DEVELOPMENT OF ABSORPTION HEAT PUMP CHILLERS WITH IMPROVED HEATING EFFICIENCY BY APPLYING HEAT PUMP CYCLE

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Abstract: Improvements have continually been made in the performance of absorption chiller-heaters in the cooling mode. On the other hand, the heating performance has not been improved because of the difficulty in constructing an appropriate heat pump cycle. The purpose of this study is to improve the heating performance of absorption chiller-heaters by using a heat pump cycle in the heating mode. We call these machines “Absorption heat pump chillers (AHPC)”. The main difficulty of constructing an AHPC is reducing the pressure of the high temperature generator. We applied two-stage evaporator and absorber to reduce the pressure. Consequently, we developed two types of AHPCs. The first type is a double-effect absorption heat pump chiller. In the heating mode, this machine uses 12°C water as a heat source to provide 45°C water for space heating. The coefficient of performance (COP) in the heating mode was calculated at 2.2. The second type is a double-output absorption heat pump chiller. This provides chilled and hot water simultaneously. The experimental results from this machine showed a combined heating and cooling COP of 3.3.

Key Words: absorption heat pump, heating efficiency, heat recovery

1 INTRODUCTION

Thermal energy is a major source of renewable energy. It appears as waste heat from co-generation systems (CGSs), heat from rivers, and ground, sea, and sewage water. The heat dissipated when cooling a space is also considered renewable heat energy. The purpose of this report is to show how to effectively use them. Absorption heat pump cycle is very suitable for this object, because it can be driven by mainly heat energy.

In the industrial sector, we have made absorption heat transformers commercially available and used waste heat from CGSs and rectifying columns. Meanwhile, carbon dioxide emissions from the commercial sector are significantly increasing and the ratio of this sector in Japan exceeded 18% in 2005. In business use, such as in office buildings, more than 30% of carbon dioxide levels are emitted through air-conditioning.

For air-conditioning use, absorption chiller/heaters are used for both cooling and heating. Their cooling performance has been improved over the years, as seen in Figure 1. However, their heating performance has not been enhanced because of the difficulty in constructing a sufficient heat pump cycle. Therefore, they are operated as simple boilers or simply used for only cooling as “absorption chillers”. In these cases, the coefficient of heating performance cannot exceed 1.0, nevertheless the heating performance is just as the cooling performance.

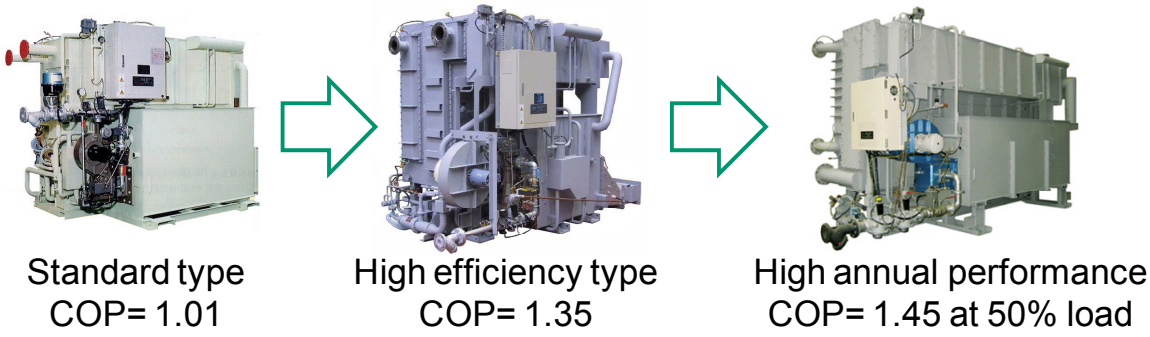


Figure 1: Improvements in cooling COP (numbers are based on high heat value)

The purpose of this study is to improve the heating performance of absorption chiller-heaters by using a heat pump cycle in the heating mode. For this purpose, we developed two types of absorption heat pump chillers (AHPC). These machines are made for air-conditioning and use LiBr/H2O as their working fluid likewise conventional machines. And They have the same functions as heat pumps in the heating mode, which makes them different from conventional absorption chiller/heaters.

2 CONSTRUCTION OF ABSORPTION HEAT PUMP CYCLE

2.1 Difficulty in constricting AHPC cycle

One of the challenges in developing an AHPC is to heat up hot water to a usable temperature for space heating, e.g., 45°C in an absorber and the condenser, without increasing the highest pressure allowed in the high-temperature generator (HG). Normally, a temperature increase in these components increases the pressure. The temperature of the hot water in the AHPC is 7°C higher than the cooling water in the conventional cycle. As shown in Figure 2, This raises the pressure of HG (p_{HG}) from around 50 to over 100 kPa.

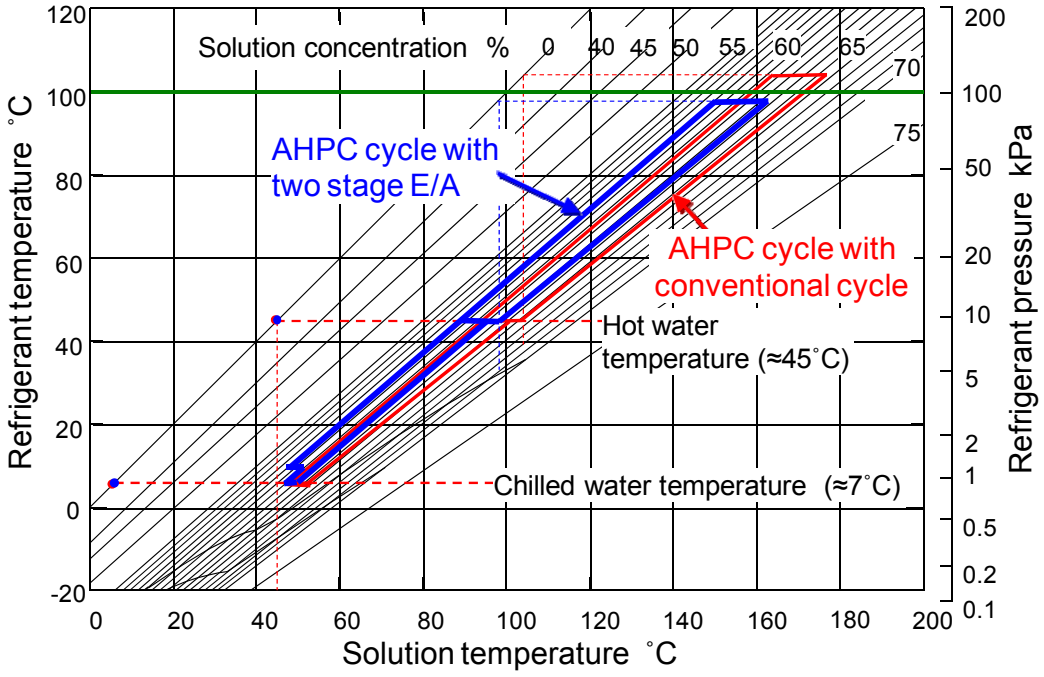


Figure 2: Schematic Duhring chart of AHPC compared with conventional cycle

This pressure rise causes two problems. The first one is a safety issue, and the second problem is that a higher steam pressure is necessary when using a steam-driven type. Therefore, reducing the level of pressure to at least highest acceptable level is necessary in order to bring AHPCs into real use.

2.2 Pressure reduction using two-stage evaporator and absorber

As a solution to this issue, we adopted the "two stage evaporator and absorber" shown in Figure 3. This configuration creates a different level of pressure between the upper and lower spaces. The pressure in the lower level is higher than that in the higher level, because the heat source water provided to the lower evaporator is higher than that in the upper evaporator. According to the Raoult's law, this will weaken the solution concentration taken from lower absorber.

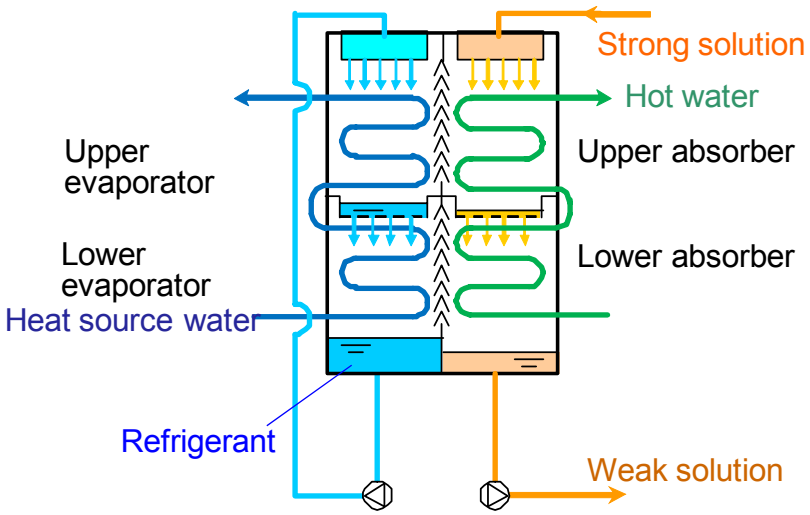


Figure 3: Configuration of two-stage evaporator and absorber

Thus, the pressure in the HG (p_{HG}), accompanied with this decrease in concentration, is reduced and balanced. In our example case shown in Figure 2, the p_{HG} changed from 102 to 87 kPa due to a 2% decrease in concentration.

3 DEVELOPMENT OF TWO TYPES OF ABSORPTION HEAT PUMP CHILLERS

3.1 Double-effect absorption heat pump chiller

3.1.1 Cycle configuration

The double-effect AHPC is an advanced absorption chiller/heater, which works as a heat pump when in the heating mode. The cycle configuration is similar to that in a conventional double-effect absorption chiller-heater. In addition, this cycle can use waste heat such as coolant of gas engines or hot water from solar panels as an auxiliary heat input.

Figure 4 shows the cycle flow diagram of a waste heat utilization AHPC. In the heating mode, this cycle takes up the low temperature heat into its evaporator and boosts up by absorption heat pump cycle. The output heat is delivered from its absorber and condenser as 45°C hot water.

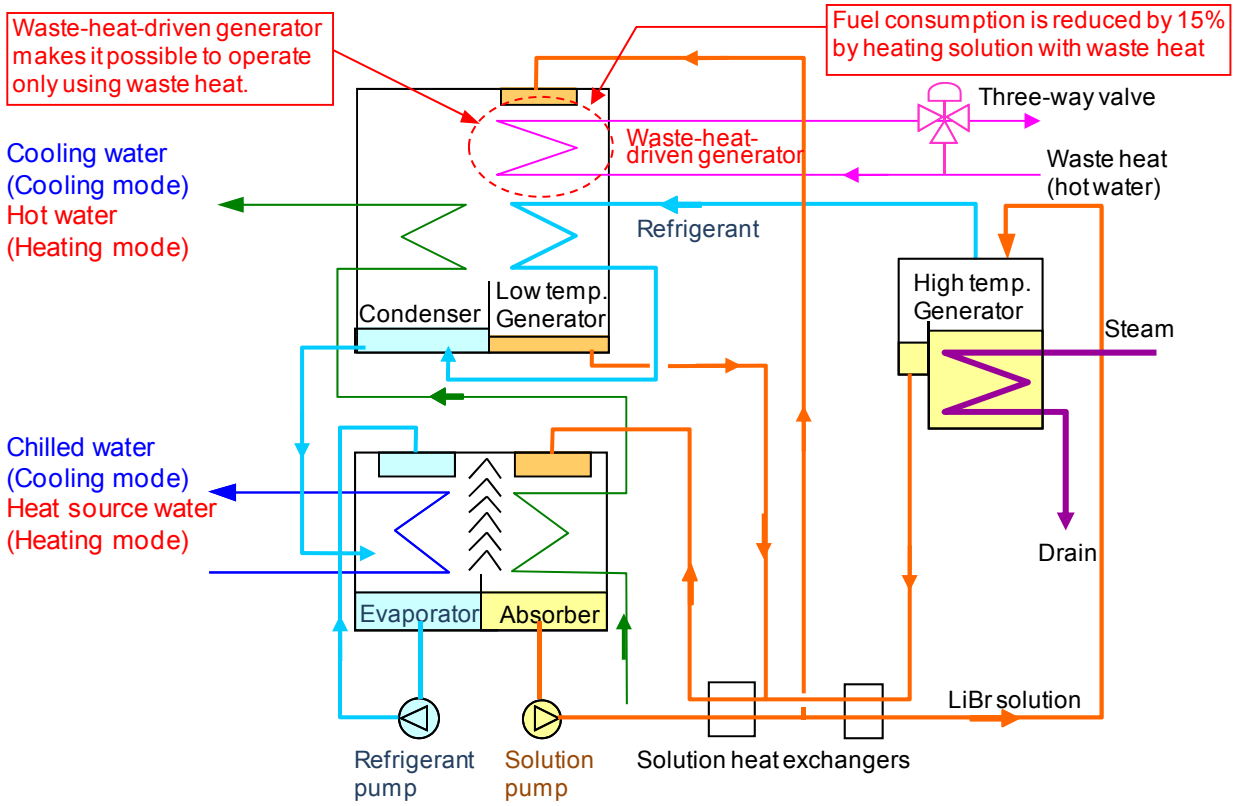


Figure 4: Cycle flow diagram of double-effect AHPC with auxiliary waste heat recovery

As shown in the Figure 4, this cycle has a waste-heat-driven generator (WG) in the same chamber as the low-temperature generator (LG). The auxiliary waste heat concentrates the LiBr/H2O solution in the WG and generates refrigerant vapor. As a result, the steam consumption is reduced by a maximum of 15%.

3.1.2 Performance calculation

We conducted a cycle simulation to estimate the performance of this new machine, using a program that has already been validated by other conventional absorption machines. Table 1 lists the conditions for our simulation.

Table 1: Performance calculation conditions

Mode	Calculating conditions
Cooling	Chilled water outlet: 7°C Cooling water inlet: based on JIS standard Flow rate of chilled and cooling water: constant
Heating	Heat source water inlet: 12°C Hot water outlet: 45 °C Flow rate of heat source water and hot water: constant
Capacity ratio of cooling and heating is 100:80	

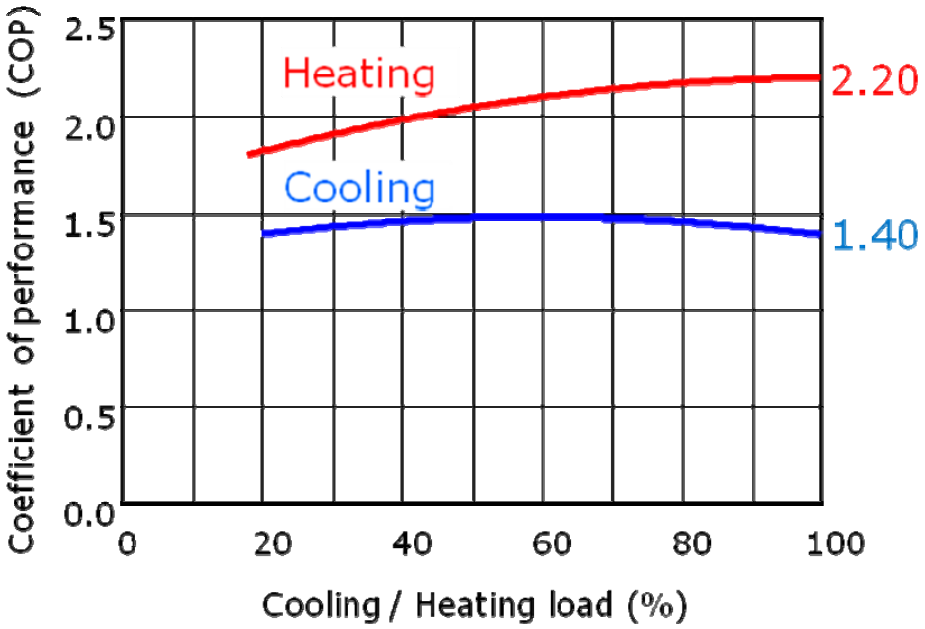


Figure 5: Calculation result of heating COP and cooling COP

Figure 5 shows the simulation results of partial load performances in both cooling and heating modes. By using heat pump cycle, the coefficient of heating performance (COPh) of this machine improved significantly. The COPh in a 100% load reached 2.2 without auxiliary waste heat (hot water), based on steam consumption.

3.1.3 Basic specifications of manufactured double-effect AHPC

We created a normal-type double-effect AHPC in 2009 base on the above results, and the waste heat utilization type was put into use in 2010. Table 2 lists the specifications for currently manufactured double-effect AHPCs. The auxiliary waste heat is assumed to be supplied from a gas engine generator of a CGS as its jacket coolant.
The COP is defined as the capacity divided by the steam heat input, and the waste heat is not included as an input. In the heating mode with auxiliary waste heat, the COPh was 2.59, thus reducing the steam consumption by 61% compared to that in conventional machines. This reduces the carbon dioxide emission by 42% annually. Figure 6 shows a photograph of such a double-effect AHPC.

Table 2: Specifications of double-effect AHPC (steam-driven type)

Item		Cooling mode	Heating mode
Capacity ratio		100	80
COP without auxiliary waste heat		COPc = 1.50	COPh = 2.20
COP with auxiliary waste heat		COPc = 1.88 (= 1.50 / 0.80)	COPh = 2.59 (= 2.20/0.85)
Steam reduction ratio by auxiliary waste heat		20%	15%
Waste heat conversion efficiency		0.8	1.7
Temperature under standard conditions	Chilled or heat source water (in/out)	(Chilled water) 12 / 7 °C	(Heat source) 12 / 9 °C
	Cooling or hot water (in/out)	(Cooling water) 28 / 33 °C	(Hot water) 40 / 45 °C
	Waste heat source water	90 / 80 °C	90 / 87 °C

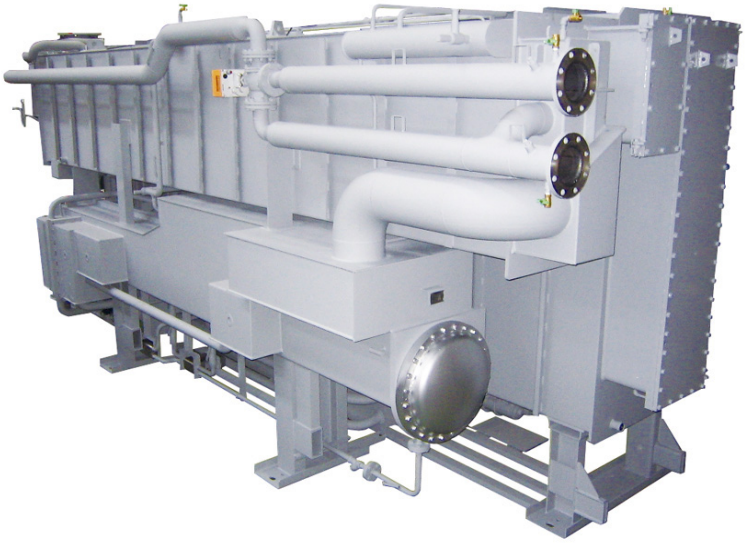


Figure 6: Photograph of double-effect AHPC

3.2 Double-output absorption heat pump chiller

3.2.1 Cycle configuration

The double-output AHPC is also an advanced absorption chiller/heater that provides chilled and hot water simultaneously to meet the demand for air conditioning. Similar to a double-effect AHPC, this machine operates as a double-effect absorption chiller in the cooling mode. In the heating mode, it operates as a double-effect absorption heat pump and provides chilled and hot water for air conditioning. This machine also uses a two-stage evaporator and absorber, as shown in Fig. 3.

A cycle flow diagram of the double-output AHPC is shown in Figure 7. The configuration of this machine is also similar to that of conventional double-effect absorption chiller/heaters.

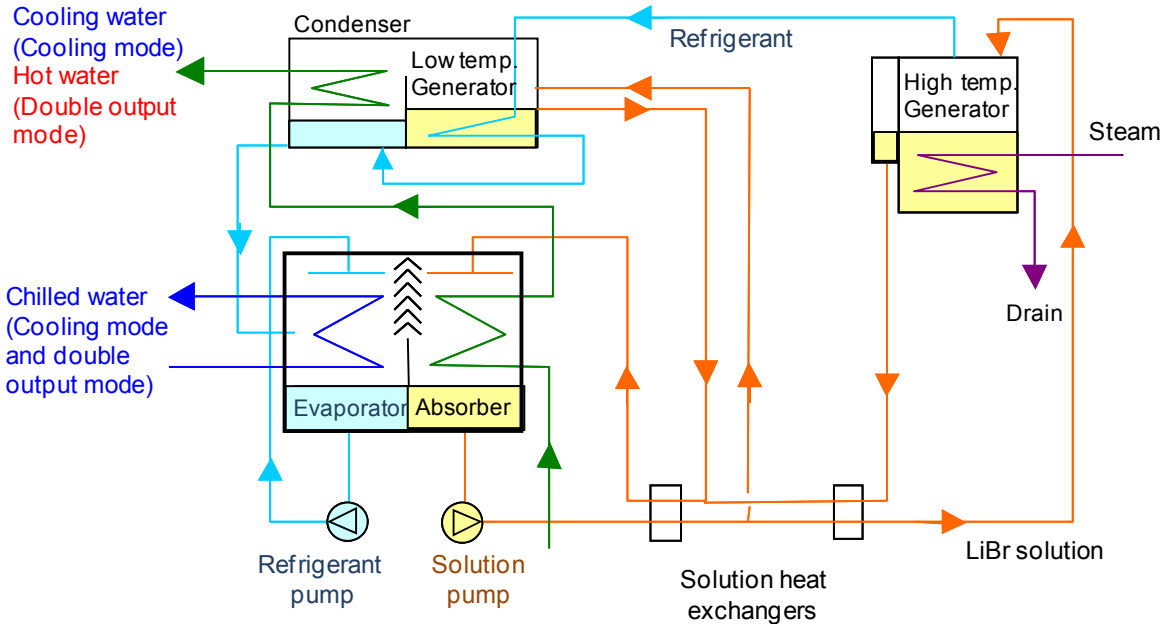


Figure 7: Cycle flow diagram of double-output AHPC

3.2.2 Definition and calculation of integrated COP (COPi)

Example specifications were calculated for the double-output AHPC, which is similar to a double-effect AHPC. The results are listed in Table 4. An integrated (COPi) is defined as:

$$\begin{aligned} COPi &= (Qheat + Qcool) / Qinput \\ &= COPh + COPc \end{aligned} \quad (1)$$

The COPh was 2.15 and COPc was 1.15. As a result, the predicted COPi was 3.3.

Table 4. Specifications and COPi of double-output AHPC.

Item	Cooling mode	Double-output mode
Capacity (Normalized)	Cooling: 100	Cooling: 38 Heating: 72 Total: 110
COP based on steam consumption	COPc = 1.40	COPi = 3.30
Water temperature (in/out)	Chilled water: 12 / 7 °C Cooling water: 32 / 37 °C	Chilled water: 12 / 7 °C Hot water: 40 / 45 °C

3.2.3 Performance calculation and test results

We have also developed a prototype of the double-output AHPC and evaluated its performance. Table 5 lists the conditions for our simulation and performance test. Figures 8 and 9 show the results of a double-output performance test. The results are in good agreement with the cycle simulation.

In Figure 8, the heating and cooling performances decrease according to the capacity. This is caused by a drop in temperature in the chilled water inlet and a rose in temperature in the hot water inlet, as shown in Figure 9. These changes degrade both the COPc and COPh and as a result, the COPi.

Table 5: Conditions of performance calculation

Mode	Calculating condition
Cooling and heating	Chilled water outlet: 7 °C Hot water outlet: 45 °C Flow rate of chilled water and hot water: constant

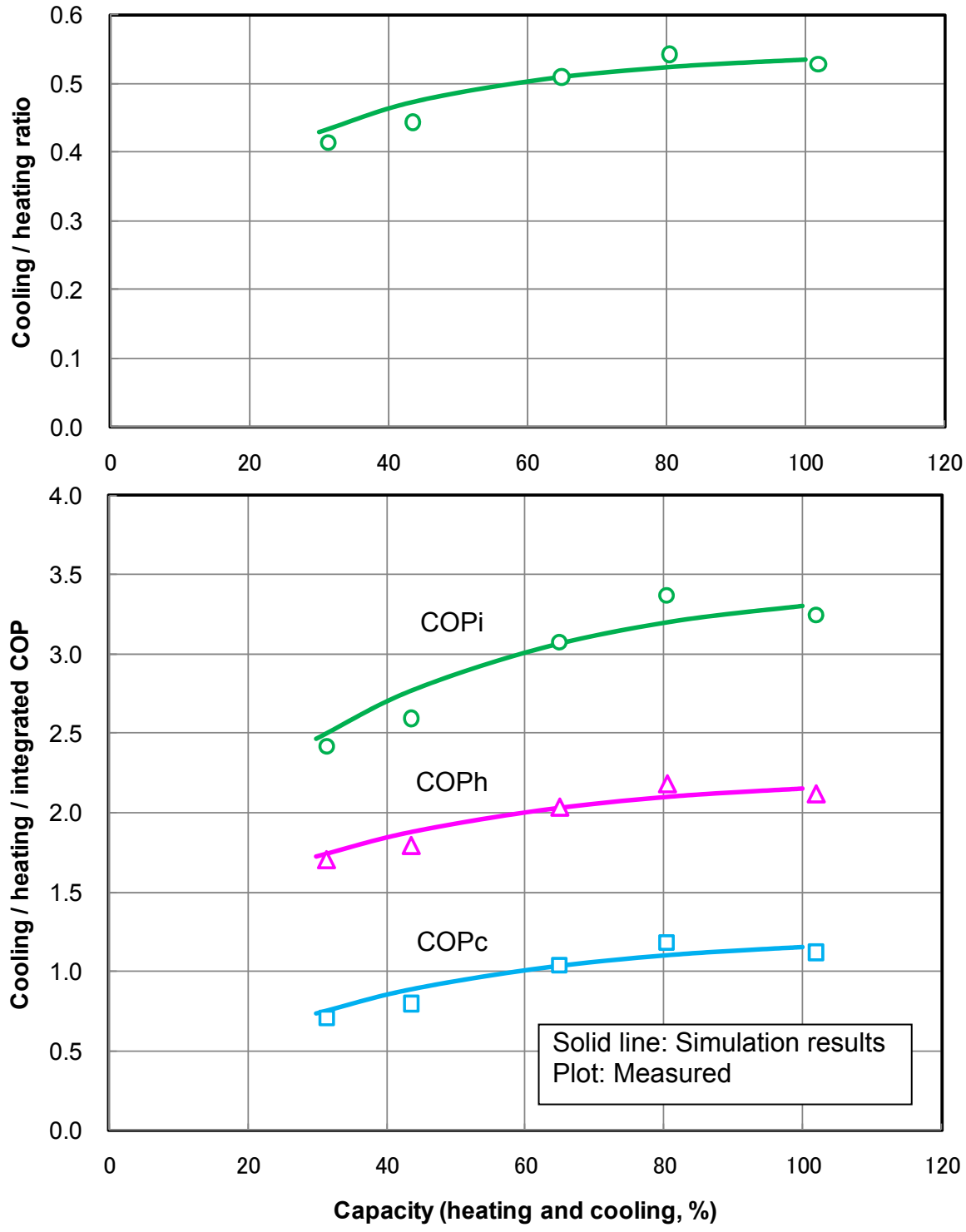


Figure 8: COP and cooling / heating ratio of double-output AHPC in double-output mode (Experimental data compared with simulation results)

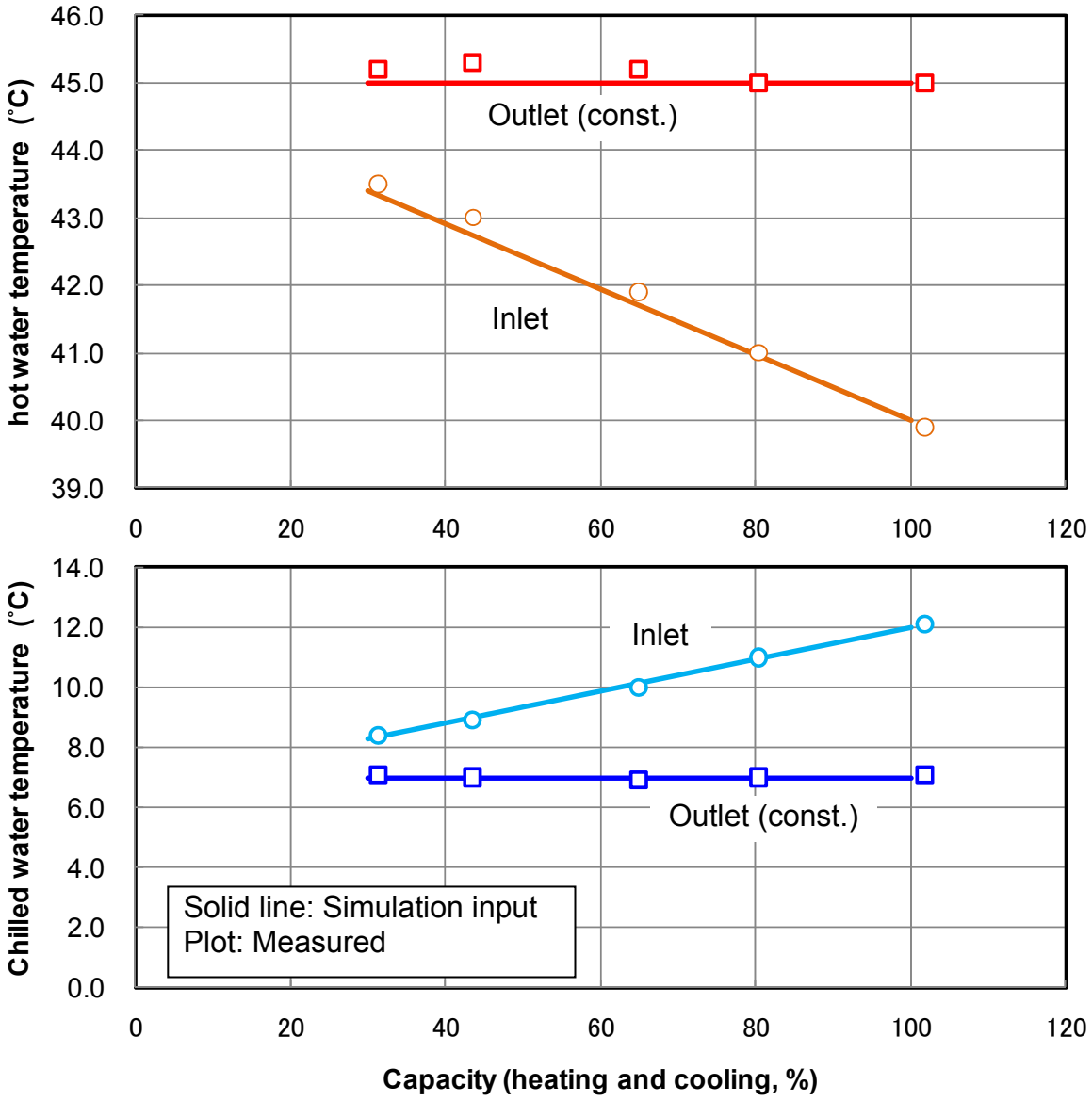


Figure 9: COP and cooling / heating ratio of double-output AHPC in double-output mode (Experimental data compared with simulation results)

3.2.4 Energy saving performance of double-output AHPC

Table 6 compares the estimated energy consumption of the double-output AHPC with that of a conventional system consisting of a high performance absorption chiller for space cooling and a boiler for space heating. In this calculation, AHPC reduces 66% of energy consumption in the double-output mode. In addition, the double-output AHPC is operated only when the heating and cooling loads occur at the same time. With this in mind, annual energy reduction is estimated to be 34%.

We estimated another case where the capacity of the double-output AHPC was selected to be 20% of the total facility. In this case, the energy saving effect was calculated at 19% annually compared with that of a conventional system that uses absorption chiller/heaters.

Table 6. Energy saving performance of steam-driven double-output AHPC

Operating mode		Conventional system (Absorption chiller and boiler)	Double-output AHPC
Cycle configuration	Cooling	High performance double-effect absorption chiller	
	Double-output	Absorption chiller and boiler	Double-output double-effect AHPC
Efficiency based on steam input	Cooling	1.40	1.40
	Double-output (cooling)	1.40	1.15
	Double-output (heating)	1.00	2.15
Assumed air conditioning load (kWh)	Cooling	281,600	
	Double-output (cooling)	80,256	
	Double-output (heating)	152,064	
Equivalent full load operating hours (h)	Cooling	800	
	Double-output	600	
Steam consumption (kWh)	Cooling	201,143	201,143
	Double-output	203,390	70,727
	Annual performance	410,533	271,870
Normalized energy consumption	Cooling	100	100
	Double-output	100	34 (66% reduced)
	Annual performance	100	66 (34% reduced)

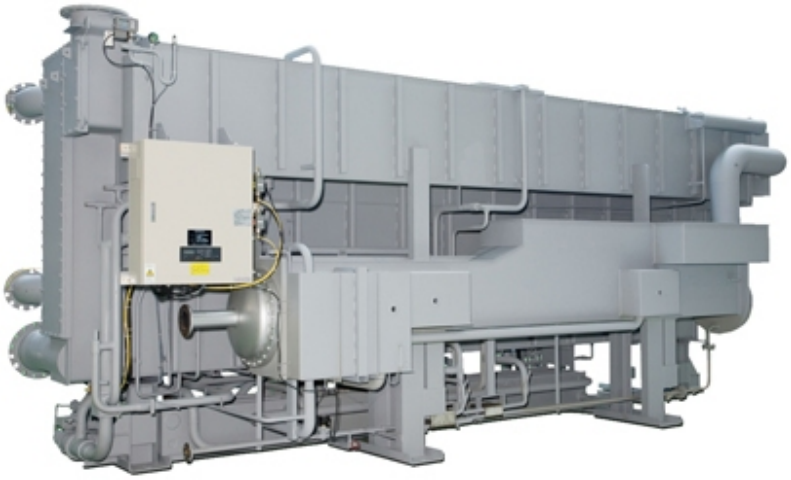


Figure 10: Photograph of double-output AHPC

Figure 10 shows a photograph of a double-output AHPC. The predicted COPi of 3.3 in Table 4 is currently the highest value in the world when using the double-effect absorption cycle.

4 CONCLUSION

We developed two types of novel AHPCs.

1) A double-effect AHPC that achieved a COPh of 2.20 by reusing low temperature waste heat, i.e. 12°C. This COPh reached 2.59 when an auxiliary waste heat of co-generation of 90°C water was obtained.

2) A double-output AHPC achieved a COPi of 3.30 by reusing the waste heat from the cooling cycle as the heat source for space heating. This reduced the steam consumption by 66% in a simultaneous cooling and heating mode. This machine is expected to reduce a large amount of the energy consumption and carbon dioxide emissions from facilities that annually have cooling and heating loads at the same time, such as data centers, business offices, commerce facilities, and district heating and cooling centers..

Finally, we are continuing our R&D of absorption heat pumps for reducing carbon dioxide emissions and mitigating global climate change.

5 REFERENCES

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