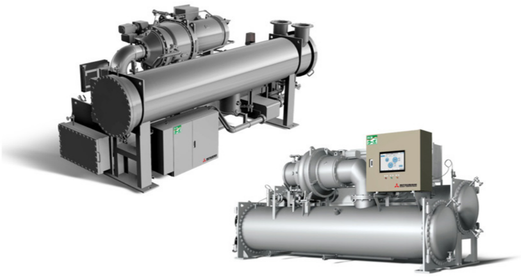
Optimization of Process Cooling for Food Using Variable Speed Centrifugal Chiller Operating at Ultra-Low Load with Low-GWP Refrigerant



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Along with the stricter regulations on refrigerants and the enforcement of the Law Concerning the Discharge and Control of Fluorocarbons for the purpose of preventing global warming, the need for low-GWP refrigerant (non-CFC) chillers has been increasing. On the other hand, in process cooling systems at food factories where chillers are used, excessive starts and stops of chillers sometimes occur because the chillers cannot follow the load variation in batch operations in which the load changes abruptly in a short time. Mitsubishi Heavy Industries Thermal Systems, Ltd.(MHI Thermal Systems) introduced a two-stage cooling system using temperature difference for which the variable speed centrifugal chiller operating at ultra-low load was adopted, an exhaust heat recovery (hot water supply) system and other technologies to promote the delivery of high-efficiency systems that allow stable continuous operation at varying loads.

1. Introduction

Conventionally, in process cooling systems at food factories, the problem has often arisen that as chillers cannot follow the load, the outlet temperature of chilled water is unstable, causing excessive starts and stops of the chiller. To avoid this problem, MHI Thermal Systems proposes optimal plant systems according to the operating conditions at customer plants by analyzing such conditions that differ by line. We introduced a two-stage cooling system using the large temperature difference produced in the manufacturing process, a heat recovery system in which the exhaust heat of the chiller is recovered to produce hot water so that the amount of steam used in the conventional manufacturing process is reduced, and cooling tower-free cooling (FC), thereby realizing high-efficiency operation and contributing to the reduction of running costs.

This report provides an overview of the systems introduced at two factories, as well as the future outlook.

2. Common matters

The features common to application examples (A) and (B) are as follows:

(1) Energy saving

Through the processes of preparation for manufacturing, manufacturing operation and finishing operation, chilled water/brine is supplied at stable temperatures/flow rates, so that product quality is stabilized. The heat source equipment and related ancillary equipment (pump, cooling tower, etc.) are cooperatively controlled so that the operation is facilitated.

(2) Manpower saving

Through the processes of operation start-up, operation and finishing operation, the operational data, preventive maintenance data, various report data, etc., can be automatically transferred to an IoT system, so that manpower is reduced. Since all the centrifugal chillers adopted are not regulated by the Law Concerning the Discharge and Control of Fluorocarbons, the burden of maintenance is reduced.

(3) Cost saving

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The original plant system provided according to the operating conditions at each plant realizes the reduction of the initial costs and running costs.

(4) Environmental performance

All the centrifugal chillers use new refrigerants with a global warming potential (GWP) of 1 or less, so that the global environmental load is reduced and the amounts of electricity and gas used in the entire plant are also reduced, resulting in the reduction of CO_2 emissions.

(5) Safety

Non-flammable or slightly flammable refrigerants with low toxicity are used for the chillers. The facility equipment is installed outdoors to eliminate concerns about noise in the plant.

(6) Space saving

Space saving is realized while maintenance space is kept within the limited installation space.

3. Application example (A)

3.1 Background

To a customer with a strong commitment to environmental conservation, such as advocating a completely CFC-free factory, we proposed the ETI-Z low-GWP variable speed centrifugal chiller, which uses the CFC-free refrigerant R-1233zd(E) with an ozone depletion potential of 0 and a global warming potential (GWP) of 1.

3.2 Issues

The chilled water return temperature differs by facility to which water is supplied. On one line, it is returned at 10°C, while on another line, it is returned at 50°C or higher. Since different lines are operated according to production schedules, the load variation is significant. In addition, if a piece of equipment is selected at the maximum high-load operation, the heat source capacity of the chiller and the overall size of the equipment become large, causing difficulties in arrangement and efficient operation. To solve these problems, we introduced cooling tower-free cooling so that the heat load applied to the chiller is reduced and the load is stabilized.

3.3 Overview of the plant system

To effectively achieve cost saving and stable operation in process cooling systems for food, it is necessary to understand the process characteristics and transfer heat stably and efficiently. Therefore, we pinpointed the characteristics of a centrifugal chiller and established a system that stably produces chilled water. In this section, the major technologies for the system are described.

(1) Cooling tower-free cooling (FC)

To improve the aforementioned issues, we divided the return chilled water line into two lines based on the production line and the production time schedule of the customer's facility and introduced a high-efficiency cooling system (cooling tower-free cooling system) in which the high-temperature return water is cooled through heat exchange with cooling water via a heat exchanger. As a result, the leveling of the load applied to the chiller and the reduction of the heat source capacity have been achieved.

(2) Bypass control of chilled water at the chiller inlet (Patent No. 5412073, as of the issue of the Technical Review)

The water temperature at the chiller inlet is reduced to or below the rated temperature of the chiller to stably control the chilled water outlet temperature.

(3) Control of variable flow rate of chilled water

The flow rate of chilled water is adjusted so that the water temperature at the chiller outlet is kept stable even if the water temperature at the chiller inlet rises.

(4) Constant control of discharge pressure of chilled water feed pump (secondary conveying pump)

Inverter control is adopted to maintain a constant chilled water discharge pressure at the secondary side irrespective of the operational state on the secondary side. A bypass circuit is provided to follow the operational state on the secondary side.

The system flow image with (1) to (4) being reflected is shown in **Figure 1**. Through the aforementioned control, the system follows the load variation on the secondary side and provides stable operation, contributing to stable manufacturing/production for the customer. In addition, the increase of the system COP, the reduction of running costs through energy saving and the downsizing of the equipment resulted in the reduction of the customer's initial costs for equipment introduction. From the aspect of facility management, the chilled water temperature and flow rate are measured and the heat quantity is instantaneously calculated and recorded for the visualization of energy consumption, which is useful for running cost management and maintenance planning.

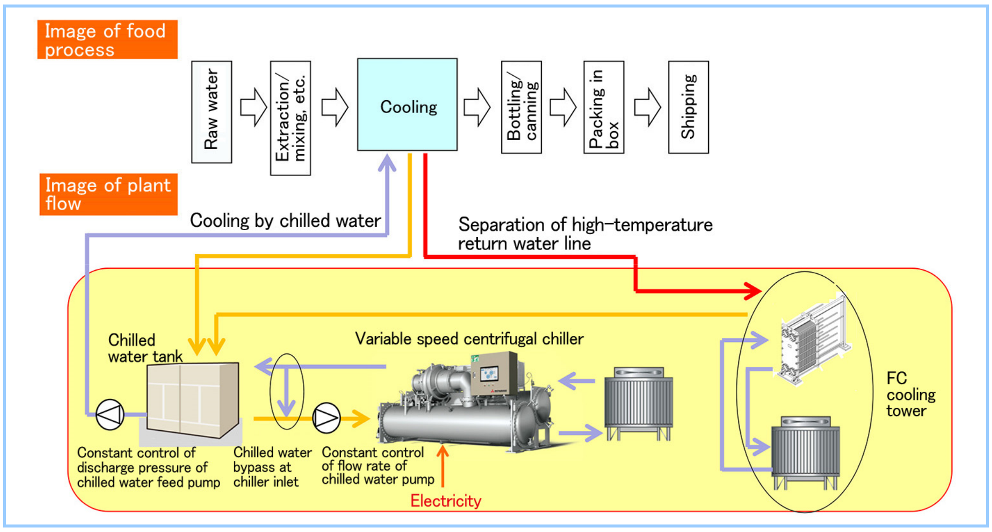

Figure 1 Image of plant flow

3.4 Results of the study

The advantages of the introduction of FC were estimated. When an FC cooling tower is not introduced, the maximum load capacity is about 326 USRt. When an FC cooling tower is introduced, the maximum load capacity is about 221 USRt, and the chiller heat source capacity was reduced by 32% in the simulation. The electric power consumption was also estimated on the assumption that operations would be conducted for 24 hours a day, 365 days a year. As a result, when an FC cooling tower is not introduced, the electric power consumption is about 900 MWh, and when an FC cooling tower is introduced, it is about 541 MWh, achieving a reduction of about 40%. The estimated monthly electric power consumption is presented in **Figure 2**.

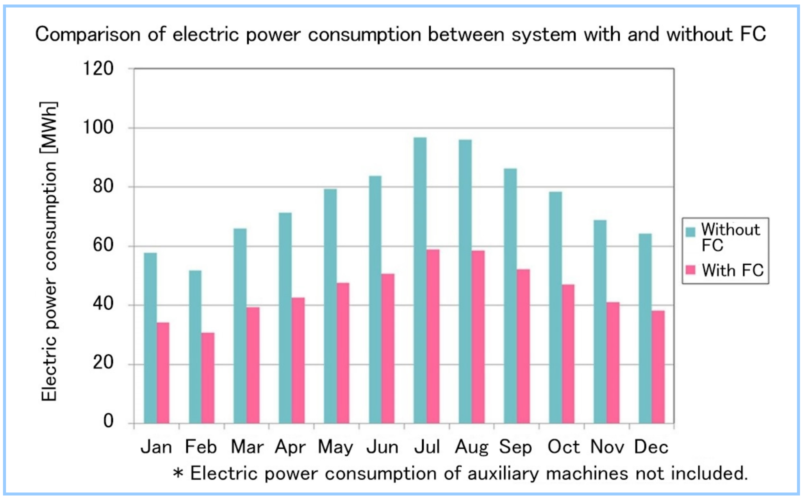

Figure 2 Comparison of electric power consumption between system with and without FC

3.5 Conclusion

With an FC cooling tower introduced, running costs were reduced by about 40%. Although a load variation occurred in which the actual load of the production facility on the secondary side increased by about five times in five minutes, the load applied to the chiller was reduced/levelled by the aforementioned system, and it was confirmed that the chiller could follow the load.

The system can supply chilled water at the temperature required by the customer, contributing to stable production.

4. Application example (B)

4.1 Background

To reduce environmental load, the ETI-Z chiller using the CFC-free refrigerant R-1233zd(E) and the GART-ZE chiller using R-1234ze(E) were delivered.

4.2 Issues

There was a task of replacing the utility brine chillers on the old line and installing water chillers for utilities on the new line. The problems were that the required utility temperature differed by line and the cooling users were scattered at various points in the factory. To solve these problems, we introduced a centralized heat source system in which the chillers for multiple lines were grouped by temperature zone and integrated and managed at a single location to supply utilities to users located at various points.

4.3 Overview of the plant system

To effectively achieve cost saving in a food process cooling system, it is necessary to understand the characteristics of the process and transfer heat stably and efficiently. We pinpointed the characteristics of the centrifugal chiller and established a system for stably producing chilled water, brine and hot water. In this section, the major technologies for the system are described.

(1) Production of hot water and reduction of warmer gas consumption through recovery of exhaust heat from chiller (exhaust heat recovery)

In the food process studied in this application, there is a product heating stage downstream of the upstream product cooling stage in a series of processes and the cooling and heating loads are generated at the same time. This characteristic is used to recover the exhaust heat from the chiller produced for the upstream cooling stage (which is normally released into the air via a cooling tower), store it in a hot water tank and use it in the downstream heating stage, so that the amount of steam usage and the amount of CO_2 emissions generated in the production of steam are reduced. (**Figure 3**(a))

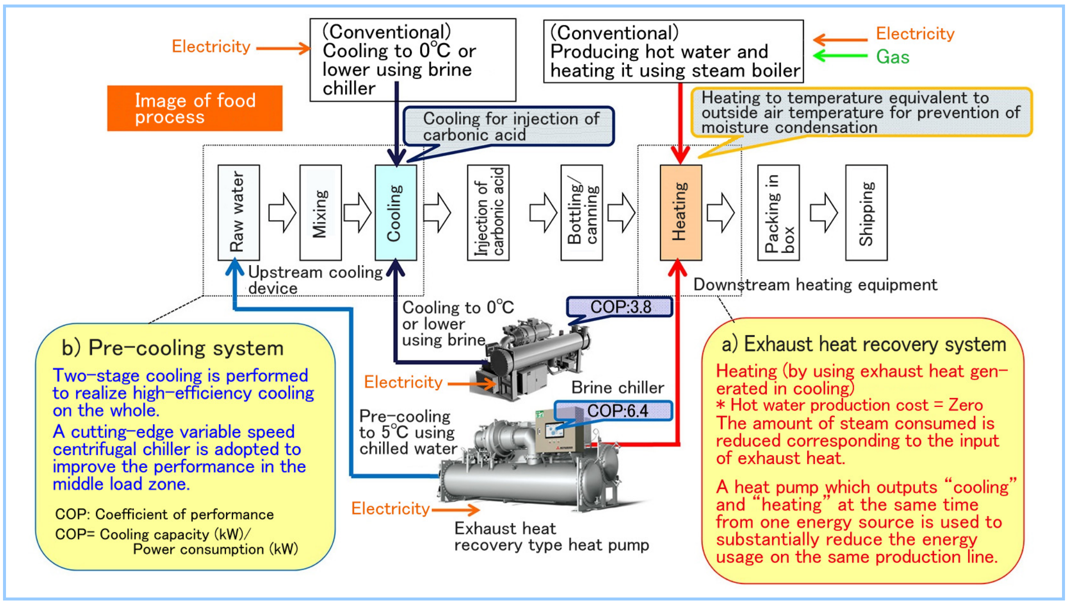

Figure 3 Image of (a) Exhaust heat recovery system and (b) Pre-cooling system

(2) High-efficiency cooling technology on the process side (Pre-cooling system)

In the upstream cooling stage shown in (1), it is necessary to stably cool products down to almost 0°C. Conventionally, products were cooled by using brine of 0°C or lower. In chillers, the smaller the temperature difference between the cooling side and the exhaust heat side is, the higher the efficiency becomes. This characteristic is used to increase the system efficiency by dividing the cooling of products into two stages: (1) pre-cooling to 5°C using chilled water; and (2) temperature compensation using brine for cooling to 0°C or lower. (Figure 3(b))

(3) High-efficiency chilled water production technology (two-stage cooling system of the variable speed centrifugal chiller)

In the production of chilled water of 5°C shown in (2), the performance characteristics of chillers – the smaller the temperature difference between the cooling side and the exhaust heat side, the higher the performance – is used to increase the efficiency by cooling the process return water at two stages where the outlet temperatures of chilled water are 11.5°C and 5 °C. Assuming that low-load operation would be required when the kind of product to be manufactured is changed, only inverter-driven chillers were adopted to improve the efficiency at low-load operation. (**Figure 4**, **Figure 5**)

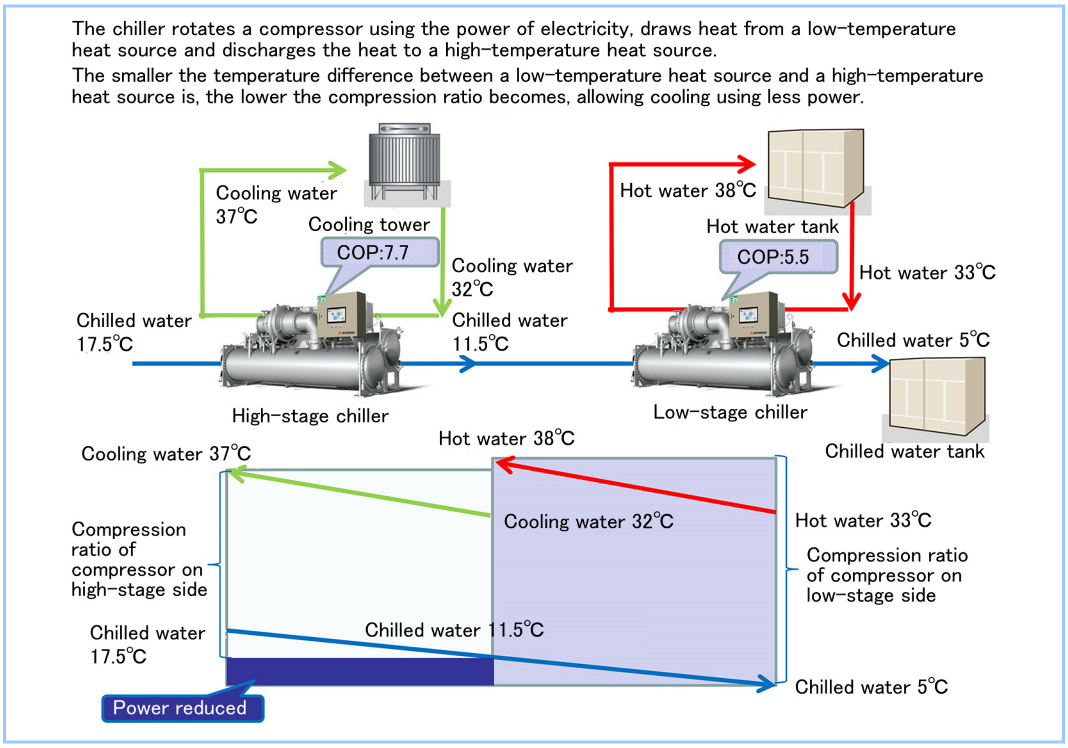

Figure 4 Image of two-stage cooling

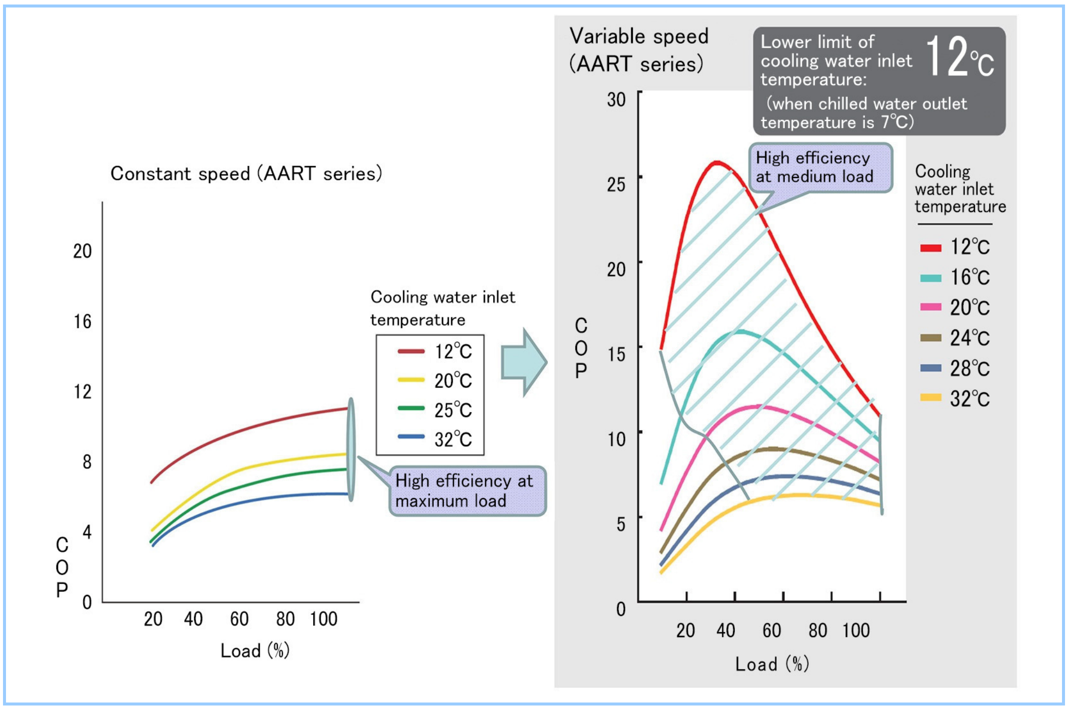

Figure 5 Image of performance characteristics of variable speed centrifugal chiller

(4) Stable production technology for chilled water and brine (Centrifugal chiller operating at ultra-low load + tank system)

To prevent excessive starts and stops of centrifugal chillers in batch operations in which the load changes abruptly in a short time, we used a centrifugal chiller operating at ultra-low load and a tank system to allow stable operation at low load without stopping the chiller. In addition, multiple centrifugal chillers for chilled water of 5°C and 11.5°C were installed, so that high-efficiency operation and risk dispersion were achieved simultaneously.

4.4 Results of the study

The advantages of the introduction of the centralized heat source system with the aforementioned features were estimated. In the simulation, this system reduced the power consumption by about 43%, compared to the case where the chillers on the old line were not replaced and latest chillers were additionally installed on the new line. The estimation results for the respective power consumption are given in **Figure 6**.

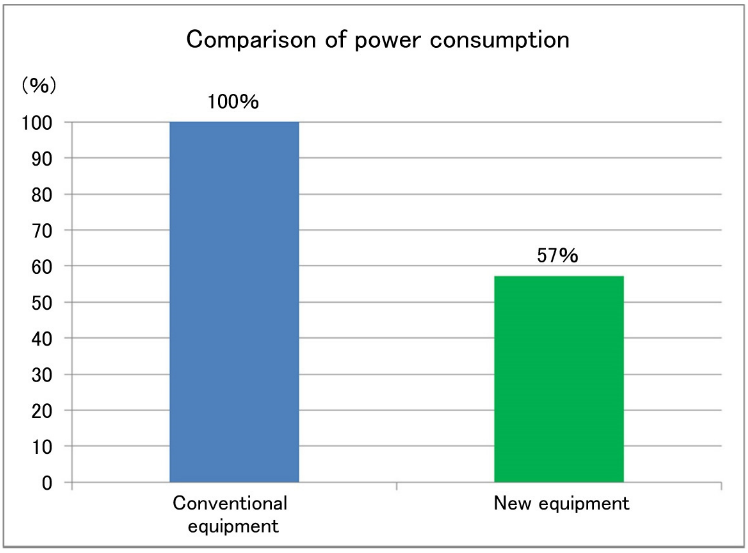

Figure 6 Comparison of power consumption between new and old systems

4.5 Conclusion

For the utility facilities of the factory which had faced the task of replacing old equipment and additionally installing new equipment, we introduced a centralized heat source system for producing and supplying brine, chilled water and hot water to multiple lines. This system reduced the power consumption by about 43% compared to the conventional system.

5. Conclusion

Our company has developed variable speed centrifugal chillers using low-GWP refrigerants to contribute to environmental conservation, and two models have been made into a series for different temperature zones and heat source capacities. This report described the application examples in which two models using low-GWP refrigerants were delivered to two factories. There are also other factories that have been introducing chillers with low-GWP refrigerants. The demand for such chillers is expected to grow in the future, and we will continue delivering this series of chillers. Since the operating conditions and the equipment installation state differ by factory and by line, "individualized drawing system" engineering is required for optimization. We will make efforts to offer optimal plant systems for production facilities with varied load patterns, while carrying out discussions with customers.