Air-sourced 90℃ Hot Water Supplying Heat Pump "HEM-90A"

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Kobe Steel has developed an air-sourced heat pump, "HEM-90A," for supplying hot water. This heat pump is capable of supplying hot water at 65-90℃ to the heating process of factories making products such as foods, beverages, automobiles and chemicals. The newly developed heat pump has achieved the highest energy efficiency among air-sourced heat pumps for supplying hot water by circulation heating. This was made possible by using a two-stage twin-screw compressor modified for high temperature operation by selecting an adequate refrigerant and optimizing an air-sourced evaporator unit. This paper introduces the features and the performance of our newly developed heat pump.

Introduction

In plants making products such as beverages, foods and automobiles, high-temperature water is needed for various processes including the rinsing/sterilizing of raw materials and painting. Conventional heat sources for such hot water include combustion-type gas boilers and heaters. Recently, heat pumps are highly evaluated for their energy-saving features, and an increasing number of them are being used as alternative heat sources.

In 2009, Kobe Steel commercialized a series of heat pumps (HAI-EFU-MINI series). This includes the HEM note 1)- Ⅱ HR, a heat pump that can simultaneously supply hot water up to 70℃ and cold water. In 2010, the company commercialized the HEM-HR90,which can simultaneously supply hot water up to 90℃ and cold water; this is an industry first.[1), 2)] These heat-source machines are being used in various production processes. Their simultaneous supplying of cold and hot water can efficiently utilize energy. Their merits are especially appreciated when both cold and hot energies are utilized for their base loads. In applications with a relatively small heat demand, however, the load balance between the cold and hot energies must be controlled. For this reason, some users have declined the introduction of these heat pumps.

In order to further disseminate heat pumps, Kobe Steel developed an air-sourced heat pump that supplies hot water without a cold-water load, the HEM-90A; it went on the market in May 2012. This paper introduces the system construction of the newly developed heat pump, as well as its features and performance.[3), 4)]

1. Features of HEM-90A

1.1 Outline

Fig. 1 depicts the flow diagram of the HEM-90A. The conventional heat pump, the HEM-HR90, which takes out cold heat and hot heat simultaneously, comprises a vaporizer for taking heat from cold water as the latent heat of the vaporization of refrigerant fluid, a screw compressor for pressurizing the refrigerant gas that is vaporized, and a condenser for providing the latent heat of condensation of the refrigerant gas to heat water. This heat pump has a very high coefficient of performance (COP),note 2) thanks to the simultaneous use of cold and hot energies; however, the ratio between the amounts of cold and hot energies taken out is determined uniquely by the temperatures of the cold water and hot water. Thus, the load balance between the cold and hot energies must be controlled in some customers' applications.

To minimize the restrictions on customers when they use Kobe Steel's heat-source machines, the newly developed HEM-90A adapts an air heat exchanger for its vaporizer so as to eliminate the load of cold water and to take out heat from the air as the latent heat of vaporization of the

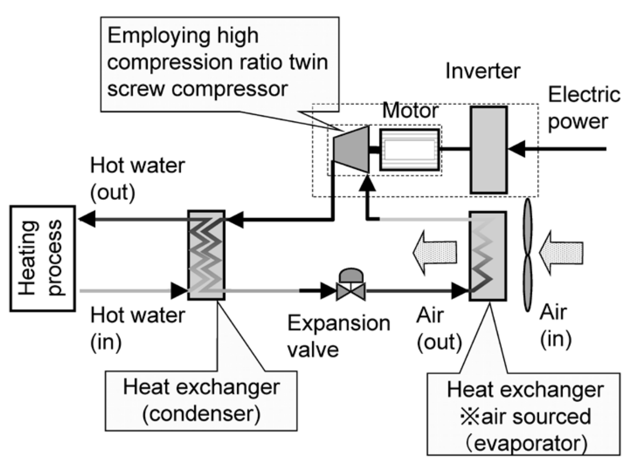

Fig. 1 Flow diagram of HEM-90A

note 1) HEM is a registered trademark in Japan of Kobe Steel.

note 2) Coefficient of performance (COP): the ratio of the heat put out over the electrical energy put in, i.e., an index of energy efficiency refrigerant. This has enabled the sole supply of high-temperature water by a heat-pump cycle.

The outline specification, the performance and refrigerating cycle of HEM-90A are shown in **Table 1**, **Table 2** and **Fig. 2**, respectively.

1.2 Advantage

The newly developed HEM-90A exploits the technology of the HEM-HR90. The new model adopts a two-stage screw compressor that can keep high efficiency even under the discharge condition of high-temperature water up to 90℃. This is combined, for example, with the optimal design of an air heat exchanger, as well as with the optimal selection of refrigerant to enable operation with high energy efficiency. As a result, the new model has achieved a heating COP of 3.4 (conditions: ambient temperature 25℃, hot water 60/70℃), the highest efficiency that has yet been achieved by a circulation-type hot-water heat pump with an air heat-source. The term "heating COP" as herein used means the ratio of the quantity of heating heat over the power supplied to a heat-pump unit.

Table 1 Specifications

Dimension (m)	L 2.84×W 1.54×H 2.70
Weight (kg)	2,990
Refrigerant	Mixture of HFC-134a and HFC-245fa
Hot water temperature at outlet (℃)	65～90
Ambient temperature (℃)	-10～40
Compressor	semi-hermetic two-stage twin-screw

Table 2 Performance (ambient temperature：25℃)

Performance（condition ①） Hot water temp. (℃)		55／65
	Heating capacity (kW)	159.1
	Power input (kW)	45.2
	Heating COP	3.5
Performance（condition ②） Hot water temp. (℃)		80／90
	Heating capacity (kW)	176.2
	Power input (kW)	62.9
	Heating COP	2.8

The newly developed heat pump requires less piping than water heat-source types. Also, it is designed to be compact (foot print: approximately 4.4m^2), notwithstanding its being an air-source type. Thus, this heat pump can be installed in the proximity of a process requiring hot water, which significantly reduces the heat transfer loss that has conventionally occurred when steam or hot water is supplied from centralized heat sources. (A more detailed description will be found in section 4.)

2. Technology for improving efficiency

2.1 Compact two-stage screw compressor with high compression ratio

Fig. 3 outlines the compact two-stage screw compressor used for the HEM-90A, as well as a single-stage compressor. The compact two-stage compressor was modified from the one that had been developed for general HVAC and refrigeration, such that it can be used for the supply of high-temperature water. Here, a cooling method was

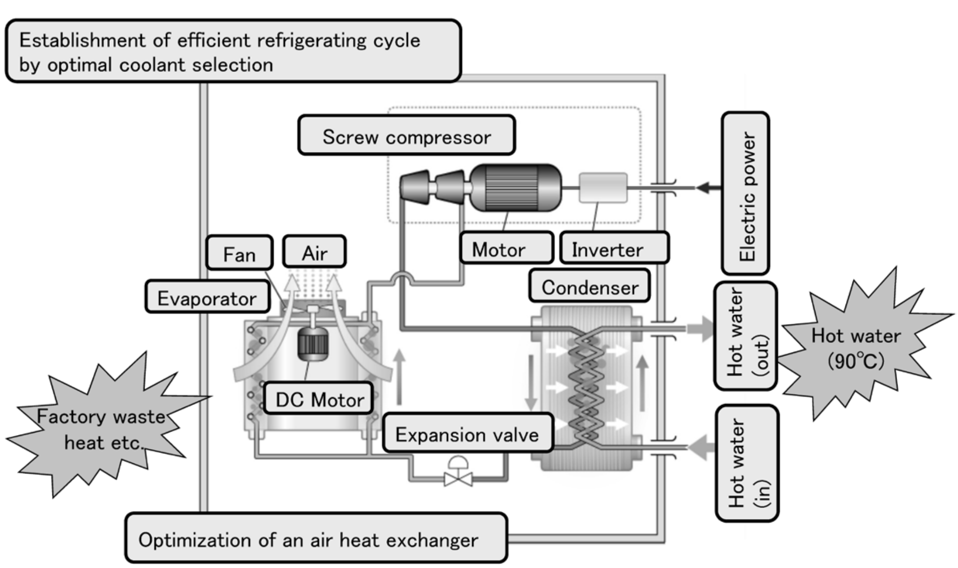

Fig. 2 Refrigerating cycle of HEM-90A

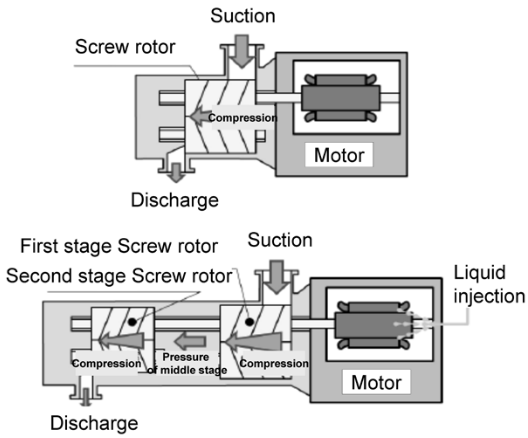

Fig. 3 Schematic view of compressor

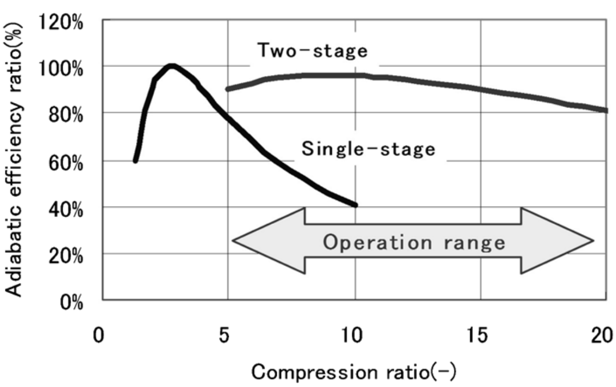

Fig. 4 Adiabatic efficiency ratio of compressor

devised, in which flashed refrigerant was sprayed directly onto the motor so as to retain the motor cooling performance even under high temperature conditions.

Fig. 4 shows the relationship between compressor efficiency (adiabatic efficiency) and the compression ratio. The term "compression ratio," as herein used, means the ratio of the discharge pressure to the suction pressure of a compressor. A heat pump requires a larger compression ratio as the temperature difference between the ambient air and hot water increases. As shown in this figure, the HEM-90A is operated in the range of a high compression ratio. In this operational range, a single-stage screw compressor sometimes exhibits significantly decreased efficiency depending on the ambient temperature and/or hot water temperature. Thus, the HEM-90A has adapted a two-stage screw compressor that can keep high efficiency over a wide compression ratio range and has realized high system performance.

2.2 Optimization of air heat exchanger

The air heat exchanger (vaporizer) adopts a plate-fin-tube type heat exchanger. If maldistribution of flow occurs during the partitioning of refrigerant into each heat-transfer tube of an air heat-exchanger, the refrigerant dries out in the vicinity of the outlet of the heat-transfer tube that receives a smaller supply of the refrigerant. Also, if the flow of air becomes nonuniform as it passes a plate fin, the heat-transfer surface does not work effectively. These phenomena can cause the decrement of heat-transfer performance.

Also the refrigerant used this time is a mixture of fluorocarbons, HFC-134a and HFC-245fa. This makes the refrigerant non-azeotropic, in which case, its evaporating temperature varies depending on the quality of the refrigerant (mass flow ratio of refrigerant gas to refrigerant liquid at a given cross-section). The mixed refrigerant has a higher viscosity and lower thermal conductivity compared with single HFC-134a. As a result, the evaporative heat transfer for a given mass velocity condition may become relatively low.

In consideration of the above concerns about the design of an air heat exchanger, we adopted an inner grooved tube for the heat-transfer tubes and a louver type for the plate fins. The specification of the fan was selected while taking into account the partitioning mechanism of the refrigerant, the arrangement of heat-transfer tubes and the footprint of the unit. The layout, including the air heat exchanger, was also optimized. The new fan specification and layout have realized excellent heat-transfer performance with minimized power for the fan.

2.3 Optimum selection of refrigerant

When the refrigerant HFC-134a is used for supplying hot water at 90℃, its temperature becomes almost equal to the critical temperature (101.1℃) at which the refrigerant undergoes a phase transition from gas to liquid, making it difficult to establish a refrigerating cycle with high efficiency. Hence, the HEM-90A has adapted a mixed refrigerant consisting of HFC-245fa and HFC-134a. The HFC-245fa has been proven in HEM-HR90, has a critical temperature (157.5℃) higher than that of HFC-134a and is readily available.

The use of this mixed refrigerant has established a single refrigeration cycle, eliminating the needs for multiple compressors and heat exchangers for transferring heat between the low order-side and high order-side, the compressors and heat exchangers required for a binary refrigeration cycle.

3. Performance characteristics

Figs. 5 and **6** show, respectively, the characteristics of the heating capacity and heating COP against ambient temperatures. Under typical operating conditions including an ambient temperature of 25℃ and hot water outlet temperature of 70℃ (hot water inlet temperature at 60℃), a heating capacity of 163.8kW and heating COP of 3.4 have been achieved.

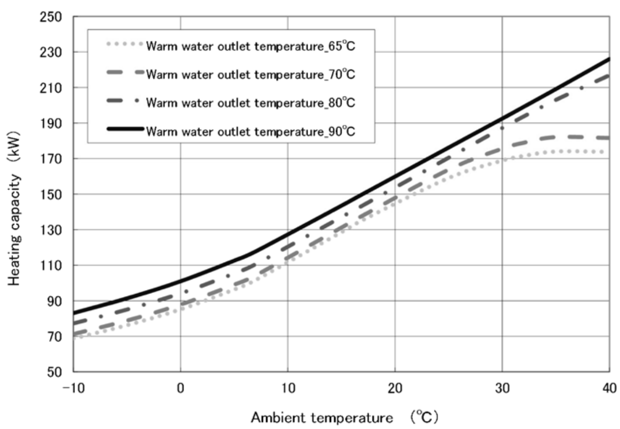

Fig. 5 Relationship between ambient temperature and heating capacity

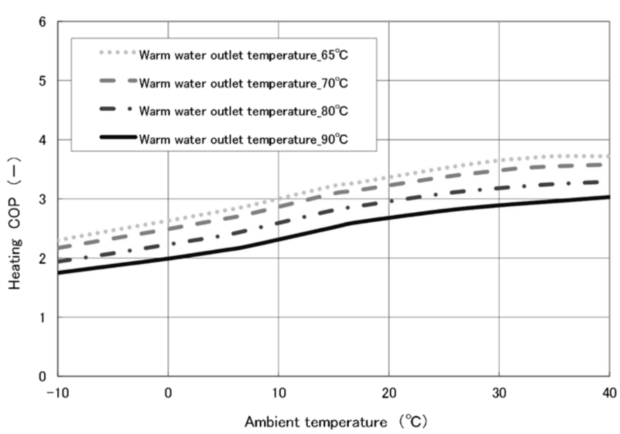

Fig. 6 Relationship between ambient temperature and heating COP

A heating capacity of 176.2kW and heating COP of 2.8 have been demonstrated even for the maximum hot water outlet temperature of 90℃ (hot water inlet temperature 80℃).

For the first time for air-sourced heat pumps, the newly developed heat pump has enabled taking hot water out at a temperature as high as 90℃ with high energy efficiency.

4. Effects of introduction

A significant amount of heat is exhausted from plants producing, for example, beverages, food and automobiles. In conventional processes, heat loss from steam supply pipes, as well as pressure loss at reducer valves, occurs when steam is supplied from a gas boiler to each process segment, as shown in **Fig. 7**. In addition, the drain is exhausted without being fully utilized after processing in many cases. Thus, in some cases, the total loss in an entire system is reported to reach as high as approximately 70%.[5)]

An HEM-90A, installed in the proximity of the process requiring steam, can have the advantages of reducing the heat loss caused by the steam pipes and utilizing the heat that is unused and exhausted from the production process. In other word, the heat exhausted to the atmosphere in a plant can be partially recovered to be reused for generating high-temperature water by a heat-pump cycle.

The following describes a quantitative evaluation of the merit of doing this. Assuming a case where the outlet temperature of the hot water is 70℃ (inlet temperature: 60℃), the application is an industrial operation running 8,000h per annum, and an existing boiler has a system efficiency of 50%, then the HEM-90A is expected to achieve significant cost reductions, a 58% reduction of running cost (**Fig. 8**)

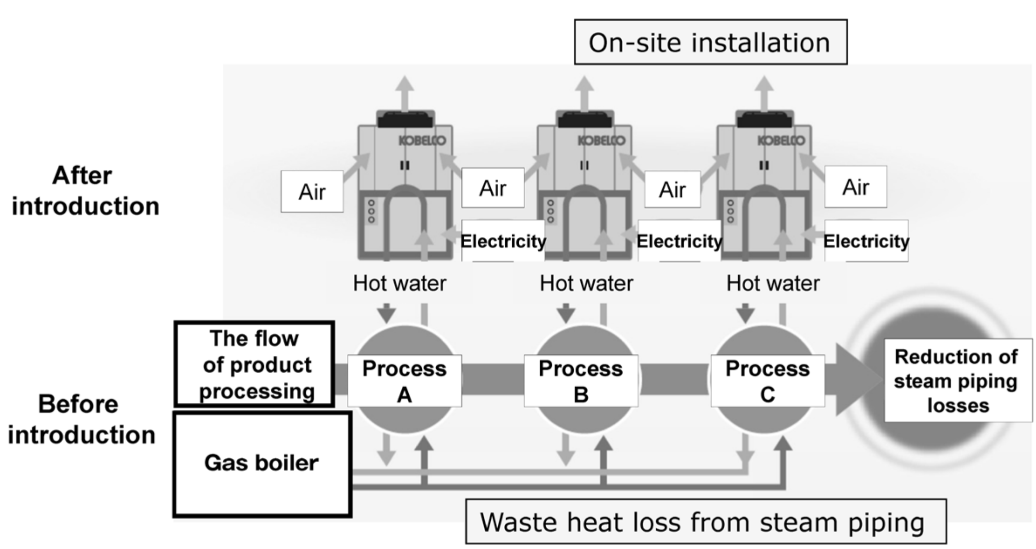

Fig. 7 Introduction method of gas boiler and HEM-90A to a process

and a 56% reduction of energy consumption (**Fig. 9**). Here, the outdoor air condition is the average temperature of Tokyo, Nagoya and Osaka areas, the electric rate unit price is 12 yen/kWh and the gas rate is 57yen/Nm^3.

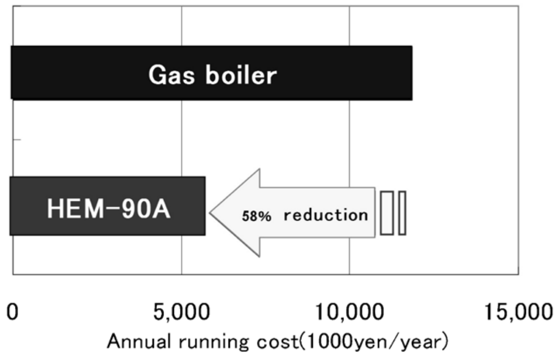

Fig. 8 Estimation of annual running cost

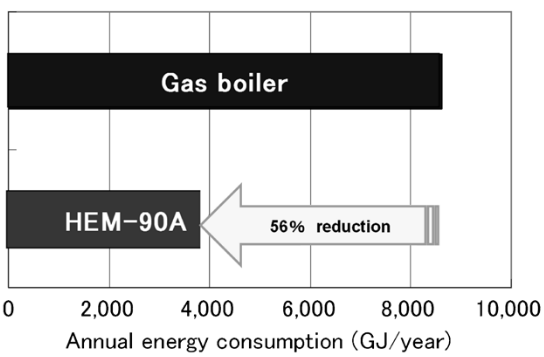

Fig. 9 Estimation of annual energy consumption

Conclusions

Since the Great East Japan Earthquake, the domestic supply of electrical power has become tight, raising concerns about the increased price of fossil fuels such as petroleum and natural gas. Under such circumstances, the best mix of conventional combustion-type boilers and electrically-driven air-sourced heat pumps, the HEM-90A, is considered to diversify the risk and to save energy. When introducing heat pumps for industrial applications, it is considered important to ascertain in advance the merits of introducing them, including economic efficiency and energy-saving, acquiring a clear picture of each process, because the method of heat utilization varies depending on the manufacturing process.

We will strive to propose heat-source machines that match the user's needs and to contribute to the wide use of industrial heat pumps.

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