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ABSTRACT

We developed an appropriate Absorption chiller to "Solar cooling system" in 2010. In addition, we added the improvement to the machine. "Solar cooling system" can be easily constructed with the machine. and, we constructed the demonstration plant, and verified the utility

1. INTRODUCTION

Absorption chillers use water i.e. natural refrigerant as a cooling medium as well as having zero ozone depletion potential because of Freon-Free, which can contribute to prevention of global warming. In addition, absorption chillers use thermal energy as driving source, and have a feature of being capable of saving electric power.
Since global warming problems are recently worsening, promotion of introduction of renewable energy sources is required for realization of low-carbon society. Under these situations, we have focused on solar energy and developed solar cooling systems in which the solar heat use system is incorporated for air-conditioning.
In the solar cooling system, water warmed by solar heat is introduced into the absorption chiller in which thermal energy is used as driving source to air-condition. This system enables solar thermal energy which is abundant in reserve among renewable energy sources and is high in energy conversion rate to be applied for air-conditioning which is high in energy consumption rate in industrial fields.
Our company has developed the solar-driven hybrid chiller exclusively designed for the solar cooling system and launched in June 2010, and built up the solar cooling system using the solar-driven hybrid chiller and conducted the demonstration test.
Conventional solar cooling system that was used single-effect absorption chiller. It was Low efficiency of absorption chiller. And the system was complicated system with a boiler for the back-up of hot water supply.
Solar-driven hybrid chillers have a feature of automatically backing up poor performance of water warmed using unstable solar heat by thermal energy such as gas, oil as well as using water warmed using solar heat preferentially. The above system allows unstable renewable resource to be used for air-conditioning without building up complicated back-up system.
Our developed solar-driven hybrid chillers and solar cooling systems are introduced as follows.

2. Solar-Driven Hybrid Chiller

2.1 Outline of Solar-Driven Hybrid Chiller

A Solar-Driven Hybrid Chiller is composed of a highly-efficient gas absorption chiller/heater with COP1.3 (gross calorific value) as a main machine which are equipped with a solar heat recovery unit comprising a heat recovery heat exchanger and special condenser.

Fig. 1: Aspect of Solar-Driven Hybrid Chiller

As shown in the cycle-flow diagram in Fig. 2, solar heat hot water is used for heating and regenerating absorbing solution at the heat recovery heat exchanger. Using refrigerant generated during this regeneration process for cooling enables the amount of fuel used for the high temp. generator to be reduced.

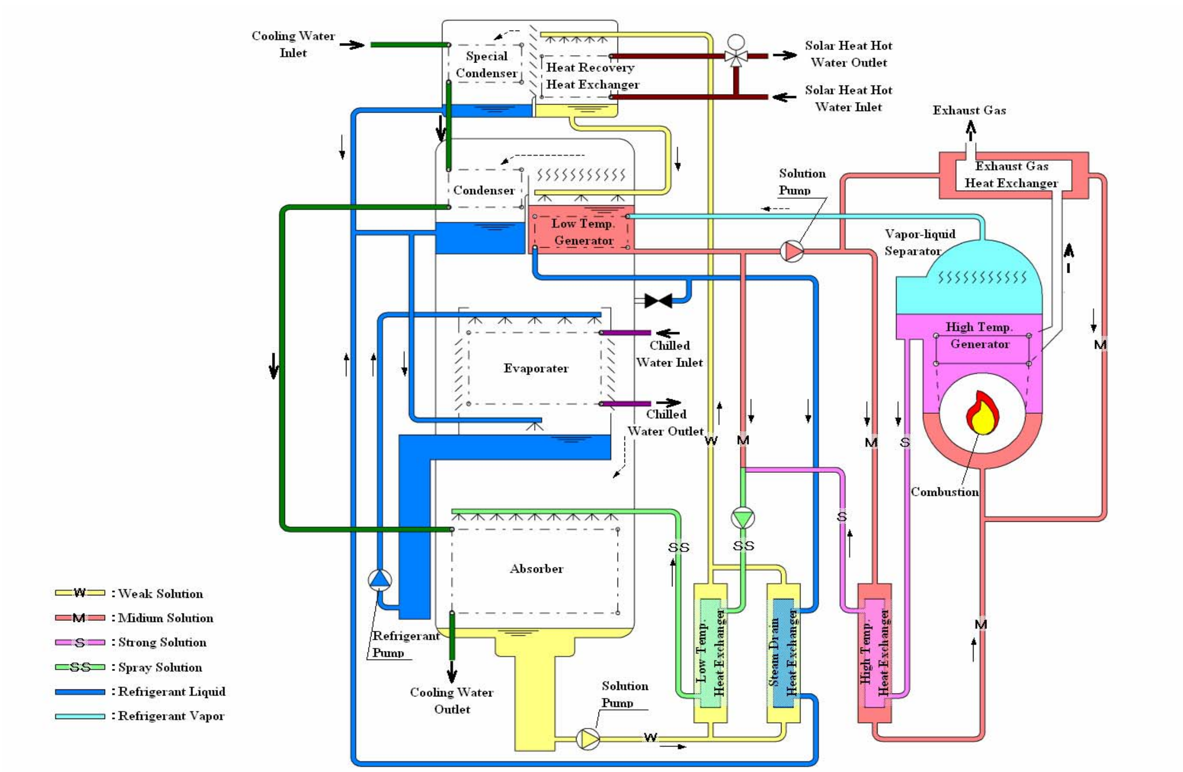

Fig. 2: Cooling cycle flow of Solar-Driven Hybrid Chiller

Generally, solar energy collectors have characteristics in which the smaller the difference in temperature between the collection temperature and outside air temperature is, the higher the collection efficiency is, therefore, it is necessary to allow solar absorption chillers/heaters to use even low temp. hot water to increase the efficiency of the overall system.
As chillers/heaters which are capable of reducing fuel consumption during cooling by introducing hot water, exhaust heat introduction absorption chillers/heaters (Gene-Link) can be considered, however, a Gene-Link is a product designed to use exhaust heat hot water at stably high temperature (83 to 90ºC) obtained by cogeneration systems, etc. and cannot use low temp. hot water.
The reason is that a Gene-Link is composed as shown in the principle drawing in Fig. 3, in which refrigerant vapor generated at the heat recovery heat exchanger and refrigerant vapor generated at the low temp. regenerator are condensed in the condenser of the base absorption chillers/heaters. Therefore, the saturated temperature of the heat recovery heat exchanger is restricted by the saturated temperature of the condenser of this absorption chiller/heater body, which prevents the log-mean temperature difference to collect low temp. hot water from being maintained.

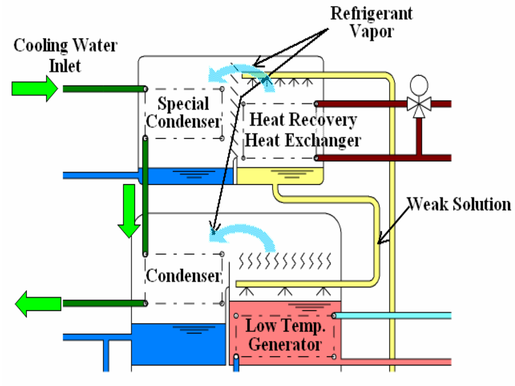

Fig. 3: Principle of Gene-Link

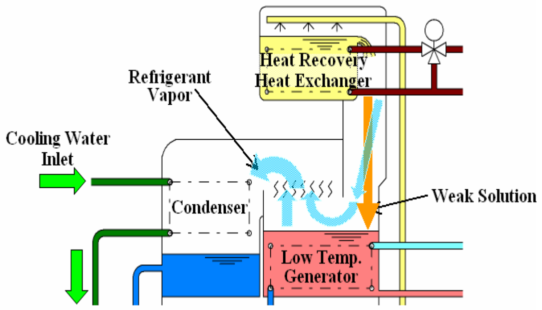

Fig. 4: Principle of Solar-Driven Hybrid Chiller

Consequently, as shown in the principle drawing in Fig. 4, in the Solar-Driven Hybrid Chiller, a condenser exclusive for the heat recovery heat exchanger is newly provided to separate the heat recovery unit and the base absorption chiller/heater and a structure to initially introduce cooling water to the special condenser is employed, which reduces the pressure in the heat recovery unit and maintains the log-mean temperature difference to collect low temp. hot water.
As shown in Fig. 5, the above system enables low temp. hot water at 75ºC under operation at the cooling rating (load factor: 100%, cooling water temp: 32 ºC) or even lower temp. hot water depending on loading conditions and cooling water conditions to be used.

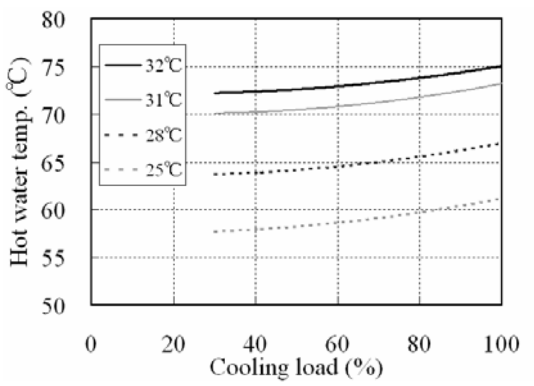

Fig. 5: Hot water temperature for which Solar-Driven Hybrid Chiller can be used

2.2 Specifications of Solar-Driven Hybrid Chiller

As a result of considering the installation area, etc. of applicable solar energy collectors, 8 models of solar absorption chillers/heaters with 80 to 300RT(281 to 1055kW) were selected as lineup.
Each basic specification of solar absorption chillers/heaters is shown in Table 1.

Table 1: Specification of product

			Solar absorption chiller-heater		(reference)
			Inlet tenmp. of hot water :90℃	Inlet tenmp. of hot water :75℃	Conventional Gene-Link
Coefficient of performance (COP)	With hot water	−	1.91	1.43	1.72
	Without hot water	−	1.30	1.30	1.29
Heating efficiency	(Without hot water)	−	0.86	0.86	0.84
Chilled water	Inlet-Outlet temp.	℃	15.0→7.0	15.0→7.0	12.0→7.0
	Flow rate	m^3/(h・RT)	0.378	0.378	0.605
Cooling water	Inlet-Outlet temp.	℃	32.0→37.6	32.0→37.2	32.0→37.6
	Flow rate	m^3/(h・RT)	1.00	1.00	1.00
Hot water	Inlet-Outlet temp.	℃	90.0→79.5	75.0→71.9	90.0→80.0
	Flow rate	m^3/(h・RT)	0.115	0.115	0.096
Heat recovery rate		kW/RT	1.40	0.41	1.12
Energy saving rate		%	32	9	26
Max. cooling capasity onli hot water heating		%	55	28	45

3. Outline of Solar cooling system

3.1 Outline of building

The demonstration plants are installed in our factory located in Kusatsu City of Shiga Prefecture and 2-story office built parallely with the factory for air-conditioning. The outline of the building is shown in Table 2.
Since the factory area of the building where the system was installed has a high roof and requires ventilation, the inside cannot be heated sufficiently even by heating. Therefore, heating is carried out only for the office, which features that heating load is very small. (the rate of heating to the annual energy consumption amount: 16 %)
This system was completed in Dec. 2010 and started to undergo full-sized verification test in Feb. 2011.

Table 2: Outline of building

total floor space	5600 m2 ・ office 1000m2 ・ factory 4600m2
Utilization	Colling : office & factory Heating : office

3.2 Outline of system

The flow diagram of this system is shown in Fig. 6. Solar heat (hot water at 75ºC to 90ºC) is introduced into the Solar-Driven Hybrid Chiller to cool in summer and Solar heat (hot water at 45ºC to 60ºC) is directly used in the heat

exchanger for heating to heat in winter. In addition, if solar heat is insufficient, the backup system to compensate for the energy through gas is available.
Evacuated glass tube type solar energy collectors which are highly efficient in a high-temp area at 75ºC to 90ºC is used for the solar energy collector. 160 sheets of collectors (260m2) which satisfy the exhaust heat recovery amount (0.6kW/RT, 126kW *cooling water at 31℃) during rated operation in case of solar heat hot water of Solar-Driven Hybrid Chiller at 75ºC were installed on the roof of the office. Further, in order to structure the installation stand of the solar energy collector as simple as possible, the structure parallel with the roof is employed.
The hot water storage tank is provided to absorb the difference of flow rate between the solar energy collector and Solar-Driven Hybrid Chiller and serves as a temporal cushion if solar radiation fluctuates suddenly.
Further, the radiator is provided to prevent hot water from boiling by excessive heat collection by operating when collected solar heat cannot be used on holidays, etc. because cooling/heating is not performed

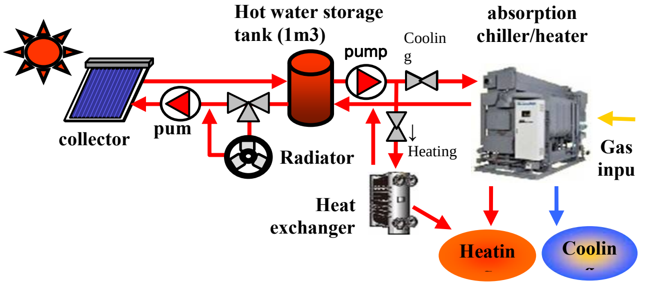

Fig.6: Schematic diagram of system

Fig.7: Aspect of Collector

Table 3: Specifications of system

Collector	<evacuated tube> 1.62m2×160 sets	total area：260㎡ (aperture area：213m2) conductor：water tilt angle：8° azimuth angle：SSE35° output(Max)：128kW
absorption chiller/heater	cooling capacity 738 [kW]（210RT） heating capacity 738 [kW]	

4. Feature of Solar cooling system

4.1 Lowering the temperature of solar heat usable area

Generally, solar energy collectors have characteristics in which the smaller the difference in temperature between the collection temperature and outside air temperature is, the higher the collection efficiency is, therefore, it is necessary to allow solar absorption chillers/heaters to use even low temp. hot water to increase the efficiency of the overall system.
As chillers/heaters which are capable of reducing fuel consumption during cooling, exhaust heat introduction absorption chillers/heaters (Gene-Link) can be considered, however, a Gene-Link is a product designed to use exhaust heat hot water at stably high temperature (83 to 90ºC) obtained by cogeneration systems, etc. but cannot use low temp. hot water.
However, in the Solar-Driven Hybrid Chiller, solar heat at 75ºC (rated) and approx. 60 ºC (under partial loading) can be used by employing a hot water heat exchanger optimized for use of solar heat and reviewing the flow of cooling water.
Fig. 8 shows the efficiency of solar energy collector used for this system, in which the collection efficiency can be improved by 3% at 75ºC and by 9% at 60 ºC in comparison with conventional conditions at 83ºC (solar radiation amount: 1000W)

4.2 Simplifying and downsizing the solar heat energy collecting facility as much as possible

The auxiliaries (Fig. 9) such as pumps, etc. to supply hot water obtained from the solar energy collector to the Solar-Driven Hybrid Chiller are required, however, those items are simplified as much as possible while considering packaging with the Solar-Driven Hybrid Chiller.
Packaging after reflecting these verification results can reduce the details of work at site and costs for building up the system as one of targets.

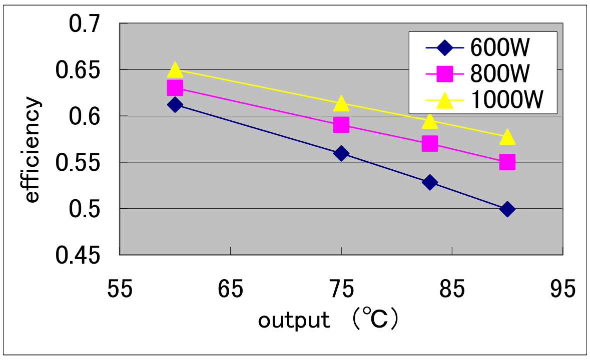

Fig. 8: Heat collection efficiency of Solar collector

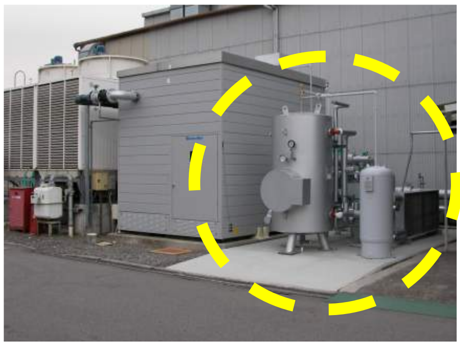

Fig.9: Collection of heat facility

4.3 Equipping the chiller/heater with the functions for controlling and monitoring the heat collection facility

When introducing the solar cooling system, it was necessary to specially build up the control functions such as starting/stopping the heat collecting facility and protecting from freezing and excessive solar heat collection of the solar energy collector, however, these control functions are assembled into the Solar-Driven Hybrid Chiller in this system and control of the overall system is enabled.
Assembling the control functions into the Solar-Driven Hybrid Chiller maximizes the saving energy effect based on the use of solar heat by strengthening the linkage with the control functions of the Solar-Driven Hybrid Chiller in addition to eliminating the needs of the special control equipment.
Some examples of linkage control with the Solar-Driven Hybrid Chiller added to this system are shown as follows:
(1) Backup linkage at the Solar-Driven Hybrid Chiller
(2) Interlocking control in response to change in pick-up temperature setting
Further, the system is equipped also with the information collection function to monitor the system operation status and energy-saving effect.
The monitor system enables daily and hourly collection amount and efficiency to be displayed, which contributes to the grasping of operation conditions and review for improvement of system.
As mentioned above, when building up the solar cooling system, cost reduction is a big issue. Assembling the control system and monitor system into the Solar-Driven Hybrid Chiller greatly serves to reduce the cost for building up the system.

5. Evaluation status and results

5.1 Heating operation

(1) Operation conditions
Fig.10 shows the operation data on March 8. From the data, it was confirmed that the solar heat priority usage function and gas-based backup function operate properly and overall system functions normally.
Further, although it was slightly cloudy and cold on the evaluation day, operation only solar heat can be made from 10:00 AM to 2:00 PM, which enabled gas amount to be reduced by 15%.
Although there were days when reduction effect was observed as mentioned above, the monthly average reduction rate was 5% in February (estimate: 43%) and 9% in March (estimate: 69%), which shows a far lower level than estimated values.
As described in Outline of building, since the area subject to heating is a part of the building in an actual operation, if converting into the air-conditioning loading factor, the data represent a mere 3% of load (daily average), in

addition, loads are concentrated on morning and night, therefore, almost no-load conditions are kept in the day time when solar heat can be used. However, the time zone is not considered when estimating, causing the big difference. In addition, underestimate of radiation around the solar energy collector can become a factor.
However, the rate of heating accounts for 16% of annual gas use amount, which shows a low level and assumed to be not much different from the estimated values annually.
(2) Improvement points
Even in single operable conditions by solar heat, the chiller/heater is constantly operated at present. However, since it is confirmed that single operable conditions by solar heat can be kept for a long time in daytime when solar heat is available, we intend to control the energy saving additionally by automatically stopping the chiller/heater during single operable conditions by solar heat.
Further, with respect to the facility aspect, we aim to improve the system by providing a heat storage tank for heating to make the best use of collected solar heat as well as taking measures against radiation after checking the construction conditions.

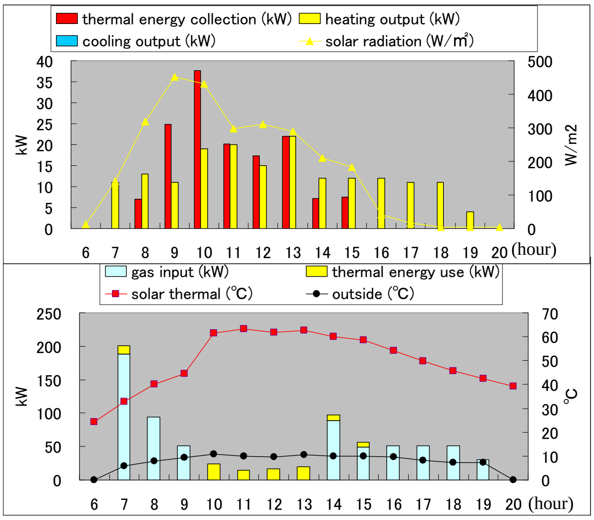

Fig.10: Operation data of heating (3th March)

5.2 Cooling operation

(1) Operation conditions
Fig.11 shows the operation data on May 20 and Fig.12 shows the operation data on June 28. From the data, it was confirmed that the solar heat priority usage function and gas-based backup function operate properly and overall system functions normally.
Because of operations with comparatively-low loads on the conditions where the maximum temperature was 28.4ºC and the air-conditioning loading factor was 23% on May 20, the gas amount could be reduced by 25%. Meanwhile, the maximum temperature was 34.5 ºC and the air-conditioning loading factor was as high as 60% on June 28, however, the gas amount could be reduced by 11%.
Cooling operation starts in late May, therefore, the monthly reduction rate shows the data only in June, however, reduction by 10% could be achieved and the results as estimated were obtained.
(2) Effect of Solar-Driven Hybrid Chiller
It was confirmed that hot water obtained from the solar energy collector is constantly used at 75ºC or less and can be used even at approx. 60 ºC during low-load operations.
In the actual system, the effect could not be quantified because fluctuation in solar radiation and load should be considered, however, use of Solar-Driven Hybrid Chiller developed exclusively for use of solar heat can reduce the pick-up temperature from the solar energy collector more than use of conventional exhaust heat introduction type absorption chiller/heater（Gene-Link）, therefore, it was confirmed that this system increased the collection efficiency of the solar energy collector and improves the efficiency of overall system.
(3) Improvement points
When changing to the low-load operation mode where the refrigerant pump of the chiller/heater activates the start/stop control, introduction of hot water is turned on and off interlinking with start/stop of the refrigerant pump, however, even in operable load only by solar heat hot water, it is confirmed that the pick-up temperature increases

due to output delay when turning on and backup control by combustion activates. We plan to review the control to minimize the delay and add it to the system.

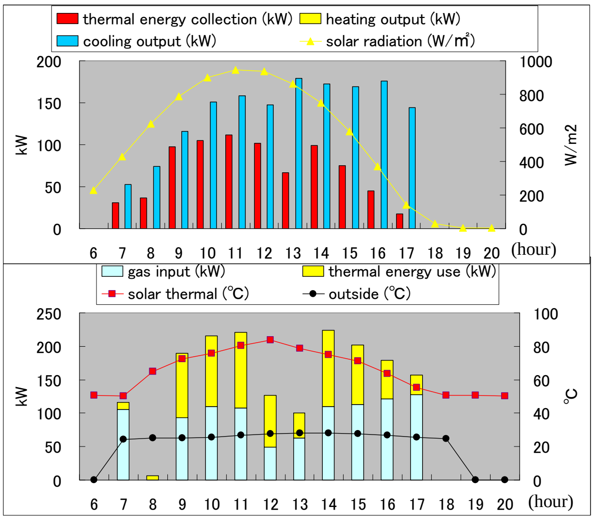

Fig.11: Operation data of cooling (20th May)

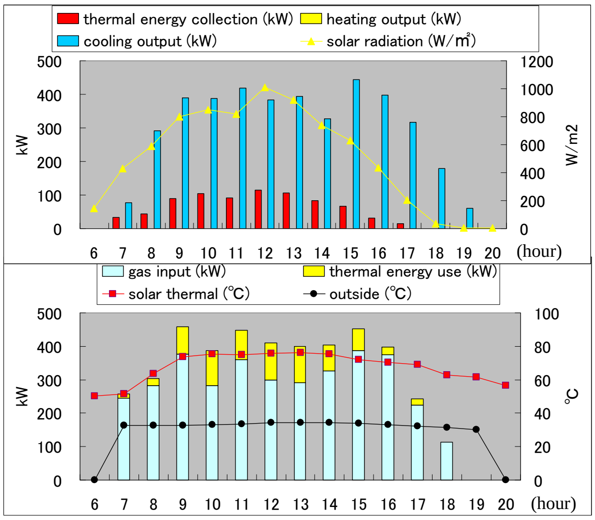

Fig.12: Operation data of cooling (28th July)

6. Conclusions

From the above-mentioned verification, the usefulness of the Solar-Driven Hybrid Chiller developed exclusively for use of solar heat was confirmed.
Further, we make sure that our built-up system is useful to make it easier to introduce a solar cooling system. By commercializing the system into which improvement points during verification were fed back in the future, we aim to make the solar cooling system to be recognized as a useful solution tool for global warming problem and promote them.

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