Research and Development of the Triple Effect Absorption Chiller-Heater Technology in Japan

This article reviews R&D of triple effect cycle developed in Japan.

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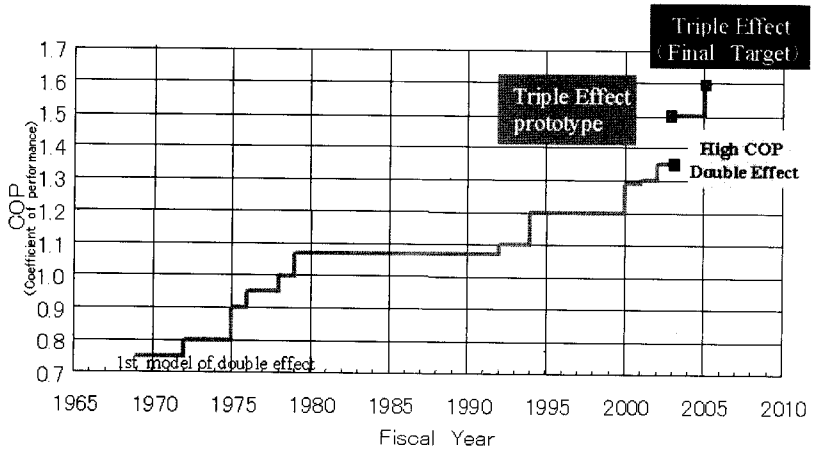
INTRODUCTION

Most of the refrigeration and heat pump technologies are dominated by vapor compressor system. The vapor compressor system, however, is highly concerned with the environmental regulations, as most of the vapor compressor technologies are using CFCs or HCFCs which are known as ozone depleting and global warming gases. As a consequence, refrigeration technologists are trying to invent or to develop an alternative to vapor compressor refrigeration devices. Thermally driven, absorption technology is one of the possible alternatives. At the moment, absorption cycle is most promising technology.

The paper summarizes briefly the current research and development in advanced technologies of triple effect absorption chiller-heater in Japan.

STATUS AND TARGET OF THE RESEARCH AND DEVELOPMENT

The Japanese gas utilities and manufacturers of absorption chiller-heaters have been developing high efficiency gas-fired double-effect chiller-heaters. The COP of the system is aimed at 1.35 as shown in figure 1. The detail of the development process is reviewed by Kashiwagi, et al, (2002).



[Fig. 1] Trend of the COP improvement of the gas-fired advanced absorption chiller-heater

Key technologies used in the development of the high efficiency absorption chiller-heater and the effects of them on COP are listed in table 1. It is found that the effect of the heat recovery in the cycle is the largest and the improvement of the thermal efficiency of the solution heat exchanger is important. On the other hand, the improvement of the absorber and evaporator is also necessary to achieve a COP of 1.35, though the value of COP, 1.35, is less than that of the heat recovery in the cycle.

The Japanese gas utilities and manufacturers of absorption chiller-heaters have been started the new project that the COP of the system is aimed at 1.60 in the triple-effect absorption chiller-heater as the Japanese national project. Table 2 shows the target of the development comparing with a state of the conventional machine. Details are mentioned in the following section based on the result report of this project in FY2001 (NEDO, 2002) and a summary report (Mori and Onoguchi, 2003).

DEVELOPMENT OF TRIPLE EFFECT ABSORPTION CHILLER-HEATERS

Outline of the project

The Japan gas association together with Japanese manufactures of absorption chiller-heaters has started a new project in the fiscal year of 2001, subsidized by a governmental organization so-called NEDO. Figure 2 shows the framework of the research. The project aims at researching and developing triple effect absorption chiller-heaters

<Table 1> Effect of each key technology on COP

Heat recovery in the cycle	0.2
– Solution heat exchanger	(0.12)
– Refrigerant heat exchanger	(0.06)
– Solution cooling absorber	(0.02)
Improvement of absorber and evaporator	0.07
– Two-stage absorption and evaporation	(0.02)
– Improvement of the KAvalue of the absorber and evaporator	(0.03)
– Enlargement of temperature difference between the inlet and outlet of the chilled water	(0.02)
Heat recovery from the exhaust gas	0.06
– Installation of air pre-heater (or solution pre-heater)	(0.06)
Total improvement of COP	0.33

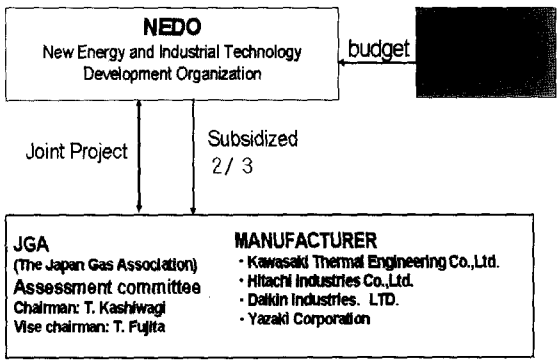
<Table 2> Status and target of the research and development on the advanced absorption chiller-heater

	Target	Conventional Machine
Type	Triple Effect	Double Effect
COP	Cooling: 1.60 (fuel based on HHV)	1.07
Volume	Within 120% (Percentage to the conventional machine)	100%
Utilization of waste heat from co-generation system	Reduction of gas consumption rate by utilizing waste heat of co-generation 20% and above	15%

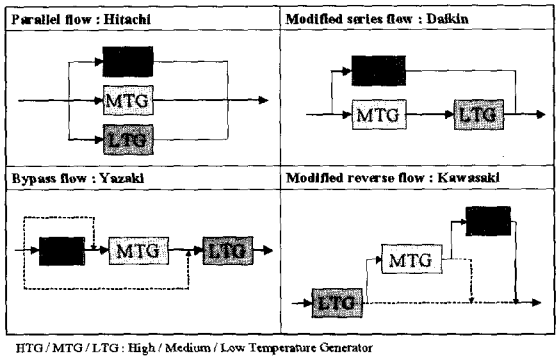
of which COP is 1.6. The brief plan of the project is listed in **table 3**. The project is scheduled to carry out for 4 years. Each of 4 participating manufacturers developed fundamental elements and a prototype machine with solution flow patterns that are characteristic to each of the manufacture as shown in **figure 3**. The Japan Gas Association (JGA) took a central role in the development of themes common to all manufacturers for the advancement of the overall project.

Development of corrosion repression technology

To build a database for the manufacturers to select suitable metal material and inhibitor, JGA started the evaluation examination of the material and inhibitor in the method of autoclave examination, the pipe examination, and the high



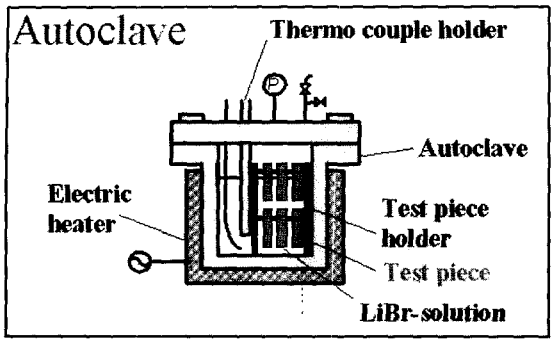
[Fig. 2] Research framework



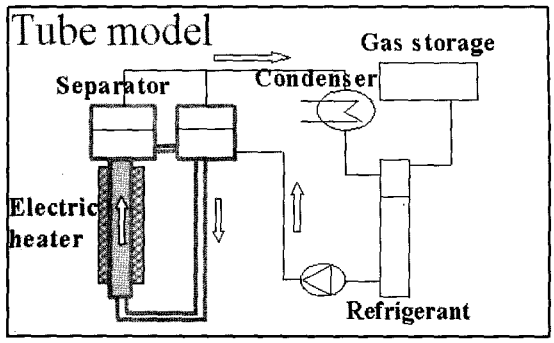
[Fig. 3] Solution flow patterns and arrangement of the generators

<Table 3> Developing points of triple-effect absorption chiller

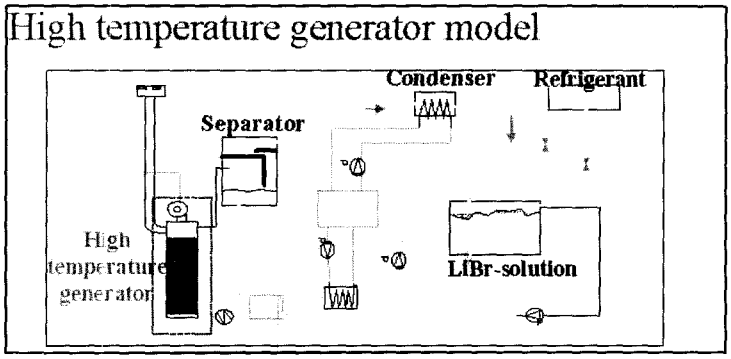
Contents		Section in charge	
		JGA	Manufacturer
Optimization of triple effect absorption cycle	Measurement of Thermodynamic Property of Lithium Bromide Solution	○	-
	Numerical Simulation of Triple Effect Cycle	○	○
R&D of key technologies (including material and inhibitor for high temperature generator to suppress hydrogen generation)	Corrosion resistance technology Adequate combination of materials & inhibiters	○	○
	Improvement of Efficiency and Downsizing	-	○
	Utilization of Waste Heat	-	○
	Development of Control Technology	-	○
Making and evaluating primary and secondary prototypes of triple effect absorption chiller-heaters		○	○
Market research	Investigation for Deregulation	○	○
	Target Cost & Market Research	○	○



(a) Autoclave test



(b) Tube model test



(c) High temperature generator model test

[Fig. 4] Test equipment diagram

<Table 4> A list of the corrosion resistance test

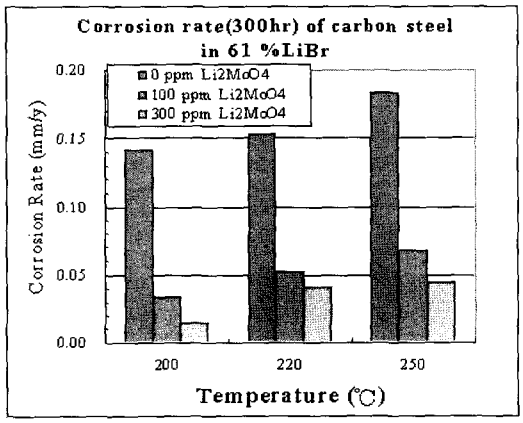
Item	Outlin
Electrochemical corrosion test	Study on the crevice corrosion mechanism of test pieces in LiBr solution
Autoclave corrosion test	Basic corrosion test of test pieces in LiBr solution
Tube model test	Corrosion test of a heat transfer tube with LiBr solution flowing inside
High temperature generator model test	Corrosion test of a small-scale high temperature generator model

<Table 5> Average hydrogen generation rate in the tube model test

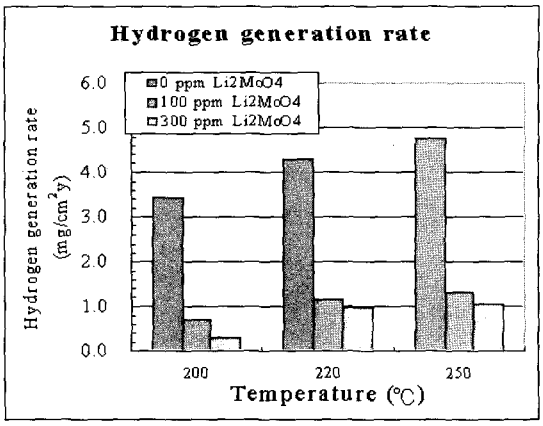
Concentration of Li2MoO4(ppm)	Hydrogen generation rate (Nml/h)	Remarks
0	1700	Temperature : 220℃ Total surface area: 0.851m²
100	10.0	
200	5.0	
300	3.5	
500	1.3	

temperature generator model examination. **Table 4** shows a list of the corrosion resistance test. **Figure 4** shows the diagram of test equipments.

The effect of inhibitor (Li2MoO4) was confirmed in autoclave examination (200oC, 100h and 300h) and the pipe examination (220oC, 1000h). **Figure 5** (a) shows the corrosion rate of carbon steel in 61% LiBr solution and **figure 5** (b) shows the hydrogen generation rate with the different inhibitor concentration and solution temperature, respectively. **Table 5** shows the averaged hydrogen generation rate in the tube model test.

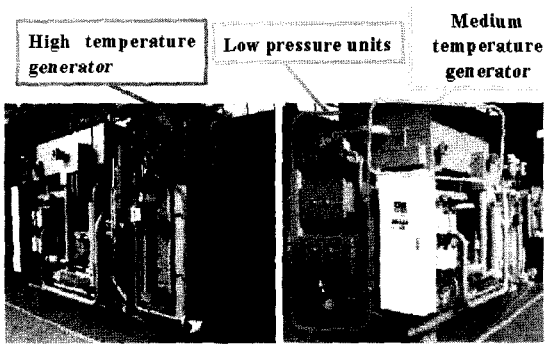


(a) Corrosion rate

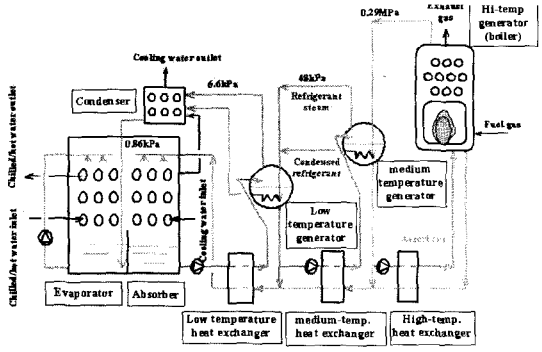


(b) Hydrogen generation rate

[Fig. 5] Results of the autoclave test



[Fig. 6] Photo of a 150 RT prototype machine



[Fig. 7] Cycle flow diagram of the prototype machine

150 RT prototype machine production and evaluation

A 150 RT prototype machine shown in **figure 6** was assembled and tested to evaluate the feasibility of the triple effect cycle and also to assess the durability. **Figure 7** shows the cycle flow diagram. Although the target COP level of 1.6 was not reached, the prototype attained a COP of 1.49 that was conventionally not possible with a double effect cycle. **Table 6** shows the operation data. For the purpose of confirming durability, an endurance test for duration of 2000 hours is planned for the prototype machine.

<Table 6> Operation data of a 150 RT prototype machine

Cycle	Modified reverse flow
COP (cooling)	1.49 (H.H.V)
Solution temperature	198℃
Manufacturer	Kawasaki Thermal Engineering Co.Ltd
Chilled water temperature	7℃
Tower water temperature	32℃
Operation hours	2100h

Investigation research for practical use

The pressure within the pipes of middle temperature generator and also the vessel of high temperature generators exceed atmospheric pressure. Because Japanese boiler and high-pressure vessel regulation imposes specific restrictions on the safety measure of any boilers/vessels operated above atmospheric pressure, JGA together with 4 manufacturers cooperated in evaluating the effect of the regulations on the implementation of triple effect machines.

To meet these safety requirements, component design, construction, and other aspects were technically reviewed and measure required to satisfying the safety regulations were evaluated. Countermeasures to insure the safety of the operation of the machine will be proposed to the related government ministries in an effort to gaining governmental approval for implementation.

CONCLUSION

The paper summarizes briefly the current research and development in advanced technologies of absorption chiller-heater in Japan. The following conclusions are obtained.

Absorption cycle is the most promising heat driven technology for heating or cooling. Japanese gas utilities and manufacturers of absorption chiller-heaters have been developing high efficiency gas-fired double-effect chiller-heaters. The COP of the system is aimed at 1.35. Analytical research shows that the heat recovery in cycle is the most important key technology to achieve high COP value. It is also found that the improvement of the thermal efficiency of the solution heat exchanger is also important.

The Japan Gas Association together with Japanese manufactures of absorption chiller-heaters has started a new project on the development of triple effect absorption chiller-heater. The COP of the proposed system is aimed at 1.6. The project is subsidized by a governmental organization so-called NEDO. Mainly, there are 4 developing points those are (1) the optimization of triple effect absorption cycle, (2) the evaluation of material and inhibitor for high temperature generator, (3) making and evaluating primary and secondary prototypes of triple effect absorption and (4) market research.

Each of 4 participating manufacturers developed fundamental elements and a prototype machine with solution flow patterns those are characteristic to each of the manufacturer. Research and development points in (a) parallel flow, (b) by-pass flow, (c) reveres flow and (d) series flow are summarized.

In the development of corrosion repression technology, the evaluation examination of the material and inhibitor in the method of autoclave examination, the pipe examination and the high temperature generator model examination have been started. The effect of inhibitor (Li_2MoO_4) was confirmed in autoclave examination (200℃, 100h and 300h) and the pipe examination (220℃, 1000h).

A 150 RT prototype machine was assembled and tested to evaluate the feasibility of the triple effect cycle and also to assess the durability. Although the target COP level of 1.6 was not reached, the prototype attained a COP of 1.49. For the purpose of confirming durability, an endurance test for duration of 2000 hours is planned for the prototype machine.

Finally, this brief review is summarized based on the NEDO public report in FY2001 on the development of the triple effect absorption chiller-heater.

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