

ICE SLURRY GENERATOR

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ABSTRACT

This paper will discuss applications of an ice slurry generator that has been in production since 1995. The unit is being used in standard ice thermal storage systems and is also being applied in some innovative projects where ice slurry is pumped to heat exchangers. The characteristics and advantages of ice slurry have been known for several years due to laboratory tests and analysis of past years. Since 1995, the advantages of ice slurry have been demonstrated in real commercial and industrial facilities utilizing the ice slurry generator discussed in this paper.

KEY WORDS

- Ice Slurry
- Ice Slurry Generator
- Thermal Storage
- TES Systems
- District Cooling
- One Pipe HVAC System
- Pumping Ice Slurry
- Ice Slurry Airhandlers

1.0 INTRODUCTION

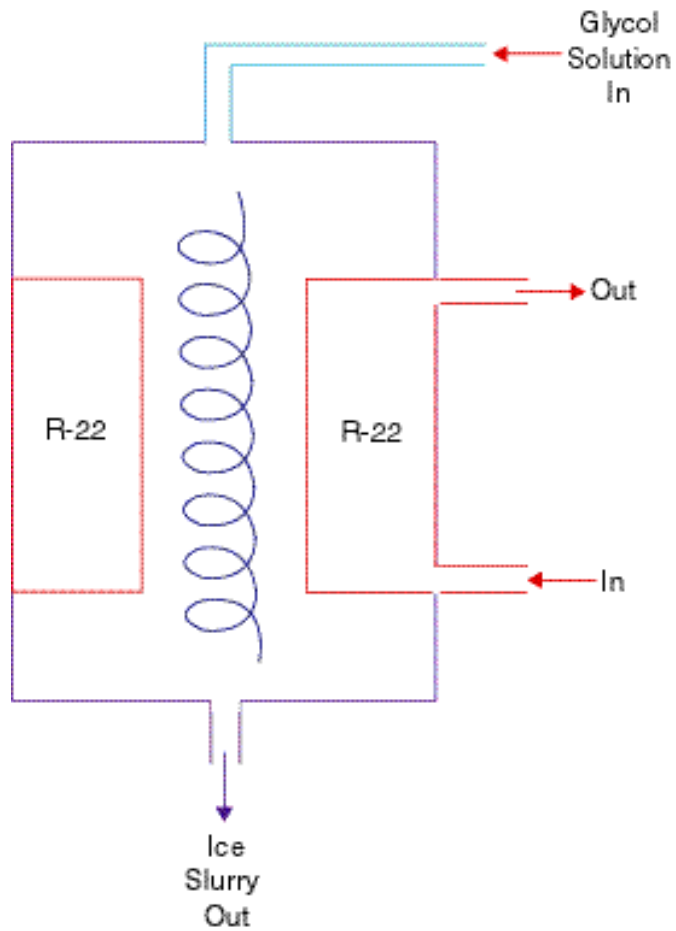
The characteristics and advantages of ice slurry have been reviewed and studied for several years going back to at least 1975. Several companies have tested ice slurry generator designs with various success. Pumping of ice slurry has been studied by several universities and laboratories, both in the United States and abroad. Some of this information will be presented at the ASHRAE Meeting in Toronto, Canada in June of 1998. The Department of Energy has sponsored studies including a study in 1990 dealing with ice slurry in district cooling systems and other applications. The ice slurry generator described in this paper was developed in the early 1990s and put into production in 1995. Since 1995, about 40 projects have used this ice slurry generator ranging from 3 tons to over 4,000 tons of ice slurry capacity and many projects are in design or planning stages. This paper will review three typical projects and discuss the basic characteristics of present and future developments of ice slurry systems.

2.0 HOW IT WORKS

The ice slurry generator is a shell-and-tube heat exchanger which accepts 7% glycol solution into the top of the generator, agitates the solution as it drops through the tubes and ice slurry exits the generator. See Figure 1.

The ice slurry generating capacity of a unit is a function of the numbers of tubes; i.e., a 50-ton model has about two times the number of tubes of a 25-ton model. The ice generating capacity is also a function of the compressor/condenser capacity which provides the 17°F refrigerant. See Figure 1.

Figure 1



The ice slurry exiting a generator can drop directly into a storage tank or the slurry can be pumped to one or more tanks located remotely from the ice generator. This paper will also discuss three projects that are pumping ice slurry to air handlers and heat exchangers.

Figure 2

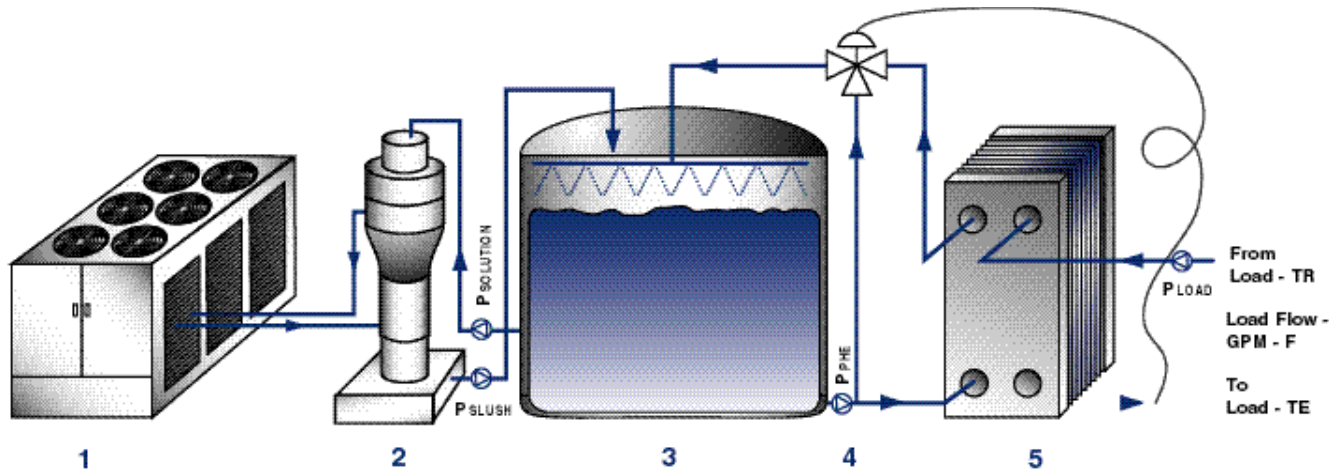
Figure 2 shows ice slurry falling into a tank. In this case, the slurry is generated by a 50-ton machine.



3.0 SYSTEM

Figure 3

Figure 3 illustrates the components of an Ice Slurry Generator System consisting of:



- (1) Compressor/condenser supplies refrigerant to the ice slurry generator (evaporator)
- (2) Ice slurry generator (evaporator)
- (3) Slurry ice storage tank
- (4) Load control pump and valves
- (5) Plate heat exchanger

As will be discussed in this paper, the ice slurry generator system can be configured in several different configurations to accomplish the goals of a specific project. This figure illustrates the basic components of an ice slurry system.

4.0 AVAILABLE SIZES

Presently, the ice slurry generator is produced in standard production sizes from 3 to 520 tons.

Figure 4

Figure 4 is a 25-ton unit. The unit base is about 3.84 feet by 4.7 feet and the height is 7.25 feet.

Figure 5, below, is a 500-ton unit. The unit base is about 15.75 feet by 6.7 feet and the height is 7.04 feet.



Figure 5



5.0 APPLICATIONS

Following are three applications from 3 tons to over 4,000 tons of ice generating capacity.

5.1 3-Ton System

An example of a small ice slurry project is illustrated by Figures 6 and 7.

Figure 6



Figure 6 shows a mini-brewery and restaurant.

Figure 7

Figure 7 shows the 3-ton ice slurry generator and storage tank which is used to cool the wort from about 210°F down to 46°F. A small 3-ton ice slurry generator can produce $(3 \text{ tons} \times 24 \text{ hrs.} \times 7 \text{ days}) = 504 \text{ ton-hours}$ of ice per week which has applications in process cooling and for any short duration load including churches and schools. These units have been installed in multiples for projects needing 6 tons or 9 tons of ice slurry capacity.



5.2 100-Ton System

Figure 8



Another typical ice slurry project is illustrated by this office building located in Sioux City, Iowa.

Figure 9



Figure 9 shows one of two 50-ton screw compressor machines which drive two 50-ton ice slurry machines.

Figure 10

Figure 10 shows one of two 50-ton ice slurry generators. The system was installed in 1996.



5.3 4,000-Ton System

Figure 11



Figure 11 shows the building which has an ice slurry generating system capable of more than 4,000 tons of ice slurry production. The facility consists of an ten (10) story Merchandise Mart and a thirty-nine (39) story office tower. The total area of the facility is approximately 2.8 million square feet.

Figure 12



Figure 12 shows one of the 500-ton ice slurry generators which consists of four (4) ice generators. The units set on top of the storage tank and drop ice slurry directly into the tank. A total of eight 500-ton units are in the project, for a total of 32 ice generators.

Figure 13



Figure 13 shows the inside of a 36,000 ton-hour storage tank. The spray nozzles are shown along the top of the tank. The tank will hold about 0.9 million gallons of glycol solution. The Korean engineering firm that designed the system reports that:

■ Conventional Chiller Operating Cost	=	\$818,788
■ Slurry Ice System Operating Cost	=	\$294,852
■ Annual Savings	=	\$523,936
■ The incentive was \$482,536, giving a 1.1 year payback.		

Figure 14

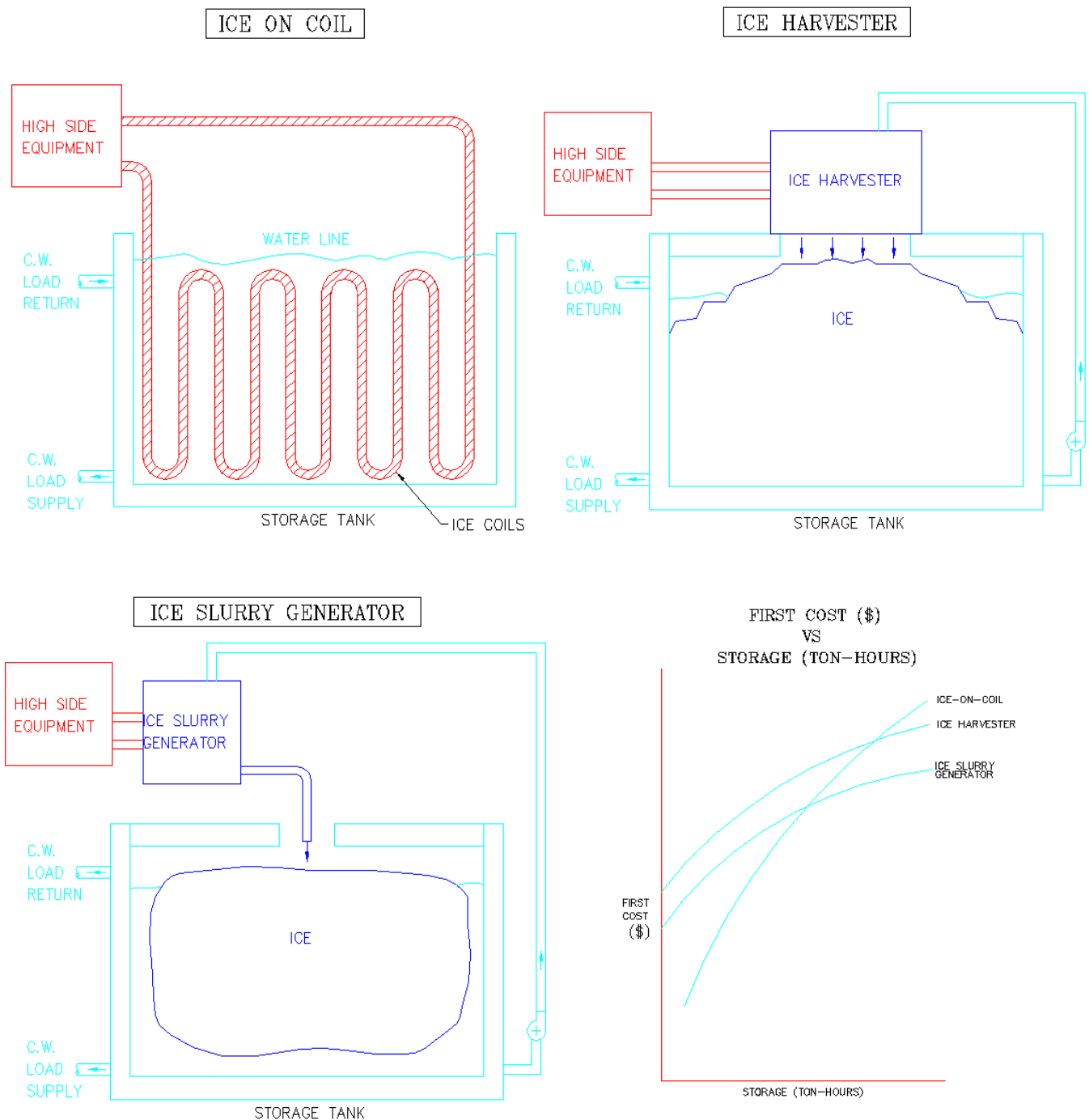


Figure 14 shows the inside of the tank, looking up into four (4) ice slurry generators. Each generator has a capacity of about 125 tons.

6.0 SYSTEM COST COMPARISON

Selecting the type of ice system for a given project is a rather complex issue; however, the basic first cost comparison can be summarized as follows. Assuming the cost of the high side equipment is about the same for ice-on-coil, ice harvester, and ice slurry; then a cost comparison is essentially a question of how many ton-hours of storage the project requires. These figures illustrate the comparative first cost characteristics of each system. The ice-on-coil system first cost is driven by how many coils, or storage ton-hours is required. The ice harvester and ice slurry systems have a first cost for the ice generator and the cost of the tank is relatively minor. Therefore, as the storage ton-hours for a given size ice generator increases, then the first-cost becomes less for the ice harvester and ice slurry systems. The individual characteristics of each project must be carefully analyzed to determine the most cost effective system.

Figure 15

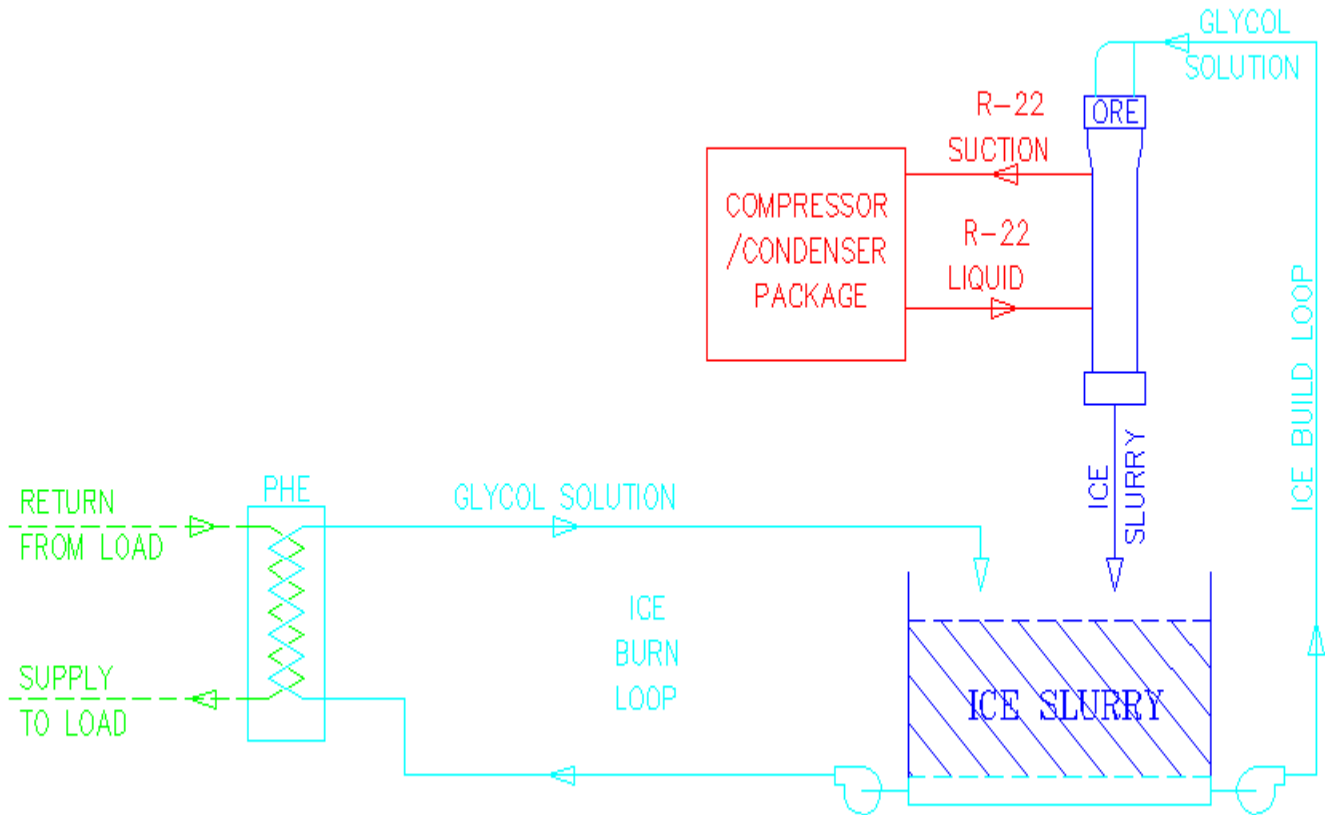


7.0 ICE SLURRY SYSTEM SCHEMATICS

The ice slurry generator (ISG) has been installed in several different configurations as illustrated below.

7.1 Process or HVAC

Figure 16

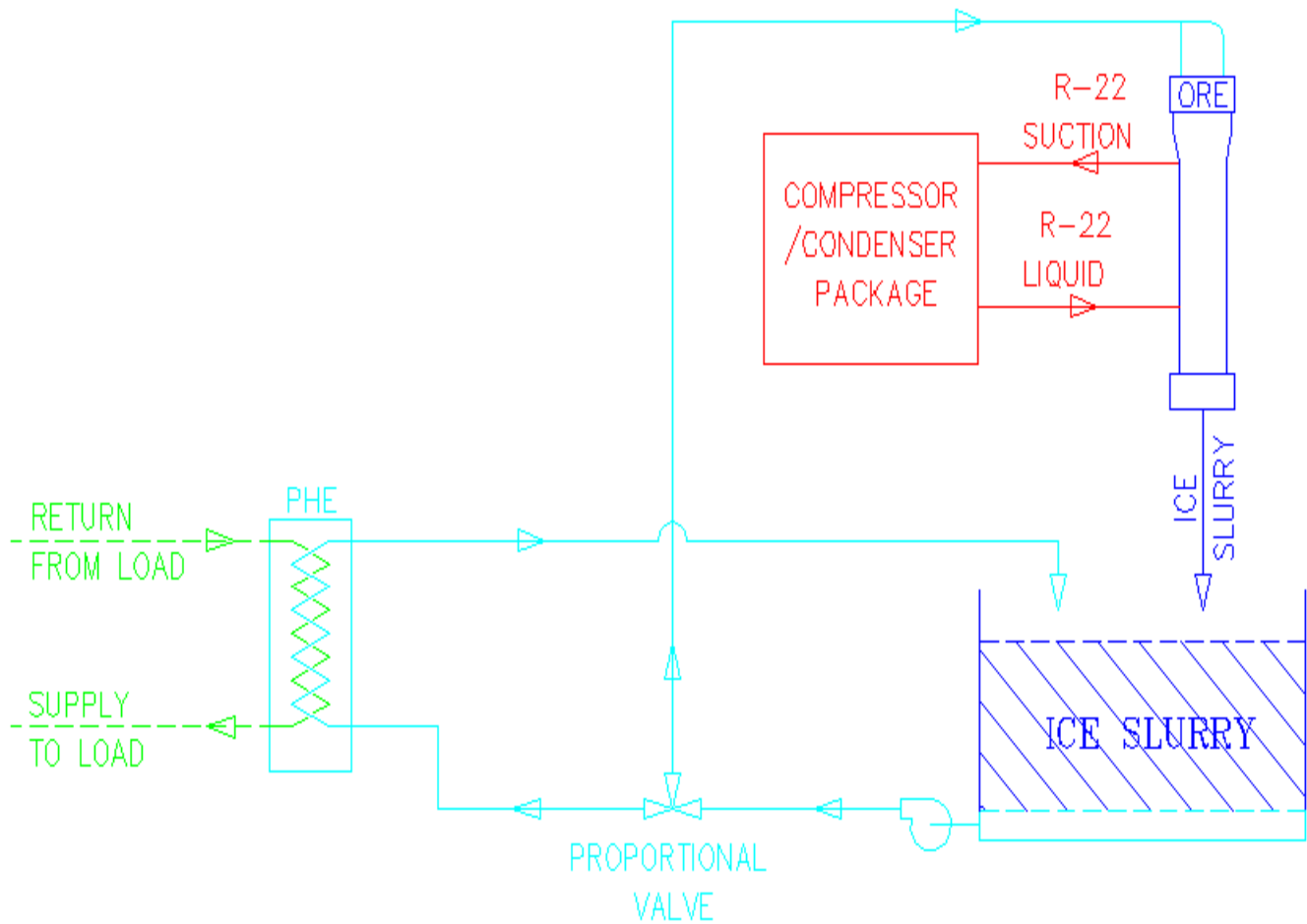


This figure illustrates a typical process cooling or HVAC application. Typically, for process cooling the ice generator runs anytime the tank is not full of ice slurry. For HVAC applications, ice is built and stored at night to be used the following day for cooling.

7.2 Build, Burn or Chill

This schematic illustrates an application where a proportional valve controls the mode of operation. The application basically consists of making ice at night, then burning the ice during the day. However, the control valve could provide flow through the plate heat exchanger to meet loads at night. Also, during the day, some flow could be directed to the ice generator which would make ice or act as a chiller depending on the temperature of the glycol solution entering the ice generator. Variations of this schematic can meet specific project requirements.

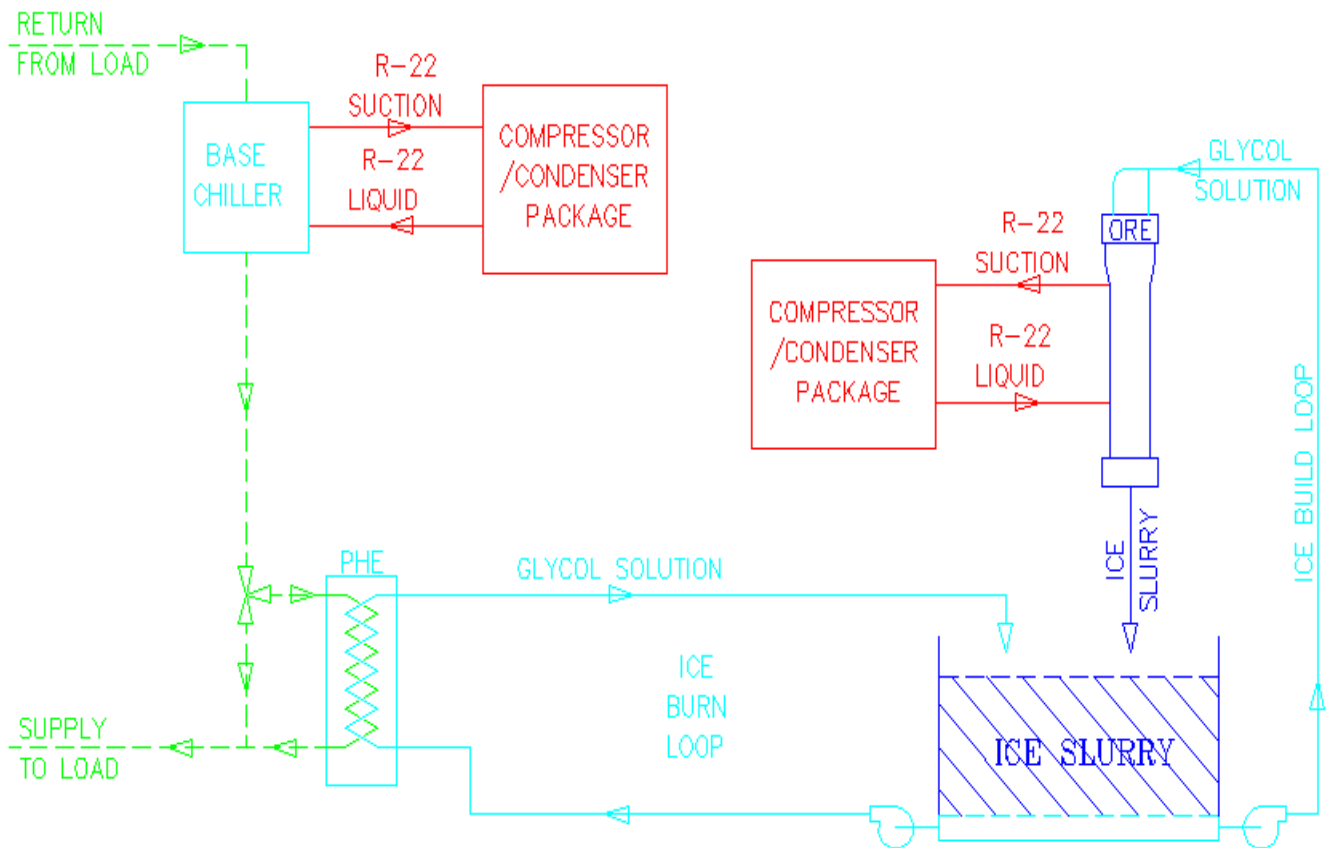
Figure 17



7.3 Base Chiller

Figure 18

This schematic illustrates the use of a base chiller. Typically, the supply water from the base chiller is diverted around the plate heat exchanger (PHE) at night and the ice slurry generator is building and storing ice. The following day, the supply water from the base chiller is provided to the PHE at a temperature above the desired supply temperature, and the ice solution provides the additional drop in temperature required by the load. Note that the efficiency of the base chiller improves as the supply temperature increases. The ice generator can run continuously (load leveling) or only during off-peak (load shifting).

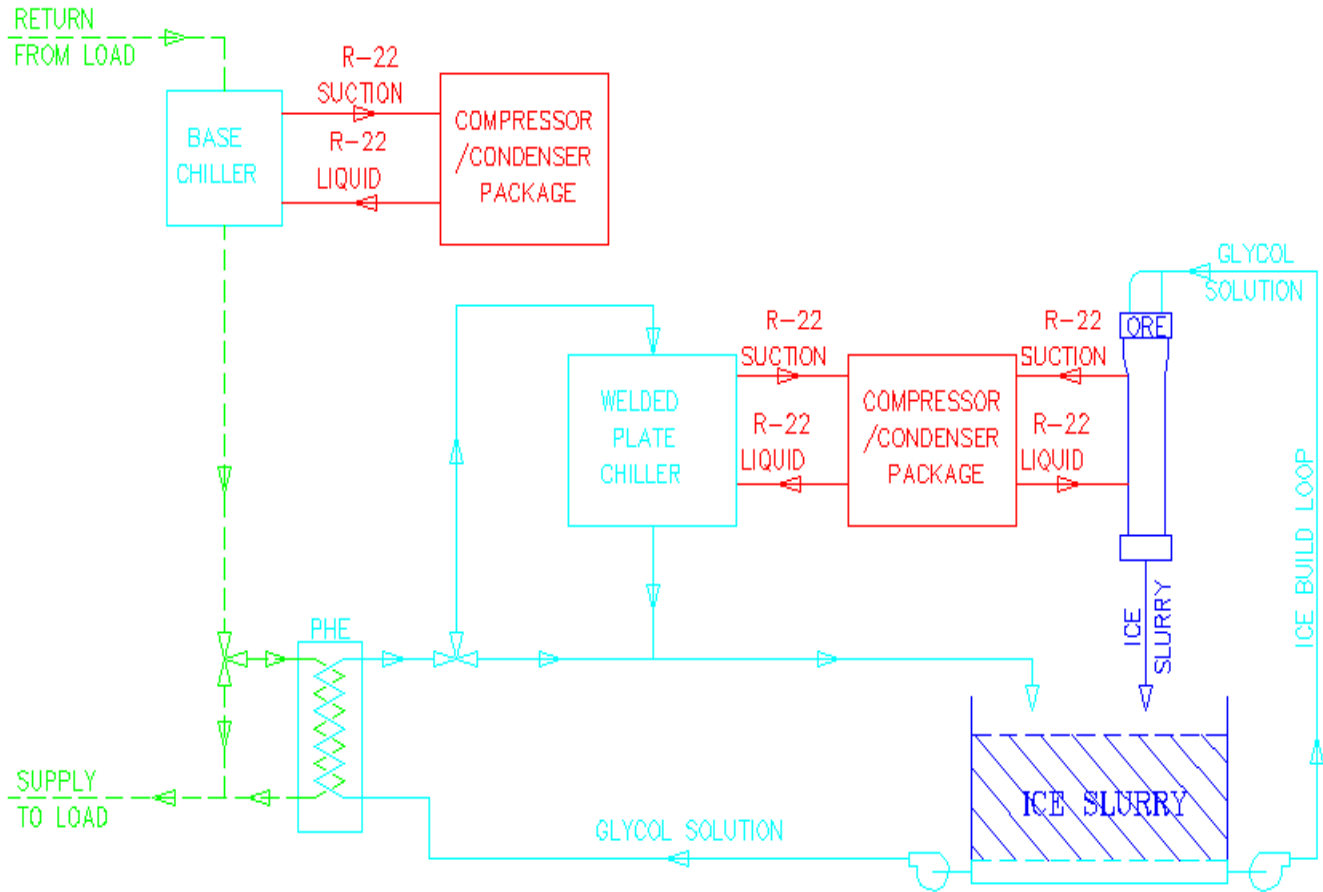


7.4 Welded Plate Chiller

Figure 19 illustrates a base chiller and also a welded plate chiller off of the ice generator high side package. Several modes of operation are possible. The base chiller can meet night loads while ice is being made and stored. The following day the stored ice can be used to provide low temperature supply water to the load with only the base chiller running or both could run under high load conditions. The base chiller would operate at high supply temperatures and, therefore, at high efficiency.

The welded plate chiller provides for using the ice slurry compressor/condenser package in the most efficient manner and also maximizing running time (i.e., making ice or acting as a chiller).

Figure 19

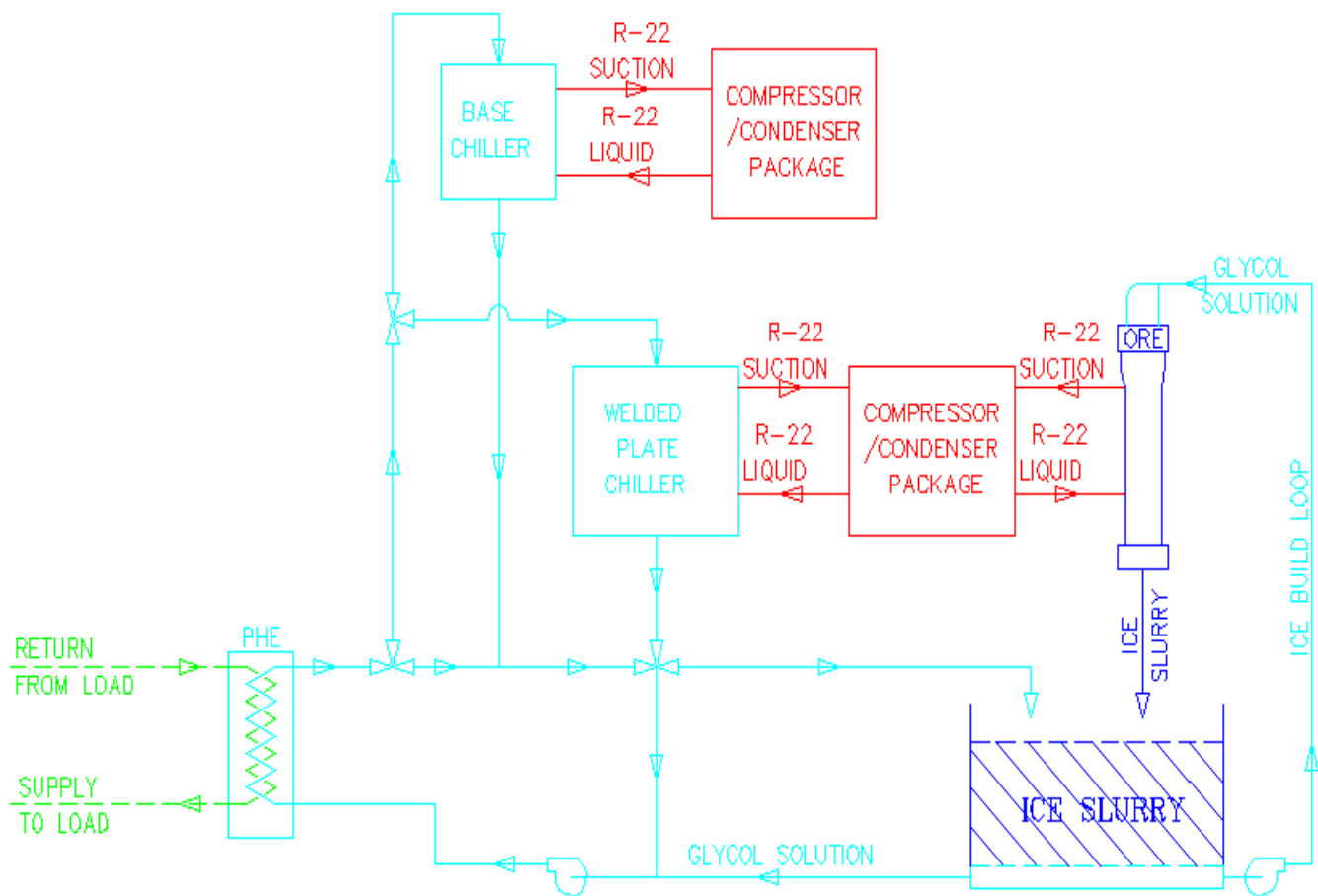


7.5 Base Chiller Inside Glycol Loop

This schematic illustrates a system that provides for efficient operation of both the base chiller and the welded plate chiller. The ice storage tank is used to drop the supply water temperature of the chillers to the desired value; therefore, the chillers operate more efficiently and at greater capacity. The PHE could be at the central plant or at each building in a district cooling system.

This configuration results in very high efficiency of operation for the chillers and may show both a first cost savings, and operating cost savings, when compared to a conventional chiller system.

Figure 20



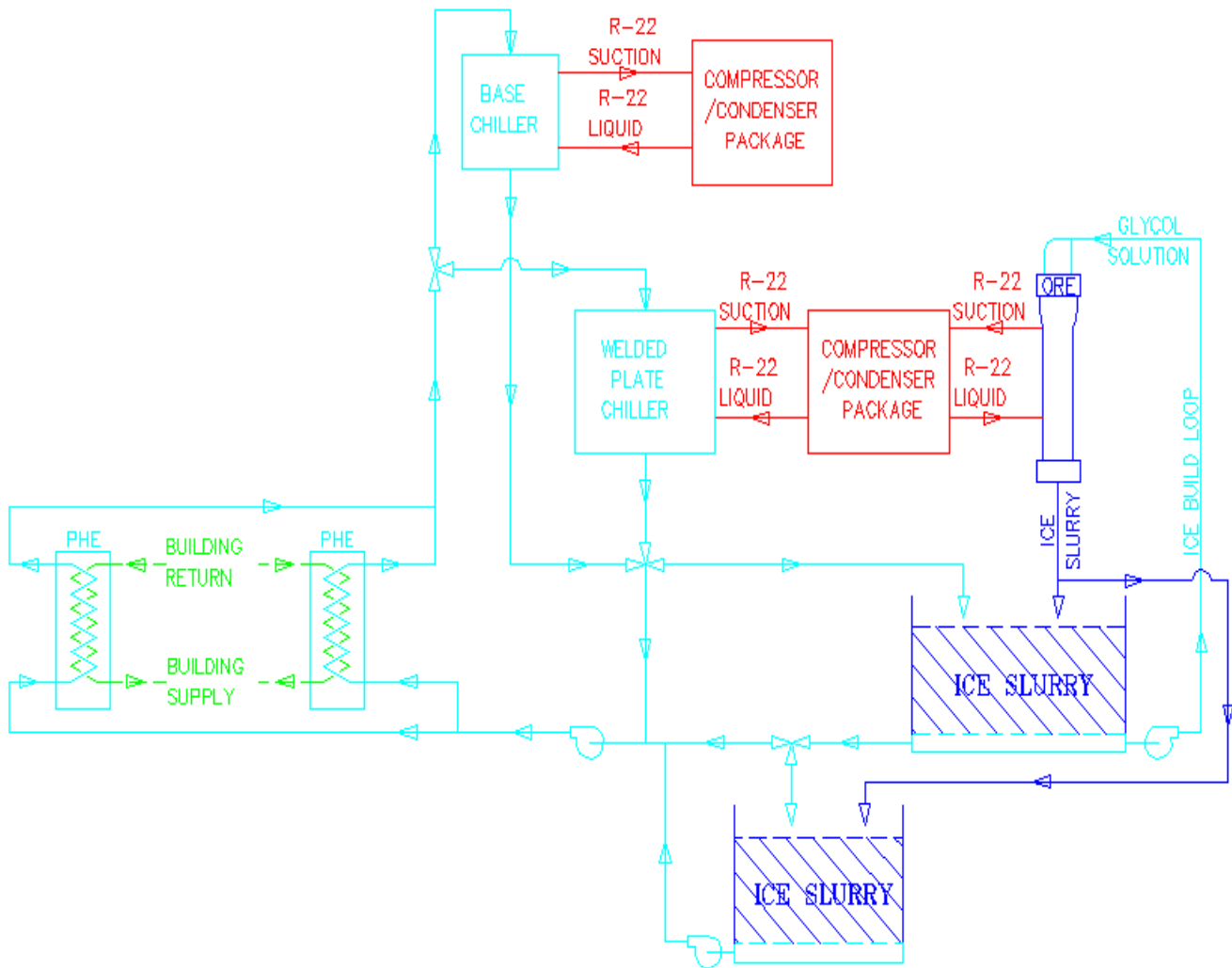
7.6 District Cooling

Figure 21 illustrates the flexibility of the ice slurry system. Multiple storage tanks are possible by the generator dropping ice into a tank and also pumping ice to a separate tank. Pulling ice slurry from one tank and storing in another tank downstream is also considered to be feasible but not shown in this figure.

For a district cooling system, glycol pumped directly from the tank to the various buildings can provide increased efficiency and minimum temperature chill water delivered to the building heat exchangers.

The system also suggests the possibility of delivering ice slurry to the building heat exchangers which offers opportunities not yet fully understood; however the following three projects to be discussed are pumping ice slurry.

Figure 21



7.7 Ice Slurry HVAC

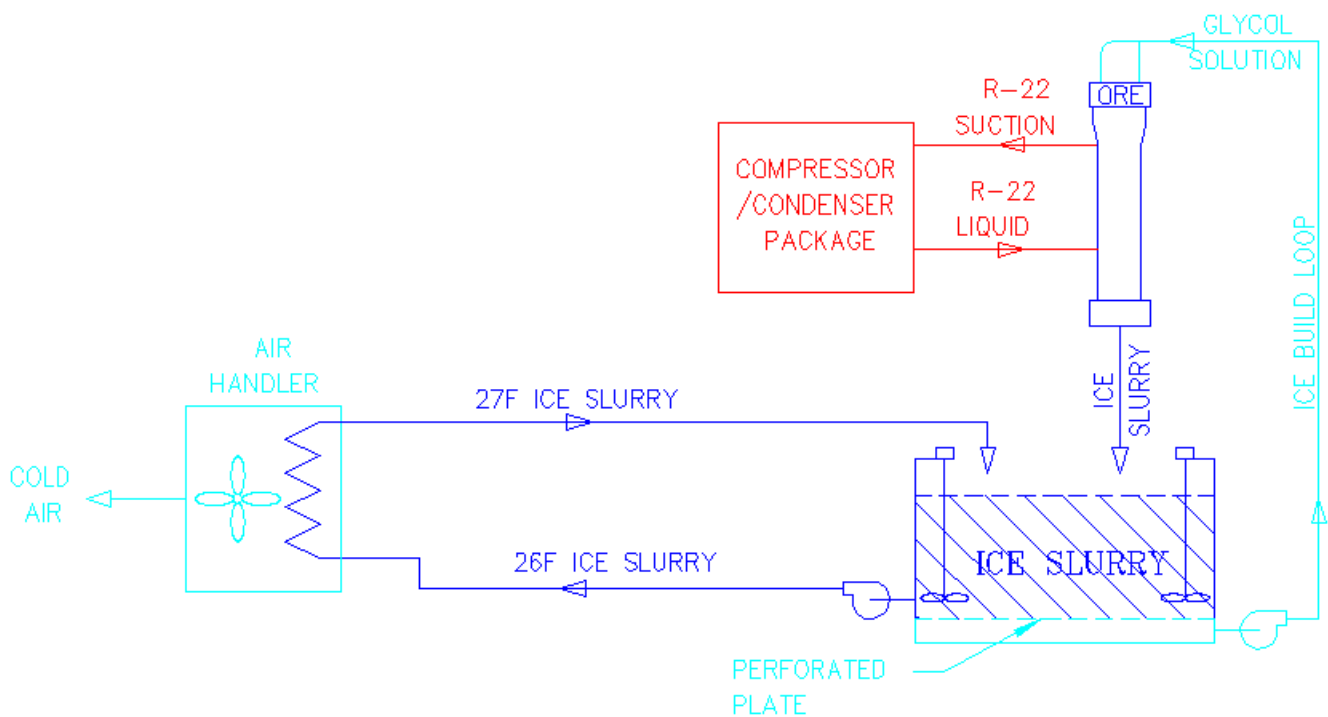
This project cools a building within a shopping strip as shown in the photograph below.

Figure 22



Figure 23

The schematic below illustrates the system which keeps the ice slurry agitated with motor driven paddle wheels in the tank.



7.8 Ice Slurry HVAC and Refrigeration Process

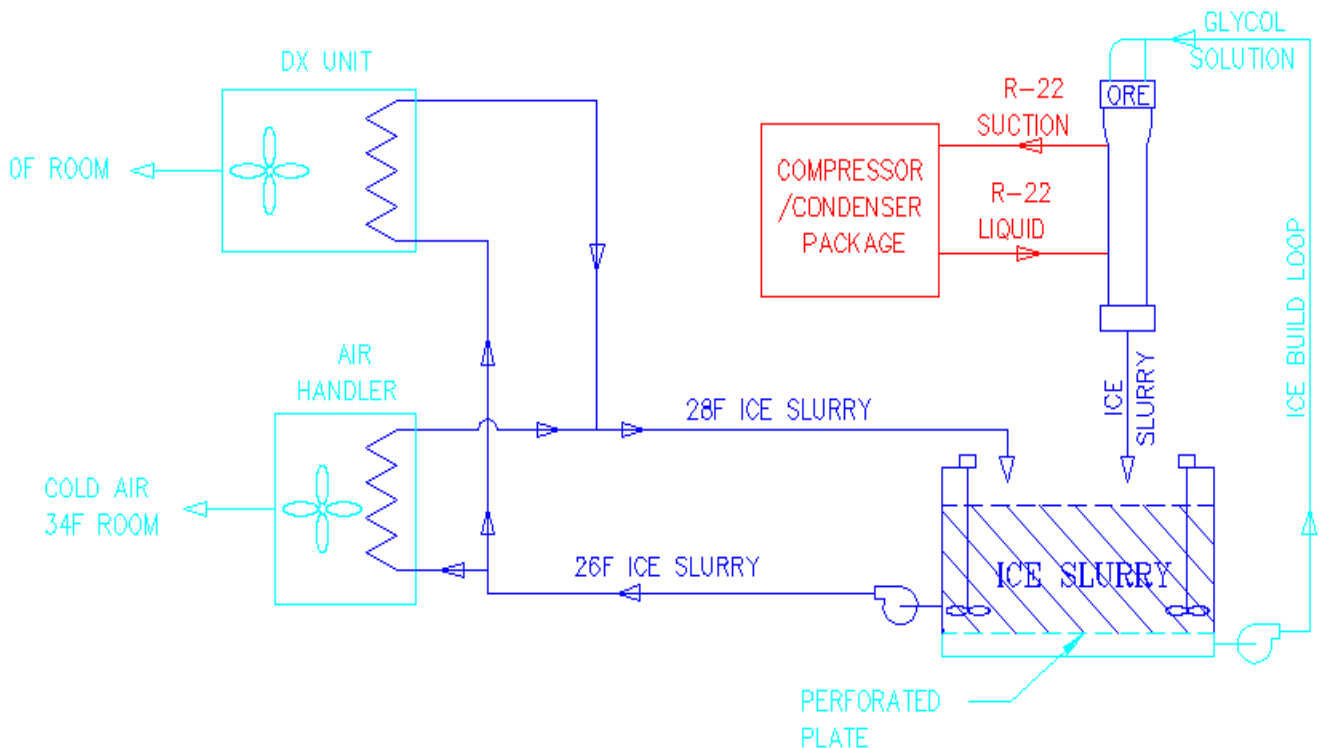
Ice slurry provides both HVAC and DX heat rejection in this process plant. The tank with agitation motors on top is shown below.

Figure 24



Figure 25

This schematic illustrates how the ice slurry is utilized. An air handler is used to control rooms to 34°F and DX heat is rejected to the ice slurry in a 0°F room.



7.9 Ice Slurry One Pipe System

A one-pipe ice slurry pumping system was installed in a 20-story office building in 1996 and has accomplished the objectives of:

- Reduced pumping power
- Low humidity control in specific rooms
- Minimized piping first cost
- Reduced electric demand chillers
- Reduced HVAC equipment first cost
- Increased building usage space

The success of this very innovative use of ice slurry suggests the potential for miniaturization of HVAC systems.

8.0 CONCLUSIONS

Ice Slurry Systems have been sold into the following countries:

Australia	Israel	Taiwan
China	Japan	Thailand
Germany	Korea	United Kingdom
Holland	Mexico	U.S.A.
Ireland	Switzerland	West Indies

The “ice slurry generator” is a production unit that is being utilized in standard thermal storage applications around the world. Of equal importance is that the unit is being utilized in some innovative projects which pump ice slurry to heat exchangers.

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