DEVELOPMENT OF A HYBRID AIR-CONDITIONING SYSTEM DRIVEN BY LOW TEMPERATURE WASTE HEAT

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ABSTRACT

Waste water with a temperature below 60°C is generally discharged because its temperature is too low for use as an energy source. If such waste heat can serve as an energy source, it can dramatically improve energy efficiency. Heating and hot water supply systems in hotels and hospitals can operate using waste heat, although air conditioning, rather than hot water supply, dominates energy consumption in administrative buildings. The invention of a new technology for exchanging low-temperature heat sources into cooling capacity for use in air conditioning is essential to encouraging the spread of CHP systems.

We are therefore developing a hybrid air-conditioning system driven by low-temperature waste heat at about 60°C. Specifically, we have established a following technology: low-temperature waste heat driven absorption system. In detail, a two-stage absorption cycle was selected which satisfied the target of a refrigeration cycle COP of 0.4 with minimum heat transfer area requirements. To demonstrate the two-stage absorption cycle driven by 60°C waste heat, the heat transfer area required by the heat exchangers were calculated using a cycle simulation software program. A proof-of-concept machine was designed and constructed based upon the results of the calculations. Operation of the proof-of-concept machine verified that the target cooling capacity and COP can be achieved utilizing the two-stage absorption cycle under 60°C waste heat conditions.

Key Words: ***absorption cycle, low temperature waste heat recovery, coefficient of performance.***

1 INTRODUCTION

Although many waste-heat recovery and utilization systems have been invented and put to practical use, these systems can only exchange relatively high temperature heat sources. Production processes generate large volumes of waste heat with a temperature of 60°C, but this waste heat is often released into the atmosphere because its temperature is considered too low to allow use as an energy source. Full utilization of this wasted source of energy would dramatically improve energy efficiency. The development of a technology for utilizing waste heat generated from distributed power systems has a number of implications for the future, as does the development of polymer electrolyte fuel cells (PEFCs). The lightweight construction and ease of installation of PEFCs have supported research and development of this technology. However, PEFCs generate waste heat that is around 60°C, and current technologies are not effective in using low-temperature heat sources.

Hotels and hospitals can use waste heat to operate hot water supply systems throughout the year. However, office buildings use much more energy, and use more air conditioning than hot water. Consequently, developing a technology to exchange waste heat into cooling capacity for use in air conditioning is important. We are therefore developing a hybrid air-conditioning system that can use low-temperature waste heat with a temperature of 60°C.

This hybrid air conditioning system comprises an absorption cycle and a compression cycle. The evaporator of the absorption cycle operates as the condenser of the compression cycle, and the evaporators of the compression cycle operate as the indoor units. See Fig. 1 for a diagram of this hybrid system. Table 1 shows the target specifications of the system.

As regards absorption cycle, commercial absorption chiller driven by hot water at 88°C adopts single effect absorption cycle. However, it is expected that the single effect absorption cycle can't be available with the heat source temperature of 60°C because of the principle. With the aim of solving this problem, optimal absorption cycle, which can be operated using low-temperature waste heat with a temperature of 60°C, is selected and demonstrated. This paper presents about it.

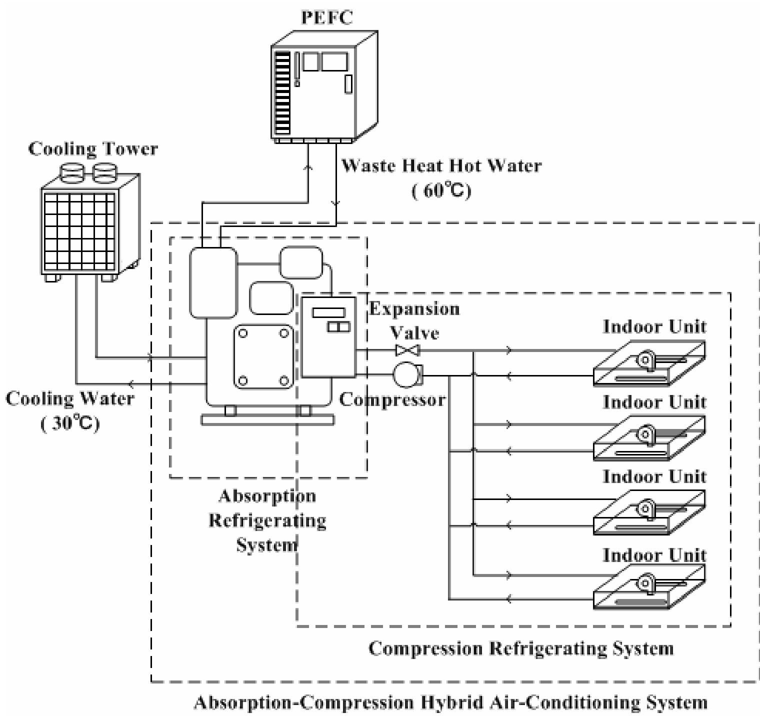

Fig. 1. Conceptual Configuration of Hybrid Air-Conditioning System

Table 1. Target System Specifications

Hybrid System	**Refrigeration Cycle**	Absorption-Compression Hybrid Cycle
	Hot Water Inlet Temp.	60°C
	Cooling Water Inlet Temp.	30°C
	System COP*	7
Absorption Cycle	**Cycle COP****	0.4
	Hot Water Inlet Temp.	60°C
	Cooling Water Inlet Temp.	30°C
	Evaporating Temp.	10°C
Compression Cycle	**Cycle COP*****	18
	Condensing Temp.	15°C
	Evaporating Temp.	7°C

*COP_{sys}=cooling capacity / total power consumption (including auxiliary power)

liary power)**COP_{Ab}=cooling capacity of absorption cycle / quantity of waste heat recovery

***COP_{com}=cooling capacity of compression cycle / power consumption of compressor

2 SELECTION OF APPROPRIATE ABSORPTION CYCLE

The three options for the absorption cycle driven by low-temperature waste heat are (1) two-stage cycle; (2) split-flow cycle; and (3) single-effect cycle combined with transformer cycle. We evaluated each cycle under simulated conditions and selected the best absorption cycle for the system. It is shown below for details.

2.1 Three Options for Absorption Cycle

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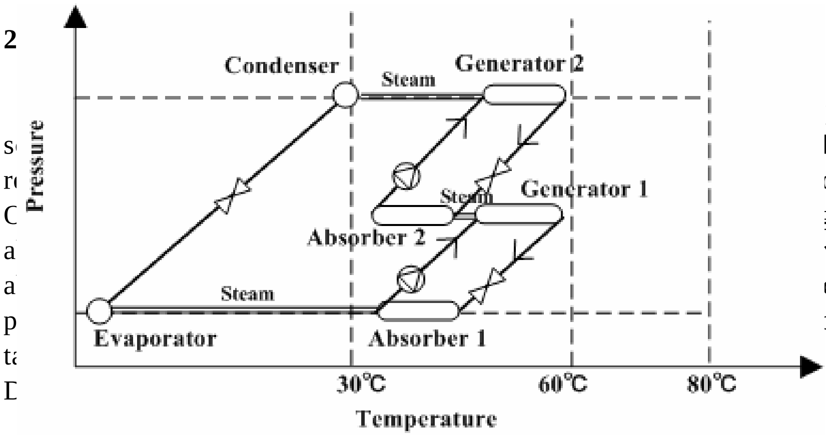

s… pressure cycle. The
r… l by 60°C heat source. The
C… ondensed at the condenser.
a… generator is directly
a… rated in an evaporator is
p… cycle, the generating
t… oduces cooling capacity at
D… 2 shows the schematic P-T

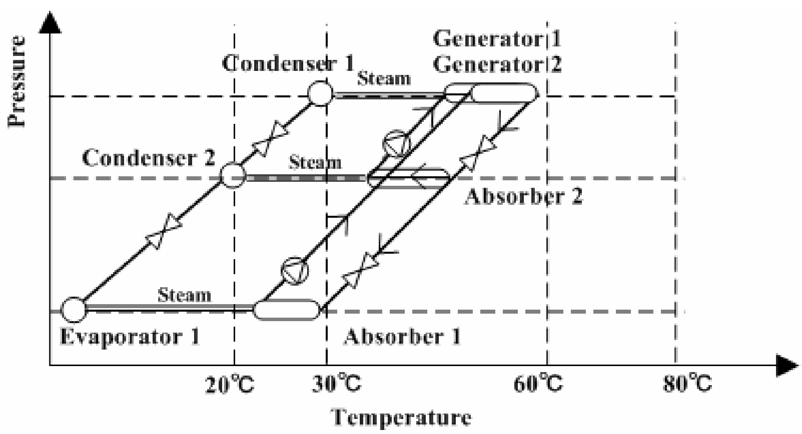

Fig. 2. Two-Stage Absorption Cycle

2.1.2 Split-flow Cycle

Although this cycle is also constituted by two cycles, a high-pressure cycle and a low-pressure cycle, the composition greatly differs from two-stage absorption cycle from the view point of a solution flow way. Fig. 3 shows the P-T Diagram of split-flow cycle. This cycle branches the strong solution from the high-pressure generator, a part is sent to the high-pressure absorber, and the other part is sent to the low-pressure absorber. The steam generated with the high-pressure evaporator is absorbed in the high-pressure absorber. At this time, cooling capacity at about 20 °C is generated in the high-pressure evaporator. The cooling capacity generated here is used for cooling the low-pressure absorber. This constitutes a low-pressure cycle and air conditioning capability is generated at target refrigerant evaporating temperature.

2.1.3 Single-effect Cycle Combined with Transformer Cycle

This cycle is the combination of a single-effect cycle and a transformer cycle. Fig. 4 shows the P-T Diagram of the cycle. At first, the low-temperature heat source at approximately 60°C is changed into the high temperature hot water of 80°C using a transformer cycle. And a single-effect cycle is driven by this 80°C hot water, and generates cooling capacity at target evaporating temperature.

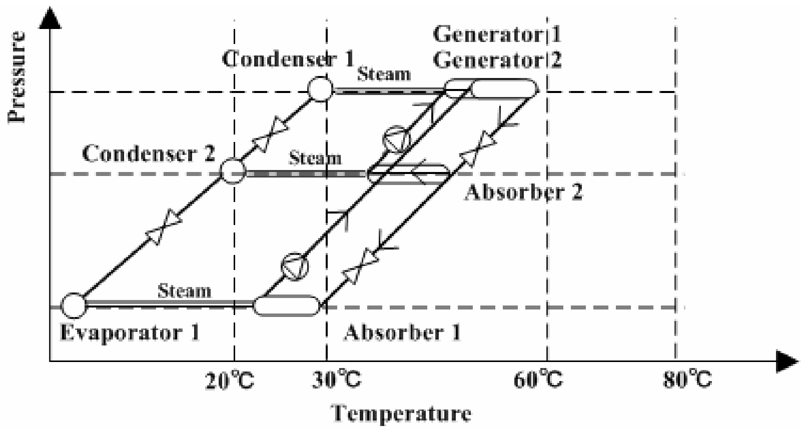

Fig. 3. Split-Flow Absorption Cycle

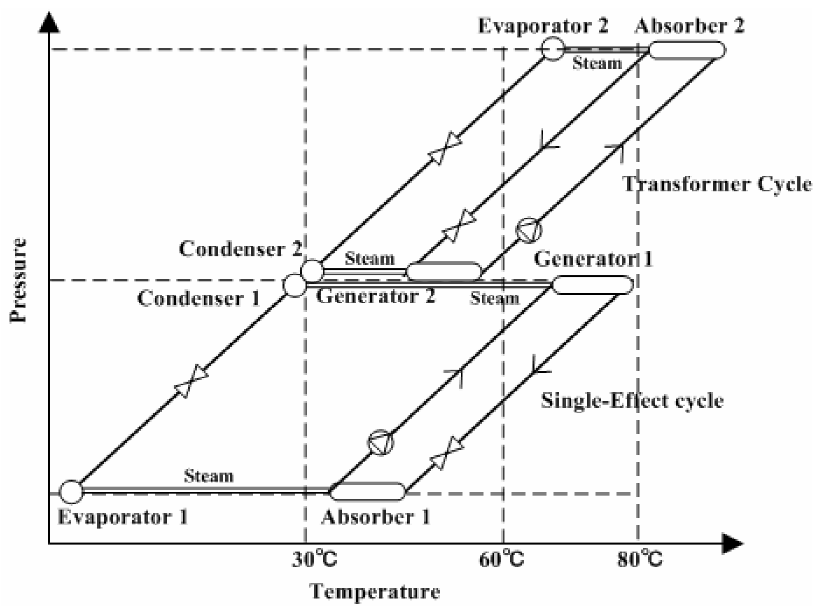

Fig. 4. Single-Effect Cycle Combined with Transformer Cycle

2.2 Pre-Evaluation of Each Cycle

Before carrying out comparison by the cycle simulation, we evaluated each cycle using the same set of standards to permit effective comparison. The two-stage cycle consists of six components, whereas the split-flow cycle consists of seven components. The single-effect cycle combined with a transformer cycle comprises as many as eight components (see Table 2), and was excluded from the evaluation due to the cost problems involved.

Table 2. The number of composition elements

	Two-Stage Cycle	Split-Flow Cycle	Single-Effect Cycle with a Transformer Cycle
Evaporator	1	1	2
Absorber	2	2	2
Generator	2	2	2
Condenser	1	2	2
Total	6	7	8

2.3 Comparison Using Cycle Simulation

2.3.1 Cycle Simulation Program

The cycle simulation program was developed using VBA of Microsoft Excel. The value indicated by McNeely was used about the heat physical-properties value of absorption solution.

2.3.2 Input Conditions of Simulation Program

KA value of each element, cooling-water inlet temperature and flow rate, hot water inlet temperature and flow rate, strong solution concentration were given as input conditions. About the cooling-water system and the hot water system, the conditions of 30°C cooling water and 60°C hot water which are standard setting conditions as a development system were given as input values.

2.3.3 Calculation Procedure of Simulation

It considered as the simulator which performs convergence calculation based on input conditions so that the heat balances, mass balances, and all the basic equations about heat transfer may be satisfied. Finally, it outputs calculation results, such as quantity of heat exchange of each element, and cycle COP, requirement heat transfer area, and so on.

2.3.4 Simulation Results

First, we created simulated conditions under which both the two-stage and split-flow cycles can theoretically achieve a target COP of 0.4. See Figs. 5 and 6 for P-T diagrams of the calculation results.

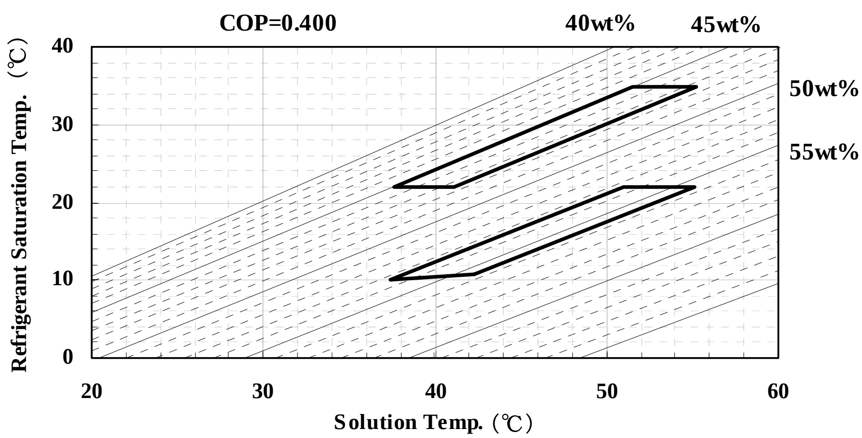

Fig. 5. Calculation Result of Two-Stage Absorption Cycle

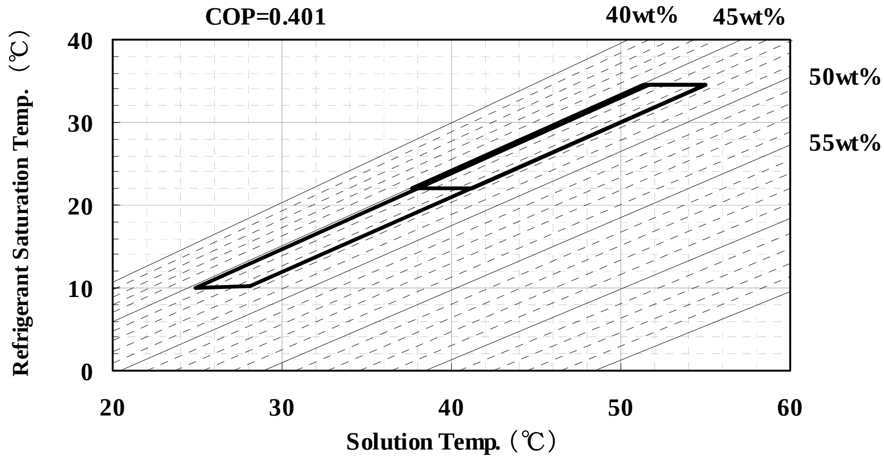

Fig. 6. Calculation Result of Split-Flow Absorption Cycle

For the purpose of practical applicability of the system, the cycle should not only achieve the target COP, but should also have the smallest possible heat transfer area because the size of the heat transfer area directly affects the weight and cost of the system. Consequently, the heat transfer area of each cycle was used as a parameter in the evaluation. See Fig. 8 for the results.

When the heat transfer areas are the same, we found that the two-stage cycle has a higher cycle COP. We decided to use a two-stage absorption cycle for the system.

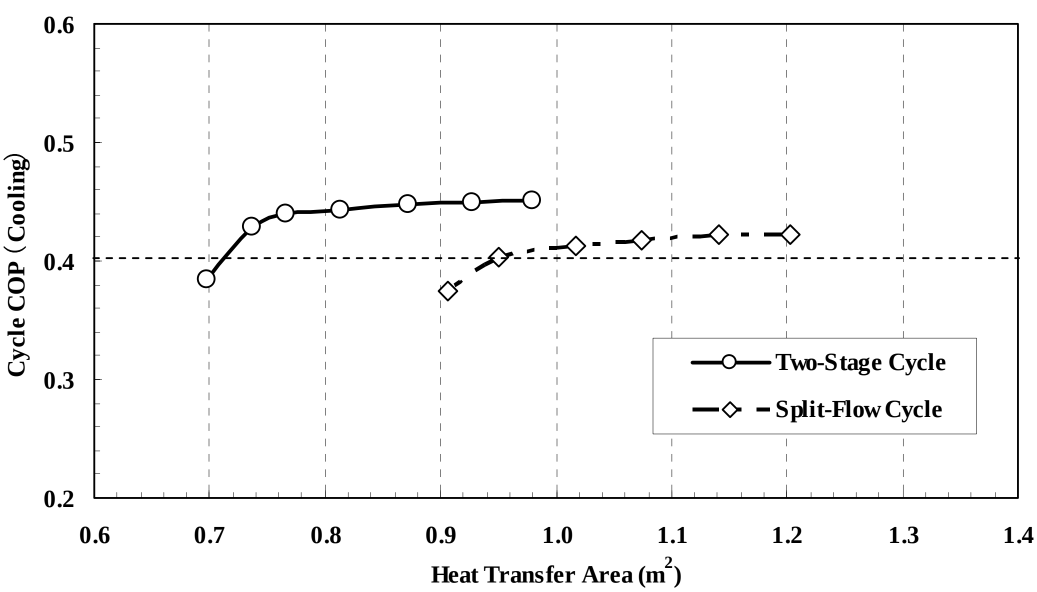

Fig. 7. Comparison of Cycle COP against the Heat Transfer Area of Each Cycle

3 DEMONSTRATION OF TWO-STAGE ABSORPTION CYCLE

3.1 Design of Proof-of-Concept Machine

Using the simulation program which was developed for appropriate cycle selection, the absorption cycle operation point for attaining the target cycle COP of 0.4 at the heat source hot water temperature of 60°C and the cooling-water temperature of 30°C was calculated. In calculation, it is necessary to take into consideration the heat dissipation to ambient environment from an absorption chiller. So, prior examination was performed. Actually, taking into consideration the surface area of a proof-of-concept machine, and the temperature difference between the environment and the solution, we concluded that approximately 5% of heat quantity was consumed by heat dissipation. The trial calculation was made by making into the conditions of the cycle COP of 0.42 which was calculated with taking into consideration 5% of heat dissipation in the cycle COP of 0.4 based on above consideration. The drawn cycle operating conditions are shown in Fig. 8.

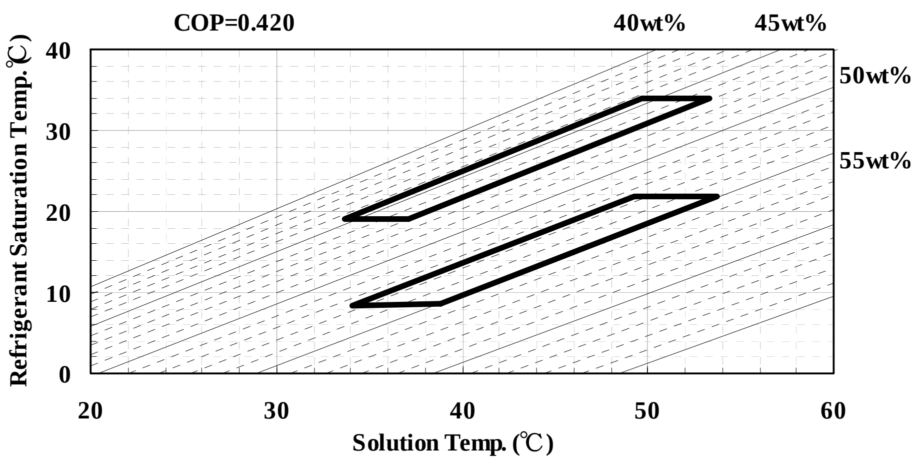

Fig. 8. Target Operation Point of Experimental Equipment

Moreover, the trial calculation of solution circulation conditions, such as concentration deference and a film Re number, was carried out based on the result calculated by the simulation software program. And basic structures of component heat exchangers, such as heat transfer area of the absorbers and generators, the number of paths, a pitch interval, and the length of heat transfer tubes, were determined. The shell & tube type was adopted as the heat exchanger of each element, such as absorbers and generators. And we decided to adopt the plate type for the solution heat exchangers.

3.2 Manufacture of Proof-of-Concept Machine

We then made a pilot system with a two-stage cycle. Fig. 9 shows visual features of equipment.

Fig. 9. The Constructed Proof-of-Concept Machine

3.3 Results of Demonstration Test

We conducted a demonstration experiment for the pilot unit with a two-stage cycle under given conditions (60°C waste heat; 30°C cooling water; 10°C refrigerant evaporating temperature). See Fig. 10 for a P-T diagram of the experimental result. The result of the experiment was similar to the result of the simulated evaluation, and demonstrated the two-stage system's high performance. Performance evaluation of the system under given conditions also proved that it can achieve the target cycle COP of 0.4.

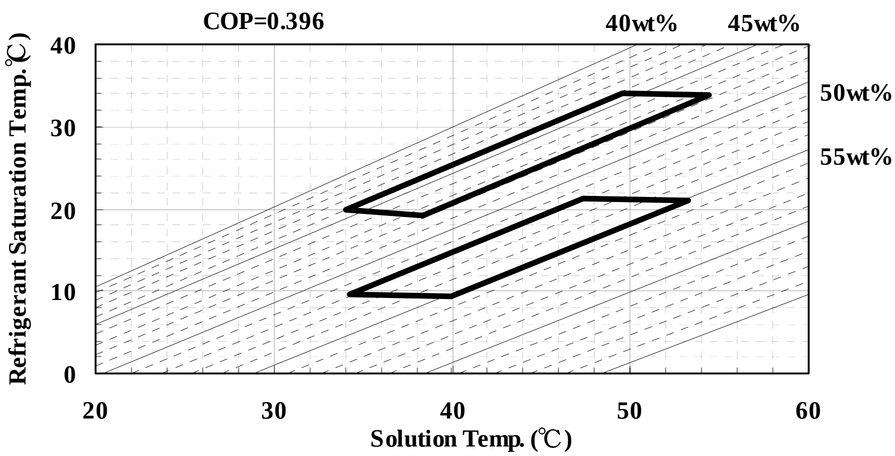

Fig. 10. P-T Diagram of Experimental Result

4 CONCLUSIONS

4.1 Selection of Appropriate Absorption Cycle

In order to evaluate the optimal cycle as an absorption cycle driven by low-temperature hot water of 60°C level, the simulator of candidate cycles were developed and the optimal cycle was selected. Consequently, it became clear that a two-stage absorption cycle can secure the high cycle COP in a small heat transfer area as compared with other cycles, and the two-stage absorption cycle was selected as an optimal cycle.

4.2 Demonstration of Two-Stage Absorption Cycle

The simulator developed at the time of optimal cycle selection was used, the principle experimental model of a two-stage absorption cycle was designed and manufactured, and the target performance was attained while proving the two-stage absorption cycle.

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