DEVELOPMENT OF HEAT RECOVERY CENTRIFUGAL HEAT PUMP FOR INDUSTRIAL-USE

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Abstract: Increasingly, Japanese households are installing heat pumps with small-range capacity for air-conditioning and hot-water supply. However, industrial heating continues to rely on fossil-fuel-fired boilers to provide the required large capacity and high temperature. We have developed two heat recovery-type heat pumps that are suitable for industrial use. One heat pump supplies hot water (90℃) sourced from water at 10－50℃. The capacity is 547 kW and COP is 3.7. The other heat pump supplies high-temperature (130℃) pressurized water sourced from water at 55℃. The heating capacity and COP is 627kW and 3.0, respectively. Both heat pumps use a centrifugal compressor driven by an inverter. This report presents the feature of our developed heat pumps.

Key Words: heat pump, centrifugal compressor, exhaust heat, heat recovery

1 INTRODUCTION

Pressured by the need to reduce CO_2 emissions, many heating facilities are replacing fossil-fuelled boiler with more environmentally friendly heat pumps. Electrically driven heat pumps with small range capacity are increasingly used as air-conditioning and hot-water supplies in households and commercial premises. Heat pump use CO_2 as refrigerant and air as heat source. However, industries continue to use fossil-fuel-fired boilers because they satisfy the high temperature, wide range demands of industrial heating processes that cannot be met by current heat pump designs.

In this paper, we introduce two heat recovery-type heat pumps developed to meet industrial requirements. One is the hot water heat pump, which heats hot water up to 90℃ and may be used as a low-temperature heat source. The other is high-temperature-pressurized-water heat pump, which heats water to 130℃.

2 INDUSTRIAL-SCALE HEAT PUMP SPECIFICATIONS

The heating requirements for domestic air-conditioning and hot water supply (40－65℃) may be sourced from outdoor air. Industrial heating demands a higher temperature source,

frequently exceeding 100℃. The temperature demands of several industrial heating processes are shown in Figure 1. As evident in the figure, the ranges and magnitudes of the heating capacity are vast.

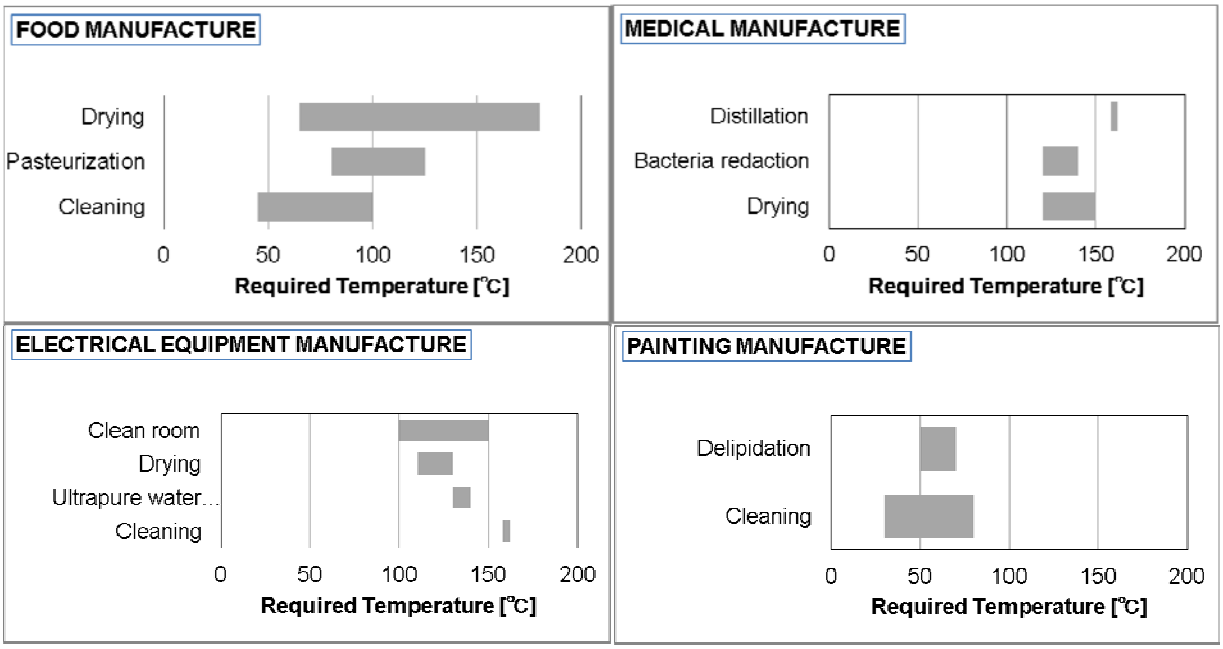


Figure 1: Temperature range of several industrial heating processes

Factories release exhaust heat that may be recycled as sources of heat pumps, however, the temperature of exhaust heat widely varies. Exhaust heat exceeding 60℃ is frequently diverted into other heating processes, while that below 50℃ is usually released into outdoor air through a cooling tower. The cooling water that condenses heat in cooled chillers also release exhaust heat. Such exhaust heats may provide high-quality source to realize high efficiency heat pump cycling. Therefore, industrial scale heat pumps must satisfy three requirements; “high temperature output”, “large capacity” and “able to source heat from exhausts of various temperatures”.

The centrifugal compressor can operate over a wide compressed ratio (i.e. wide temperature range) and can potentially yield high efficiency. Furthermore, frequency of the centrifugal compressor can be controlled by an inverter, thereby supplying hot water over a wide temperature range and extracting heat from a variety of exhausts. The centrifugal compressor coupled to an inverter has been widely applied in chilling devices. Here we apply this technology to our heat recovery pumps. Base on the aerodynamic technology developed in the chilling industry, we use HFC-134a as the refrigerant.

3 HEAT RECOVERY TYPE HOT WATER HEAT PUMP

The heat recovery-type hot water heat pump supplies hot water 90℃ from source water at 10－50℃. The maximum capacity is 547 kW at 90℃ hot water/50℃ heat source water and COP is 3.7. (Nishii 2011)

3.1 Outline

The heat recovery-type heat pump consists of two-stage centrifugal compressor, an evaporator that recovered heat from the source water, a condenser that heats the hot water, an economizer, a main and a sub-expansion valve and a control device. The evaporator, condenser, and economizer adopt brazing plate heat exchangers to realize highly efficient

heat transfer performance together with downsizing. The system flow and appearance of this heat pump are shown in Figure 2 and the specification at the maximum hot water temperature are shown in Table 1

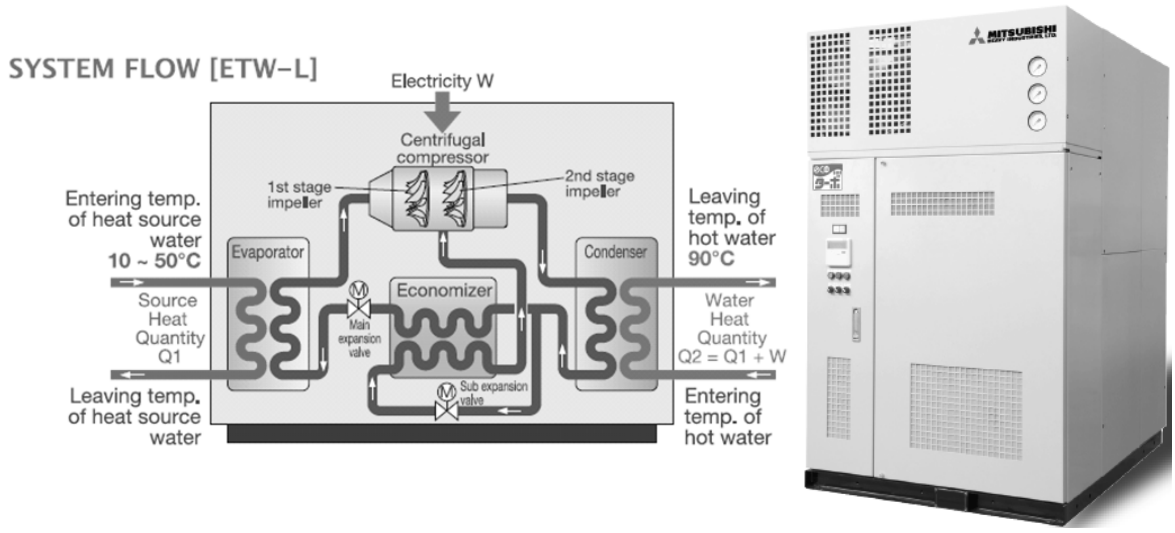


Figure 2: System flow and appearance of hot water heat recovery-type hot water heat pump

Table 1: Specifications of heat recovery-type hot water heat pump at maximum hot water temperature

Item	Specification
Heating Capacity	**547 kW**
Power Supply	**380-440 V 3 ϕ (50/60 Hz free)**
Consumption Power	**148 kW**
COP (Hot Water)	**3.7**
Hot Water	**Entering 80℃ / Leaving 90℃**
Heat Source Water	**Entering 50℃ / Leaving 45℃**
Refrigerant	**HFC-134a**
Dimension	**L1.55 m, W1.2 m, H2.0 m**
Weight at Operation	**2700 kg**

3.2 Application

In many industrial manufacturing plant, water supplied at 90℃ hot water is sufficiently hot for cleaning, pasteurization, and drying. If required to preheat boiler feed water, the boilers heating capacity and fossil fuel consumption can be reduced. Low-temperature heat source water can simultaneously realize a hot and chilled water supply. To maintain a clean room in which temperature and humidity are controlled by a desiccant air conditioning equipment, the heat pump can supply chilled water for air cooling and hot water to regenerate desiccant element (exiting moisture), as shown in Figure 3.

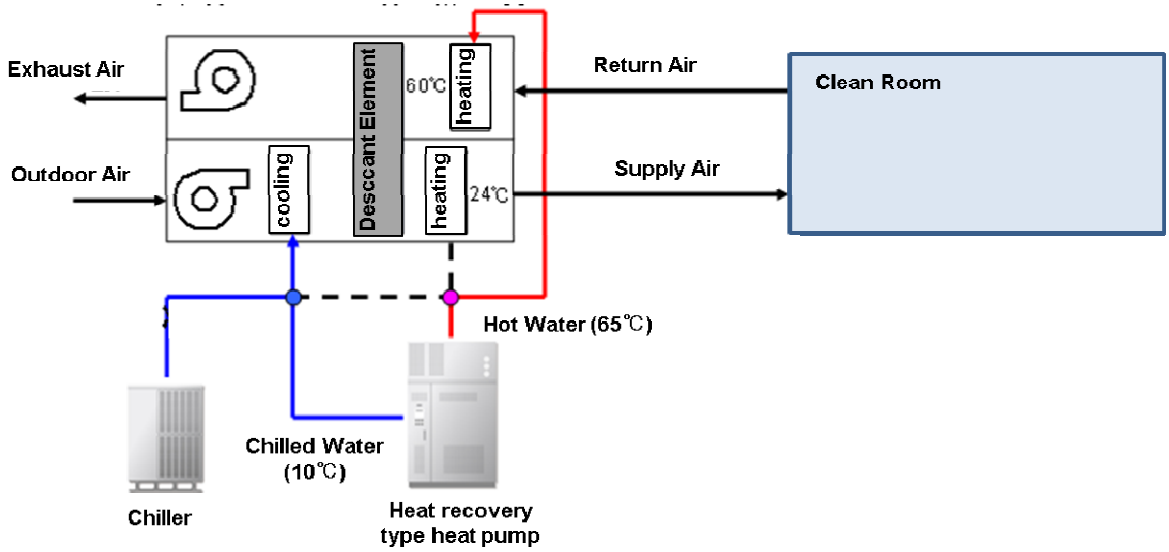


Figure 3: Schematic of system flow of desiccant system

4 HEAT RECOVERY-TYPE HIGH TEMPERATURE HEAT PUMP

As shown Figure 1, some industries required water exceeding 100 ℃ for drying, pasteurization, and other heating processes. These industries require a high pressure design with a large capacity, high-temperature heat pump. Such requirements, which are easily satisfied by fossil fuel boiler, are highly demanding for electrical heat pumps. However, since water exceeding 100℃ accounts for a large proportion of industrial energy consumption, we have developed a heat recovery-type heat pump that supplies pressurized water at 130℃.(Umezawa 2013)

4.1 Features

The specifications of the developed heat recovery-type high temperature heat pump are listed in Table 2.

Table 2: Specifications of heat recovery-type high temperature heat pump

Item	Specification
Heating Capacity	627 kW
Power Supply	400 V 3 ϕ (50/60 Hz free)
Consumption Power	209 kW
COP	3.0
Pressurized Water	Entering 70℃ / Leaving 130℃
Heat Source Water	Entering 55℃ / Leaving 50℃
Refrigerant	HFC-134a
Dimension	L3.2 m, W2.4 m, H2.5 m
Weight at Operation	6500 kg

The features of the developed heat pump are listed below;

A) The heated medium uses pressurized water to downsize and reduce the transportation power.
B) Supercritical refrigeration cycling is achieved by a single refrigerant (HFC-134a).

C) To heat the pressurized water to 130℃, the suction refrigerant gas supplied to the compressor is heated by an inter-cooler.
D) The newly developed compressor and heat exchanger are resistant to high temperature and pressure.

The critical temperature and pressure of the refrigerant HFC-134a are 101.15℃ and 4.16 MPa(abs), respectively. When heating pressurized water to 130℃, the refrigerant gas conditions at the compressor discharge exceed the critical point of HFC-134a. The supercritical characteristics of HFC-134a are plotted in Figure 4. On the basis of these characteristics, the inter-cooler is installed before the compressor and heating suction refrigerant gas. In this design, the discharge gas from the compressor is prevented from over-pressurizing but retain its high temperature. The refrigeration cycle includes a two-stage compression and one-stage expansion with an inter-cooler (see Figure 5).The temperature and pressure of compressed gas is 145℃ and 5.0 MPa(abs), respectively.

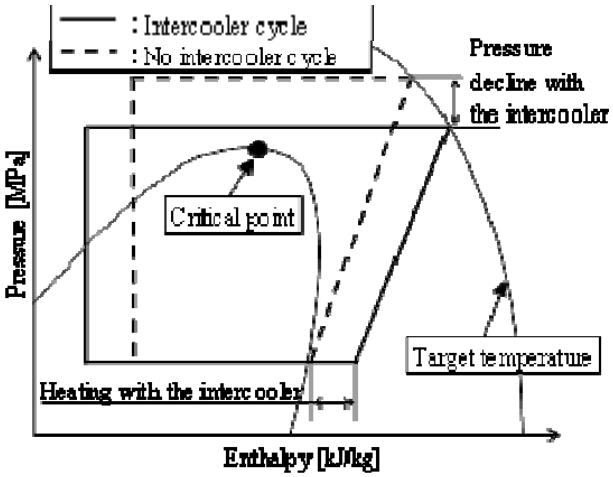


Figure 4: Supercritical characteristics of HFC-134a

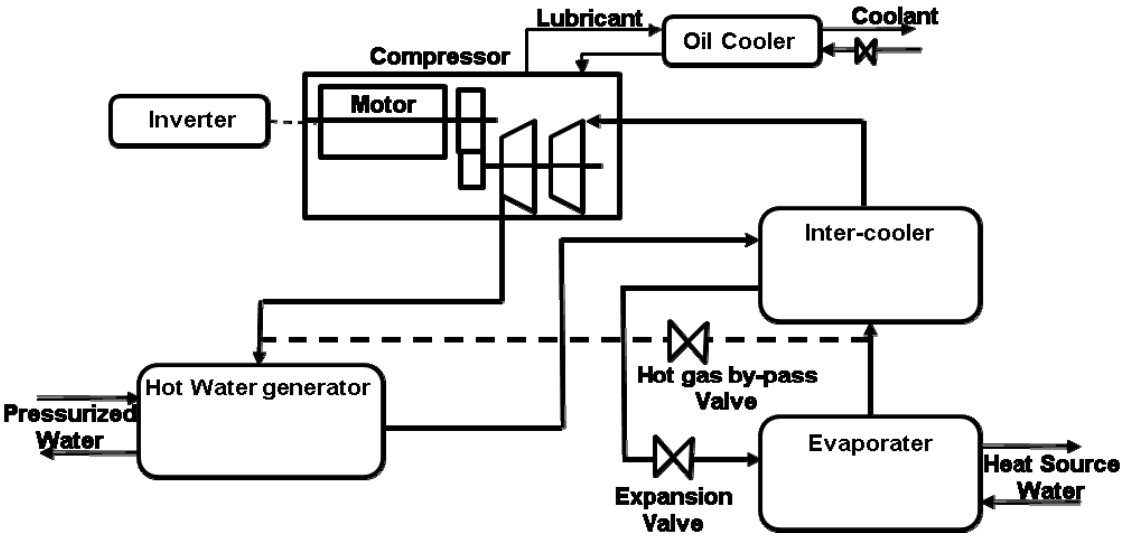


Figure 5: System flow of high temperature heat pump

The structural members and driving mechanism of the compressor were improved to resist to high temperature and pressure. The open impeller is made of carbon steel, and the first- and second-stage impellers are optimally balanced to reduce the refrigerant flow friction and

attain high efficiency. To generate a large capacity with supercritical cycle, the hot water generator and intercooler are protected by a reinforced brazing plate heat exchanger with high heat capacity and strong pressure resistance.

The aerodynamic characteristics of the compressor, and Cv characteristics of the expansion valve and hot gas by-pass valves are specified on the control board. The compressor frequency and valve openings are controlled by micro-computer calculation to retain safety and high efficiency over the entire operation range.

4.2 Performance

Prior to shipment, the developed high-temperature heat pump was subjected to operational testing. The conditions of the performance test listed in Table 3 and results are plotted in Figure 6. The heat pump delivered its expected output, namely, 130℃ pressurized water supply, 627kW capacity and COP 3.0.

Table 3: Performance test conditions of high-temperature heat pump

Item		Test Result
Output of the Heat Pump		250－627 kW
Pressured Water	Temperature	Entering 70℃ / Leaving 130℃
	Flow Rate	1.0－2.5 kg/s
Heat Source Water	Temperature	Entering 55℃
	Flow Rate	21.9 kg/s

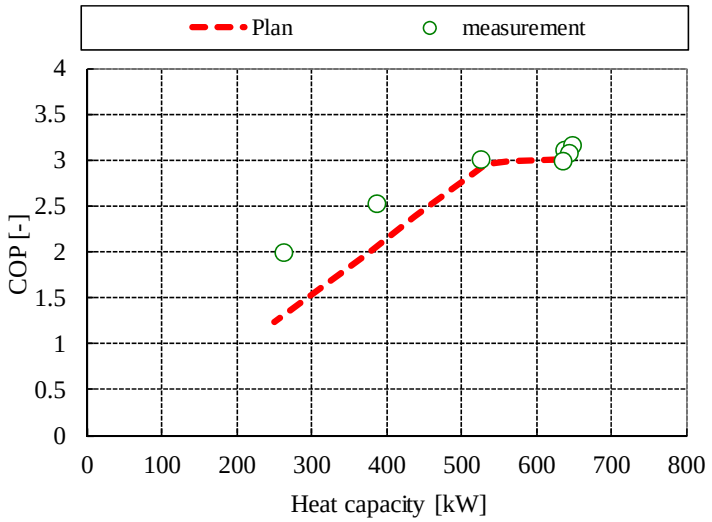


Figure 6: Test results of high-temperature heat pump

5 CONCLUSION

Developing heat pumps that satisfy the high demands of industry is essential for reducing CO_2 emissions and mitigating global warming. In this paper, we introduced two newly developed heat recovery-type heat pumps; one providing a variety of heating required by industrial operations, the other supplying water at 130℃ for more stringent requirements. However, to fully satisfy the high-temperature and efficiency demands of industry, our heat pumps require further development.

6 REFERENCES

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