

AN ABSORPTION / COMPRESSION HYBRID SYSTEM FOR HIGH TEMPERATURE HEAT PUMP

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Abstract: Recently, also at the temperature level above 100°C, there are great demands of heat pumps in order to reuse heat that is often exhausted. In this study, absorption/compression hybrid cycle was studied based on the chart analysis. Water is supposed as a main refrigerant and glycerol as an absorbent.

The hybrid system is composed of the same components of conventional compression system, which are a compressor, a condenser, an expansion valve and an evaporator. And to have to have high temperature lift, internal heat exchanger is added to the system.

In the analysis, ideal condition was assumed; two-phase compression can be possible and that there is no pressure drop and heat leak at heat exchangers.

The analysis showed that moderate COP could be obtained by the hybrid system at low-pressure ratios without excess super heat of the gas discharged by the compressor.

Key Words: heat pump, high temperature, hybrid, absorption, compression

1 INTRODUCTION

In many industrial processes, heat has been supplied mainly by the combustion of fuel especially when the heat demand temperature is more than 100°C. This is because the initial and the running costs of the boiler were relatively low. And recently, also at the temperature region, there are great demands of heat pumps in order to reuse heat that is often exhausted and to decrease CO₂ emissions.

For the high temperature heat pumps for such temperature region, water is promising. When the temperature lift is high, the pressure and super heat become large. In order to solve these problems, the possibility of applying absorption/compression hybrid cycle has been investigated. The feature of the hybrid cycle are that pressure and/or pressure ratios are small and this can prevent excess superheat and that when internal heat exchanger is added, large temperature lift is obtained.

As a working fluid mixture, it is desirable that it is environment friendly, and it has no toxicity and low flammability. In this study, refrigerant mixture water/glycerol is supposed.

2 ABSORPTION/COMPRESSION CYCLES

There are many variations in absorption/compression cycles. The major working fluid is an ammonia/water mixture (Groll and Rademacher 1994). Figure 1 shows the outline of the system discussed in this study. Figure 1 (a) is a cycle of which components is the same as the conventional heat pump system. Figure 1 (b) has an internal heat exchanger to exchange heat from the high-pressure side after condenser to the low-pressure side after the evaporator. The hybrid cycle is categorized in to two types. One started from the absorption

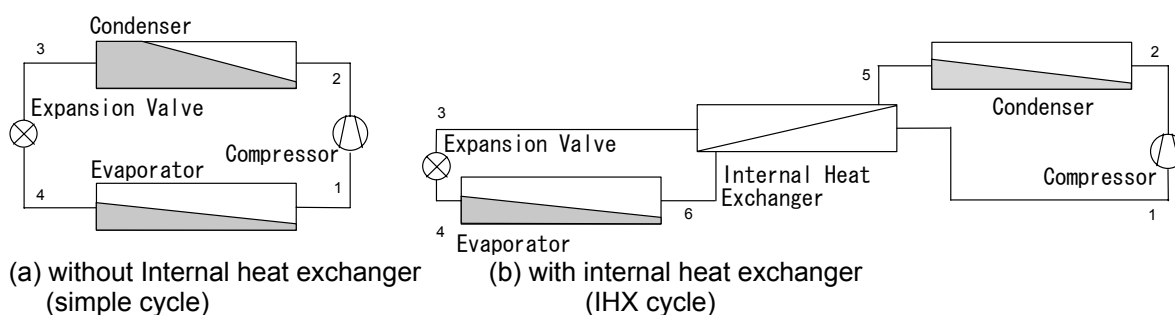


Figure 1: Absorption/Compression Hybrid Cycle

cycle, in which a compressor is used to assist the performance of desorber (evaporator) and the absorber (condenser). The other type originated from the conventional vapor compression cycle. This latter type is the object of this study. In the conventional system, sometimes non-azeotropic refrigerants are used in order to decrease the heat exchanger loss. And internal heat exchanger is often used in order to decrease expansion loss. The absorber replaces the high boiling point refrigerant. And internal heat exchanger in Figure 1 (b) is not special apparatus only for hybrid cycle.

In the absorption/compression cycles, solution pump is often used to send liquid from the compressor suction point to the compressor discharge point. In the system supposed here, the solution pump is not attached, supposing that the volume ratio of the liquid to the gas is small and the compressor mechanism is durable for two-phase compression.

3 VAPOR –LIQUID EQUILIBRIUM OF WATER/GLYCEROL MIXTURE

The vapor-liquid equilibrium of water/glycerol mixture is shown in Figure 2. At the pressure region from 0.1 to 0.5MPa the boiling point difference between water and glycerol is about 200°C. The large difference in boiling points satisfies one of the conditions necessary to the absorption/compression hybrid cycle. The vapor-liquid equilibrium was calculated based on the literature (David et al. 1970, Fukui Y. 1999). The NRTL equations were used to calculate the vapor-liquid equilibrium. NRTL parameters given by the literature were used: $E_{12} =$

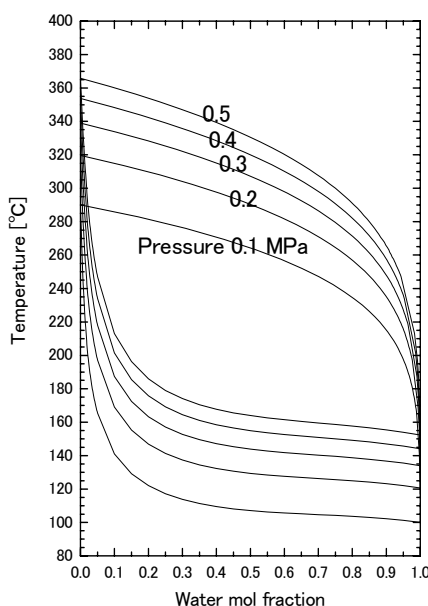


Figure 2: Liquid-Vapor Equilibrium of Water/Glycerol

726.96, $E_{21} = -19.56$, $\alpha = 0.218$.

4 CALCULATION METHOD

In the calculation of the heating COP, the following assumptions were made:

1. Isentropic compression at the compression (1-2 in Figure 1).
2. Isenthalpic expansion at the expansion (3-4 in Figure 2).
3. No heat leaks from each components and no pressure drop at heat exchangers.

The calculation was executed, first giving the working fluid conditions; low pressure (P_1 , P_4 and P_6), high pressure (P_2 , P_3 and P_5) and temperatures at compressor suction T_1 and at the point before the expansion valve T_3 . From the condenser (in Figure 1(a)) or internal heat exchanger (in Figure 1(b)), only liquid exits and flows into expansion valve. And the mass flow rate of each components of the working fluid which flows at each point of the cycle are equal to the mass flow rate of the component at the point before the expansion valve (point 3 in Figure 1). Only liquid phase exists at point 3, and at other points, the some of the gas phase and liquid phase mass flow of each component equals to that of point 3. The temperature at the entrance of the evaporator (4) is determined so that enthalpies become the same between point 3 and 4. The temperature at the entrance of the condenser is determined so that the entropy at the exit of the compressor matches the entropy at the entrance of the compressor.

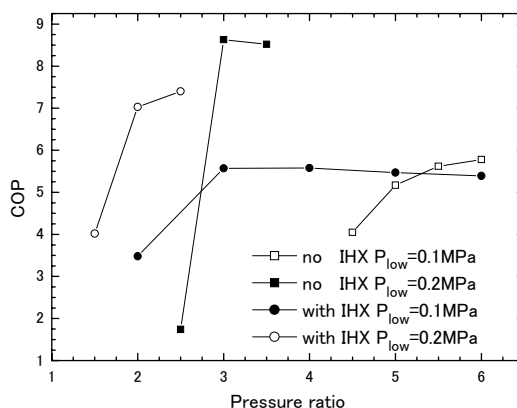
In the system, which has internal heat exchanger, the temperatures at the exit of condenser and at the exit of the evaporator were determined satisfying the following conditions:

4. The smallest temperature difference is 5°C to exchange heat.

5 RESULT

5.1 Basic Characteristics of the Cycle

Figure 3 shows the heating COP of the simple cycle without internal heat exchangers (simple cycle) and the cycle with internal heat exchanger (IHX cycle). Square symbol shows simple cycle COP and circle symbol shows IHX cycle COP. A black symbol shows the COP of the low side pressure is 0.1MPa, and white the COP of the low side pressure is 0.2MPa. The



**Figure 3: Heating COP
(temperature lift: 150-175°C)**

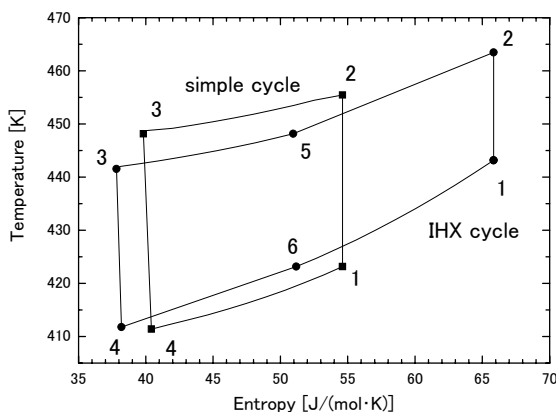


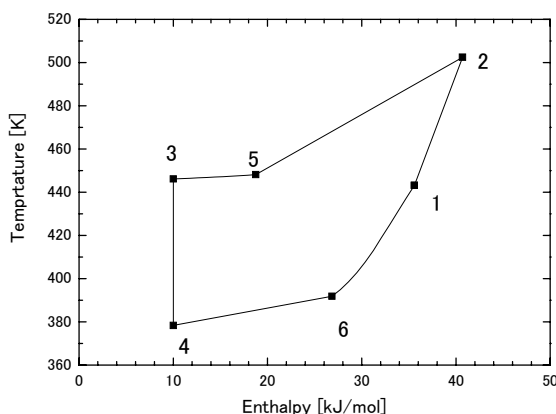
Figure 4: T-s Diagram of the Cycles

temperature condition is that the evaporator exit temperature is 150°C and the condenser exit temperature is 175°C. The maximum temperature lift is 25°C.

It is seen that higher suction pressure gives high COP and low pressure ratio. And the COP curve becomes peaky when the suction pressure is high. The maximum COP 8.63 on these conditions is obtained by the simple cycle with the suction pressure 0.2MPa and with the pressure ratio 3. When the value is decreased supposing the isentropic efficiency is 0.7, COP 6.0 is still expected. When pure water is used, the pressure for the condensation pressure is 0.89MPa and the pressure is reduced to 0.67. The pressure of the IHX cycle is 0.56 of the pure water condensing pressure. A merit of the hybrid cycle appears here in the form of lowering pressure conditions. In this case, the COP value of IHX cycle is smaller than the simple cycle, but the highest temperature reached by IHX cycle is higher than that reached by simple cycle. Figure 4 shows the T-s diagram of both cycles on the highest COP. With the small temperature lift conditions, simple cycle gives higher COP than IHX cycle. The reason is that internal heat exchanger has a roll of increasing temperature lift, but it also produces the heat exchange loss within the internal heat exchanger itself. It is important to adjust operating conditions for heat source and heat sink and to choose the suitable cycle.

5.2 Typical operations of IHX Cycle

Figure 5 shows heats released and absorbed by the IHX cycle. And Table 1 shows the temperature and pressure conditions and component of the working fluid. The highest



**Figure 5: T-h Diagram of the IHX Cycle
(temperature lift: 56°C)**

temperature reaches to 229°C with the lowest temperature 105°C. The temperature lift is about 56°C, calculated from t_5 and t_6 . Calculating the average temperature, $(t_4+t_6)/2$ and $(t_2+t_5)/2$, it is about 90°C. Such high COP result with these temperature conditions were not obtained when the low side pressure is 0.2MPa. Further Investigation must be executed on wider cycle conditions to find the best design of the system.

The circulating liquid volume at the compressor entrance is about 0.2% of the total volume flow, and compressor is expected to be tolerable for this liquid ratio. In order to have 10kW heat output swept volume ratio of 11.5L/s will be required. This relatively large swept volume ratio is one of the disadvantages of the hybrid cycle.

Table 1: Conditions of simple cycle (Figure 5)

points		1	2	3	4	5	6
temperature (°C)		170	229.3	174	105.2	175	118.7
pressure (MPa)		0.1	0.7	0.7	0.1	0.7	0.1
water mol fraction	gas	0.99	0.98	1.00	1.00	1.00	1.00
	liq.	0.04	0.10	0.69	0.61	0.60	0.23

6 CONCLUSIONS

The Absorption/compression hybrid Cycle that uses the working pair water/glycerol has been introduced. By the chart analysis, the following conclusion can be drawn:

1. The system with water/glycerol can produce practical COPs.
2. For small temperature lift, simple cycle without internal heat exchangers shows high COP and for large temperature lift, internal heat exchanger cycle shows high COP.
3. Higher suction pressure of the compressor is desirable to have high COP.

7 REFERENCES

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