12th IEA Heat Pump Conference 2017

Field test study on the performance of air source heat pump installed at various industrial processes in Japan

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Abstract

In industrial process in Japan, steam boiler or electric heater has been used as heat sources. In particular, since the steam boiler has issues on heat radiation loss and drain loss by long pipe arrangement, it has been reported that utilized heat is quite low. In this background, we developed an industrial hot water heat pumps with high efficiency and can expect the large energy saving effect and CO_2 reduction of the industrial processes. In order to confirm the actual performance of the hot water heat pump, we carried out the energy measurement for heat insulation process of daily products and molds. As the result, we confirmed that 38-69% of large energy saving and CO_2 reduction was possible in comparison to the existing heat sources such as the steam boiler or the electric heater. Moreover, it was found that air source heat pump was effective not only the energy saving effect but also the improvement of the work environment and stabilization of product quality. Although the heat pump has been introduced at a variety of processes, there was an issue that construction costs increase in the case of application to cleaning process of the machine parts. As a solution, we have developed a direct heating type of the developed heat pump that can heat the washing liquid directly.

Selection and/or peer-review under responsibility of the organizers of the 12th IEA Heat Pump Conference 2017.

Keywords: Air source heat pump; Industrial process; High temperature; Saving energy

1. Introduction

In recent years, heat pumps have been progressed as one of the most effective among the technologies for the energy problems and carbon dioxide reduction in the field for business such as air-conditioning, refrigeration and hot water supply. However, in industrial heating processes, heat pumps have not fully used, boilers and electric heaters as the heat sources have been mainly used. Especially, boilers have issues on heat dissipation loss such as combustion loss, radiation loss and drain loss since they are often centralized and transport vapor to destinations by long pipe arrangement as shown in Fig.1. Thus, the energy actually used is limited to about half of the input energy [1]. Some processes require direct steam while others use hot water. Our survey indicates that, to keep the internal tank temperature constant, the energy consumed by circulation heating systems that use water at a temperature of 90°C or lower amounts to approximately 67 million GJ only in Japan [2]. Therefore, in industrial heat source fields, high energy efficient and high output water temperature heat-pumps are expected to replace existing centralized boilers, as a means of energy saving, carbon dioxide reduction and cost reduction.

In this background, we have developed an air-source heat pump which enables a highly efficient production of high-temperature water [2]. For widespread use of industrial heat pump, we have conducted demonstration tests

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of the heat pump, was to clarify the energy efficiency and environmental performance under the comparison with the conventional system. Although the heat pump is applicable to a variety of industrial processes, there was a issue that construction costs increase in the case of application to cleaning process of the machine parts. Therefore, we have developed an improved heat pump in order to solve this issue. This paper provides a series of these efforts.

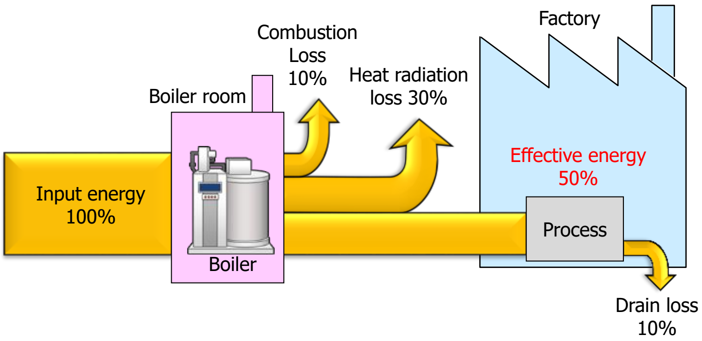


Fig.1 Image of energy loss in heating process using boiler as heat source

2. Outline of developed heat pump

The specifications of the developed heat pump are shown in Table 1. Both a heat source unit and a supply unit are designed to be as compact as 0.29 m^2 so that they can be installed in a narrow spaces in factories. The heat source unit can operate in an ambient temperature range of as low as -15ºC DB to as high as 43ºC DB, being able to produce hot water of 50ºC to 90ºC. In addition, the heat source unit and supply unit or several supply units can be piled in accordance with the layout of production process. They can also be installed separately. The refrigerant pipe can be extended up to 30 m and with a level difference of up to 10 m. These features improve the degree of freedom for installation layout. By installing the heat source unit at a location where exhaust heat is generated in the factory, the system can obtain the effect of gathering exhaust heat, enabling a much higher efficient operation.

Table 1. Specifications of developed heat pump

Trade name	CAONS140	
Unit	Heat source unit	Supply unit
Appearance		
Refrigerant	R410A	R134a
Dimenstion (Width×Depth×Height)	900mm×320mm×1,340mm	900mm×320mm×700mm
Weight	90kg	91kg
Ambient temperature	-15~43ºCDB	5~43ºCDB
Humidity	5 to 85%RH	
Output water temperature	50~90ºC	
Rated heating capacity	14.0kW	
Rated COP*	3.5	
Power supply	3Φ200V(50Hz/60Hz)	

*Ambient temperature=25ºCDB/21ºCWB, Inlet temperature of hot water=60ºC, Outlet temperature of hot water=65ºC

3. Field test of developed heat pump

In order to evaluate the energy saving effect of the developed heat pump, we carried out energy measurement for the dairy-products heat insulation process and mold heat insulation process. These results of field tests are shown as follows.

3.1. Daily-products heat insulation process

Energy measurement was conducted at daily-products heat insulation process of SHINSHU MILK LAND Co., Ltd. from August 2012 to March 2014. Heat pump was introduced at September 2013 as shown in Fig.2. Figure 3 and 4 show the outline of conventional system and the heat pump system, respectively. In order to keep warm the dairy products in two jacket tanks, hot water of 80~82ºC is required. In the conventional system, daily products were kept warm by pouring the steam directly. In the heat pump system, hot water of 85ºC from the heat pump was circulated. At the time of start-up and raw material input in the morning, additional steam was used.

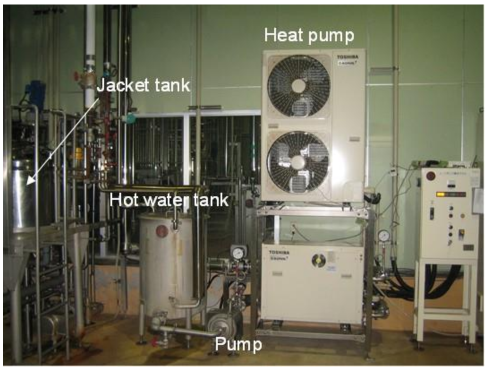


Figure 2. Heat pump system of daily-product production process

Figure 5 shows monthly averaged value of COP for the heat pump and ambient temperature. Despite the hot water outlet temperature was 85 ºC, the average COP of the developed heat pump was 2.73. Since the heat pump was installed inside the room as shown in Fig.2, COP was maintained high values throughout the year and there was no defrost operation in the winter season. Table 2 shows comparison of annual primary energy consumption and CO_2 emission. The primary energy consumption and CO_2 emission of the developed heat pump was reduced to be 38% and 50% lower than those of the conventional system, respectively.

After changing to the heat pump system, since the temperature in the jacket tank was substantially constant, leading to stabilization of the product quality. Moreover, since there are no steam leakage from the jacket tank, the temperature and humidity of the working environment is reduced. In summer season, temperature humidity index (THI) of working area which often used as the discomfort index became from 83 to 79, resulting in a working environment improvement. When the THI reaches 80 everyone feels uncomfortable [3].

In addition, cold wind from the heat source unit has been utilized as a spot cooler for worker, was also serve effectively as a working environment improvement. Though this system use the steam at the time of system start-up, the system without the steam may be possible by installing a schedule timer.

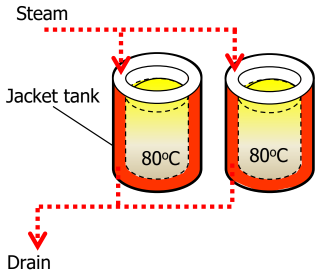


Figure 3. Conventional system

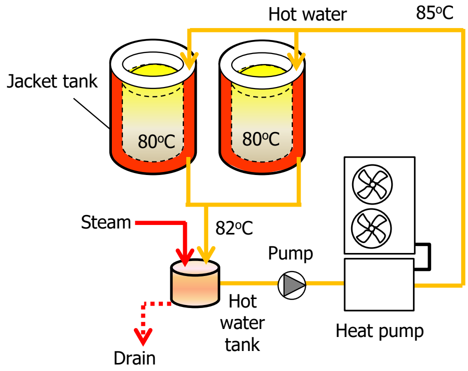


Figure 4. Heat pump system

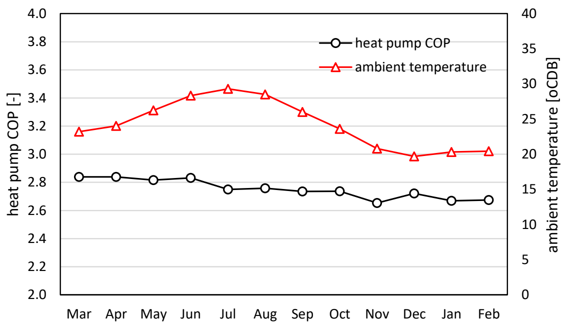


Figure 5. Monthly averaged values of COP

Table 2. Annual primary energy consumption and CO_2 emission

	Conventional system (Boiler steam)	Heat pump system (Boiler steam+heat pump)	Reduction rate (%)
Primary energy consumption(GJ/Year)*1,*2	481	300	38
CO_2 emission(ton-CO_2/year)*3,*4	34	17	50

*1: Primary energy consumption of electric power: 9.76MJ/kWh
*2: Primary energy consumption of A heavy oil: 39.1MJ/L
*3: CO_2 emission coefficient for electric power: 0.509kg- CO_2/kWh (Chubu Electric Power, 2013)
*4: CO_2 emission coefficient for A heavy oil 2.77 kg-CO_2/L (Ministry of the Environment, Government of Japan)

3.2. Mold heat insulation process

Figure 6 shows configuration of a conventional system in mold heat insulation process of resin. Measurement was conducted at Toyoda Gosei Co., Ltd. from July 2014 to March 2016. In the conventional system, Each mold was connected to each electric heater type temperature controller which was to supply hot water of 60 ℃. As shown in Fig.7, heat pump system consists of a heat pump, two pumps, two tanks and a heat exchanger. The heat pump supplies hot water to several molds.

In view of the smooth launch of Monday, the conventional temperature controllers had been operated even in holiday. After the heat pump system with a timer was introduced, the system was stopped during holiday. Taking into account the operation start time, the heat pump system was started on early Monday morning and was stopped late Friday evening.

Table 3 shows comparison of annual primary energy consumption and CO_2 emission. Because of the running time reduction and the effect of introducing high-efficiency heat pump, the primary energy consumption and CO_2 emission of the developed heat pump were reduced to be 69% lower than those of the conventional system. In addition to this energy-saving, the working environment of the summer season has been improved by cold air from the heat source unit. Moreover, because the heat pump system was concentrated in the dead space of the factory, working space can be effectively utilized.

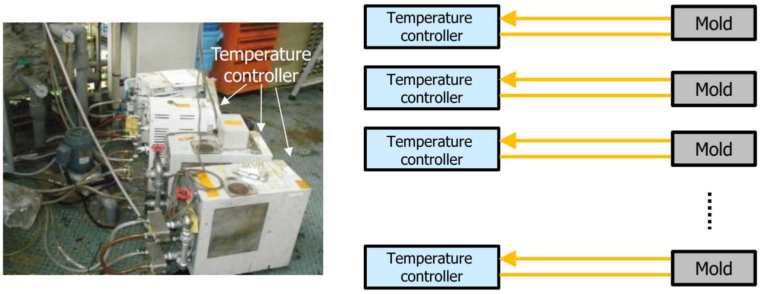


Fig. 6. Conventional system

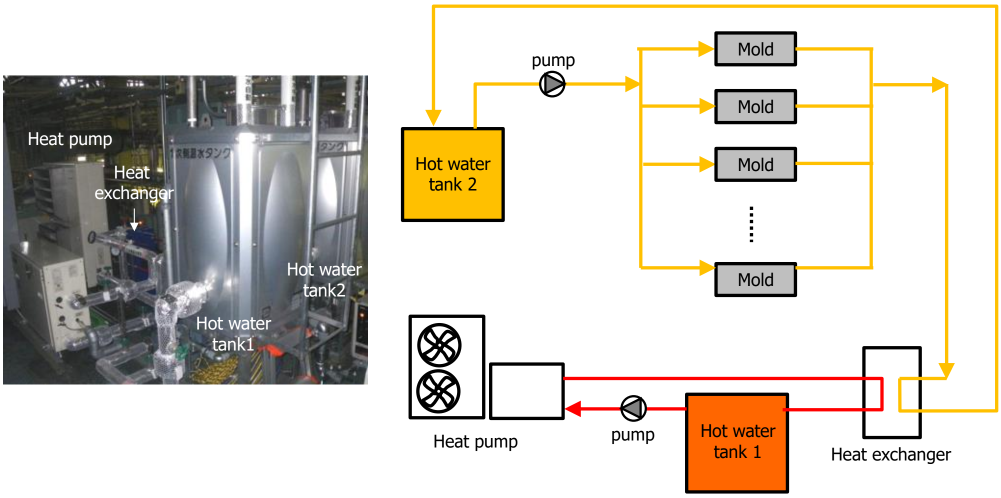


Fig. 7. Heat pump system

Table 3. Annual Primary Energy Consumption and CO_2 emission

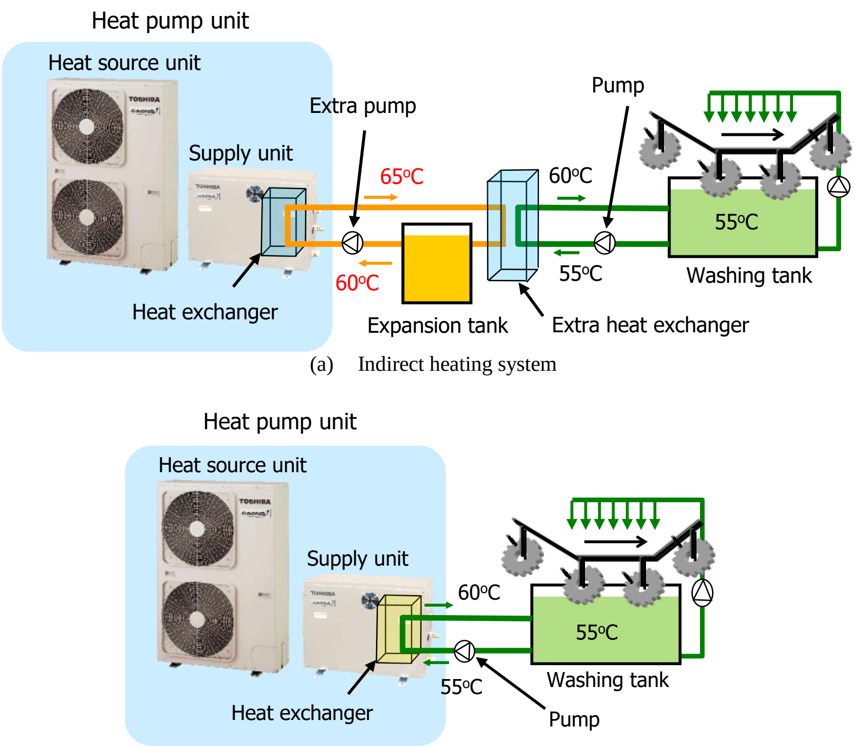
	Conventional system (Electric heater)	Heat pump system (Heat pump)	Reduction rate (%)
Primary energy consumption(GJ/Year)*1	1,683	524	69
CO_2 emission(ton-CO_2/year)*2	83	26	69

*1: Primary energy consumption of electric power: 9.76MJ/kWh
*2: CO_2 emission coefficient for electric power: 0.482kg- CO_2/kWh (Chubu Electric Power, 2015)

4. Modification of heat pump for washing process

4.1. Issue of washing process

The developed heat pump has been introduced at various industrial processes such as food production process, insulation process, drying process and washing process after being supplied to market. Basically, in the case of introduction to the washing process of the mechanical part, because the heat exchanger of the supply unit has solubility for the washing liquid, it is necessary to use indirect heating system which consist of an expansion tank, an extra heat exchanger and pump as shown in Fig.8(a). Therefore, both large installation space and high initial cost became major disincentive the heat pump introduction. To solve these issue, we developed direct heating type of the developed heat pump that can directly heat the washing liquid as shown in Fig.8(b).



(b) Direct heating system

Fig. 8. Heat pump system for washing process

4.2. Outline of direct heating type heat pump

Direct heating type heat pump (DHP) consists of a heat source unit and a supply unit as well as the original heat pump (OHP) shown in Table 1. A water heat exchanger, water pipes, and temperature sensor holders with respect to the wetted part, were changed to SUS316 with corrosion resistance in the washing liquid. Heating capacity, maximum outlet temperature and dimensions of DHP are equivalent to those of OHP. Fluid that can be directly heating in DHP is weak alkaline washing liquid or low pure water. Applicable pH range of DHP is from 8 to 12.

DHP is equipped with a water heat exchanger enlarging the cross-sectional area of flow channel compared to the OHP. However, by optimizing the heat transfer area and the refrigerant flow control, the efficiency of DHP is almost same as that of OHP.

4.3. Field test of direct heating type heat pump

Due to heating the dirty liquid directly as shown in Fig.8(b), it is anxious about accumulation of dirt inside the water heat exchanger of the supply unit. In order to evaluate the influence of the dirt on performance, DHP was introduced to a washing process of mechanical parts for air-conditioning as shown in Fig.9. Mechanical parts are washed by showering the weak alkaline washing liquid of 60°C. Dirty liquid after filtering is reused as clean liquid. In this system, the clean liquid is directly heated by DHP

Figure 10 shows time series change in flow rate and pressure loss between inlet and outlet of the water heat exchanger. Though the flow rate didn't change so much, pressure loss was increased and decreased repeatedly. It was found that pressure loss was mainly decreased by the washing liquid change or cleaning of the water heat exchanger. After the cleaning of the heat exchanger every 4 month, it was confirmed that pressure loss became about 10kPa which was level at test start. As a result, the influence of the dirt on performance was minimal, continued availability by periodically washing liquid change or the cleaning of water heat exchanger was confirmed. Based on this field test, a function to inform the cleaning timing of the heat exchanger was installed for DHP. It is noted that it is possible to extend the cleaning cycle of the time-consuming water heat exchanger to 6-7 months by adjusting the timing of the washing liquid change recently.

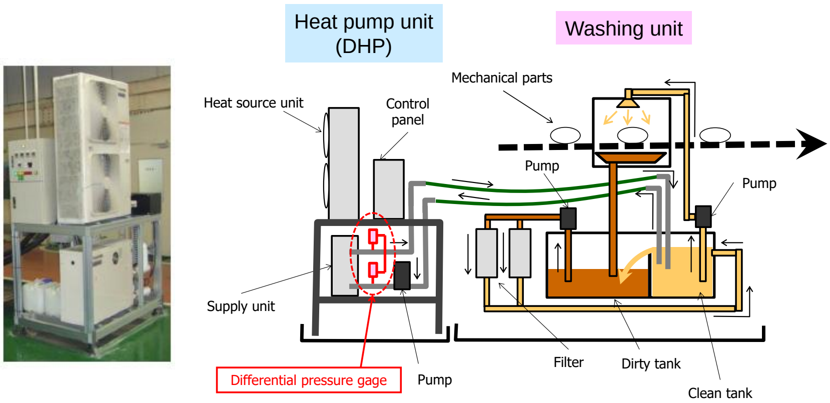


Fig. 9. Outline of direct heating system for washing liquid

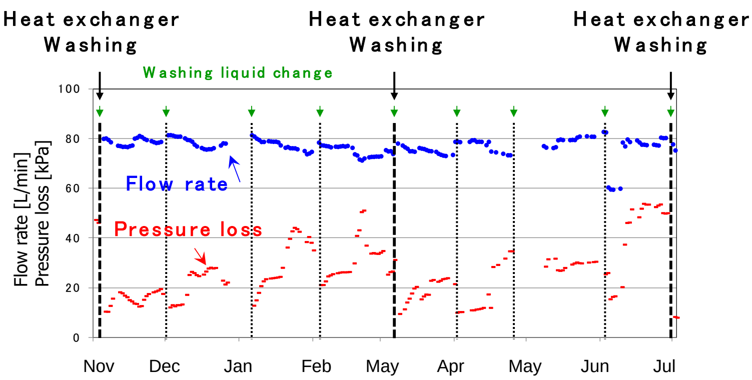


Fig. 10. Time-series change in flow rate and pressure loss

4.4. Impact of introduction

Based on the field test results, we calculated the introducing impact of DHP for the washing process. Figure 11 and 12 show the result of estimated primary energy consumption and CO_2 emission of the conventional gas boiler, electric heater, indirect heating system and direct heating system as shown in Fig.8, respectively.

Since direct heating system using DHP does not need extra heat exchanger as shown in Fig.8, the hot water outlet temperature can be 5ºC lower than that of the indirect heating system. Due to improvement effect of COP by this hot water outlet temperature decrease and reduction effect of

an additional pump, the energy consumption of the direct heating system is estimated to be 14% lower than that of the indirect heating system, 66% lower than that of the electric heater and 55% lower than that of the gas boiler. The CO_2 emission of the direct heating system are also expected to be significantly reduced than that of the other systems.

-Estimate condition-

Operation time	:	18h/day, 239day/year
Heating load	:	Values of actual washing process (10-14kW)
Ambient temperature	:	Values of actual washing process (7-24ºC)
Washing liquid temperature	:	60ºC
System efficiency	:	Electric heater 100%, Gas boiler 50%
Calorific value	:	Electric 9.97MJ/kWh(8:00-22:00), 9.28MJ/kWh(22:00-8:00) Gas 46.05MJ/Nm^3
CO_2 Emission coefficient	:	Electric 0.482kgCO_2/kWh (Chubu Electric Power, 2015) Gas 2.36kgCO_2/Nm^3

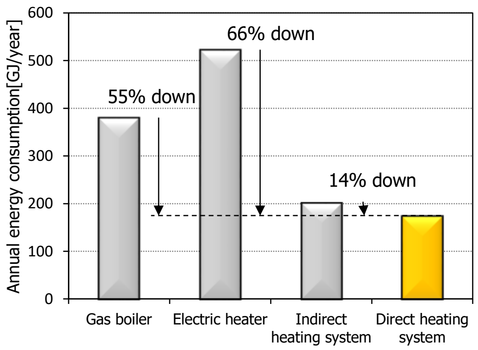


Fig. 11. Estimated primary energy consumption

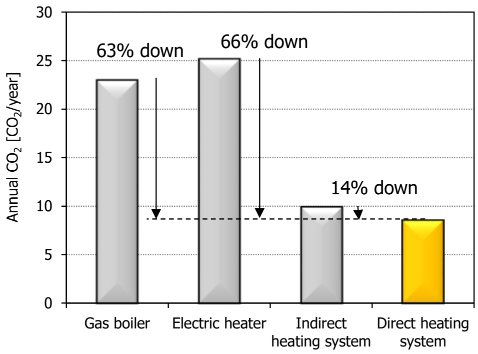


Fig. 12. Estimated CO_2 emission

Direct heating system may also reduce the system cost since the extra heat exchanger and the additional pump are reduced. When switching over to heat pump system from boiler system, 7.7 years of payback period for the indirect heating system can be shortened to 5.6 years for the direct heating system. Moreover, installation space of the direct heating system can be reduced by 41% relative to that of indirect heating system. As stated above, significant benefits from the viewpoint of efficiency, cost and installation space can be obtained.

5. Conclusions

For energy saving, cost reduction and carbon dioxide emission reduction of the industrial process, we have developed a heat pump that can supply the hot water of up to 90ºC with high efficiency. In addition to the industrial fields such as food warm process, the mold heat insulation process and washing process of the mechanical parts described in this paper, developed heat pumps including direct heating type have been also introduced such as the hot spring warming of hotels. Therefore, we are expecting a widespread expansion of the commercial use of the developed heat pump. In order to meet the needs of various customers, we want to contribute to the development and widespread use of high-temperature heat pump in the future

Acknowledgements

The authors would like to thank the SHINSHU MILK LAND Co., Ltd. and the Toyoda Gosei Co., Ltd. for cooperating of this study. The authors would also like to thank Mr Yoichi Miyaoka and Mr Takashi Namiwo for technical advices and support for this study.

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