DEVELOPMENT A HIGH-EFFICIENT SLURRY ICE GENERATION AND TRANSPORTATION SYSTEM USING A NATURAL REFRIGERANT.

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ABSTRACT

Ice thermal storage systems are being developed and marketed as one of the means of electric load levelling . Conventional ice thermal storage systems are of static type. These systems are reported to have bad responses to heat load and require large pipes to deliver cold heat. This makes initial investment and running costs high. Dynamic ice systems have been developed to offset some of the disadvantages of the conventional static systems. Dynamic ice is mainly produced by using brine solutions. These solutions not only lower the solidification temperatures , thus lowering COPs,but most of them are not friendly to the environment.

We have developed a highly efficient slurry ice generation and transportation system using both environmentally friendly ammonia as the refrigerant and water as the coolant. Water is super cooled to –1.5°C before it is delivered to a super cool releaser where slurry ice is produced. By using water, the COP is not only improved as compared with brines, the application range of the system widens from air conditioning to cover other areas such as the food industry and machinery.

This paper reports on the development and application of a 66kW cooling capacity system with a COP of 3.5.

KEYWORDS: *Natural Refrigerant, Super cooling, Slurry ice, Ice packing factor (IPF)*

1. INTRODUCTION

The use of natural refrigerants has attracted renewed interest over the past decade because of the need to turn to energy efficient and environmentally friendly refrigerants. We have conducted research on the use of ammonia in various applications. Our recent application was in production of slurry ice for air conditioning and food processing.

We developed a highly efficient slurry ice generation and transportation system using both environmentally friendly ammonia as the refrigerant and water as the coolant. Water is super cooled to –1.5°*C* before it is delivered to a super cool releaser where slurry ice is produced. By using water as the coolant, the COP is not only improved as compared with brines, the application range of the system widens from air conditioning to cover other areas such as food processing where slurry ice can be directly applied.

2. SYSTEM CONCEPT.

Figure 1 shows the system layout. The system is mainly composed of a compressor, condenser,

Super cooler, pre heater, super cool releaser and a storage tank. Water in the storage tank is kept at a constant level by the water supply system. Water from the tank is pumped through the pre heater where it is pre heated

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from 0 to 0.5°*C*. It then passes through a filter where any impurities are removed and supplied to the super cooler where it is cooled from 0.5°*C* to −1.5°*C* before being released to a super cool releaser where the super cool is released and slurry ice (0°*C*) is produced.

In the super cooler water is cooled as ammonia evaporates. Ammonia is then supplied to a compressor where it is compressed to high temperatures and pressure before being supplied to the condenser where it is cooled. The refrigerant then passes through an electric expansion valve where the temperatures and pressure drop to the evaporating conditions, evaporates in the super cooler and returns to the compressor to complete the cycle.

In order to keep the cooling duty constant the discharge pressure and evaporating temperature are kept constant by controlling the condenser cooling water inlet temperature and use of the evaporation pressure regulator. The super cooled water is in unstable state such that small disturbances within the super cooler and the piping before the super cool releaser would trigger release of the super cooled condition into slurry ice thereby clogging the heat exchanger or piping.

This condition does not often occur but incase it occurs part the hot gas from the compressor is supplied to the super cooler (Figure 1 defrost line) where the temperature of water is raised above 0°*C* to melt the clogged ice. Clogging is detected by either increase in pressure of (or drop in) the water flow rate. It takes less than a minute to defrost and return to normal operating conditions. During ice storage mode the system runs until the amount of slurry ice stored reaches 33% that of the total amount of water (Ice packing factor).

In this particular system, cold water of 0.5 to 4°*C* was required in the processing of shrimp. This was supplied from the bottom of the tank.

Table 1 shows the specifications of the system. A reciprocating compressor operated at a constant speed of 1170rpm was used. The condenser is a shell and tube while the super cooler and pre heater are plate type heat exchangers. An electrical expansion valve and soluble oil were used to realize a direct expansion system resulting in minimum refrigerant charge (15kg) and automatic operation.

3.TEST RESULTS AND DISCUSSIONS

Figure 2 shows a typical example of the operating conditions. The evaporation temperature is controlled at about -4°*C*. Water is super cooled to around -1.5°*C* in a plate heat exchanger, and the temperature before the super cooler is maintained at around 0.5°*C*. The graph shows data of 10hours of operation and an example of clogging and defrost. Clogging in the super cooler or piping after the super cooler is detected by rise in the super cooler water pressure. When the pressure reaches a certain point valves are automatically changed to defrost mode. Some of the discharge gas from the compressor is directed into the super cooler. The high temperature discharge gas heats the water in super cooler thus defrosting the super cooler or the piping after the super cooler. During the defrost mode, the temperature of water at the exit of the pre heater is also raised to ensure quick defrost. The defrost process completes in less than a minute.

It can be deduced from this graph that this system can offer slurry ice at higher evaporation temperatures than other conventional systems and that the evaporation temperature is constant throughout the operation time. This offers a higher and constant COP in contrast with other conventional systems where the evaporation temperature (COP) falls as ice forms(1).

Figures 3, 4 and 5 show super cooled water impinging on the super cool releaser and forming slurry ice, stored slurry ice and processing of shrimp.

As shown in figures 3, 4 and 5 super cooled water impinges on the super cool releaser losing the super cool and in the process forming slurry ice. Ice formation continues until the stored IPF reaches about 33%. During the processing of shrimp cold water is taken out of the storage tank and used directly in the process. To keep the water level constant water is added in the tank from the water supply system. The water added to the tank is about 20°*C*, therefore, the temperatures in the storage tank rise as processing continues.

Figure 6 shows the heat extraction processes. As shown in the figure the stored IPF is about 38%. As cold water is taken from the tank, the temperatures in the tank rise from about 0 to 5°*C*. All the stored ice was used during the processing of shrimp. Water in the storage tank did not rise above 5°*C* despite the fact that water of about 20°*C* is added to the tank.

Figure 7 shows the temperature profiles in the storage tank during heat extraction. It can be seen that the bottom and middle of the storage tank are still below 5°*C* and sensible heat is still available for use after shrimp processing.

4. CONCLUSIONS

We have developed a direct expansion slurry ice generation system using ammonia, a natural refrigerant as the working fluid. Through the development research we reached the following conclusions.

1. Slurry ice is produced from environmentally friendly water. Therefore, the waste water produced during the processing of shrimp does not require special handling / treatment.
2. Since the system uses environmentally friendly water, slurry ice can be directly used during processing of food stuffs.
3. Unlike the conventional brines which lower the evaporation temperature (COP) as ice generation proceeds, the evaporation temperature in this system is high and constant. A high system COP of 3.5 was realized.
4. Use of plate heat exchangers, soluble oil and an electronic expansion valve enabled direct expansion, optimization of the refrigerant charge and automatic operation of the system.

References

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Table 1 Specifications of the system

Refrigerant	Ammonia
Compressor	Reciprocating type N4K 1170rpm
Condensing Temperature	35°*C*
Evaporating Temperature	-4°*C*
Super heat / super cool	3°*C* / 5°*C*
Refrigeration Capacity	66kW
Water flow rate	28m^3/h
Super cooler inlet temperature	0.5°*C*
Super cooler outlet temperature	-1.5°•*C*
Ice packing factor	33%
Super Cooler Heat exchanger	Plate type
Storage Tank	13m^3
System COP	3.5

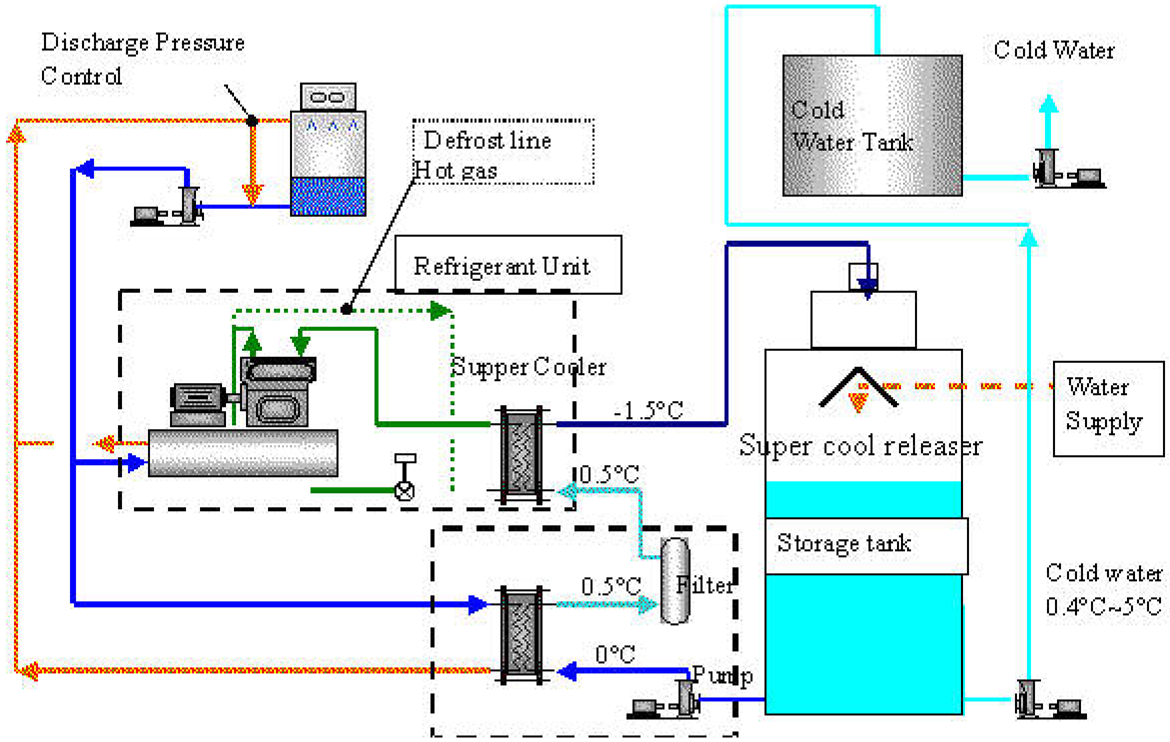

Figure 1 System layout

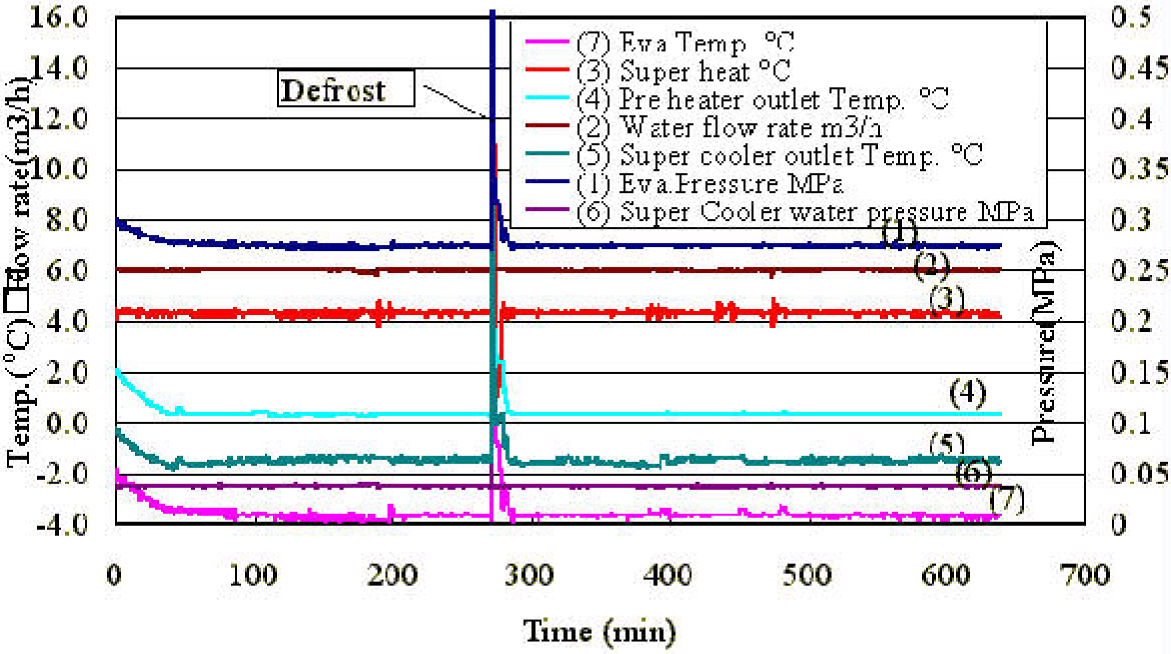

Figure 2 Example of operating conditions

Figure 3 Slurry ice formation

Figure 4 Stored slurry ice

Figure 5 Processing of shrimp

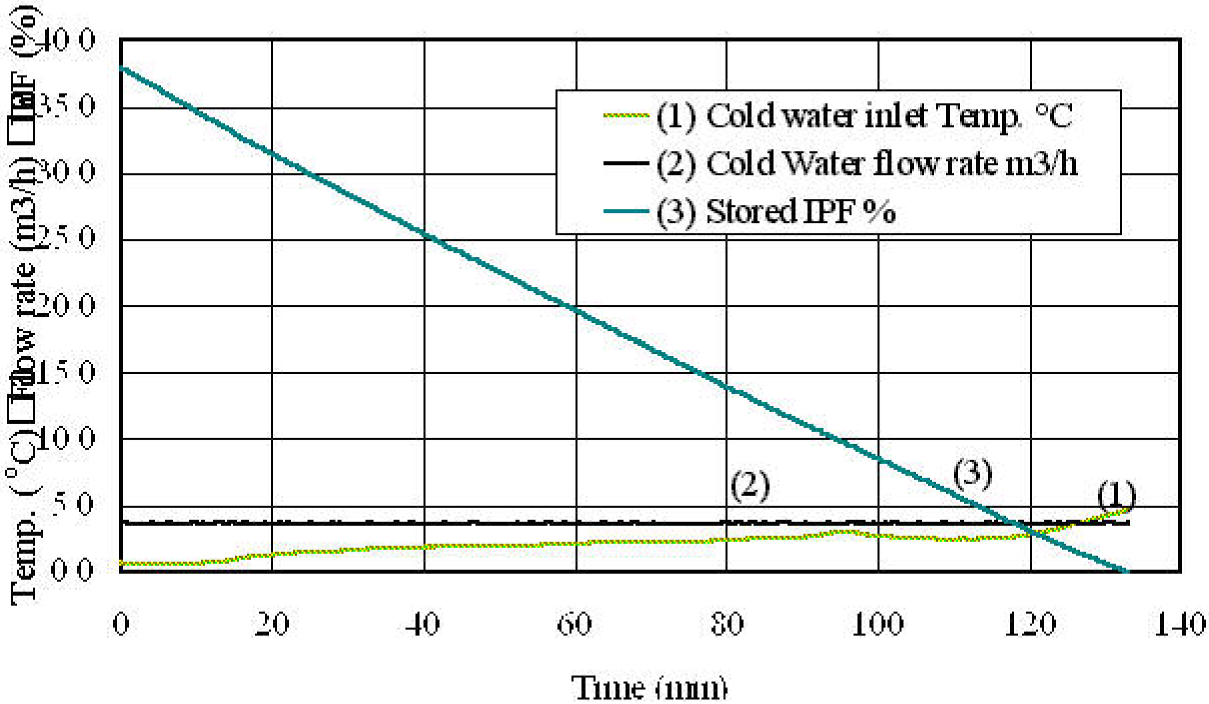

Figure 6 Heat extractio n process

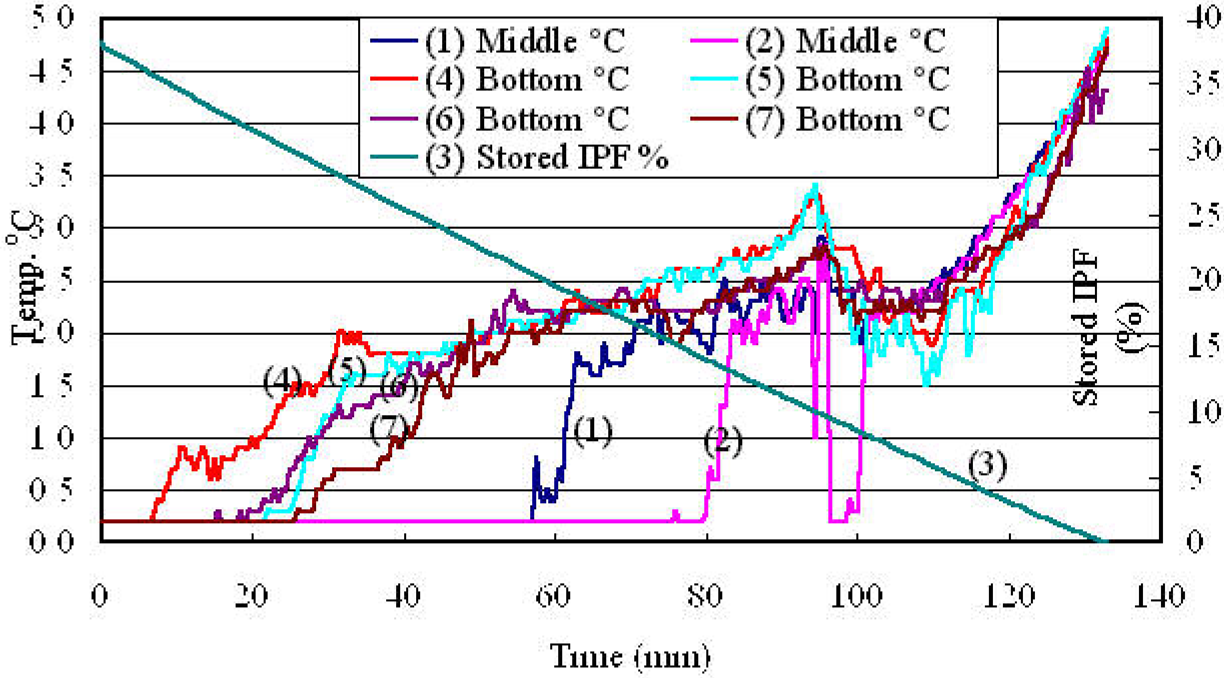

Figure 7 Temperature profiles in the storage tank during heat extraction