Ice pond refrigeration system for agricultural cold storage

submitted by the Japanese National Team

The Hokkaido National Agricultural Experimentation Station has developed an ice pond refrigeration system which uses cold outdoor air in winter to manufacture natural ice using a layered ice-making process. The latent heat of fusion in the ice is then used during the warm season for agricultural cold storage using a water-air heat exchanger. The system creates a finely-tuned low-temperature/high-humidity environment, suitable for long-term potato storage. Energy consumption and running costs are lower than for conventional refrigeration systems.

Introduction

Unlike in Europe and America, irradiation is not commonly used in Japan to inhibit sprouting in potatoes. To prevent this, and to keep them fresh until the beginning of summer, they are stored at low temperatures (around 2°C) using electric refriger-ators. However, this is uneconomical due to the high costs involved. In Hokkaido, the major potato-producing area in Japan, cost-efficient cold storage technologies have been sought to enable the supply of high quality potatoes all year round.

The banning of ozone-depleting materials such as chlorofluorocarbons (CFCs) has also made it necessary to develop economical and safe CFC-free refrigeration technology. The eastern and central areas of Hokkaido have mean air temperatures between -6°C and -12°C in January and February, making it energy efficient to store the energy in cold winter outdoor air and reuse it for cold storage in warmer months.

This led the Hokkaido National Agricultural Experimentation Station, and the Ministry of Agriculture, Forestry and Fisheries, to develop an ice pond refrigeration system (IPS). The system produces large quantities of natural ice over the winter months, then, during the warmer months, the latent heat of melting ice is used to provide cool air in vegetable storehouses. The developers have demonstrated long-term potato storage at Sarabetsu, in central Hokkaido. Testing was carried out in collaboration with agricultural cooperatives and other local associations.

Ice pond refrigeration system

The demonstration system consists of an ice pond, a storehouse and a machine room (see Figure 1).

The volume of the ice pond is 1,200 m^3, dimensions are 18 m x 26 m, depth is 3.5 m, and it is lined with a waterproof sheet of polyvinyl chloride. A roof frame is set up to

Figure 1: Schematic of the ice pond refrigeration system, showing the ice-making subsystem (top) and cooling subsystem (bottom).

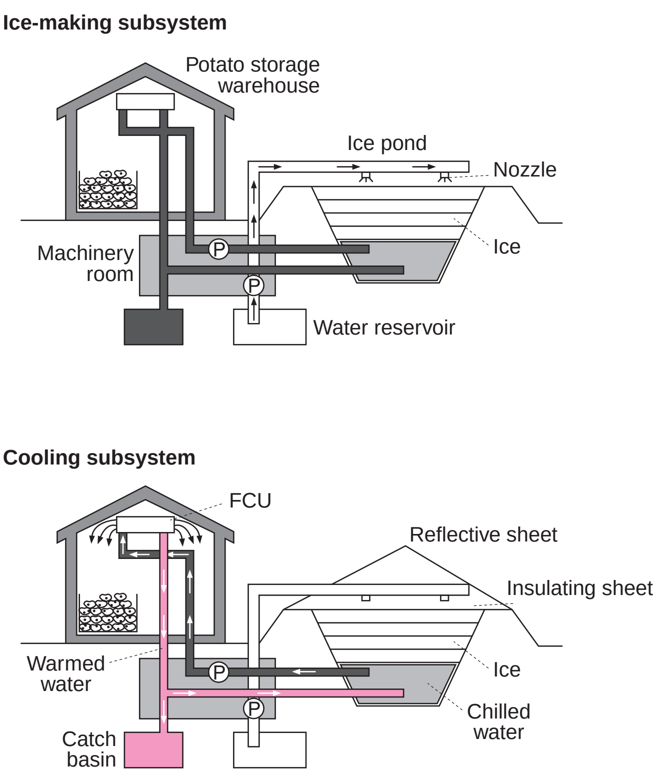
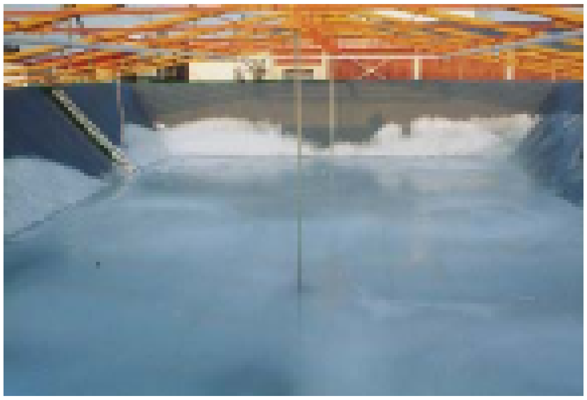


Photo 1: The ice pond in operation.



enable a tent to be pitched over the pond. A water pipeline with sprinkler nozzles is arranged over the pond to make ice in winter (Photo 1). The storehouse can accommodate 200 tons of potatoes. Ten 0.14 kW fan coil units (FCUs), each containing a finned-tube heat exchanger, are suspended from the ceiling (Photo 2). The machine room houses four 2.2 kW pumps, one of which sprays water over the pond, while the other three circulate chilled water between the pond and the FCUs. A water tank is constructed beneath the room.

The ice-making method and automatic control system

A layered ice-making method is used. Six nozzles, each capable of sprinkling water in a circle (radius 4 m), spray water on the frozen pond surface to a depth of 0.3 - 0.5 mm, at a time when the ambient air is cold enough to freeze. Thin layers of ice accumulate, and the process is repeated automatically as each layer freezes.

The most important characteristic of this system is the fully automated water sprinkling operation, which must be repeated frequently throughout the winter. A value known as degree hours of frost is calculated by multiplying the outdoor temperature below freezing by time. At higher wind speeds the water film freezes faster, even if the temperature is constant. Thus, the temperature-wind integrated number (TWIN) was conceived as a new freezing index. This value is obtained by multiplying the degree hours of frost by coefficients indicating the wind effect. These coefficients are determined from an empirical formula as a function of wind speed, e.g. 1 at a wind speed of 0 and increasing as wind speeds increase.

Water sprinkling is controlled by a computer program, and involves the following steps:

1. a set volume of water is sprayed over the ice pond;
2. the TWIN value required to freeze the water film is calculated;
3. the TWIN value is calculated every minute after each sprinkling, using outdoor air temperatures and wind speeds;
4. assuming that the water film is completely frozen when the TWIN value exceeds the set value, steps 1 to 3 are repeated.

The automatic control shortens the intervals between sprinkling as air temperatures drop and/or wind speeds rise, thereby producing homogeneous ice (Photo 2). A Japanese patent has already been granted for this control system.

Insulation and preservation of ice

Once ice-making is completed, after around 100 days in an average winter, the pond surface is covered by a 12 mm thick insulation sheet. To further minimise melting, a tent (a white tarpaulin sheet with a reflective aluminium coating on the outer surface) is pitched on the frame over the pond (Photo 3).

Cooling the storehouse

Potatoes harvested in autumn are kept in the storehouse. The indoor temperature is gradually lowered by introducing outdoor air and kept at 2-3°C throughout the winter. In spring, when outdoor temperatures rise, the storehouse uses the ice pond refrigeration system.

In cooling mode, circulating pumps deliver water cooled by ice in the pond to the FCUs in the storehouse, which is cooled by cold air from the FCUs. Computer control of the FCUs keeps the temperature at a constant 2°C.

Some water must periodically be discharged from the pond as the ice melts, as the build-up of water causes

Photo 2: Interior of the potato storehouse.

the temperature of circulating chilled water to rise.

Performance

Ice-making
Approximately 920 m^3 of 2.9 m thick ice, and 970 m^3 of 3.1 m thick ice were manufactured respectively during the first two years of operation (January to March 1992, and November 1992 to March 1993). Both winters were warmer than usual. Around 1,200 m^3 of 4 m thick ice could be manufactured under normal winter conditions.

The ice in the pond inevitably contained a lot of air bubbles. Measurements made on ice core samples, see Photo 4, indicated that the latent heat of fusion per unit volume of ice in the pond was 76-78% that of pure ice.

Cooling
The storehouse containing around 180 tons of potatoes was cooled from the end of March to the end of June. The control system successfully maintained the storehouse temperature at 2°C and the relative humidity at around 93%, providing a suitable environment for potato storage. The highest recorded cooling capacity was around 13 kW. However, inadequate storehouse insulation made the capacity insufficient after the beginning of June.

The storehouse was also used for pre-cooling cabbages and asparagus until late August, when the ice in the ice pond melted away. The FCUs effectively used 41-47% of the latent heat stored in the ice pond.

Quality of stored potatoes
Weight loss through storage differed between varieties of potatoes, and ranged from 1-4%, which is acceptable. The system almost completely inhibited sprouting in the potatoes and preventing the skins from wrinkling. The potatoes were kept in such good condition that it was difficult to distinguish them from fresh potatoes. Long-term cold storage also increased the sugar content in the potatoes to between two and five times that of potatoes before storage, enhancing their sweetness.

Economics
The coefficients of performance (COPs) of the FCUs ranged from 1.7 to 2.1. The overall COP of the system, taking the electricity consumption of the ice-making process into account, was approximately 1.4. In the storehouse cooled by an electric refrigerating machine, the COP was 1.0. Thus, the ice pond refrigeration system saves energy and running costs for agricultural cold storage.

Conclusion

In comparison with conventional refrigeration systems, the ice pond is less convenient to use and has higher initial costs. However, as CFCs will soon be banned, the ice pond system provides a realistic alternative to CFC-free refrigeration technologies in cold areas.

A distinctive characteristic of this IPS is that settings can be varied, allowing the user to control the temperature very accurately. Therefore this system is not limited to cold storage and/or pre-cooling of agricultural products. It can also be used to cool agricultural structures such as greenhouses and livestock barns, using temperatures higher than those for cold storage, or to air condition houses.

Before introducing this IPS, local weather conditions should be studied, as well as the system's ability to meet the required demands. Developing these design techniques is another important task to be addressed.

For further information please contact the Japanese National Team (address on back cover).

Photo 3: The ice pond (left) and potato storehouse (right) in summer.

Photo 4: A core sample from the ice pond.