ICE SLURRY THERMAL ENERGY STORAGE FOR CHEESE PROCESS COOLING

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Abstract

Many industrial processes require a large load to be cooled in a relatively short period. These loads often utilize supply chilled-water temperatures in the range of 34°F (1.1°C) to 36°F (2.2°C). The low water temperatures can be supplied from conventional "on-demand" chillers, such as falling film water chillers or shell-and-tube chillers using a brine solution. The low water temperatures can also be supplied from thermal energy storage (TES) systems, such as static ice builders, or dynamic ice systems, such as an ice harvester or slurry ice maker.

The benefits of using a TES system in industrial processes, versus an "on-demand" chiller, include smaller refrigeration equipment, "reserve" cooling capacity, lower electrical capacity requirements, and lower energy costs.

This paper outlines a unique type of dynamic slurry ice system applied to a cheese processing plant. Dynamic ice systems separate the manufacture of ice from the storage of ice. These systems are capable of satisfying very large loads of short duration by rapidly melting stored ice. Rapid melting of ice is achievable with dynamic ice-type TES systems because the warm water returning from the load comes in direct contact with the ice in storage.

Introduction

This paper presents a specialized application for a cheese plant in Hanford, California. Raw milk is purchased from local dairies and is processed into cheddar cheese. The long-term objective of the plant is to produce 200,000 pounds (90,720 kg) of cheddar cheese daily. The short-term processing requirements of the plant are about 100,000 pounds (43,360 kg) per day. Throughout the plant there are several processes that require product cooling. Some of these processes are cooled over several hours throughout a day, while other processes require rapid, nearly instantaneous product cooling.

A variety of chilling methods are typically considered for food processing plants. One characteristic common to all of the chilling types considered is the ability to provide 34°F (1.1°C) to 35°F (1.6°C) water to the load(s). The low water temperature is necessary to achieve 38°F (3.3°C) process product temperature. The primary factors considered in determining which type of chilling system will be used include load diversity, electrical rate structure, equipment first cost, installation cost, and operating cost and system expandability.

"On demand" chillers include flat plate (baudelot-type) falling film chiller, and shell-and-tube chillers. These chillers operate simultaneously with the load, as cooling is demanded, at the capacity corresponding to the load. When applied to a fluctuating load profile, the chiller must be capable of responding to the changing load by rapidly modulating the capacity of the compressor. If a peak process load occurs during the electric supplier's on-peak period, the plant owner will realize a significant charge in the demand portion of the monthly electric bill. Most electric chillers are rated at 44°F (6.6°C) supply water temperature and are derated by as much as 30% when operating at lower supply water temperatures.

Ice-based TES systems have been used regularly in processing applications. Ice TES systems operate independently of the process cooling loads to build and store ice. An ice system can be sized to operate in a load-shifting or a load-leveling strategy. In a load-shifting strategy, the ice maker runs at night, during off-peak times, thereby avoiding on-peak electrical demand and energy charges. In a load-leveling strategy, the ice maker is allowed to operate 24 hours a day, independent of the electric rate structure.

Ice builders are referred to as static-type ice systems. Ice builders consist of plastic, steel, or copper coils submerged in a tank of water. A low-temperature brine or a refrigerant is circulated through the coils to extract heat from the water surrounding the coil. To satisfy the process cooling loads, the ice is melted typically in one of two ways. Either the water is circulated through the tank to the load and back to the tank, melting the ice farthest from the coil (external melt), or brine is circulated through the coil to the load and back to the coil, melting the ice nearest the coil (internal melt). Agitation of the water can be achieved by bubbling air through the water in the tank, enabling a consistent 36°F (2.2°C) supply water temperature.

Ice harvester and slurry ice makers are referred to as dynamic ice systems. Ice harvesters are chillers that have the ability to produce ice fragments. The evaporators are either flat plates or tubes and are mounted over an ice/water storage tank. In the ice-making mode, water is circulated from the storage tank over the evaporator surface where ice is formed. The ice is periodically released into the tank using a defrost cycle.

Slurry ice makers are chillers that have the ability to produce ice, but rather than fragmented ice, the ice produced has the consistency of slush or snow. A slurry ice maker is unique in that the ice that is formed does not adhere to any heat transfer surface; no defrost cycle is required to release the ice from an evaporator and there is no insulating effect of ice on a coil.

The benefits of using a TES system in industrial processes, versus an "on-demand" chiller, include smaller refrigeration equipment, "reserve" cooling capacity, lower electrical capacity requirements, and lower energy costs.

Cooling Load Analysis

The cooling loads in the cheese plat include: (1) cheese starter cooling, (2) whey protein concentrate, (3) finish tables, and (4) ultra filtration (UF) vessels. The magnitude of these loads, based on 200,000 pounds (90,720 kg) of daily cheese production, is identified below:

Cheese Starter

The processing of cheese starter is performed in various steps. Four of these steps require cooling of the cheese starter. Initially the cheese starter is cooled from 185°F (85°C) to 78°F (25.5°C) and held for 12 hours. An exothermic reaction gradually increases the temperature of the cheese starter. The starter is periodically cooled to maintain the product within a desired 83°F (28.3°C) to 78°F (25.5°C) temperature range. The product is then cooled to 42°F (5.5°C) and held at a desired temperature range of 45°F (7.2°C) to 40°F (4.4°C), which also requires periodic cooling to maintain this desired temperature range. The cooling loads of each of the four steps are as identified below:

Step 1: Starter is cooled in one hour, from 185°F (85°C) to 78°F (25.5°C). The heat absorbed is 904,150 Btu/h, or 75.3 ton-hours.

Step 2: Starter is cooled for one hour, four times in a 12-hour period, from 83°F (28.3°C) to 78°F (25.5°C). The heat absorbed is 42,250 Btu/h, or 14.1 ton-hours.

Step 3: Starter is cooled again in one hour from 80°F (26.6°C) to 42°F (5.5°C). The heat absorbed is 321,000 Btu/h, or 26.1 ton-hours.

Step 4: Starter is cooled for one hour, six times in a 24-hour period, from 45°F (7.2°C) to 40°F (4.4°C). The heat absorbed is 42,250 Btu/h, or 21.1 ton-hours.

Whey Protein Concentrate

The processing of whey protein concentrate is performed in various steps. Two of these steps require cooling of the whey protein concentrate. The concentrate is gradually cooled from 78°F (25.5°C) to 38°F (3.3°C). After being heated to 122°F (50°C), the concentrate is cooled to 38°F (3.3°C). The cooling loads of each of the two steps are as shown below:

Step 1: The whey protein concentrate is cooled for 17 hours from 78°F (25.5°C) to 38°F (3.3°C). The heat absorbed is 110,000 Btu/h, or 155.8 ton-hours.

Step 2: The whey protein concentrate is cooled for three hours from 122°F (50°C) to 38°F (3.3°C). The heat absorbed is 231,000 Btu/h, or 57.8 ton-hours.

Finish Tables

The product on the finish tables is cooled from 85°F (29.4°C) to 60°F (15.5°C) 25 times in a 19-hour period. The heat absorbed is 137,171 Btu/h, or 217.2 ton-hours.

Ultra-Filtration Vessels

The ultra-filtration vessels realize a 22,000 Btu/h load 20 times a day, or 36.7 ton-hours.

Miscellaneous Loads

Additional miscellaneous loads exist as recirculating line losses, thermal storage tank losses, process tank losses, heat exchanger losses, and pump heat. These losses are estimated at 60,000 Btu/h, or 120 ton-hours per day.

The above loads are presented in Table 1. The summation of loads over a design day equals 724 ton-hours. This load, when leveled over 24 hours, can be satisfied by a TES system having a capacity of 30.2 tons (724 ÷ 24 = 30.2) (see Figure 1). An ice storage tank having an internal volume capable of storing 93.7 ton-hours (approximately 2,800 gallons) is required.

Equipment Selection

The cheese plant owner took into account several factors in analyzing which cooling system to use in the plant. A water chiller was initially considered by the owner to satisfy the cooling loads. Such a chiller would require a capacity greater than 110 tons to satisfy the largest single hourly load. Since the peak occurs for only one hour during a design day, the chiller would operate unloaded more than 95% of the time, resulting in very inefficient chiller operation. If the daily peak load occurred within the electric utility's peak period, substantial demand charges would be assessed. The electrical service for a chiller would be larger and more costly than for a TES system. If the chiller failed or required maintenance, there would be no source of cooling during the "down" time.

Because the load profile has significant diversity throughout a design day, various types of ice TES systems were considered to "level" the load and to reduce electrical costs. It was realized by the owner that TES systems also offer redundancy. If the compressor was shut down for maintenance, the stored ice would allow for continued cooling of product.

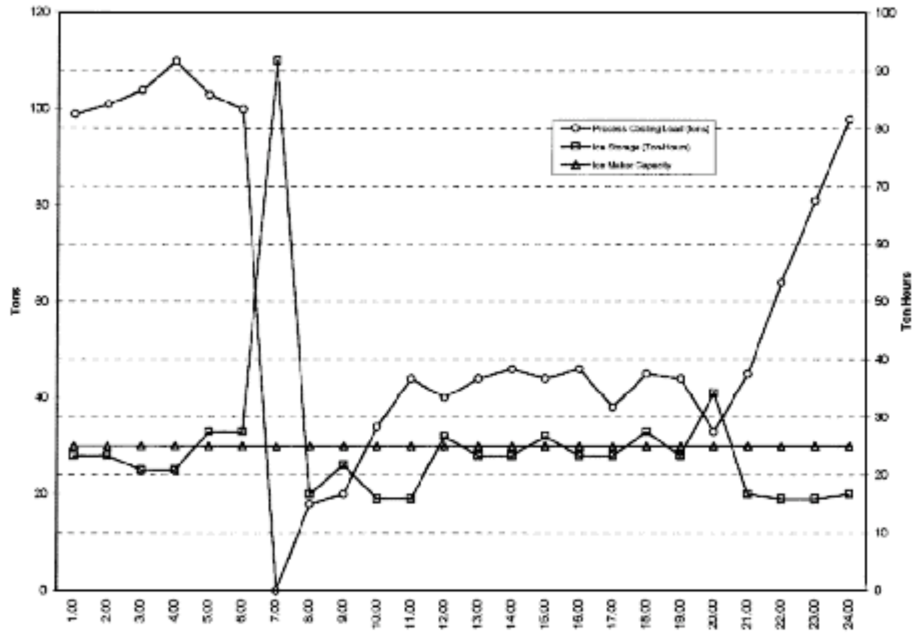
Although the owner recognized that ice builders are relatively inexpensive in first cost, other factors weighed against the decision to select this system. These factors included the reduction in efficiency of the compressor as the ice thickness on the tubes increased. This is due to the insulating effect of the ice on the heat transfer coil. Also of concern was the potential for premature replacement of the coil due to corrosion of the steel tube submerged in water and the limited service accessibility of the coil for maintenance.

An ice harvester was also considered but was not selected for several reasons. The ice harvester requires a defrost cycle. This cycle can consume as much as 15% of the compressor capacity, reducing the gross efficiency of the system. Ice harvester evaporators have to be mounted on top of the ice storage tank, and thus the storage tank must be designed and constructed to support the weight of the evaporator in a frozen-up failure mode. This system was also cost prohibitive relative to the other systems considered.

A slurry ice maker was considered for the cheese plant application. The slurry ice systems consists of a slurry ice generator and a condensing unit. The slurry ice system is mated to an ice storage tank (see Figure 2). The tank contains an initial solution of 7% propylene glycol and water, which is converted to a slurry as it flows through the generator. The slurry exits the generator at a 5% to 10% concentration and can be pumped into the tank. Because the slurry ice can be pumped, the slurry generator can be located next to the storage tank at grade level. The generator does not have to be mounted on top of the tank, allowing for tanks to be constructed of low-cost polyethylene.

The cheese plant owner elected to apply the slurry ice system because of its high ice-making efficiency, the expandability of the system to meet long-term loads, the layout flexibility of the components, and the reasonable cost relative to the other systems. Since the plant was not going to be operating at full capacity during the first year of operation, the owner selected a system that provides less than 30.2 tons of capacity yet is expandable to meet the full future load of the plant. The system applied has an ice-making capacity of 22 tons at 95°F (35°C) design ambient temperature. A 6,500-gallon (24,605-L) polyethylene tank was installed that is capable of storing 217 ton-hours of latent capacity. The excess tank volume includes 130% redundant storage capacity, [(217 - 93.7)/93.7 x 100], providing reserve cooling in case of a system shutdown or maintenance.

Figure 1 - Capacity vs. Load



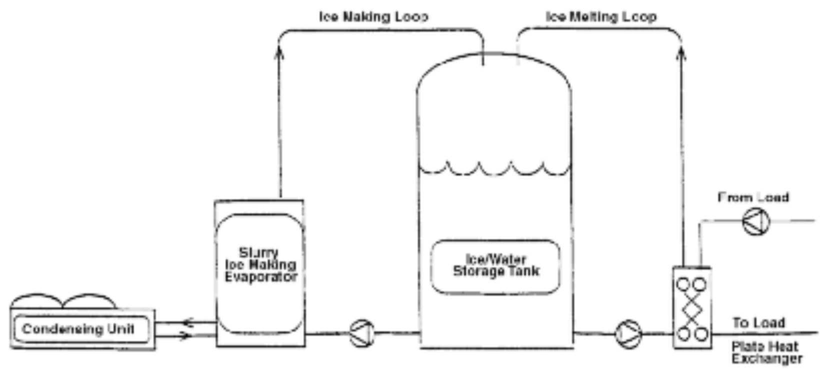
Operation

The operation of the system incorporates two distinct cooling loops: an ice-making loop and an ice-melting loop. The separate loops allow the various loads to be satisfied independently of the operation of the ice maker.

The ice-making loop consists of a slurry ice-making evaporator, an air-cooled condensing unit, and an insulated polyethylene storage tank. The tank contains an initial fill, to the 70% level, of water and propylene glycol (7% by volume), which has a freeze point of 28.5°F (-1.9°C). During ice-making operation, the water is pumped from the bottom of the storage tank, through the slurry ice-making evaporator, and returns to the tank in the form of slurry ice. As the water in the tank is converted to ice slurry, the glycol becomes more concentrated. When the tank is nearly full of ice, the corresponding freeze point of the more concentrated slurry is approximately 26.0°F (-3.3°C). The ice-making system's controller initiates a shut-down sequence when this reduced tank temperature is realized.

The ice-melting loop consists of the ice/water storage tank and various heat exchangers to satisfy the loads. When the loads call for cooling, water is pumped from the bottom of the tank through the load heat exchanger and back to the tank. The water provided from the tank is initially at about 27°F (-2.7°C) but can rise as high as 34°F (1.1°C) when the tank is nearly depleted of ice. The warm water returning from the load to the tank is distributed through a full coverage spray nozzle in the top of the tank. This nozzle evenly distributes the warm water onto the ice. Since ice floats, it is always at the top of the tank, sacrificially absorbing the heat of the load. Because there is no heat transfer barrier between the heat of the load returning to the tank and the ice, the ice can readily absorb large loads of short duration.

Figure 2 - Slurry Ice System Schematic



Conclusion

Thermal energy storage using ice as the storage medium has regularly been applied in a variety of industrial applications. Some of these applications include dairies, wineries, food processing plants, beverage plants, printing processes, and manufacturing plants. The benefits of using a TES system in industrial processes include smaller refrigeration equipment, "reserve" cooling capacity, lower electrical capacity requirements, and lower energy costs.

Dynamic ice TES systems, which separate the manufacture of ice from the storage of ice, are capable of satisfying very large loads of short duration by rapidly melting stored ice. Rapid melting of ice is achievable with dynamic ice-type TES systems because the warm water returning from the load comes in direct contact with the ice in storage and because the ice fragments/crystals have a very high surface area-to-volume ratio.

The slurry ice-type system does not require a defrost cycle (resulting in high operating efficiencies). This type of system does not experience the insulating effect of ice on a heat exchanger since the ice does not "grow" on a heat transfer surface. Slurry ice systems have a lower design weight, provide greater equipment flexibility since the slurry ice is pumpable, and provide lower water temperatures to the load compared to other TES systems.

A cheese plant is one type of process or industrial application that incorporates the use of a dynamic slurry ice-making TES system to satisfy its loads.

The future potential of slurry ice makers includes the pumping of ice slurry through a district cooling piping network. Since the thermal capacity of a slurry solution is substantially greater than the thermal capacity of circulated water, the transport pipe sizes and pumping requirements would be greatly reduced.

References

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