# DEVELOPMENT OF TRIPLE-EFFECT ABSORPTION CHILLER-HEATER

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## ABSTRACT

Reducing energy consumption in air conditioning systems has become an urgent issue in recent years, and the efficiency of the absorption chiller-heater systems widely used in office buildings and other facilities needs to be improved. The Japan Gas Association and four manufacturers of absorption chiller-heater systems, at the request of the New Energy and Industrial Technology Development Organization (NEDO), developed a commercially viable version of a triple-effect absorption chiller-heater.

The prototypes produced by all four companies have achieved a cooling COP of 1.60, a major improvement in energy efficiency compared to current double-effect systems. The durability of these systems is now being evaluated, and the results will be used to develop a commercially viable triple-effect system.

**Key Words:** ***absorption chiller-heater, triple-effect, high efficiency.***

## 1 INTRODUCTION

Reducing energy consumption in air conditioning systems has become an urgent issue in recent years. Improvements are being made every year in the efficiency of heat pumps and centrifugal chillers, which compete with absorption chiller-heaters, and major improvements in the efficiency of absorption chiller-heater systems are also expected. However, over thirty years have passed since the double-effect systems now in use first began to spread, and many improvements have already been made. With the development of the commercial version of such a system with a cooling coefficient of performance (COP) of 1.35, the upper limits which can be attained using such systems have probably been reached. To improve efficiency further, multi-effect systems now need to be developed. Note that here ‘COP’ refers to the ratio between cooling capacity and the amount of input heat in the form of gas fuel as measured using higher heating value.

As part of a joint research project with the New Energy and Industrial Technology Development Organization (NEDO), the Japan Gas Association and an alliance of four companies have been working since 2001 on a project entitled "Development of a High-performance Triple-effect Chiller-heater." The aim is to develop a triple-effect absorption chiller-heater with much higher efficiency and to develop a commercially viable system. The work being done in this project is described below.

## 2 OVERVIEW OF PROJECT

### 2.1 Principles and Features of a Triple-effect Absorption Chiller-heater System

The triple-effect absorption chiller-heater system now under development is an extension of the lithium bromide (LiBr) double-effect systems currently commercially available with a newly added high-temperature, high-pressure generator. As can be seen from the Dühring diagram in Figure 1, there are three generators (a high-temperature, a middle-temperature, and a low-temperature generator). By using gas heating or some other form of heat source to heat the high-temperature generator and using the high-temperature heat as it cascades downward through the absorption cycle, it is possible to obtain a higher cooling COP than is possible with a double-effect system. This design has been adopted for the following reasons:

a) A lithium bromide/water system provides the highest possible efficiency.

b) By utilizing the LiBr/$H_2O$ system that builds upon already-proven double-effect systems, R&D can focus solely on those points which must be added to a double-effect system, thus improving the chances of successfully developing a commercial product within the limited time available.

c) The same components as used in double-effect systems can be shared, thus reducing production costs.

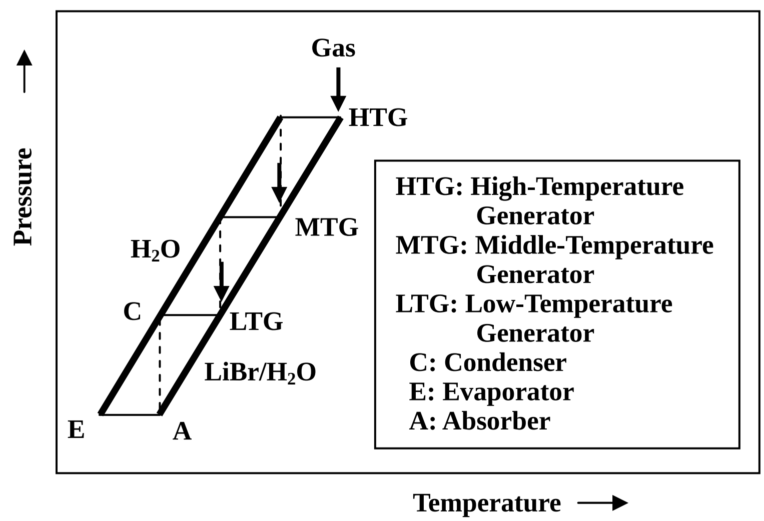



**Fig. 1. The principles of a triple-effect cycle**

However, as shown in Fig. 1, with a triple-effect system the pressure of the coolant and the temperature of the LiBr solution become higher. It is for this reason that it becomes necessary to develop technologies to make it possible to meet governmental restrictions concerning the safety of the boiler and pressure vessel and to prevent corrosion from occurring as a result of increases in the temperature of the LiBr solution.

## 2.2 Project Objectives

The objectives of the current development work on a triple-effect system are as follows:

a) To achieve a cooling COP of 1.60 or higher (as measured using a higher heating value) through the use of the triple-effect cycle. (Average COP for existing double-effect systems 1.07.)

b) To keep the volume of the system to 120% or less of current systems, to meet the demand for replacement systems in existing buildings.

c) To develop technologies for using the waste heat of co-generation systems. Specifically, to reduce the amount of gas consumed when making use of waste heat, to increase fuel savings from 15% with our current “Genelink” absorption chiller-heater with auxiliary waste heat recovery, to over 20%.

## 2.3 Project Schedule and Structure

The project was scheduled to last four years until fiscal year 2004. The first two years were used principally to develop component technologies (Mori et al.2003). In FY 2003 primary prototype systems were created and evaluated. In FY 2004, the final year of the project, secondary prototype systems were created and are now being evaluated. Over the next two years, a working commercial version of the systems will be developed.

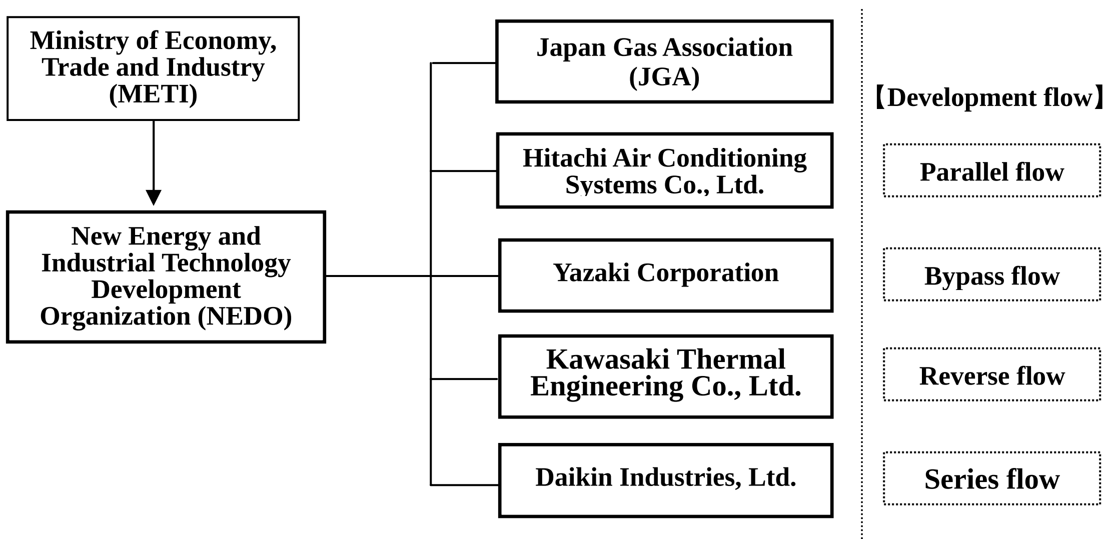


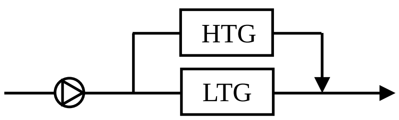

**Fig. 2. Organizational chart**

The project structure and participating companies and entities are shown in Fig. 2. The main role of the JGA in this project has been to handle the general oversight and day-to-day management of the project; to perform cycle simulations, corrosion evaluations, and prototype performance evaluations; and to handle regulatory issues. The four companies have been responsible for the developing component technologies and prototype systems and performing evaluations of these systems.

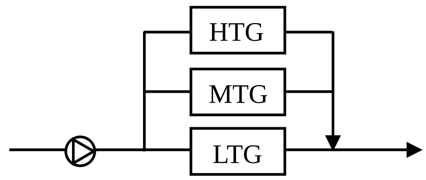
**Table 1. Current double-effect flows and newly developed triple-effect flows**

Hitachi Air Conditioning Systems Co. Ltd. (Parallel flow)

Double-effect

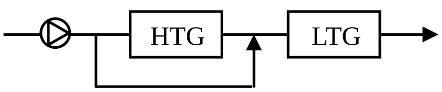



Triple-effect

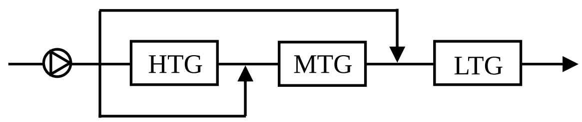



Yazaki Corporation (Bypass flow)

Double-effect

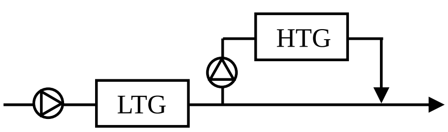



Triple-effect

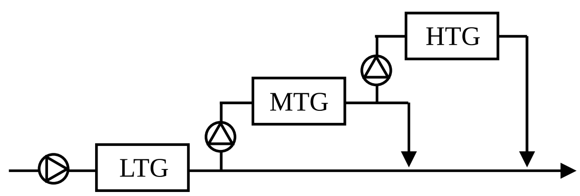



Kawasaki Thermal Engineering Co. Ltd. (Reverse flow)

Double-effect

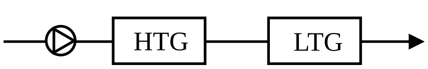



Triple-effect



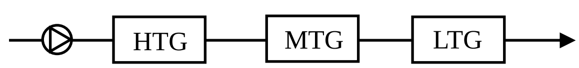

Daikin Industries, Ltd. (Series flow)

Double-effect

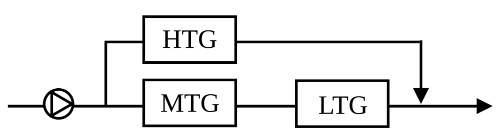



Triple-effect

Simple series flow




Improved flow design




The four companies all use different solution flow systems in their current double-effect systems, and in the triple-effect system as well they each developed their own flow systems based on their existing flow systems. The current double-effect flow systems, and the new triple-effect flow systems developed based on them, are compared in Table 1. Daikin Industries decided that it would be difficult to attain the project's objectives using a simple series flow and so developed a new and improved flow system. The cooling capacities of the prototypes, developed by each of the four companies, range from 352 kW to 1055 kW.

## 3 RESULTS OF DEVELOPMENT TO DATE

### 3.1 Development of Anti-Corrosion Technologies

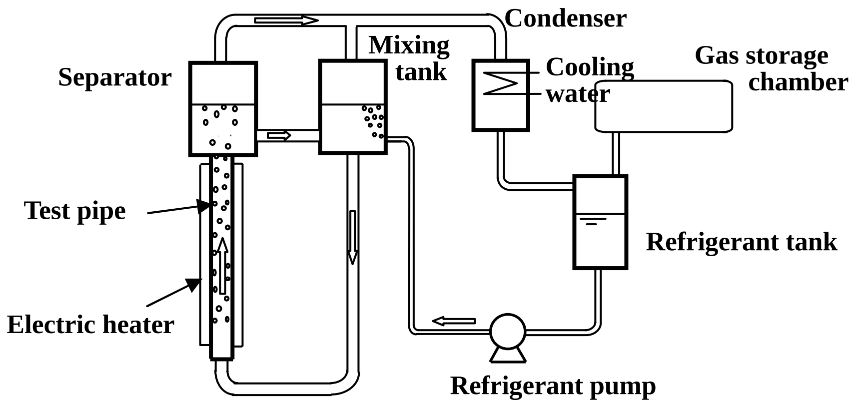



**Fig. 3. Schematic diagram of pipe model test.**

In order to study the corrosion resistance of the materials when exposed to solution temperatures of 200°C or more (i.e., conditions comparable to the actual operating conditions in the high-temperature generator of a triple-effect system) and to determine the effects of lithium molybdate ($Li_2MoO_4$) corrosion inhibitors, the heat transfer pipes to be used in a high-temperature generator were tested through simulations. A view of the device is shown in Fig. 3. A convection current of LiBr solution is created within the test pipe by heating the solution with an electric heater placed at the test section. Unlike a static autoclave test, this system includes both heat transfer and solution flow, so it is possible to evaluate corrosiveness with accuracy closer to that of an actual system.

#### 3.1.1 Changes in the volume of gas generated

Figure 4 shows the results of the pipe testing. Tests were performed using the carbon steel and $Li_2MoO_4$ inhibitors currently used in double-effect systems.

While the amount of hydrogen gas generated increases dramatically during the initial stages of operation under the temperature (220°C) of a triple-effect system, the level later stabilizes to some 5-8 times the amount generated at the double-effect system temperature (160°C), and as long as inhibitor concentrations were controlled, no increase over time could be seen over 8,000 hours of operation.

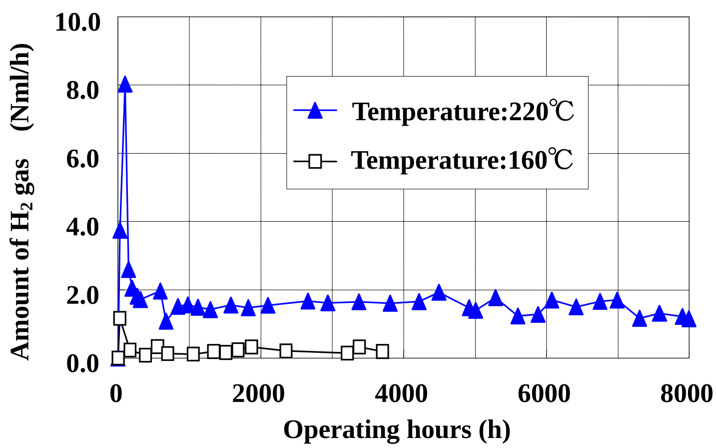



**Fig. 4. Results of pipe test.**

When the amount of hydrogen gas generated by corrosion exceeds the capability of the absorption chiller-heater to vent non-condensed gases, it impedes stable operation. In view of the ratio between the area of the heating unit (heat transfer pipes) used in these pipe tests against the area of the non-heated portion, the difference between the amount of gas generated by a double-effect and a triple-effect system may become even smaller. In fact, it was found that no problems occurred during over 24 hours of continuous operation using the primary prototypes developed by each of the four companies in FY 2003, and the amount of gas generated was within allowable limits. The results suggest that the volumes of gas generated over even longer times of operation could be handled as long as the inhibitor concentration levels are properly controlled.

### 3.1.2 Progression of corrosion in heat transfer pipes and other parts of system

Figure 5 shows the maximum depth of pitting corrosion in heat transfer pipes occurring after 2000, 4000, and 8000 hours of operation at the specified temperatures. While the degree of pitting occurring using artificially aged heat transfer pipes was greater at 220°C than at 160°C, the depth of the pitting did not increase proportionally over time. Moreover, while a rapid increase could be seen in the amount of hydrogen gas generated in samples from 2000 and 8000 hours of operation which had been subjected to the same initial stage of aging at 220°C (up to about 150 hours) and the

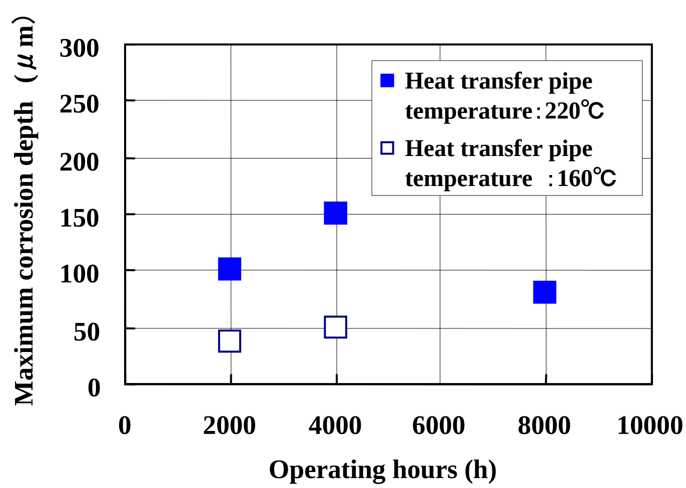



**Fig. 5. Maximum corrosion depth of heat transfer pipe.**

amount of gas generated was almost the same, less gas was generated with the 4000-hour sample. As the 2000-hour and 8000-hour samples came from the same lot whereas the 4000-hour sample came from a different lot, the differences in amount of hydrogen gas generated in the initial stages were likely caused by the initial condition of the surface of the pipes used.

### 3.1.3 Effect of initial condition of the surfaces of materials on corrosion

The condition of the surfaces of heat transfer pipes and other components during the production process differs from one company to the next depending on factors such as whether or not acid wash is performed. As the initial surface condition of these materials (the presence or absence of a mill scale, scratches, or rust) might have an effect on later anti-corrosion properties, such effects of the initial surface condition were evaluated.

The results of electrochemical testing and pipe testing suggest that the amount of corrosion occurring might be reduced by using acid-cleaned materials. On the other hand, with materials where rusting occurs after acid wash, the amount of corrosion occurring in rusted areas was found to be greater, and so rusted areas seem to serve as a starting point for localized corrosion. It is therefore important to prevent rusting during the production process when using materials subjected to acid wash.

These results indicate that corrosion could be prevented adequately over the long term by properly preparing the initial surface condition of the material and performing aging, i.e., by creating a passivation film on the surface and properly controlling inhibitor concentrations and other factors. We are continuing to perform a variety of corrosion tests and studying the optimum methods of preparing surfaces and performing aging.

## 3.2 Performance Evaluation of Prototypes

### 3.2.1 Device performance

Using the component technologies developed thus far, all four companies created primary prototypes (with cooling capacities from 352 kW to 1055 kW) and performed preliminary performance evaluations. An example prototype is shown in Fig. 6.

**Fig. 6. View of a 1055kW prototype.**

All of these prototypes achieved a cooling COP of 1.60 or higher at the rated load, thus meeting one of the objectives of this project. In addition, as shown in Figure 7, when operating under partial load the cooling COP sometimes exceeded that of the rated load, thus showing good performance under partial load.

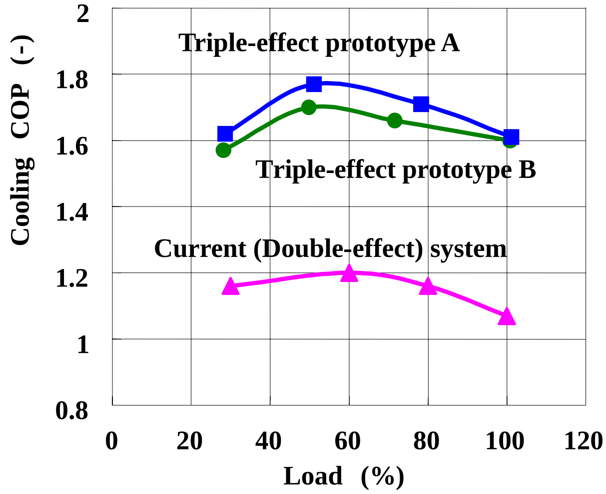



**Fig. 7. Characteristics of prototypes under partial load.**

### 3.2.2 System evaluation

Partial load data for prototypes from all four companies were compared with data from current double-effect systems. The data for triple-effect systems was obtained by taking the averages of the data for all four prototype systems. Assuming a system with a peak load of 1054 kW, a comparison was performed of cases in which a single 527-kW triple-effect and a single 527-kW double-effect system were used (Case A) and cases in which two 527-kW double-effect systems were used (Case B). In Case A, a load of up to 527 kW was taken as the base load for the triple-effect system.

An example of the estimates obtained is shown in Table 2 (data concerning the second system used in both cases are omitted). Under the conditions assumed for Table 2, it was found that the gas consumption during cooling decreased by 30%.

**Table 2. System evaluation**

| | Case A | Case B |
|---|---|---|
| **Expected conditions** | | |
| System | Triple-effect 527 kW system (1)<br>Double-effect 527 kW system (1) | Double-effect 527 kW system (2) |
| Building | Type: Hotel<br>Floor area: 12,000 $m^2$ | |
| Load | Cooling load: 4,201 GJ (from April to November)<br>Cooling load trend data provided by the Society of Heating, Air-conditioning, and Sanitary Engineers of Japan | |
| **Results of simulation** | | |
| Average cooling COP | 1.67 | 1.17 |
| Gas consumption during operation<br>Note: Figures in parentheses indicate relative percentage with respect to double-effect systems | 54,800 $m^3$ (70.0) | 78,200 $m^3$ (100.0) |

### 3.2.3 Field tests

To check the durability and responsiveness to load under actual loads of the 527 kW prototype (COP 1.5) created in 2001, the prototype was installed at a regular client site and subjected to field-testing beginning from January 2003. The prototype has operated cumulatively for 12,000 hours to date (as of the end of December 2004), and no significant problems have occurred.

## 4 CONCLUSION

In 2004, the final year of the project, the four participating companies created secondary prototype systems and achieved project objectives in terms of system volume and gas reduction levels. The initial performance of these systems has already been confirmed and the durability of these systems is now being evaluated.

After using the results of these tests to design final prototypes and perform field-testing after the completion of the project, work will be done develop a commercially viable version of the triple-effect system.

## REFERENCES

K Mori, M Oka, K Ohhashi: "Development of Triple-effect Absorption Chiller-heater," 22nd World Gas Conference, Tokyo, 2003.