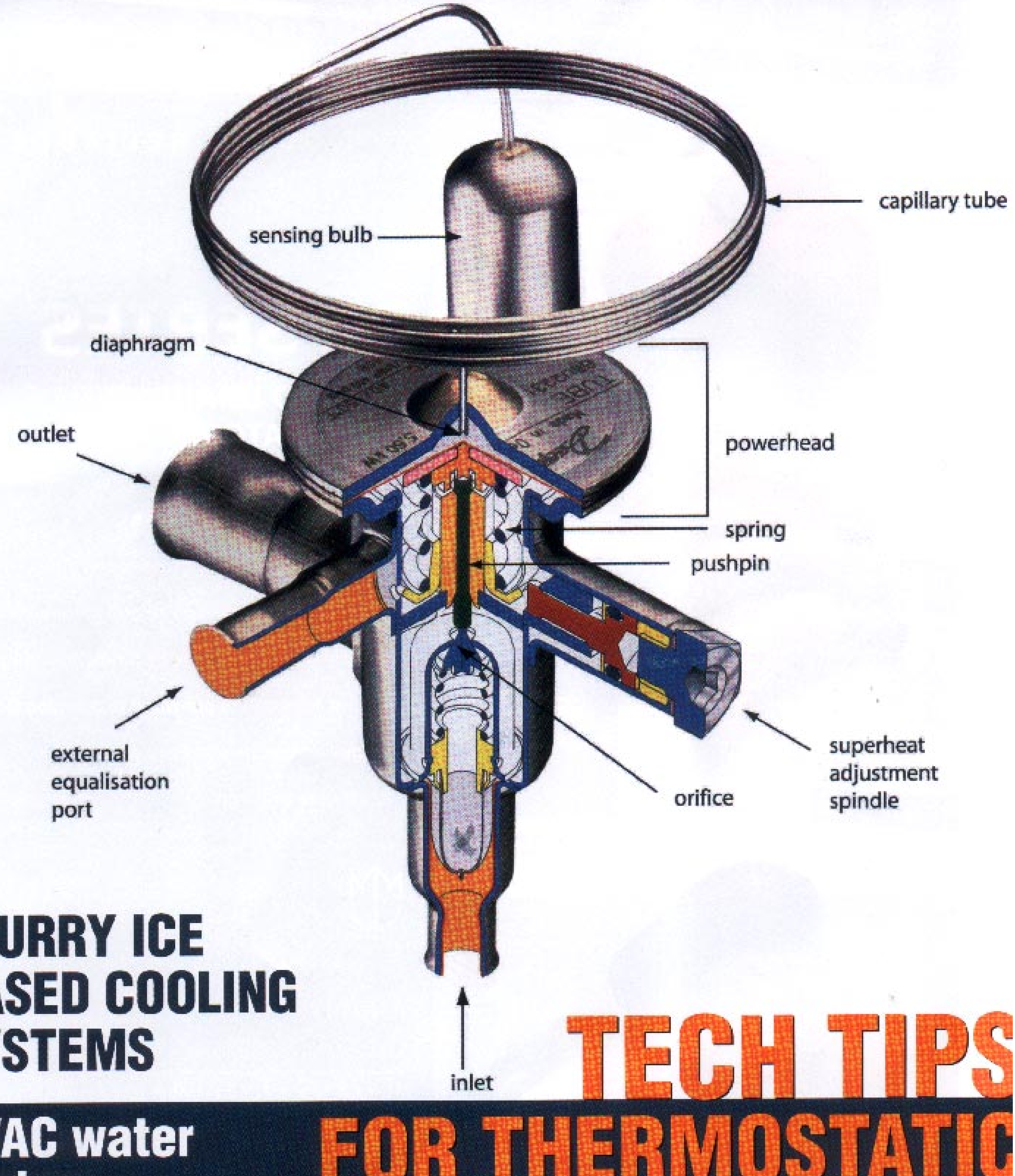
AIRAH JOURNAL

Australian Refrigeration Air Conditioning & Heating

September, 2001 Volume 55 No.9



SLURRY ICE BASED COOLING SYSTEMS

TECH TIPS FOR THERMOSTATIC EXPANSION VALVES

HVAC water system balancing

PRINT POST APPROVED PP255003/00490

Slurry ice based cooling systems

By Z. Ure, IIR Associate Member*

Abstract

Environmental concerns over the ozone depletion potential of some CFCs used today have prompted a search for alternative cooling technologies. A number of Dynamic and Static ice production methods have been developed for various applications.

Slurry ice technology is the latest addition to existing other ice production techniques and it has the potential to achieve considerable environmental as well as economic benefits for both central cooling systems and direct ice production for ever expanding ice applications.

Any conventional primary refrigerants can be used for slurry ice production. The cooling capacity of slurry ice can be four to six times higher than that of conventional chilled water, depending on the ice fraction. The nature of the Binary (Crystal) ice formation allows end users to pump the ice and there are many slurry ice-based cooling systems operating around the world.

Most air conditioning installations are based on ice storage, where the warm return water is used to melt the ice when required. Slurry ice is also circulated in close loop distribution systems directly for process and product chilling applications.

This paper investigates the advantages and disadvantages of using slurry ice cooling systems. The most important physical properties and behaviour of ice slurries are presented in a form that will help practising engineers and consultants to develop effective and efficient Slurry-Ice based cooling system designs

Introduction

It is vital to establish a balance between 'energy consumption' and ,environment protection' and therefore any change in refrigeration technology by means of introducing new refrigerants or by adopting new techniques must be carefully balanced to reduce the overall environmental impact.

Environmental concerns over the ozone depletion potential of some CFCs used today have prompted a search for alternative cooling technologies. Slurry ice technology is the latest addition to existing other ice production techniques and it has the potential to achieve considerable environmental as well as economic benefits for both central cooling systems and direct ice production for ever expanding ice applications.

Any conventional primary refrigerants can be used for slurry ice production. The cooling capacity of slurry ice can be four to six times higher than that of conventional chilled water, depending on the ice fraction. There are many slurry ice-based cooling systems operating around the world and most air conditioning installations are based on ice storage, where the warm return water is used to melt the ice. Slurry ice is also circulated in close loop distribution systems directly for process, district and product cooling applications.

Current ice production technologies

Ice production techniques can be divided into two main groups namely Dynamic and Static systems, Table 1, and the produced ice can be used either directly to chill the product such as fish, vegetables, meat, poultry etc. or indirectly as secondary coolant for the latent heat cooling effect such as ice storage TES systems for air conditioning and process cooling as a secondary cooling medium

STATIC ICE PRODUCTION	DYNAMIC ICE PRODUCTION
1 - Ice Builders	1 - Plate Harvester
2 - Ice Banks	2 - Tube Harvester
3 - Encapsulated Ice Modules	3 - Flake Ice Machines
(a) Balls	4 - Binary Ice Machines
(b) Flat Containers	

Table 1: Current Ice Production Technology

Slurry ice technology

Slurry-ICE is a suspension of a crystallised water-based ice solution and the icy slurry can be pumped, hence, it is also called 'BinaryICE" 'Liquid-ICE' or 'Pumpable-ICE' The handling characteristics, as well as the cooling capacities can be matched to suit any application by means of simply adjusting the percentage of ice concentration. Slurry-Ice comprises microscopic ice crystals giving a total surface area for heat exchanging that is very large in comparison with the conventional ice builder concept and therefore ice instantly melts to meet the varying cooling load [1-7]. This ensures steady and accurate system leaving temperature control.

Slurry ice handling

The important benefit of slurry ice is the 'increased cooling capacity' compared with a conventional chilled water systems. Hence, it offers reduced pipe sizes, smaller pumps and versatile tank arrangement [51. Slurry-ICE systems not only offer a significant installation cost reduction but also the operating costs can also be reduced due to lower pumping energy requirements. The behaviour of ice slurries and their variation with ice fraction are reviewed in this section.

Pipelines and transport. The use of slurry ice significantly decreases the volumetric flow requirements. Hence, reduction in pipe diameter and this benefit is illustrated in Figure 1.

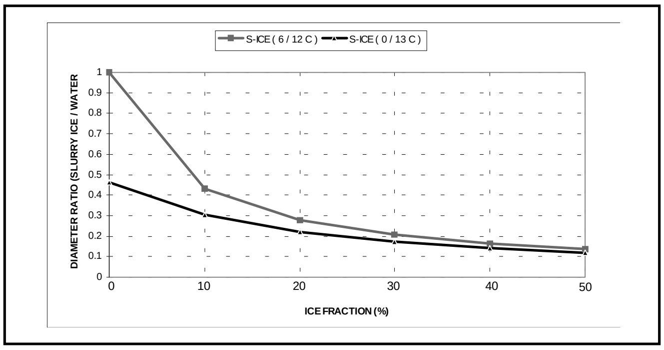


Figure 1: Pipeline diameter reduction comparison

The recommended parameters are shown in Figure 2. Ice fractions above 0.25 requires further design considerations and when transporting slurry ice, velocities should be maintained about 0.5 m/s.

Slurry Ice behaviour

Pipework. The density of slurry ice decreases marginally with an increase in ice fraction. However, this decrease in density is not enough to make an observable difference in the pressure drop measurements. At low velocities, the reduction of turbulence allows phase separation

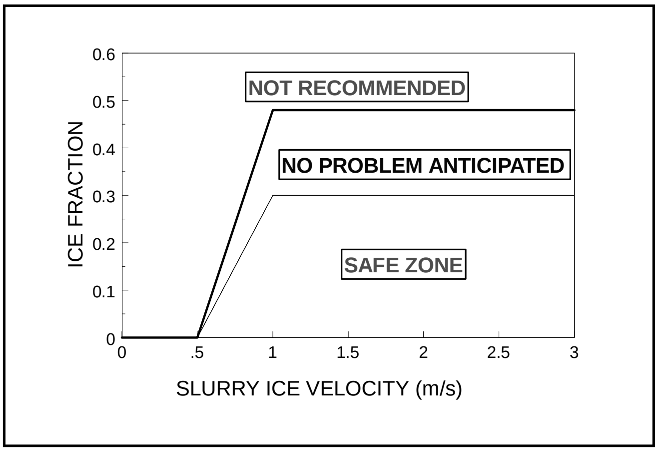


Figure 2: Slurry Ice velocity vs ice fraction study

to occur with ice floating to the top of the channel.

Heat exchangers. The overall heat transfer coefficient across a plate heat exchanger for melting the slurry ice indicates that an increasing ice fraction reduces the overall heat transfer coefficient. At the higher mass flow rates, a 17-20 % reduction in the heat transfer coefficient can be expected when the ice fraction was increased from 0 to 15 %. In particular, if an existing chilled water plate heat exchanger is converted for slurry ice operation for an identical duty the heat transfer across the plate heat exchanger reduces due to laminar rather than turbulent flow. Although the heat transfer coefficient is reduced, the latent heat of ice keeps the primary liquid at or near the freezing point for a significant fraction of the heat exchanger surfaces.

Pumps. There are no problems associated with pumping ice slurries up to 30 % ice fraction for small spherical ice particles (diameter 1 mm). At ice fractions above 0.40, slippage of the standard centrifugal pump impeller has been observed and therefore ice fractions above 0.40 may require positive displacement pumps. For a constant flow, the pump head decreases slightly for an increase in slurry ice. The existing sites and laboratory test results indicate pump head decreases by about 10 % from 0 to 0.25 ice fraction. Furthermore, it is vital to allow sufficient pump head capability to overcome the start-up operation which requires higher pump head due to lack of ice concentration i.e. reduced latent heat capacity within the solution.

Pipe fittings and valves. Existing experimental studies as well as the installed slurry ice loops have utilised a wide variety of standard commercial pipe fittings, including elbows, tees, couplings, bushings, and reducers. It is essential to select the line components for the temperature ranges at which the slurry is circulated and a line component which has an internal vertical riser such as regulation valve chamber which may be clogged during stagnant and reduced flow conditions, could cause extra pressure drop or even complete blockage.

Slurry Ice vessels. The pumpable characteristic of Slurry-Ice offers the designers the flexibility of shape, size and location for the ice storage tank [7]. Sectional rectangular and factory finished cylindrical tanks can be utilised to suit almost every application. If the design requires a concrete tank installation, a suitable tank pipe sealing system must he selected in order to handle the temperature variations. SlurryIce is lighter than the solution, hence, floats at the top of the tank. The major technical challenge is to keep the ice in the concentrator fluidised. This fluidisation can be accomplished by installing a mechanical mixer or alternatively, a passive technique by means of utilising warm return solution.

Slurry ice storage

Distributed Slurry Ice storage

Centrally produced Slurry-Ice is distributed to a number of tanks located at each location around the cooling network. The slurry-ice enters the tank where the lighter ice crystals are separated, usually by gravity. Ice-free water from the storage tank may be used by the environmental and process cooling system as shown in Figure 3.

The distributed storage tanks act like buffer vessels between the distribution system and the individual environmental and process cooling load requirements. Hence, it allows the distribution system to supply the average cooling load rather than the peak load. The refrigeration system generates slurry-ice continuously and this slurry-ice is pumped to the distributed storage tanks, which provide a buffer function.

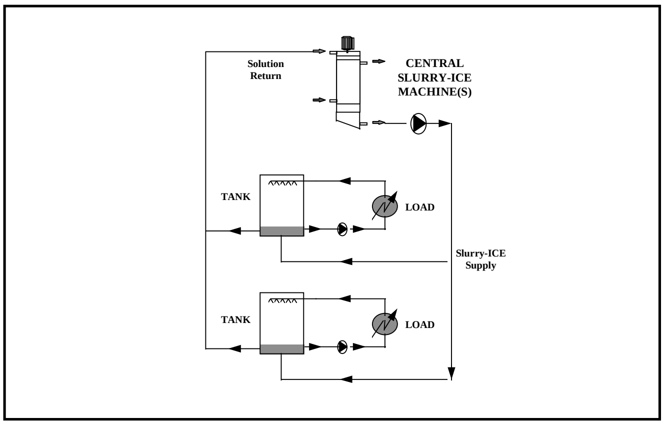


Figure 3: Distributed Slurry Ice storage

Central Slurry Ice storage

A large scale space cooling system may require a central storage tank(s) located near the central refrigeration plant as shown in Figure 4.

The storage vessel provides a buffer facility between the refrigeration system and the actual cooling demand.

This technique can be applied utilising two operating strategies. Slurry-Ice can be stored within the storage tank and utilised only to cool return water from the system for redistribution. Alternatively, SlurryIce can be stored and fluidised during peak hours for distribution. With both approaches, the volume of storage is reduced compared to chilled water storage. Distribution of Slurry-Ice during peak demand will additionally reduce the distribution network pipe diameters.

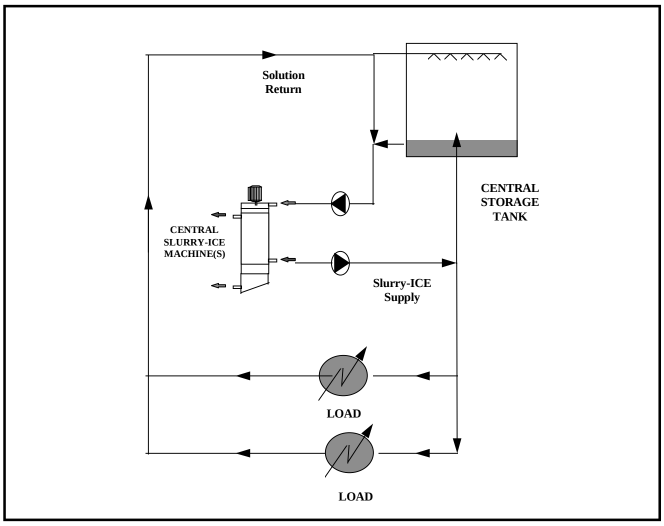


Figure 4: Central Slurry Ice storage

'Free Liquid' storage tank design

It is typically a large, non-pressurised tank and the storage tank is filled to approximately 80% with water. As the Slurry-Ice enters the tank, ice crystals stratify and float to the surface of the liquid. The ice gradually accumulates from the surface of the storage tank down to the bottom of the tank.

Top charging. The top charging configuration enhances the maximum ice fraction within the storage tank, minimising the size of this component. The weight of each successive layer of ice creates a compacting force as the ice pack tries to float on the surface. Continued charging forces the ice pack gradually downwards to the bottom of the tank. When the ice reaches the bottom of the tank, further ice production causes the liquid level to drop. The exposed ice is no longer partially supported by the water and hence ice is compressed further.

Bottom charging. Slurry-Ice is distributed across the bottom of the tank using a simple piping system. A bottom charging configuration relies upon the buoyancy of ice to push the ice pack up. Continued ice storage gradually causes the ice pack to reach the bottom of the storage tank. However, once the ice has reached the bottom, the distribution piping may be blocked, preventing further ice storage.

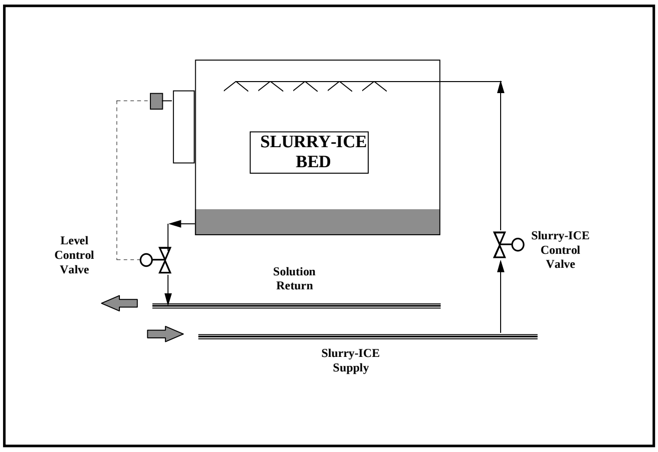


Figure 6: Free liquid Slurry Ice tank concept

'Flooded' storage tank design

Slurry-ice is pumped into the storage tank where the ice is filtered out so that the water leaving the tank is ice free. Since flooded storage tanks are pressurised, this concept is intended for use in a distributed storage system with multiple smaller tanks as shown in Figure 6.

The system has several advantages over conventional 'free liquid' designs. The increase in ice fraction in storage and the simplification of the controls are advantages.

The possibility of short circuiting the return water between inlet and outlet should be avoided. The 'flooded' storage tank concept requires an expansion tank to accommodate the increasing volume of fluid within the system as ice is produced. Conventional 'free liquid' storage concepts accommodate the expanding volume within the vapour space at the top of the tank.

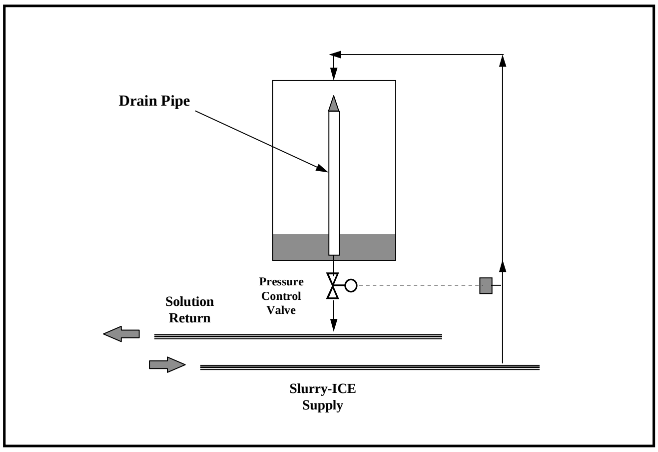


Figure 6: Flooded Slurry Ice storage tank concept

Slurry ice utilisation

The use of slurry-ice in large scale cooling systems can dramatically affect the distribution pipe size and pumping power requirement. However, using slurry-ice in existing processes designed for chilled water requires additional consideration.

Direct Slurry-Ice concept

The direct Slurry-Ice method involves sending the slurry-ice from the distribution pipe directly to the cooling coils as shown in Figure 7.

Experiments with plate heat exchangers and other operating experience indicates that the potential for ice blockages in this kind of equipment is very limited.

The increased energy carrying capacity of slurry-ice will substantially decrease the required flow rate to meet a given cooling load. Under these conditions, the internal heat transfer coefficient would be reduced due to lower velocity.

However, the temperature difference between the air and slurry will be greater than the original air to chilled water difference and therefore this increased LMTD is sufficient to offset the reduced heat transfer coefficient due to lower velocities described above.

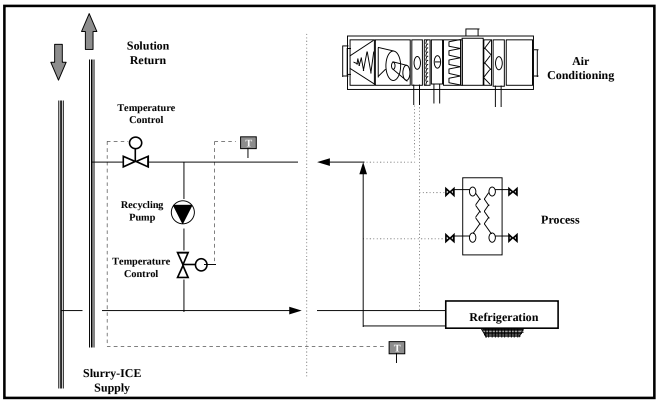


Figure 7: Direct Slurry Ice application

Distributed ice storage concept

One solution to overcome the potential problem associated with sending Slurry-Ice directly into conventional air-handling equipment is to implement distributed ice storage.

The local ice storage tank is then used to separate ice from the carrier water, ice free water can then be pumped from the storage tank and delivered to the air handling equipment, as illustrated in Fig. 8.

The flow rate of the cold water can be selected to match the design requirements of the existing chilled water equipment. Similarly, the design inlet temperature requirements can be matched by installing a mixing valve upstream of the circulation pump. One part of the warmed water leaving the heat exchanger is returned to the ice storage tank for re-chilling as the water passes through the ice pack. The other part is re-circulated with the cold water entering from the tank.

The distributed ice storage technique is a relatively simple way to integrate Slurry-Ice without affecting the operation of existing heat transfer equipment. Distributed ice storage also provides a simple means of load levelling

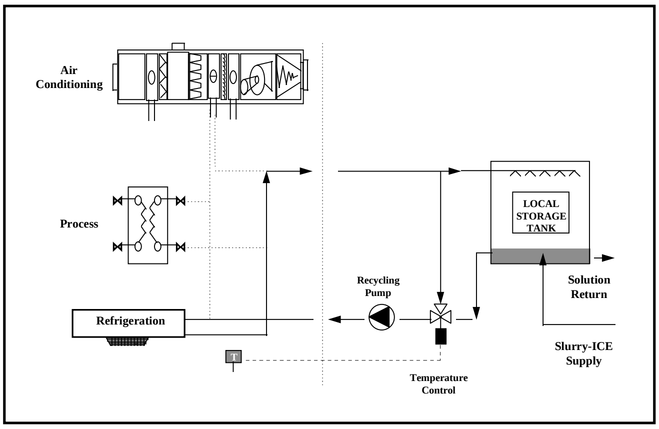


Figure 8: A typical distributed slurry ice application

Warm water recycled slurry ice concept

The warm water recycle concept was conceived to facilitate the use of ice slurries without affecting the design conditions of existing heat transfer equipment, while eliminating the need for local ice storage.

The basis of the idea is to transform a low flow, high cooling capacity Slurry-Ice into high flow, lower cooling capacity solution.

The method involves the use of a warm water recycle stream from the discharge of the heat exchanger as shown in Figure 9.

The warm water is mixed with the incoming Slurry-Ice to completely melt the ice and produce the desired flow rate and design inlet temperature

Slurry-ice supply: return heat exchanger concept

This technique involves the use of a warm water capacity by means of slurry-ice supply to warm water return heat exchanger.

The heat exchange rate is dictated by the load on the cooling coil. A simple isolating valve on the return line should ensure a sufficient amount of slurry-ice passes through the heat exchanger to satisfy the cooling load, which must be taken away by the return water.

Hence, the system can be considered a self balancing heat exchanger and in case of no duty requirement, the supply slurry-ice can be stopped.

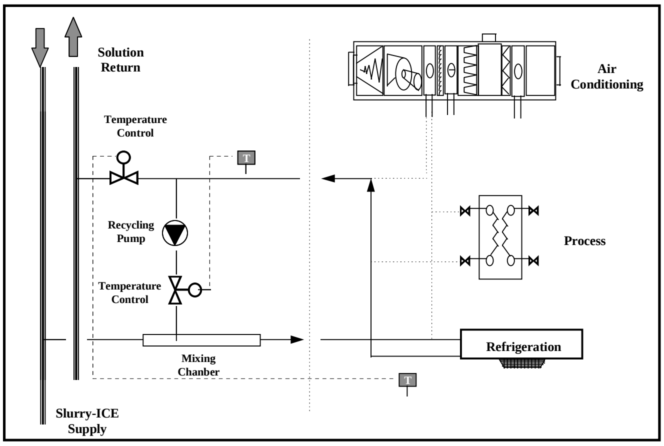


Figure 9: A typical warm water recycled slurry ice application

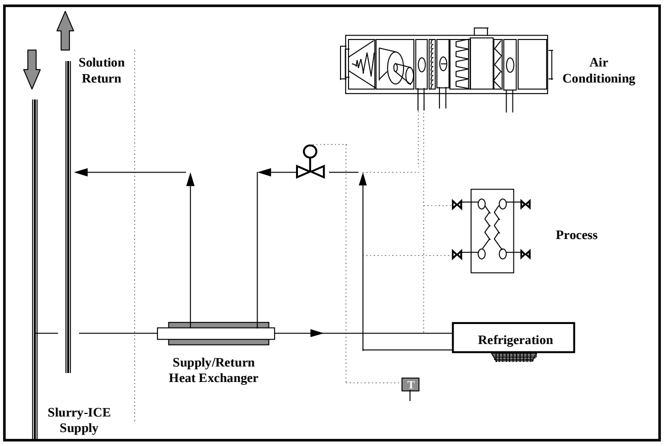


Figure 10: Slurry ice supply/return heat exchanger application

Conclusion

There are many slurry ice-based cooling systems operating around the world and a slurry ice cooling system can provide all the benefits offered by any other thermal energy technologies, such as:

• Reduced Equipment Size
• Capital Cost Saving
• Energy Cost Saving
• Energy Saving
• Improved System Operation
• Flexibility for the Future Capacities

Moreover, the pumpable characteristic over any other type of ice storage systems offers efficient compact equipment design, flexibility for the location of the storage tank(s) and the most economical capacity and duty balancing for any given application.

The storage tank can be placed under, beside, inside, or on top of a building and can be in any shape and size to match the building and architectural requirements. As it is microscopic ice crystals, ice melts quickly to meet varying cooling loads instantly.

The challenge for the designers is to explore the possibility of every alternative design solutions which can minimise the use of energy for the refrigeration system. A Slurry-ICE based cooling systems complete with a thermal energy storage may be the answer for some of the refrigeration applications for an environmentally friendly and economical alternative.

Nomenclature

CFC - ChloroFluoroCarbon   TES - Thermal Energy Storage

References

1. Ure Z., 1996, Alternative Technology, *RAC Journal, Partners in Europe Issue*, p. 20-22.
2. Beggs C., 1993, Developments in Ice Thermal Storage, *RAC Journal, Issue*, p. 24-28.
3. Paul J. Jahn E., 1997, Ice-Application of Liquid, Pumpable IceSlurries and Status of the Technology, *The Institute of Refrigeration Proceedings, UK*
4. Gladis P. S. et al, 1997, *EPRI International Conference on Sustainable Thermal Energy Storage*, Minneapolis, Minnesota, USA.
5. Malter L., 1996, Binary Ice-Generation and Applications of Pumpable Ice Slurries for Indirect Cooling, *Application for Natural Refrigerants Proceedings*, p. 527, Aarhus, Denmark
6. Snoek W. C., 1994, First North American Conference & Exhibition on Emerging Clean Air Technologies and Business Opportunities, Toronto.
7. Ure Z., 1996, Ice Production in the next Millennium, *Processing*

Z.Ure, IIR Associate Member, EPS Ltd , Unit 32, Mere View Ind. Est., Yaxley, Cambs., PE7 3HS, UK, email: z.ure@epsltd.co.uk, website: www.epsltd.co.uk.
This paper was reproduced as published in the IIR Procedings Series, "Refrigeration Science and Technology" - Sofia, Bulgaria, 1998 with permission from the International Institute of Refrigeration, 177, Boulevard Malesherbes, 75017 Paris - France, phone: +33 1 4227 3235, fax: +33 1 4763 1798, email: iifiir@iifiir.org, website: www.iifiir.org