0.309 BTU/HR-FT_2-F/FT
VISCOSITY (27°)	2.8 CENTIPOISES
DENSITY	8.77 LB/IMP. GAL.

The ice generator 52 is shown in further detail in Figure 2 of the drawings, and includes a freezing cylinder 10 which has a dasher chamber 12 through which the secondary refrigerant is continuously circulated by means of a pump 14. The refrigerant enters the chamber from line 66 and is cooled to be partially frozen to generate a partially frozen solution in which fine ice particles are retained in suspension. The mixture is then discharged through line 18 to the thermal storage heat exchanger 52.

A tank 23 containing concentrated solute is fed into line 64 to add solute to the system as required and a water feed line 24 is provided to replace water removed as ice to maintain the desired concentration of the secondary refrigerant.

Within the dasher chamber 12, a scouring paddle is continuously rotated by motor 26 to scour the sides of the chamber and to prevent an ice build-up on them. The scouring paddle is of a standard design in these machines. The dasher chamber is surrounded by a jacket 28 to which a condensed refrigerant is continuously supplied from condenser 30. The refrigerant evaporates in the jacket and as it does so, it cools the secondary refrigerant in the chamber to form the ice particles. The expanded refrigerant travels from the jacket to the compressor 32 where it is compressed and delivered to the condenser for continuous

recycling as in a conventional refrigeration cycle. There is no discussion of ice separation etc., i.e. after the ice flows from the dasher.

As indicated, the freezer, dasher and scouring paddle and associated refrigerant circuit are standard and well known pieces of equipment and their structures are not therefore described in detail.

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DENSITY	8.77 LB/IMP. GAL.

To assist in an understanding of the manner in which ice is generated by the ice generator 52 reference may be had to Figure 3 of the drawings, which show characteristic curves of a brine mixture suitable for use as a secondary refrigerant in which the solvent is water and the solute is NaCl.

This solution will freeze at the eutectic temperature or temperature of eutectic indicated in the drawing. The physical phenomena that occur as the temperature of such a solution is cooled toward the freezing point depend upon its concentration. If the concentration is represented by a point to the left of the point D_1 of the curve, ice crystals may form and as a result the concentration of the solvent in the solute increases as the freezing temperature is approached.

The temperature represented by the point D on the curve is known as the eutectic temperature and the concentration represented by the point D_1 on the curve is known as the eutectic concentration.

Referring to Figure 3, if a solution of concentration "x", less than the eutectic, at a temperature above 32° F, is cooled, it will not solidfy when 32° F is reached (point A), but will continue to cool as a liquid until point B is reached. At this point, ice crystals of pure water will begin to form, accompanied by removal of their latent heat. This increases the concentration of the residual solution. As the temperature is lowered, these crystals continue to form, and the mixture of ice crystals and brine solution forms a slush. When point C is reached, there is a mixture of ice crystals C_2, and brine solution of concentration C_1, in the proportions of 1_1 parts of brine to 1_2 parts of ice crystals in (1_1 + 1_2) parts of mixture. When the process has continued to point D, there is a mixture of m_1 parts of eutectic brine solution D_1, and m_2 part of ice D_2, all of the eutectic temperature. As more heat is removed, the m_1 parts of eutectic brine freeze at uniform temperature until all latent heat is removed. The frozen eutectic is a mechanical mixture of salt and frozen water, not a solution, and consequently the latent heat must be corrected for the heat of solution. If this is positive, it decreases effective latent and heat if negative, it increases the effective latent heat.

If the initial solution concentration is greater than the eutectic, salt instead of water freezes out as the temperature is lowered, and the concentration decreases until, at the eutectic temperature, eutectic concentration is reached. In brines used as refrigerating fluid, salt sometimes freezes out because its concentration is too high. This is undesirable when ice is to be generated and therefore when using brine as the secondary refrigerant a concentration of the brine less than the eutectic and preferably about point B on the eutectic curve is maintained.

Applying this principle to the apparatus shown in Figures 1 and 2, the secondary refrigerant is not cooled to the eutectic temperature but is maintained at a temperature at which ice will form.

As ice is formed, the ice and the concentrated mixture form a pumpable slush-like composition which is forced into thermal storage heat exchanger 53. If necessary, water is added to the mixture that is returned to the dasher chamber of the freezer from a supply 24 to maintain the desired concentration of the mixture. Water is preferably added at a constant rate on a continuous basis but it can be added at intervals provided that the concentration of the secondary refrigerant does not get too high. If the concentration gets too high the process becomes less efficient and if it becomes so high that it passes the eutectic point salt or other solute will be deposited in the tank. As concentration gets high ice yield gets low. If concentration is too low one gets too much ice for easy mechanical operation of the unit.

Because a certain amount of brine will be removed with the ice and provision is made for maintaining salt strength with concentrator 23. It can be operated to add salt as required.

The cylinder 10 is an especially efficient ice making device because it employs an efficient heat transfer from the refrigerant to the water that is formed into ice. As the water freezes to take up its heat of crystalization, heat is taken up around the entire surface of the crystal that forms. It represents a very large surface area per unit of water.

To avoid the formation of a layer of ice on the wall of the cylinder 10, which would tend to reduce the heat transfer surface of the ice, the scouring paddle operates at a speed that is fast enough to carry the cooled layer of mixture at the side wall towards the centre of the container before the cooled layer crystallizes on the side wall of the container. The paddle tends to move the cooled surface layer in a spiral path towards the longitudinal central axis of the chamber whereby it mixes with the general body of mixture in the chamber and cools the general body of mixture to form ice crystals throughout the body of the mixture. The speed will vary with equipment design and operating conditions but with two scouring blades and cylindrical chamber having a diameter of about 3 inches a scouring paddle rotation of about 350 r.p.m. was found satisfactory.

The transformation of water from the liquid to the crystal or solid state takes place suddenly and requires a very substantial amount of energy. The liquid brine must be cooled below its freezing point before crystallization will take place. It is so cooled in a surface layer on the side of the chamber but in the interval before crystallizatioon takes place the so cooled surface layer is moved by the rotating scouring paddle from the side wall of the container towards the centre of the container. The cooled liquid thus removed from the side wall surface of the chamber crystallizes into ice on the centers of crystallization present in the liquid. Thus, the brine acts a secondary refrigerant in the formation of ice throughout the body of the mixture.

The paddles rotate around the heat exchange wall of the chamber and preferably form a scoop angle therewith of about 45° in the direction of rotation to force the cooled liquid towards the centre of the chamber on a continuous basis.

As an example, a typical heat exchange chamber having a diameter of 3 inches has heat transfer coefficient between the brine and refrigerant of 500 BTU's per hour per square foot per degree Farenheit and the temperature difference between the refrigerant and the brine is 10° F.

Thus, the capacity of the unit is 500 x 10 = 5000 BTU's per hour per square foot of chamber wall.

The blades in the unit rotate and scour the sides of the chamber 350 times per minute and there are two of them so that the dwell time of the surface layer of mixture at the side wall of the chamber is $\frac{1}{350x2}$ = 0.00143 minutes = 0.000024 hours.

The heat given up by the brine mixture to the heat exchange wall in this time is 5000 x 0.000024 = 0.120 BTU's per hour per rotation of the blade per square foot.

To form ice requires 150 BTU's per pound of ice.

Thus in one rotation of the paddle there is sufficient heat exchange to form 0.0119/150 = 0.00079 pounds of ice per square foot of chamber wall.

Ice at 28° F has a density of 57.3 lbs per cubic foot. Assuming that 0.00079 lbs per square foot of ice form on each rotation of the auger the maximum thickness of the ice layer before removal from the side of the chamber is .00079/57.3 = 0.000013 inches. This is not enough to constitute an ice layer.

The diameter of the ice crystals harvested from the unit are between .002 and .003 inches. This is 154 to 384 times the thickness of ice that could be formed on the wall between scouring so that it is clear that with this rate of scouring crystals cannot grow to a harvestable size on the side wall of the heat exchanger. The 0.09 seconds that the brine contacts the wall is not sufficient for crystal formation.

The mixture adjacent the cooling surface of the container that is subcooled in this method is about 0.2 degrees Centigrade lower that the mixture freezing point. The heat given up by the brine to the heat exchanger is 0.119 BTU's per rotation of the blade per square foot of heat exchanger area. This amount of heat transfer represents a subcooling of the mixture to about 0.2° C below its freezing point. Thus, with the ice generator shown in Figure 2, the subcooled layer is of infinitesimal thickness as noted above. The subcooled layer is removed as it is formed and at a fast rate so that apart from this very small volume the temperature is substantially the same throughout most of the volume of the container. It is more conducive to good crystal growth throughout the container for harvesting.

The scouring rate will vary with equipment and capacity but in every case the idea is to scour at a rate that avoids cooling substantially below the freezing point at the surface and crystal growth on the side of the heat exchanger chamber whereby to promote crystal growth and formation throughout the body of the mixture.

The mechanical scouring of the surface will achieve a high scouring rate capable of preventing crystal growth on the container wall. It gives a good yield of ice crystals. It will be apparent that for a given piece of

equipment the yield of ice will increase with temperature rate of heat transfer. If the rate of heat transfer from the container wall to the mixture tends to be less than 4000 BTU's per square foot per hour of container wall the method becomes inefficient. High ice output for a given size piece of equipment is the key to successful operation. Rates of heat transfer of between 4000 and 5000 BTU's per square foot per hour are contemplated. The higher the rate the more efficient the operation as to capacity.

This method further achieves a vast improvement in machine capacity over a method wherein the crystals are permitted to grow on the wall of the chamber and are then harvested by scraping them from the wall with a lower speed auger. With such a method the temperature of the bulk of the mixture is always substantially above freezing and formation of ice crystals takes place only on the limited area of the wall of the chamber. It is not possible to form ice crystals in the bulk of the mixture that is above freezing temperature.

Solutions other than brine could be used. The solvent should, of course, be water based to make ice but the solute could be any nontoxic material that has a suitable eutectic characteristic. Substitutes for salt might be glycerine, propylene glycol, ethanol or calcium chloride.

In addition to those secondary refrigerants identified on page 6, a proprietary binary solution containing water and emulsifying, antibacterial, antifungal and anticorrosive agents has been used to generate ice particles having a diameter of about 0.002 to 0.005 inches. The liquid also has controlled amounts of alcohol or glycol (for thermal storage applications) so that the working temperature may be set at 28F. The ice crystals remain separated and do not form solid blocks of ice because the emulsifier prevents them from agglomerating in the binary solution. Since they do remain separated, the ice crystals have a higher heat transfer coefficient than solid ice and require no space-stealing freezer tubes in the storage tank and do not "bridge" in storage line conventional ice does.

The ice crystals grow throughout the liquid rather than from the wall outward in a layer. Crystals that form near the wall may attach themselves to the wall but they are removed from the wall as the blades rotate. The growth throughout the liquid is achieved by prevention of larger build up at the cooled surface by mechanical scouring at a rate so that the temperature at the wall is not more than one degree centigrade below freezing temperature and is preferably no more than 0.2 degrees centigrade less than freezing temperature.

The foregcing example is of a subcooling of about 0.2 degrees centigrade. The subcooling throughout the mixture cannot be more than this. The amount of subcooling with this invention is necessarily small because the subcooled layer must be removed before it grows to any appreciable size. Subcooling up to one degree centigrade at the surface is contemplated. Greater subcooling than this would result in poor heat transfer.

The unit with a chamber diameter of three inches and three feet in length referred to above has been operated to produce 400 pounds of ice per hour.

Whilst the ice generator has been described with reference to the heat pump 50 it will be appreciated that it may be used as a supply of ice for other purposes such as food preservation. In this case a separator 20 indicated in ghosted outline in Figure 2 would be used to separate the solution from the ice and hold the solution in a holding tank 22. Water feed 24 then be applied directly to the holding tank rather than to the return line 64.

Separation of ice from the slush can be done many ways including centrifugal separation as will be apparent to those skilled in the art.

An alternative form of ice generator is shown in Figures 4 and 6. The ice making machine 110 includes a housing 112 having upper and lower end plates 114, 116 respectively and side walls 118. The end plates 114, 116 are square when viewed in plan and cooperate with the side walls 118 to define an enclosed housing. The housing 112 is preferably made from an insulated material to reduce the heat transfer across the walls 114, 116, 118.

An inlet 120 is provided on the upper plate 114 to receive the secondary refrigerant, and an outlet 122 is provided in the lower plate at a diametrically opposite location. Thus, fluid entering the inlet 120 is forced to traverse the housing 112 to reach the outlet 122.

An agitator shaft 124 extends through the housing 112 between the plates 114 and 116 and is rotatably supported at opposite ends by bearings 126, 128 located exteriorly of the housing. The shaft 124 is driven by a motor 130 that is supported on the upper plate 114.

A pair of heat exchanger assemblies 132, 134 is located in the housing 112. The heat exchanger assemblies extend between opposite peripheral walls 118 generally parallel to the end walls 114, 116 and normal to the axis of rotation of the shaft 124. Each of the heat exchanger assemblies 132, 134 is formed with a central aperture 136, 138 respectively to accommodate the shaft 24.

Each of the heat exchangers 132, 134 is of similar construction and accordingly only one will be

described in detail. The heat exchanger 132 is formed from a pair of spaced parallel plates 140, 142 of generally circular shape. The plates 140, 142 are maintained in spaced relationship by a honeycomb structure 144 that has open mesh partitions to permit the flow of fluid between the plates whilst maintaining a structural connection between them. An inlet 146 is associated with each heat exchanger and passes through the side wall 118 of the housing. At a diametrically opposed location, an outlet 48 is provided so that coolant may flow from the inlet 146 through the honeycomb structure between the plates 140 and 142 to the outlet 148.

The space between the heat exchangers 132, 134 and the walls 118 is sealed by spacers 49 located in each corner of the housing 112. An aperture 151 is provided in one of the spacers associated with each heat exchanger to permit flow of fluid from one side of the heat exchanger to the other. Successive apertures 51 are arranged in diagonally opposite corners of the housing 112 so that fluid flowing through the housing 112 is caused to flow across each of the heat exchangers 132, 134.

Each of the plates 140, 142 has an outwardly directed heat exchange surface 50 that contacts the fluid provided through the inlet 120. To inhibit the deposition of ice upon the surfaces 150, an agitator assembly is connected to the shaft 124. The agitator assembly consists of a series of disks 152, 154, 156 that are secured to the shaft 124 for rotation therewith. The disk 152 is located between the heat exchanger 132 and the upper end plate 114; the disk 154 is located between the two heat exchangers 132, 134 and the lower disk 156 is located between the heat exchanger 134 and the lower end plate 116.

Extending from each of the disks 152 toward a respective one of the surfaces 150 is a pair of blades 158. The blades 158 are pivotally connected to the disk 152 by a hinge 157 and in the operative position are inclined to the plane of the disk. The blades 158 terminate in a bevelled edge 160 that is in a scraping relationship with the surface 150. The blades 158 are generally rectangular in shape and are accomodated in a rectangular slot 159 in the surface of the disk. The blades 158 are biased into engagement with the surface 150 by flow of fluid past the blades up in rotation of the shaft 124. Resilient biasing means such as torsion springs may be incorporated into the hinge 157 to bias the blades toward the respective surface 150.

The disks 152, 156 each carry a pair of blades 158 directed to the upper heat exchange surface 150 of the heat exchanger 132 and lower heat exchanger surface 150 of the heat exchanger 134 respectively. The disk 154 carries two pairs of blades 158, one pair directed to the undersurface of the heat exchanger 132 and the other pair directed to the upper heat exchange surface 150 of the heat exchange 134. Each pair of blades is aligned on a diameter of the disk with the two pairs disposed at 90° to one another.

In operation, brine is fed to the inlet 120 and circulates through the housing 112, around the heat exchangers 132, 134 through the apertures 151 to the outlet 122.

The primary refrigerant, usually freon, is introduced through the inlet 146 of each of the heat exchangers 132, 134 from the condenser 30 where it flows through the heat exchanger to the outlet 44. As the freon passes through the heat exchanger it absorbs heat through the heat exchange surfaces 150 and boils. The brine in contact with the heat exchange surfaces is thus supercooled. To avoid deposition of the ice on the surface 150 which would inhibit further heat transfer, the agitator assembly is rotated by the shaft 124. Rotation of the shaft 124 rotates the disk 152 and thereby sweeps the blades 158 over their respective heat exchange surfaces 150. The movement of the blades removes the super cooled brine from adjacent the surfaces 150 and distributes it through the body of the brine solution. The super cooled brine will crystalise on centers of crystallisation present in the solution and in turn act as new centres of crystallisation to generate three dimensional crystallisation of the water within the brine solution and thus promote the formation of ice in a crystalline manner. The brine solution with the crystallized ice in suspension is extracted from the outlet 122 where it may be passed to a separating tower (20) for removal of the balance of the brine solution and conveyed to a storage device or directly to the induce for the ice or directed to the thermal storage heat exchanger 52.

The disposition of the heat exchangers in a plane normal to the axis of rotation of the shaft 124 facilitates the modular expansion of the ice making machine for increased capacity without imposing significant additional structural loads upon the apparatus.

It is anticipated that the capacity of the device utilising a pair of heat exchangers with a diameter of 30 inches would be 6-12 tons per day. The plates 50 would typically be between 3/8 - 1 inch thick to provide good heat transfer between the coolant and the brine solution with the honeycomb partitions 144 providing the required strength.

The shaft 124 will be rotated at 150-400 rpm with a throughput of 9-18 gallons per minute.

If desired, the surfaces 50 may be coated with a release agent to inhibit the deposition of ice on the surface. Such a coating may typically be polytetrafluoroethylene, or a silicone water repellant liquid such as Dow Cornings Latex; Silicone 804 or Silicone 890. These may be painted and baked on in accordance with

the normal use of such coatings. If coatings are utilised then the blades 58 may act as wipers rather than scrapers as the coating will in itself discourage the deposition of the crystals.

Figure 7 shows schematically an alternative arrangement of the heat exchange and agitators in which the disks 152, 154 and 156 are replaced by oscillating wipers 170. The wipers may be driven by any suitable form of oscillating mechanism, but again their axes of rotation are normal to the plane of the heat exchanger assembly.

It will be appreciated that the blades 158 may be supported on any convenient carrier assembly connected to the shaft 124, such as a spider arrangement, rather than the discs 152, 154, 156. Further the plates 140, 142 may be maintained in spaced relationship by studs extending between and normal to the plates 140, 142. Whilst the additional surface area provided by the honeycomb portion 44 is considered beneficial, satisfactory results may be obtained by utilizing the studs and a coating on the interior of the plates to promote heat transfer. Such a coating is available from Union Carbide under the trade name High Flux coating.

Claims

1. A heat pump having a heat source, a heat sink and a thermal storage heat exchanger in which heat energy is cyclically accumulated and discharged by circulation of a secondary refrigerant therethrough, the improvement wherein:
the secondary refrigerant is an aqueous solution having a concentration which is below its eutetic concentration;
the heat sink is adapted to super cool the aqueous solution to generate a partially frozen solution in which fine ice particles are retained in suspension; and
the thermal storage heat exchanger has a storage chamber adapted to receive said partially frozen solution from the heat sink and to separate the ice particles from the liquid phase refrigerant to form a porous ice bed and a substantially ice free liquid bath, and wherein the thermal storage heat exchanger is adapted to receive heated refrigerant and to discharge the heated refrigerant into said chamber such that it is placed in intimate contact with the ice bed in a manner such that it may pass through the pores of the porous ice bed prior to its return to the bath.

2. A heat pump as claimed in claim 1 wherein the ice bed is formed so that it floats on said bath such that the ice bed is compressed by its own buoyancy to form a compact high density porous ice bed.

3. A heat pump as claimed in claim 2 wherein the heated refrigerant is returned to said chamber a substantial distance above the bath and wherein the liquid phase refrigerant is withdrawn from the bath at a level below the ice bed.

4. A heat pump as claimed in claim 3 wherein the heated refrigerant is returned to the chamber at a level above the ice bed.

5. A heat pump as claimed in claim 3 wherein the partially frozen binary solution is admitted to the chamber at a level below the ice bed such that the ice particles float upwardly to form the ice bed in use.

6. A heat pump as claimed in claim 3 further comprising a bath level sensing device for monitoring the level of the bath in the chamber, said sensing device being operable to deactivate said heat sink when the level of liquid phase refrigerant in the bath drops below a predetermined level.

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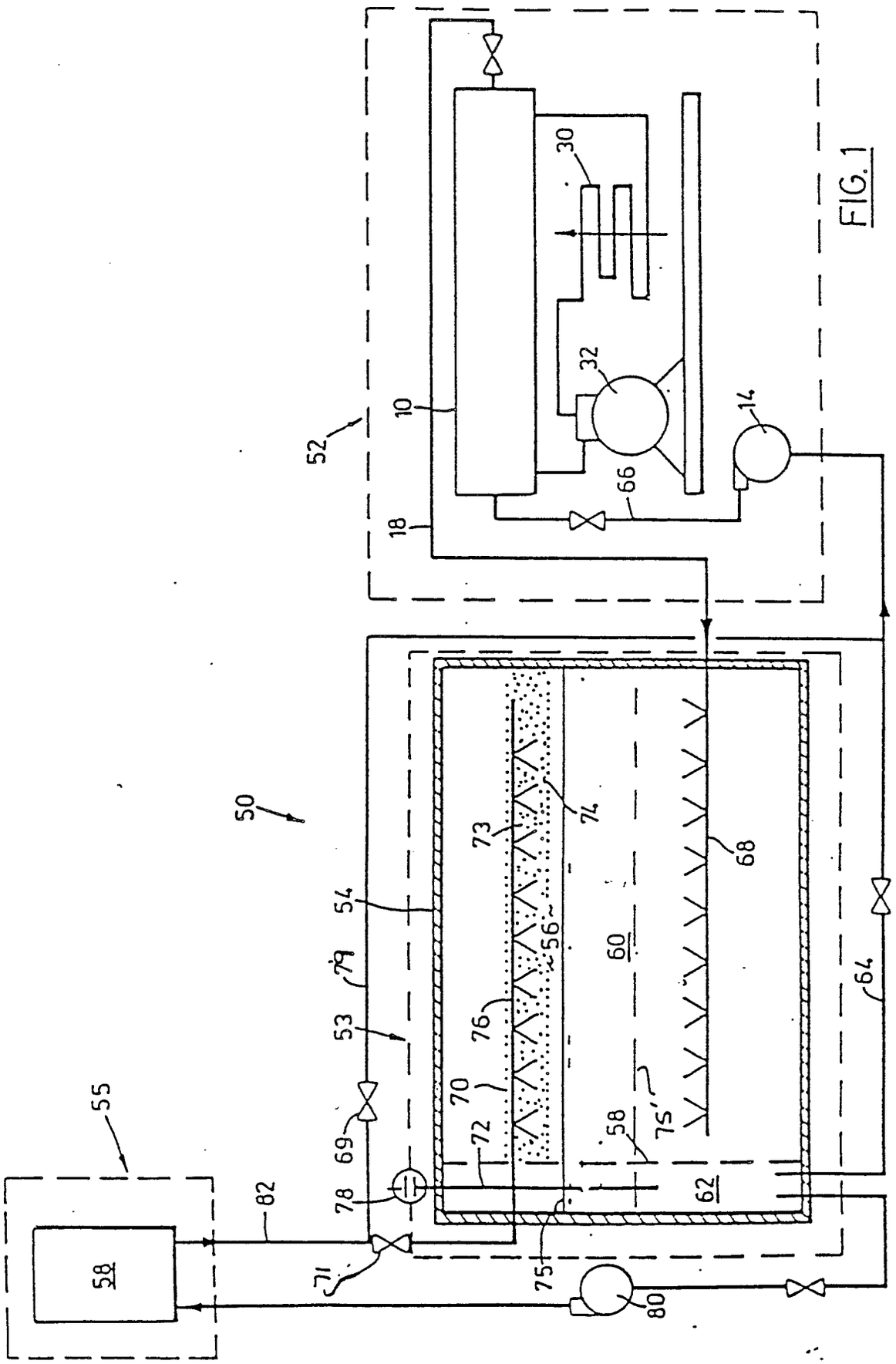


FIG. 1

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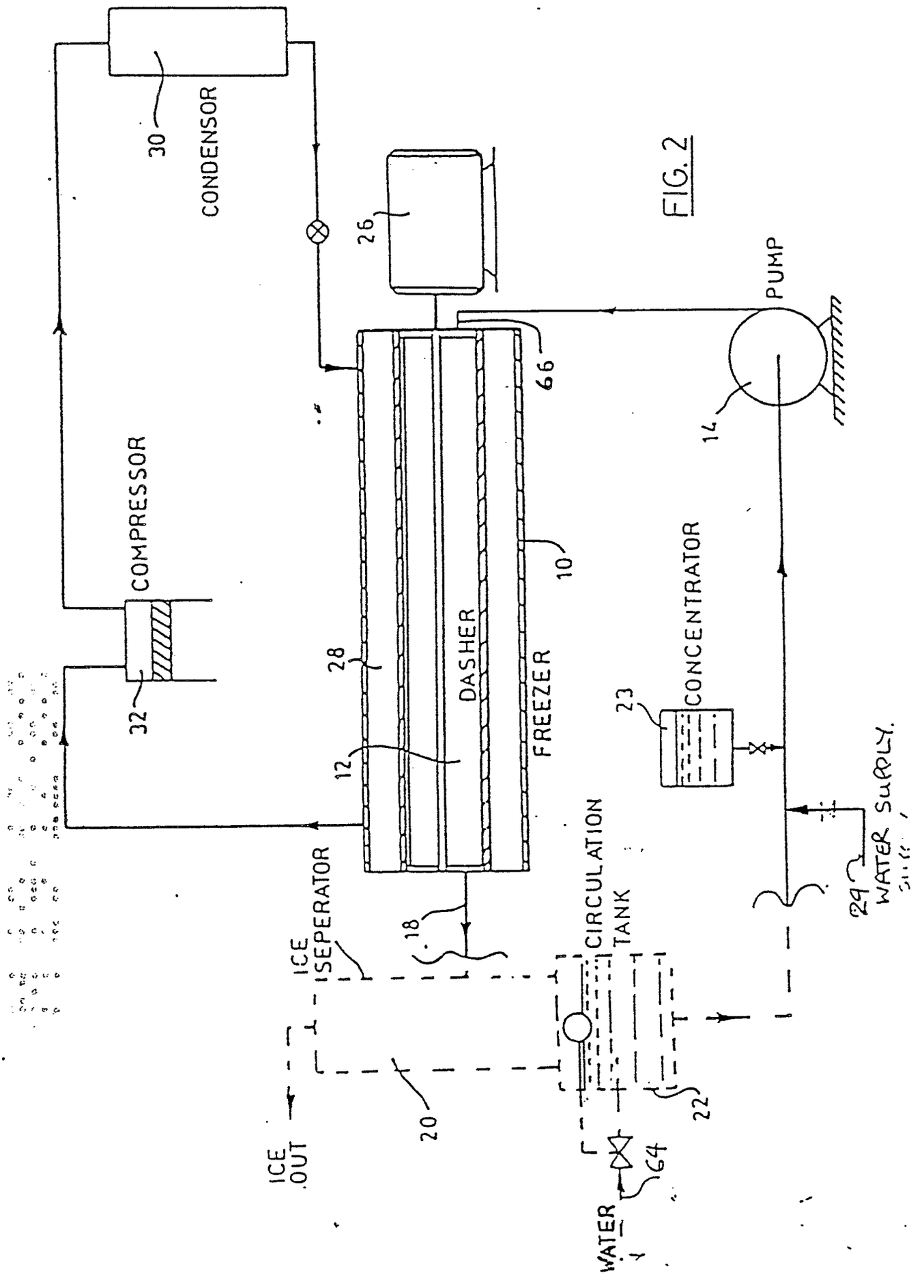


FIG. 2

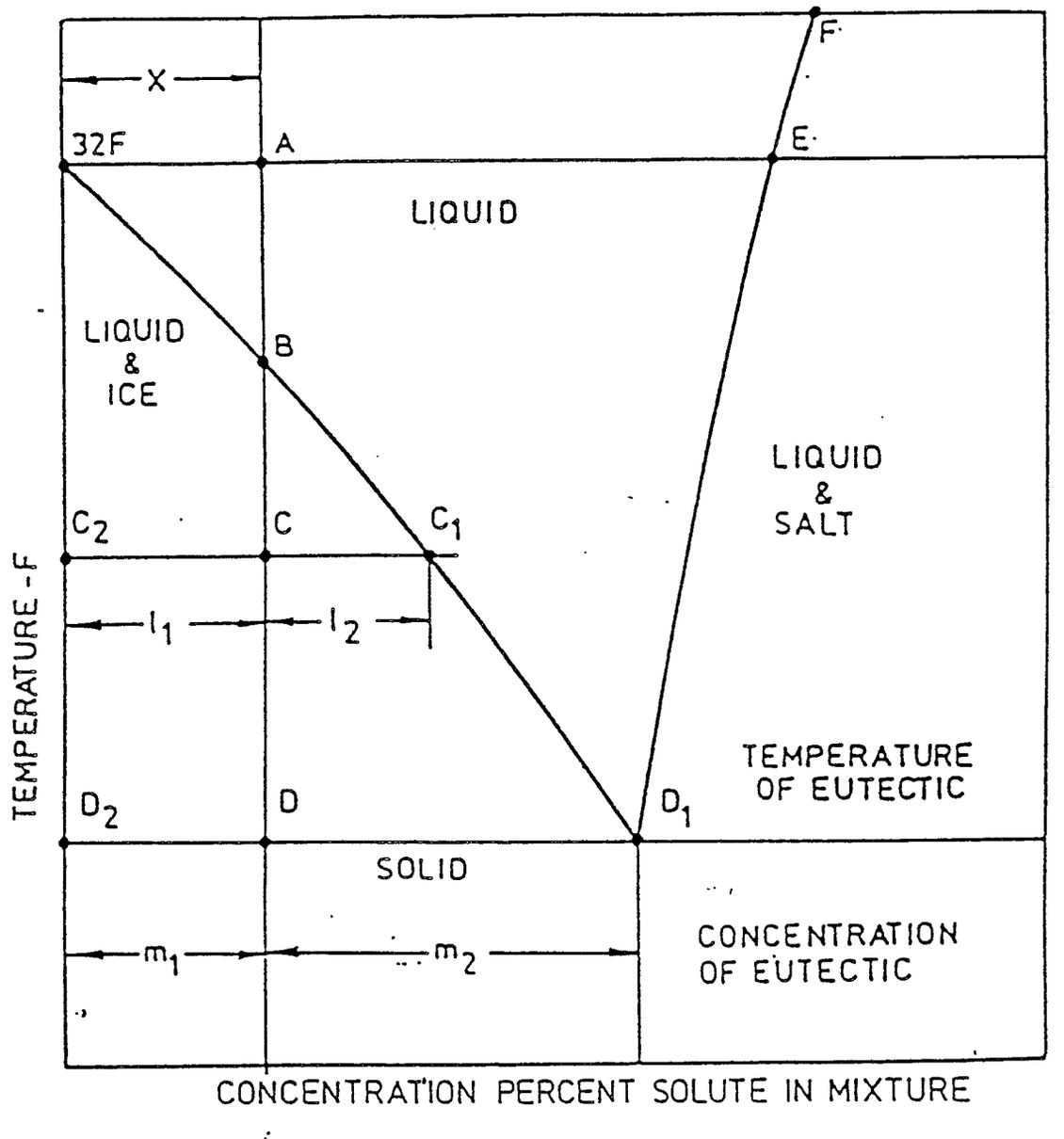

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D
D1
TEMPERATURE
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FIG 3

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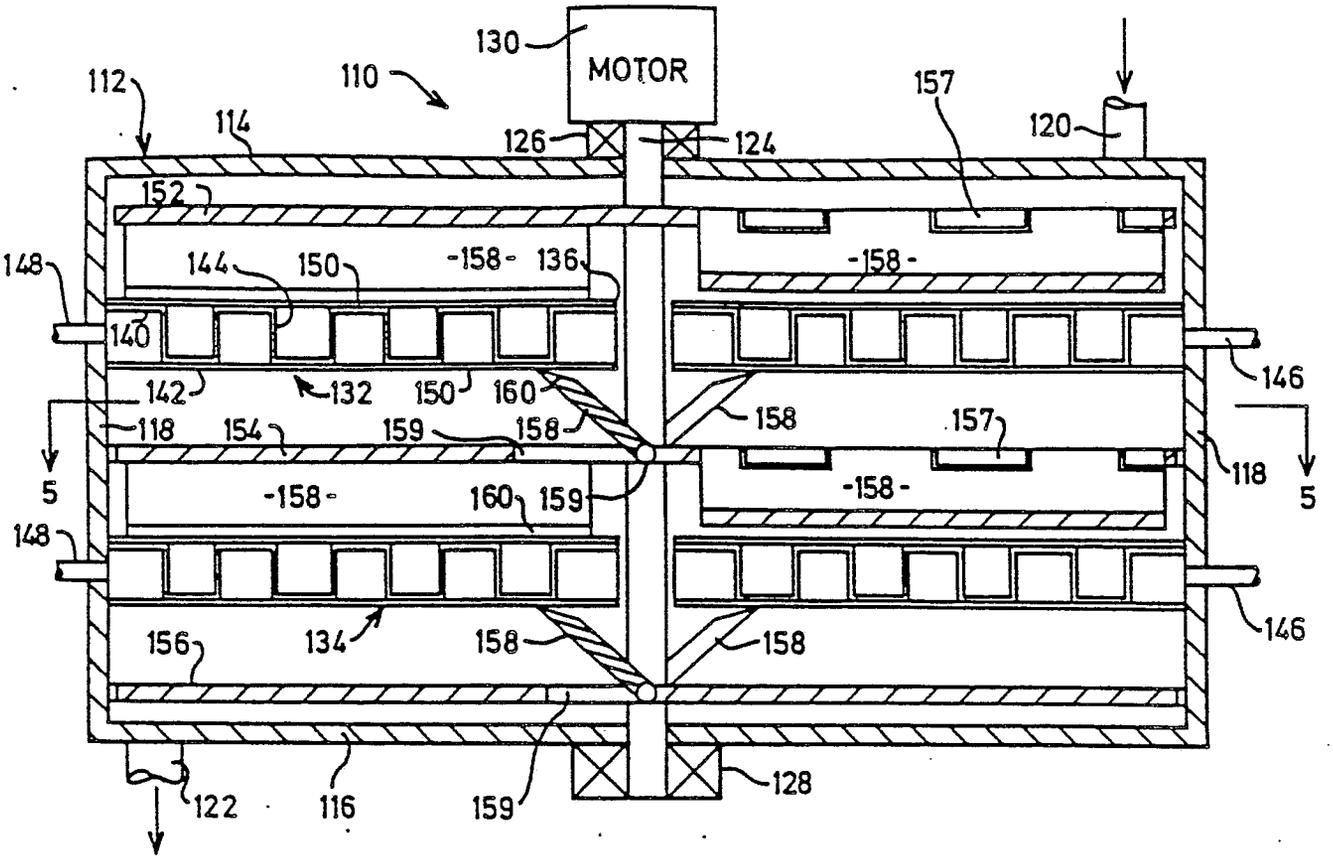


FIG. 4

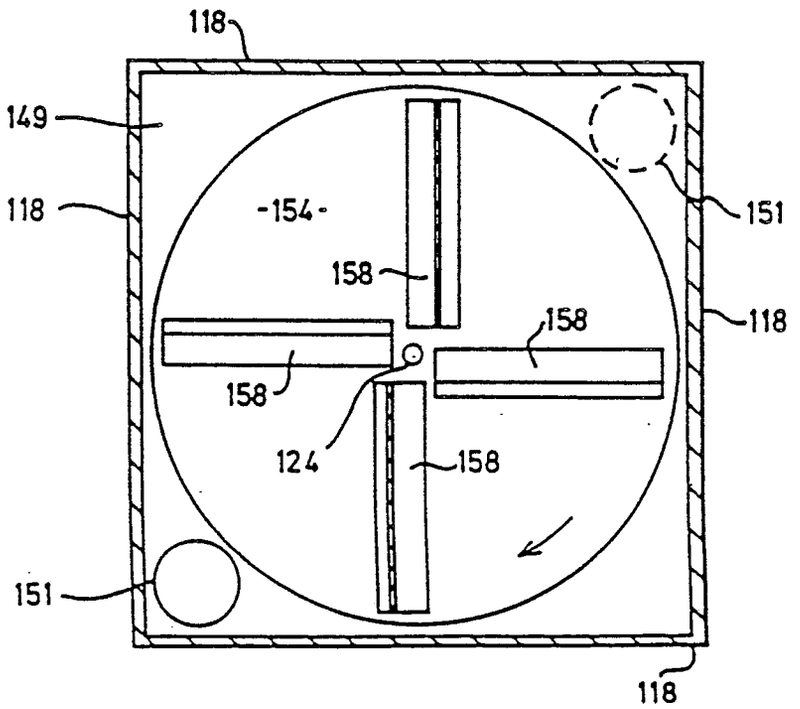


FIG. 5

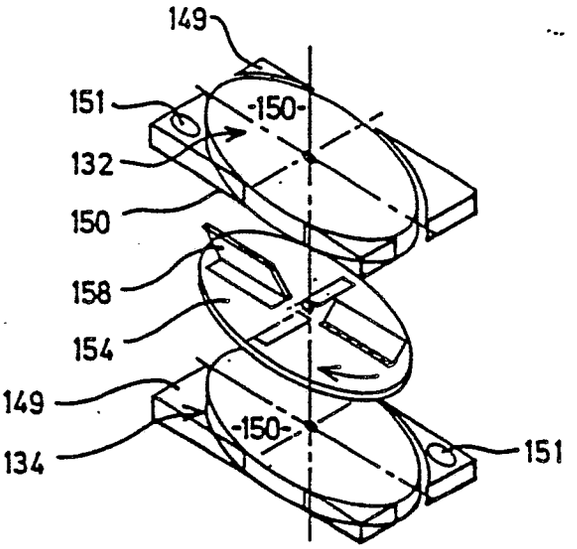


FIG. 6

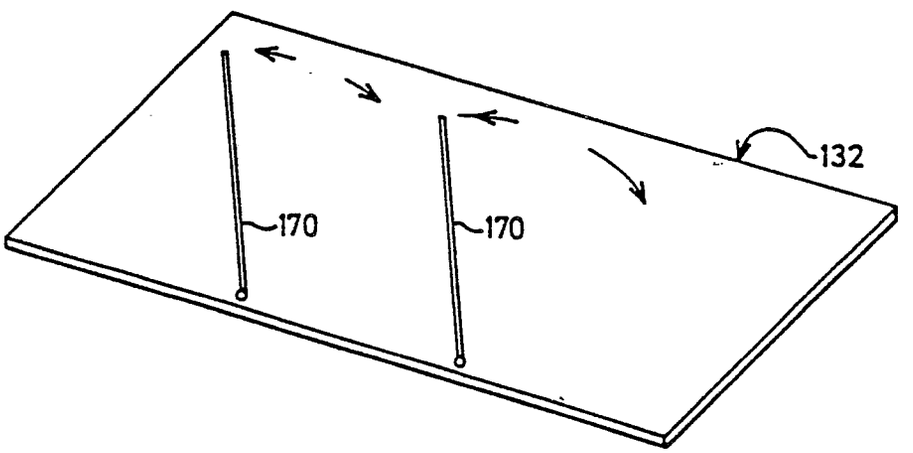


FIG. 7