

Related Application

The present application claims priority from provisional patent application number 61/851,921, filed March 14, 2013. That filing is incorporated herein by reference.

Field of the Invention

The present disclosure relates to a new and improved closed loop refrigeration system using ice slurries.

Background of the Invention

Refrigeration systems are commonly used to cool an air space, cool equipment, and to keep food or perishables at chilled temperatures. Conventional refrigeration systems typically consist of three components: a compressor, a condenser and an evaporator, as well as various piping, valves and controls that connect all the components. These components work together to cycle a refrigerant through the refrigeration system. The compressor compresses the refrigerant so that it turns from gas to liquid at a relatively high temperature. The condenser then transfers this heat to the atmosphere. The resulting cold liquid refrigerant is then sent to the evaporator, which removes the heat from the cabinet or space by turning the liquid refrigerant into a gas. That refrigerant gas is returned to the compressor and the refrigeration cycle is repeated.

One problem faced with such systems is that the cooling and refrigeration process requires large amounts of electrical energy to operate. This places a high demand on electric utilities during on-peak periods, usually during waking hours of the weekday. Utilities must provide enough generating capacity to meet this demand. Evenings and weekends are off-peak demand periods and much less of the total generating capacity is used then. To encourage a better or more uniform demand for electric power, many utilities charge a reduced rate for electricity used during off-peak periods. Thus, there is an ongoing demand to find ways to shift or transfer as

much as possible of required electrical consumption to off-peak periods to take advantage of the reduced rates.

One method that is known in the field of refrigeration systems is the use of an ice slurry (see, e.g., U.S. 4,584,843). Specifically, known methods for refrigeration in a process where an aqueous liquid is fed through a freeze exchanger in indirect heat exchange with a refrigerant to convert at least part of the aqueous liquid to ice. Such methods further include feeding the aqueous liquid-ice mixture from the freeze exchanger to an ice storage tank to provide an ice slurry and aqueous liquid therein, and removing cold aqueous liquid from the ice storage tank for feeding through a heat exchanger in indirect heat exchange with a fluid to be cooled and used for cooling purposes, with the now warmed aqueous liquid exiting from the heat exchanger and returning to the ice storage tank to be cooled by contact with the ice therein.

Existing approaches, however, each run into one or more system or processing limitations which make them unacceptable for certain existing refrigeration applications. For instance, in certain processing applications, an excess of ice can have an adverse impact on the operation of the system, e.g., due to agglomeration and clogging. Alternative systems provide for the use of other refrigerants which have adverse environmental impacts (e.g., due to unavoidable leakage over time) as well as undue costs (e.g., due to the high volume of refrigerant and the cost of replacement involved). Thus, there is a need for an improved refrigeration system to reduce these shortcomings.

Definition of Terms

The following terms are used in the claims of the patent as filed and are intended to have their broadest plain and ordinary meaning consistent with the requirements of the law.

An ice slurry mixture means “a phase changing refrigerant.” A multicomponent ice slurry mixture means “a phase changing refrigerant including micro-crystals formed and suspended

within a solution of water and a freezing point depressant.” Slurry ice has greater heat absorption compared with single phase refrigerants because the melting enthalpy (latent heat) of the ice is also used.

A freezing point depressant means “a solute to water which decreases the freezing point of the water, such as ethylene glycol, propylene glycol, various alcohols (Isobutyl, ethanol), salts (CaCl_2 , NaCl) and sugar (sucrose, glucose).”

A closed loop refrigeration system means “a refrigeration system in which the coolant may be recycled continuously.”

A heat load means “the amount of heat entering the area to be controlled by the refrigeration system.”

An agitator means “an apparatus for mixing a liquid or liquid solid mixture.”

Where alternative meanings are possible, the broadest meaning is intended. All words used in the claims set forth below are intended to be used in the normal, customary usage of grammar and the English language.

Objects and Summary of the Invention

It is herein provided a new and improved closed loop refrigeration system that uses ice slurries.

In one aspect, a closed loop refrigeration system comprises an ice slurry mixture which comprises ice, water, and a freezing point depressant. The system also comprises a first storage device for storing the ice slurry mixture, and an agitator disposed in the first storage device. The agitator agitates the ice slurry mixture in at least an intermittent manner. The system further comprises a first conduit connecting the first storage device and a heat load, and a first pump disposed on the first conduit for pumping the ice slurry mixture through the first conduit from the first storage device to the heat load. At least some of the ice melts in the

heat load. The system also comprises a second conduit connecting the heat load and a second storage device. The second storage device is connected to the first storage device. The system further comprises a second pump disposed on the second conduit for pumping the ice slurry mixture containing the melted ice through the second conduit from the heat load to the second storage device.

In another aspect, a closed loop refrigeration system comprises an ice slurry mixture which comprises about 5 - 60% ice, about 20 - 95% water, and about 0- 50 % a freezing point depressant. The system also comprises a first storage device for storing the ice slurry mixture, and an agitator disposed in the first storage device. The agitator agitates the ice slurry mixture in at least an intermittent manner. The system further comprises a heat load, a first transporter for transporting the ice slurry mixture from the first storage device to the heat load, and a second transporter for transporting the ice slurry mixture from the heat load to a second storage device. The second storage device is connected to the first storage device.

In a further aspect, a method comprises providing an ice slurry mixture comprising about 5 - 60% ice, about 20 - 95% water, and about 0 - 50 % a freezing point depressant in a first storage device, and agitating the ice slurry mixture stored in the first storage device in at least an intermittent manner. The method also comprises pumping the ice slurry mixture through a first conduit from the first storage device to a heat load. At least some of the ice melts in the heat load. The method also comprises pumping the ice slurry mixture containing the melted ice through a second conduit from the heat load to a second storage device.

It should be noted that not every embodiment of the claimed invention will accomplish each of the objects of the invention set forth above. In addition, further objects of the invention will become apparent based the summary of the invention, the detailed description of preferred embodiments, and as illustrated in the accompanying drawings. Such objects, features, and

advantages of the present invention will become more apparent in light of the following detailed description of a best mode embodiment thereof, and as illustrated in the accompanying drawings.

Brief Description of the Drawings

Figure 1 shows a system schematic of a preferred embodiment of a configuration of a closed loop refrigeration system operating in accord with the present invention during off peak power consumption hours.

Figure 2 shows a system schematic of a preferred embodiment of a configuration of a closed loop refrigeration system operating in accord with the present invention during peak power consumption hours.

Figures 3 a-b show cross sectional views of a standard elbow and a lead in chamfer elbow, respectively, with the chamfered lead in reducing steps in the ID size of the flow path for a conduit section in accord with the present invention.

Figure 4 shows a system schematic of another preferred embodiment of a configuration of a closed loop refrigeration system operating in accord with the present invention during peak power consumption hours.

Figure 5 shows a system schematic of a preferred embodiment of a configuration of a closed loop refrigeration system operating in accord with the present invention during off peak power consumption hours.

Figure 6 shows an example thermocouple engagement for monitoring operation of a section of conduit during operation in accord with the present invention.

Detailed Description of the Preferred Embodiments of the Invention

Set forth below is a description of what is currently believed to be the preferred embodiment or best examples of the invention claimed. Future and present alternatives and modifications to this preferred embodiment are contemplated. Any alternatives or modifications

which make insubstantial changes in function, in purpose, in structure or in result are intended to be covered by the claims in this patent.

Practically all modern refrigeration systems are closed loop, meaning that the refrigerant is enclosed (as opposed to being purposefully vented into the atmosphere) in the system and thus must fill all the coils and piping. A typical supermarket has 3,000 – 4,000 pounds of refrigerant in all its various refrigerated display cases, walk-in coolers, etc. Despite all precautions, some refrigerant inevitably leaks from the system, causing environmental damage and incurring substantial maintenance and repair expenses as well as the high cost of replacement refrigerant. For example, some synthetic refrigerants cost hundreds of dollars per pound, and refrigeration systems may lose up to 30 – 40 % of its refrigerants in a single year. The same issues apply to refrigeration systems used in home and auto air conditioners, which often need service and refilling.

Typical known refrigerants include water, ice, hydrocarbons, propane, butane, ammonia, chlorofluorocarbons, freon, hydrochlorofluorocarbon, hydrofluorocarbon, methyl formate, methyl chloride, sulfur dioxide, etc. Some of these refrigerants such as water and ice were found to be problematic, in part because ice tends to agglomerate and clog the refrigeration system. Furthermore, ice refrigeration systems can be quite expensive.

Additionally, a number of these refrigerants were found to be harmful when leaked into the environment (*e.g.*, toxic, ozone depletion, global warming, etc.). To help reduce the volume of environmentally unfriendly refrigerants used (and leaked to the environment), secondary loop refrigeration systems were designed. A secondary loop refrigeration system has two refrigeration circuits: a primary refrigeration circuit and a secondary refrigeration circuit. Consequently, a secondary loop refrigeration system incorporates two different refrigerants to provide cooling: a primary refrigerant in the primary refrigeration circuit and a

secondary refrigerant in the secondary refrigeration circuit.

In a secondary loop refrigeration system, one circuit is used to cool the other circuit (which is used to cool the target air space or equipment). Thus, there may be multiple compressors and heat exchangers that link the two circuits. The configuration of secondary loop refrigeration systems is subject to various designs as known in the art. Typically, the primary refrigeration circuit remains in a machine room and is used to cool the secondary refrigeration circuit (which is used to cool the target air space such as the supermarket refrigerator or industrial equipment, etc.)

By using the primary refrigerant to cool the secondary refrigerant, the overall volume of the refrigerant needed to cool a target space is reduced compared to a conventional refrigeration system.

The primary refrigerant may be a synthetic or natural chemical.

The secondary refrigerant may be water when used above its freezing point. Many cooling functions require temperatures close to or below the freezing point of water, in which case substances are added to water to lower its freezing point, much like anti-freeze in an automobile. Sodium chloride, calcium chloride, low carbon glycols, such as ethylene glycol, propylene glycol, butylene glycol and polyglycols thereof, and alcohol are all examples of freezing point depressants that can be used in circulating water-based cooling solutions. However, salt solutions can be corrosive and glycol solutions may have increased viscosity if the concentration of glycol is high.

Carbon dioxide can also be used as a secondary refrigerant. However, carbon dioxide systems operate at higher pressures than other refrigerants, which demands special piping and fittings.

Brine (salt-based) or water solution refrigerants in secondary loop systems operate at

relatively low pressures, but still require substantial pumps, valves and piping.

As such, both known conventional and secondary loop refrigeration systems have a number of shortcomings (*i.e.*, refrigerant harmful to environment, excess refrigerant needed, substantial piping, etc.). Thus, there is a need for an improved refrigeration system to reduce these shortcomings.

It has been discovered that the use of ice slurries in a closed loop refrigeration system reduces many of the shortcomings found in current conventional refrigeration systems and current secondary loop refrigeration systems.

Figure 1 shows a closed loop refrigeration system 10 according to one embodiment of the present invention that uses an ice slurry which comprises ice, water and propylene glycol. There is also present an ice slurry generator or ice maker 12 for generating the ice slurry. A storage device 14 is provided for storing the ice slurry. The storage device includes an agitator 16 that agitates the ice slurry in an intermittent matter to prevent agglomeration. The agitation of the slurry can be further aided by the use of a mixer 18 which is also used to receive slurry supply from the storage device 14 for mixing with warmer ice slurry returning from the heat load 26. Additionally, a peristaltic pump 20 is used to pump the ice slurry from the ice slurry generator along a first conduit 22 to the storage device and/or along a second conduit 24 to a heat load 26. At least some of the ice melts in the heat load. A vibration motor (not shown) is used for vibrating said first and/or second conduit to help prevent the ice from agglomerating. In addition, a second pump 28 is used to pump the ice slurry from the heat load (thus containing melted ice) along a third conduit 30 to the ice slurry generator for regenerating the ice slurry in mixer 18 or in melt storage device 32, depending upon the system demands (e.g., heat load 26 demands or whether operation is occurring peak electricity hours).

As shown in Figure 2, an embodiment of the present invention provides for interruption,

decrease or stoppage of the ice maker 12 to accommodate for load demands (e.g., to decrease ice maker usage during more expensive electricity hours). In such an instance, the continuing generation of the ice slurry is provided by the extra ice slurry previously generated and stored in the storage device 14, which is combined with the warmed ice slurry returning from the heat load 26. In this manner, it can be observed that the closed loop configurations system can maintain a ice slurry supply for heat load 26 in the absence of the constant operation of ice maker 12. Of course, those of ordinary skill will understand that this operation will also permit a reduced, as opposed to a stopped operation of the ice make 12 so as to lessen (rather than stopping) the draw of electricity during peak hours.

This closed loop refrigeration system according to one embodiment of the present invention can be employed in a secondary loop refrigeration system as the secondary circuit. The various elements of the embodiments of the invention will be described in more detail below.

Ice Slurries

Ice slurries are a type of phase change material that can transfer heat. A phase change occurs when ice melts, water boils or wax melts. It takes energy to cause such a change, called the heat of fusion or the heat of vaporization. 144 BTU/lb is required to melt ice as compared to 1 BTU/lb per degree Fahrenheit of so-called sensible heat for water. (Sensible heat is the amount of heat that is added or lost by a substance due to a change in temperature.) Thus, ice has a superior thermal capacity compared to water.

Since it is difficult to circulate pure ice, it has been discovered that ice in the form of an ice slurry can be circulated through a refrigeration system. However, it has been found that the ice slurry comprises small, smooth ice crystals that are capable of flowing in a slurry through very small tubes; otherwise, it will aggregate easily and prevent circulation at high ice

loading. Acceptable ice slurries include those described in U.S. Patent Nos. 6,244,052; 6,413,444; 6,547,811; 7,389,653; 7,422,601; and U.S. Patent Publication Nos. 2009/0125087; 2009-0255276, all of which are herein incorporated by reference.

Ice slurries may also be generated using any conventional ice slurry generator known in the art, including the Lanikai frozen drink machine or other scraped surface heat exchangers..

Ice slurries (or ice slurry mixture) used in one embodiment of the present invention comprise a mixture of ice, water and propylene glycol. In one example, ice can be present in an amount up to 60% (*e.g.*, ice loadings of 20-30%, 30- 40%, 40-50%, 50-60%, etc.). In another example, propylene glycol can be present in an amount up to 50%, and preferably no more than 50% or whatever is the eutectic composition of the freezing point depressdant. (The eutectic point is that temperature and composition at which a mixture freezes without separation into two phases.) In a further example, water is present in the remaining amount (*e.g.*, 40%, 50%, 60%, etc.).

In one embodiment, the ice is first formed as small, smooth crystals and stored as a concentrated slurry (*e.g.*, 40-60% ice loading) that is too thick to circulate by itself. When ready for use, the stored concentrated ice slurry is diluted to about 20-30 % ice loading at the appropriate temperature by mixing with another medium (*e.g.*, a return melted slurry).

Experiments have shown that slurries with 20 % ice loading have approximately the same viscosity as pure water at the same temperature, but yet have enhanced heat transfer coefficients. As such, high ice loading is desirable to maximize the thermal capacity of the ice slurry. Slurries of 20 – 35 % ice loading have been found to circulate well while providing good thermal capacity. In use, all the ice eventually melts and the solution warms slightly, adding some sensible heat to the heat of fusion.

The use of an ice slurry refrigerant in a closed loop refrigeration system is more

environmentally friendly than refrigerants used in a conventional refrigeration system. Additionally, using an ice slurry refrigerant in a closed loop refrigeration system uses fewer parts and is simpler to control than a conventional refrigeration system.

Additionally, combined with the lower flow required for a given heat load, the use of an ice slurry refrigerant in a secondary loop system has lower capital, maintenance and operating costs than does a brine or carbon dioxide system.

Components

The concentrated ice slurry is stored in a storage device 14, which may be any conventional storage container known in the art. The storage device includes an agitator 16, which can be any conventional mixing device known in the art. During storage, intermittent gentle agitation is applied to prevent aggregation of ice crystals.

A peristaltic pump 20 can be used to pump the ice slurry from the ice slurry generator along a first conduit 22 to the storage device. A peristaltic pump or progressing cavity pump 28 can also be used to pump the ice slurry along a second conduit to a heat load. It has been discovered that the "pulsing" action of peristaltic pump (as opposed to a centrifugal pump) helps to prevent the ice in the ice slurries from aggregating and clogging the conduits.

In addition, it has also been discovered that using a vibration motor along the conduits can also help prevent the ice in the ice slurries from agglomerating and clogging the conduits. This is especially true when using vibration to promote flow of the concentrated ice slurry from the storage device.

Any conventional conduits known in the art can be used with the various embodiments of the present invention.

The heat load represents any device in which the target air space is being cooled (*e.g.*, refrigerator or jacketed vessel, etc.). At least some of the ice in the ice slurry will melt in the

heat load.

Any conventional pumps known in the art (or a peristaltic pump) can be used to pump the ice slurry from the heat load (thus containing melted ice) along a third conduit to the ice slurry generator for regenerating the ice slurry.

Modes

Furthermore, the advantage of reduction in energy when using the embodiments of the present invention can be realized by operating the disclosed technology in different modes (*i.e.*, by coordinating the power requirements of the refrigeration system with the different electricity rates charged during the day and night). For example, the power requirements of the refrigeration system can be operated in accordance with the daily fluctuations in energy prices (*i.e.*, off peak vs. peak rates).

Energy is needed to power the compressors in a refrigeration cycle that produces cold temperature. The cost of electricity in most places is a function of demand because electricity suppliers and utilities have a variety of sources, which have a range of efficiencies and costs. The largest and most efficient power plants - coal, nuclear or gas heated, are used to supply the base load, while smaller more flexible peak shaving units are employed when demand exceeds base load. Utilities typically price electricity to penalize use at peak times (*i.e.*, daytime) and motivate use at off-peak times (*i.e.*, evening). Sometimes the difference between night and day, or peak and off-peak, rates can be a factor of two.

To take advantage of the lower off-peak rates, it is advantageous to operate the refrigeration compressors in the present disclosure only when rates are low, and storing the cold temperature. Making ice is one way to store the cold temperature and is used in ice-making units, where water is typically frozen around metal coils filled with refrigerant. The cold temperature is recovered when needed by circulating water past the coils, melting the ice and

cooling the water, which then circulates as a heat transfer medium to where it is needed (*i.e.*, air coolers, heat exchangers or process chillers).

Examples

By way of illustration, the present disclosure will be described in more detail in the drawings, photos and pages that follow. One skilled in the art will realize that many various designs are possible under the present disclosure and that these examples are only illustrative and not meant to include all such possibilities. In addition to the advantages discussed above, these examples also illustrate use of an auger freezer (instead of conventional freezer), the absence of size reduction step, the absence of valves to control flow of slurry, and the absence of ripening or crystal modification step. One skilled in the art will appreciate that there are many other advantages of the present disclosure.

Definitions: ice slush was straight from a Lanikai machine 12. Ice slurry was processed with the intent to increase the ability to flow and be pumped. ID: inside diameter. OD: outside diameter.

Setup (Materials and Equipment) includes a Lanikai frozen drink machine; a MasterFlex peristaltic pump; an Electric drill, 0-550RPM; Variac; a tile saw pump; a heated water bath; Coleman coolers (2); thermocouples, T type, Omega 5TC-TT-T-36-72 (8); a measurement computing USB -Temp ID:02; a digital thermometer, Digisense ID:428763; a graduated cylinder; a stopwatch; a stir rod; and a paint mixer.

Example 1: Night Mode

An aqueous solution of a freezing point depressant, such as propylene glycol is mixed in a large container. A Lanikai is filled with the mixed solution until there is approximately 1 cm of standing solution in the Lanikai holding tank. The fill pump fills the holding tank up to the proper level. All three tubes are set in the peristaltic pump heads. The smaller diameter

tubing should be on a separate pump from the two larger tubes. The mixed output tube is directed at the heat exchanger cooler and the pure ice is sent to the ice storage cooler. The heat exchanger cooler is filled with solution and the circulation pump is turned on. The heat load source is then turned on and the load pump is heated. Subsequently, the Lanikai output valve is opened and all peristaltic pumps are turned on and control knobs adjusted to desired settings.

Example 2: Day mode

The tubing from the head #2 (the tubing going to ice storage) on peristaltic pump #1 is removed. Head #1 is kept intact. The tubing in ice storage is moved to a location it will not touch the mixer, but is adequate enough to extract uniform slurry. The output nozzle on Lanikai faceplate is closed. The direction of peristaltic pump #1 is reversed, and the flow of peristaltic pump #2 is readjusted to desired thickness.

Example 3: Slush flow control experiments

The closed loop slurry system requires a controlled flow of ice slush throughout the system. Initial experiments were performed to evaluate different methods of ice slush flow control from the Lanikai frozen drink machine. The following experiments were performed with a 10% by volume concentration solution of propylene glycol mixed with tap water.

The Lanikai machine features a main valve on the front face plate that allows dispensing of the ice slush. The main valve consists of a sliding cylinder sealed by o-rings that can be infinitely adjusted between fully open and fully closed. When fully opened, the diameter of the orifice is approximately 1" in diameter. By varying the position of the valve and therefore the orifice size, the flow of ice slush can be controlled. However, the valve position that generates approximately 300 mL/min output flow was found to jam and stop flowing after approximately 2-3 minutes of flow at 300 mL/min through the orifice. The flow

rate was found to gradually decrease until flow became essentially zero or "jammed". The ice slush just inside the outlet of the Lanikai is visible due to the clear front plate. When a jam occurs, the ice slush visually appeared to be a high concentration of ice which likely caused the stoppage of flow or an "ice jam". The flow can be restarted by opening the valve and in effect creating a larger orifice.

The opening below the main valve on the front plate of the Lanikai can be fitted with a section of 1" ID rigid tubing, bonded to the opening and then connected to a piece of 1" ID flexible tubing. Placing the flexible over the rigid tubing is intended to increase the ability of the ice slush to flow by eliminating the step which would otherwise be created when using certain standard fluid fitting connectors. Flow through the flexible tubing can be controlled by varying the height of the opening and overall length of the tube relative to the Lanikai and therefore varying the static fluidic pressure differential and amount of friction. These two variables were experimentally adjusted to control the flow rate to approximately 300 mL/min. However; the rate was found to slow after several minutes and eventually stop almost completely or form an "ice jam" as previously discussed. A vibrator motor was connected to the flexible tubing to vibrate the ice slush along the tubing. The vibration was found to have two effects: both to increase the flow rate and to increase the consistency of the output flow rate over time. An experiment was performed where the Lanikai machine was run continuously for several hours and the output flow rate measured every 15 minutes. Over the 6 hour period, flow rate ranged between 252 and 292 mL/min. The Lanikai machine with a flexible tube was connected and coupled to a vibrator motor as described above. The closed loop system requires controlled flow of ice slush at various locations. Depending on the final closed loop configuration, changing the relative height of the ice slush output may not always be feasible or easily controlled. To allow more flexibility in system design, the ice slush flow can be

controlled by connecting a peristaltic pump to the outlet spout of the Lanikai faceplate and then fully opening the main valve on the Lanikai. A MasterFlex peristaltic pump (7523-10 drive with 7518-00 head) with W' OD x 0.375" ID (McMaster 5554K16) was connected to the outlet of the Lanikai via a W' push to connect fitting (McMaster 51055K22) and run continuously for over an hour successfully.

In this example, the output of the Lanikai was connected to the peristaltic pump via the Yi' tubing and a push to connect connector.

Ice slush flow can also be controlled using a rotating auger similar to a setup found in a food processing feeder bin. An auger drive system was prototyped and evaluated experimentally by driving the 1" x 17" auger drill bit (Menards 2423429) inside a section of 1" ID rigid PVC tubing (McMaster 49035K25). With approximately 60% ice concentration, the ice flow can be controlled by varying the rotation speed of the auger down to zero RPM which corresponds to zero mL/min. If ice concentration drops below a critical value, the ice slush can flow through the pipe even with zero auger rotation. The critical value of ice concentration is dependent in part to the location of the auger relative to the outlet spout on the Lanikai machine. When configured with the auger drive approximately 150 mm below the output spout on the Lanikai faceplate, the non-rotating auger can control ice slush flow. The maximum flow created by the auger is limited and is less than proportional to theoretical rate calculated by multiplying the linear speed at which the helix translates axially through the tube by the cross sectional volume of the void in the auger. As a result, the ice slush will be constantly mixed by the helix of the rotating auger as the ice slush translates along the tube.

A number of different auger drive and peristaltic pump configurations were experimentally evaluated. An experiment was performed with with a section of clear PVC pipe attached to the Lanikai and the 1" connected to an electric drill. The auger approximates a

progressing cavity pump, which could serve in a larger embodiment of the invention.

In the previously described experiments, ice slush from the Lanikai was found to flow well through 1" tubing and pipes provided total flow lengths were limited to approximately 500 – 1000 mm and in pathways with less than 180° of total directional change. It was also noted that steps in the ID size of the flow path negatively impacted the ability of the ice slush to flow. Standard PVC pipes and connectors create a step in the ID where the pipe meets the connector. The step was reduced by creating a lead-in chamfer as shown in Figures 3 a-b, such reduction of step being useful for either of the first conduit 22 or second conduit 24.

Example 4: Closed Loop Experiments

An initial closed loop system configuration was evaluated experimentally. The system evaluated featured two ice slush flow control mechanisms (a driven auger and a peristaltic pump) as well as a submersible pump. The ice slush from the Lanikai machine was driven at approximately 300 mL/min into the storage container. From the storage container, the ice slush was pumped into one leg of a wye fitting and then into the simulated heat load. A submersible pump was at the bottom of the heat exchanger and pumped the melted slush both into a flow control valve and then into other leg of the wye fitting as well as back into the storage reservoir of the Lanikai. The Figures 1 and 2 show a schematic view of this setup. Thermocouples were placed at different locations along the fluid flow path in the system.

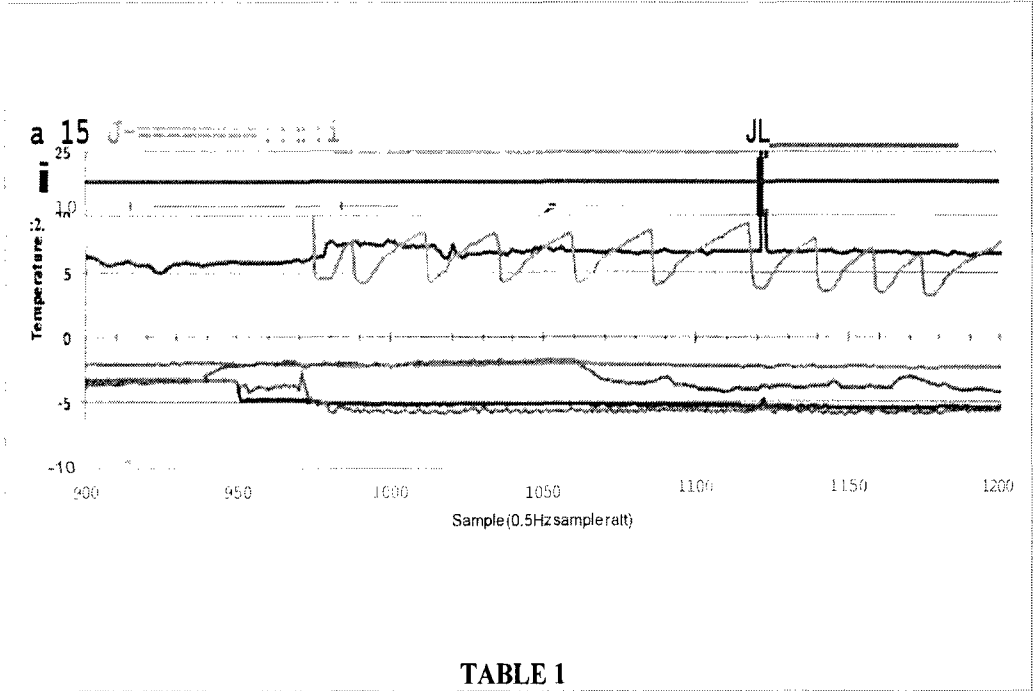
This initial evaluation was started with room temperature fluid in the return reservoir of the Lanikai, ice storage as well as the heat exchanger; however, the Lanikai was allowed to run and create a -5.5°C ice slush prior to opening the main valve on the Lanikai. The main valve was opened at approximately sample 950 in the DAQ record and is evident by the rapid drop in Lanikai outlet temperature. Due to limitations in this configuration, no automated slush

agitation exists in the ice storage container. Throughout the test, the ice storage container was manually agitated using a stirring rod or by spinning a paint mixer at approximately 100 RPM near the storage outlet to the peristaltic pump. The drop in temperature at approximately sample 1060 in the DAQ record can likely be attributed to the point at which manual mixing was increased such that fresh ice slush from the Lanikai had been mixed with the warmer slush already in the ice storage container.

Table 1 below shows the temperature versus time plot for the various locations during an initial closed loop evaluation from May 12, 2012 (non calibrated values reported). The variation in the "Out of Heat Exchanger" temperature is a result of the configuration used to refill the Lanikai reservoir. The submersible pump used to refill the reservoir is only turned on when the reservoir is below a minimum level.

12MAY2012 Closed Loop Test (Auger to Storage, Peristaltic from Storage)

-Lanikai Reservoir -Ambient -Bottom of Storage Container -Lanikai Outlet Spout
-Into Heat Exchanger -Into Storage -Out of Heat Exchanger



Example 5: Peristaltic Ice Slush Pumping Experiment

An experiment was performed to evaluate the ability of the peristaltic pump to move ice slush continuously for several hours. A section of 1/2" OD x 0.375" ID tubing (McMaster 5554K 1 6) was connected to outlet of the Lanikai via a shim section of 1" PVC pipe and a 1/2" NPTF reducing tee fitting and a 1/2" push to connect to 1/2" NPTM fitting (McMaster 51055K22). To simplify this experiment, the flow circuit was reduced so that the ice slush was pumped directly to the "heat load" cooler where a submerged pump pumped the melted ice slush back to the Lanikai reservoir.

Flow rate of the slush into the heat exchange cooler was recorded and measured manually with a stopwatch and graduated cylinder throughout the test. Temperature was also monitored via thermocouple at various locations. At approximately data point 7500 the peristaltic pump was turned off in an attempt to create an 'ice jam' at the outlet of the Lanikai. After 20 minutes, the peristaltic pump was turned on again with no evidence of irregular ice slush flow. The heat exchanger was not fully melting the ice slush and therefore the melted slush being pumped back into the Lanikai continued to decrease in temperature. And as a result, ice slush temperature being pumped into the heat exchanger also continued to decrease as evident by the three temperature traces (RESERVOIR, LANK CLOSE, INTO HEAT EXCH) decreasing between approximately 0 and 4500. During this time period, the flow rate was measured 5 times and varied between 140 and 152 mL/min.

At approximately data point 4300, it was noticed that the ice slush in the flexible tubing was separated by air pockets making up for approximately 30% of the volume in the tubing. The air pockets were likely caused by the ice slush becoming thick (cold) as discussed previously. The temperature at the Lanikai outlet when the ice pockets were noticed was -6.8°C. At this point, warmer (room temperature) melted ice slush was added to the heat exchanger and

therefore raised the temperature of the outlet slush again. Repeating this test with the same setup and more closely observing the ice slush flow rate obtained given a constant peristaltic pump setting may indicate the temperature at which the ice slush is no longer able to be pumped with a given setup. Based on these results, it is reasonable to expect the coldest temperature for this setup to be approximately -7 to -8°C .

Table 2 shows the temperatures versus time throughout the test:

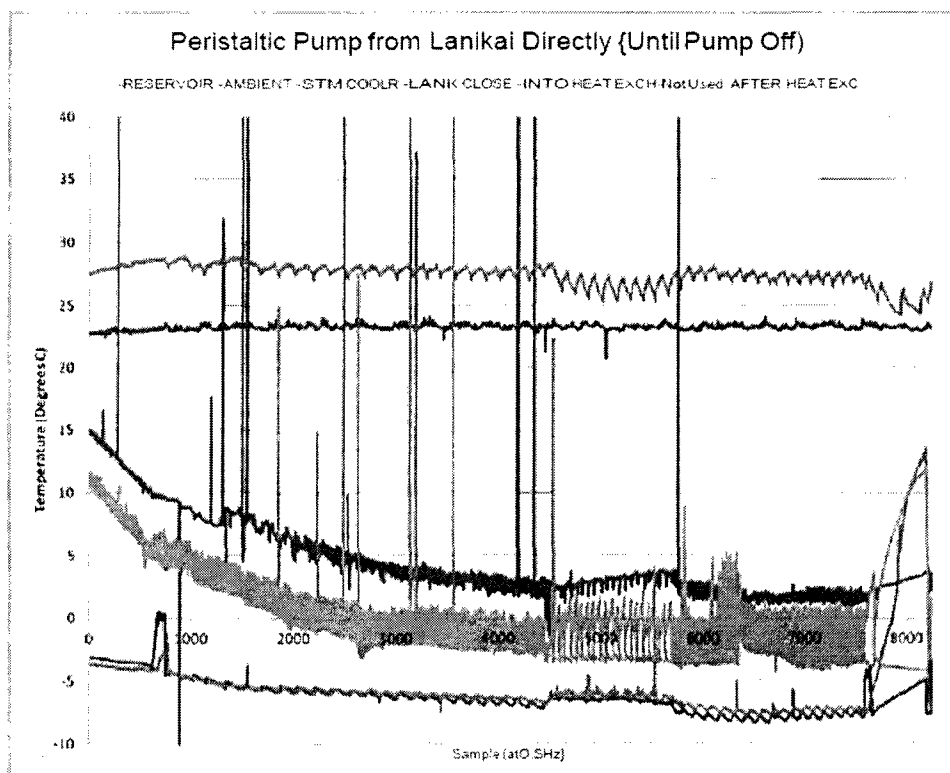


TABLE 2

Example 6: Ice Slush Auger, Storage and Waring Blender Experiments

Bench testing was performed to evaluate the effect of storing ice slush overnight. A 48 Qt (45.4 L) size Colman cooler (Sears 80529711) filled with approximately half way with ice slush was stored for approximately 8 hours in the ambient lab environment. The cooler used incidentally had four 2" diameter holes in the cover that remained unsealed during the test and the cooler lid was also slightly propped open. Some kind of mild agitation will be needed to prevent icebergs from forming in the stored slush. Additionally, using an intermittent agitation method should also be considered to prevent adding too much energy into stored ice and therefore reducing the cooling capacity.

Example 7: Closed Loop "Reversible Path In/Out of Storage"

A slightly different system architecture was put together to further improve the control over the system and simplify the required components. The main feature of this architecture is that the ice slush pathway between one of the peristaltic pumps 20 or 28 and the storage container 14 allows for either forward or reverse ice slush flow depending on the intended day or night mode operation. Temperatures throughout the flow loop can be recorded via thermocouples placed inside the tubing at various locations. Figures 4 and 5 show a block diagram of the system flow path in this configuration, as well as the thermocouple location and ID numbers.

The thermocouples were placed in the following locations identified by their location in the schematics:

Channel 0 - Lanikai Reservoir Tank 32
Channel 1 - Ambient
Channel 2 - Lanikai Output 22
Channel 3 - High Ice 14
Channel 4 - Mixed Output to Heat Load 24
Channel 5 - High Ice Storage 14
Channel 6 - Fill Tube 10

This system was first run in night mode for 2 hrs 45 min, followed by day mode operation for 1 hr. During night mode, Peristaltic Pump One was set to 100 mL/min such that the two pump heads combined were pumping 200 mL/min of ice slush from the Lanikai machine. The mixing drill with a rectangular mixing head was set to a slow, constant speed. At the same time, Peristaltic Pump Two was set to 50 mL/min creating a lower ice concentration ice slurry mix flowing into the heat exchanger. At the transition to day mode operation, the tubing from Head One on Peristaltic Pump One was removed to allow free ice slush flow through that segment.

The main valve of the Lanikai was closed to prevent back flow and Peristaltic Pump Two was slowed to 30 mL/min given that the ice concentration of the ice slush in storage had decreased slightly due to melting (this was detected by an increase in thermocouple #4 temperature as well as a visual assessment of the ice slush flowing into the heat exchanger. The plot of Table 3 below shows the resulting temperatures from the two modes of operation.

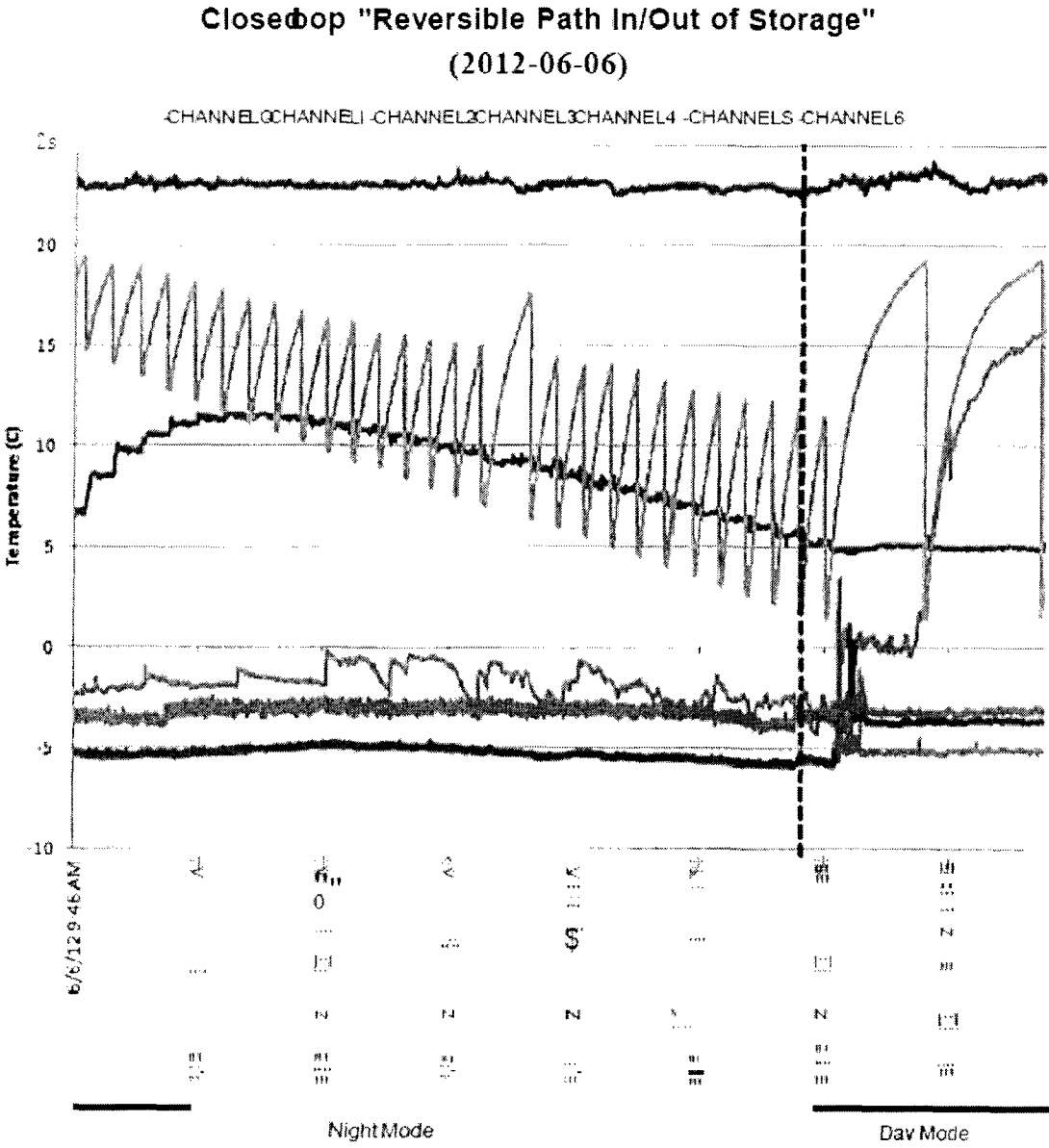


TABLE 3

The following plot of Table 4 shows a close up of the sub-zero temperature range for the same experiment:

Closed Loop "Reversible Path In/Out of Storage"
(2012-06-06)

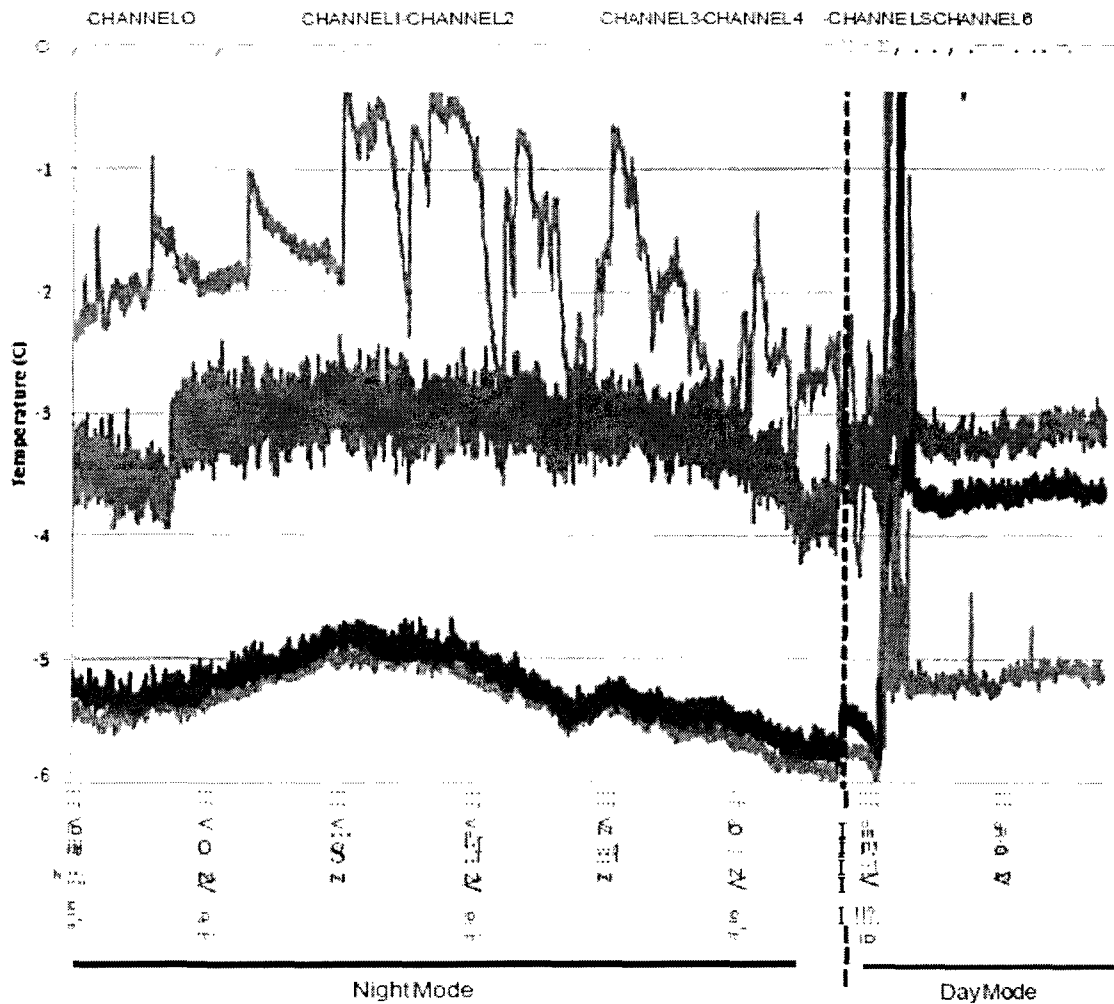


Table 4

The ice slush temperature flowing into the heat exchanger varied between approximately -4°C and -2.6°C throughout the test. Excluding the brief period during the transition between the two modes, the ice slush temperature remained constant during the transition to day mode.

Example 8: Lanikai Power Consumption

The power characteristics of the Lanikai machine were characterized with an off the shelf

"Kill-A-Watt EZ Plug Power Meter." An experiment was conducted where the Lanikai was connected to the power meter, filled with room temperature propylene glycol mix and then turned on. Cold compressor on the Lanikai machine is controlled via a belt tension switch that is coupled to the main drive auger inside the main chamber. As the contents in the chamber cool, the ice concentration increases causing the torque on the auger to increase. When the torque reaches a certain limit the condenser is switched off. The time period from initial startup to when the compressor was first turned off was recorded as well as the temperature of the contents at that point. The following table 5 summarizes the findings.

Date	Initial Temperature (c)	Com pressor 'ON' Time	Final Temperature (c)	kWH
6/20/2012	23	50 min	-5	
6/25/2012	23.5	45min 21sec	-5	0.66
6/26/2012	21.2	40 min 16 sec	-5.2	0.59

Table 5

Both a peristaltic pump and an auger drive were found to successfully control the flow of ice slush in the system. Both the peristaltic pump and auger drive appear to allow precise flow control; however, the auger requires a certain minimum ice concentration to maintain control of the flow rate. Use of the main valve or addition of a gate valve after the auger could prevent ice concentrations from dropping below the critical valve. Additionally, when an auger drive is used, the vertical distance between the auger and the ice slush distance should be considered and minimized where possible to prevent fluid separation in the ice slush along the vertical distance.

Example 9: Thermocouple Setup

Figure 6 shows how a thermocouple can be inserted into a section of flexible tubing

as could be used with conduits such as the first 22 or second 24 conduit. Create a small 2-4 mm long slit in the flexible tubing then insert a section of a metal tube with the tip ground to a sharp point through the slit in the flexible tubing. Insert the thermocouple through the cannula of the metal tube, then pull the section of metal tubing through the ID of the flexible tubing.

Thermocouple Calibration. As part of the experimentation described herein, a three point calibration was performed as described in Table 6:

Degrees C	Digisense	Ch 0	Ch 1	Ch 2	Ch 3	Ch 4	Ch 5	Ch 6	Ch 7
Ambient	21.5	23.13	22.95	23.74	22.78	-	21.19	22.36	22.32
Water & Slurry Mix	12.92	13.6	13.66	13.67	13.76	-	12.76	12.86	12.83
Slurry	-6.39	-5.25	-5.24	-4.57	-5.19	-	-6.07	-5.59	-5.73
Location for 12MAY2012 Test		Lanikai Reservoir	Ambient Under Table	Bottom of Storage Container	Lanikai Outlet Spout	NA	Into Storage Container	Out of Heat Load	Into Head Load

Table 6

The above description is not intended to limit the meaning of the words used in the following claims that define the invention. Rather, it is contemplated that future modifications in structure, function or result will exist that are not substantial changes and that all such insubstantial changes in what is claimed are intended to be covered by the claims. Likewise, it will be appreciated by those skilled in the art that various changes, additions, omissions, and modifications can be made to the illustrated embodiments without departing from the spirit of the present invention. All such modifications and changes are intended to be covered by the following claims.

What Is Claimed:

1. A closed loop refrigeration system, comprising:
 - an ice slurry mixture comprising ice, water, and a freezing point depressant; a first storage device for storing the ice slurry mixture;
 - an agitator disposed in the first storage device, wherein the agitator agitates the ice slurry mixture in at least an intermittent manner;
 - a first conduit connecting the first storage device and a heat load;
 - a first pump disposed on the first conduit for pumping the ice slurry mixture through the first conduit from the first storage device to the heat load, wherein at least some of the ice melts in the heat load;
 - a second conduit connecting the heat load and a second storage device, the second storage device connected to the first storage device; and
 - a second pump disposed on the second conduit for pumping the ice slurry mixture containing the melted ice through the second conduit from the heat load to the second storage device.
2. The system of claim 1, where the freezing point depressant comprises a low carbon glycol or the corresponding polyglycol.
3. The system of claim 2, where the low carbon glycol is selected from the group consisting of ethylene glycol, propylene glycol, butylene glycol, a corresponding polyglycol, and a mixture thereof.
4. The system of claim 2, where the low carbon glycol is propylene glycol.
5. The system of claim 1, further comprising an ice slurry generator, the ice slurry generator connected to the first and second storage devices.
6. The system of claim 1, further comprising a vibrator disposed on the first or

second conduit, the vibrator vibrating the ice slurry mixture contained in the conduit.

7. A closed loop refrigeration system, comprising:

an ice slurry mixture comprising about 5 - 60% ice, about 20 - 95% water, and about 0 - 50 % a freezing point depressant;

a first storage device for storing the ice slurry mixture;

an agitator disposed in the first storage device, wherein the agitator agitates the ice slurry mixture in at least an intermittent manner;

a heat load;

a first transporter for transporting the ice slurry mixture from the first storage device to the heat load; and

a second transporter for transporting the ice slurry mixture from the heat load to a second storage device, the second storage device connected to the first storage device.

8. The system of claim 7, where the freezing point depressant is propylene glycol.

9. The system of claim 7, where the freezing point depressant is about 10 - 50% of the ice slurry mixture.

10. The system of claim 7, where the ice is about 20 - 35% of the ice slurry mixture.

11. The system of claim 7, where the first or second transporter is a pump.

12. The system of claim 7, where the first or second transporter is a progressing cavity pump.

13. The system of claim 7, further comprising an ice slurry generator, the ice slurry generator connected to the first and second storage devices.

14. The system of claim 13, wherein the ice slurry mixture from the heat load is transported to the ice slurry generator for regenerating the ice slurry mixture.

15. A method, comprising the steps of:

providing an ice slurry mixture comprising about 5 - 60% ice, about 20 – 95% water, and about 0 – 50 % a freezing point depressant in a first storage device;

agitating the ice slurry mixture stored in the first storage device in at least an intermittent manner;

pumping the ice slurry mixture through a first conduit from the first storage device to a heat load, wherein at least some of the ice melts in the heat load;

pumping the ice slurry mixture containing the melted ice through a second conduit from the heat load to a second storage device.

16. The method of claim 16, where the pumping is with a progressing cavity pump.

17. The method of claim 16, further comprising generating the ice slurry mixture and introducing the ice slurry mixture to the first storage device

18. The method of claim 16, further comprising vibrating the ice slurry mixture contained in the conduit.

19. The method of claim 16, further comprising regenerating the ice slurry mixture containing the melted ice after the ice slurry mixture containing the melted ice is pumped from the heat load to the second storage device.