Solar Air-conditioning System Using Absorption Chiller

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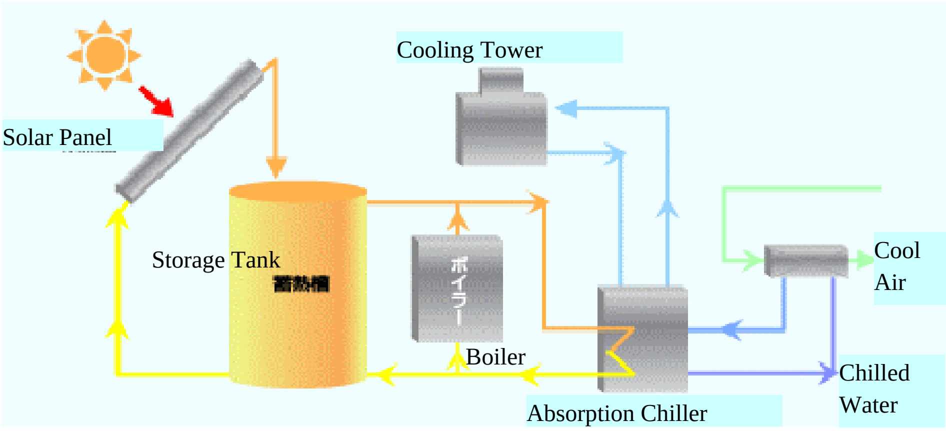
Abstract: We report the outline and the performance of single-double effect combined absorption chiller for "Solar air-conditioning system". It is composed of a highly-efficient absorption chiller as a main machine which are equipped with a solar heat recovery unit. It enables low temp. solar hot water at 75degreeC under operation at the cooling rating (load factor: 100%, cooling water temp: 32degreeC) or even lower temp. hot water depending on loading conditions and cooling water conditions to be used. And we constructed the demonstration plant of this system in Japan. We report the outline and the performance of the chillers and demonstration plant. Finally we report the new model plant at University of Indonesia completed in January 2014 and will estimate its effects of solar absorption chillers using solar energy on GHG emission reduction and air pollutant emission reduction in Indonesia.

Key Words: Absorption chiller, Solar heat, Solar air-conditioning system, Demonstration plant, Indonesia

1 INTRODUCTION

Absorption chillers are units to supply chilled water using gas and oil as fuel. In Japan, absorption chillers have been widely used for industrial and commercial central air-conditioning because they contribute to electric-load leveling in summer because of capable of cooling using little power, and use water having zero ozone depletion potential (ODP) as refrigerant. Meanwhile, the global warming issue has worsened markedly in recent years, which causes us to be confronted with the urgent task of realization of low-carbon society. Absorption chillers are also strongly required saving-energy.

Under these situations, we has developed a single-double effect combined absorption chiller exclusively designed for the solar cooling system and launched in August 2010. And we constructed the demonstration plant in Japan. We confirmed that the solar heat priority usage function and gas-based backup function operate properly and overall system functions normally. In summer, fuel gas reduction by 10% could be achieved and the results as estimated were obtained. Finally we report the new model plant at University of Indonesia



From NEDO homepage

Figure 1: Conventional Solar System

completed in January 2014 and will estimate its performance. We evaluate of the effects of solar absorption chillers using solar energy on GHG emission reduction and air pollutant emission reduction in Indonesia and investigation of the feasibility of these technologies.

2 SOLAR ABSORPTION CHILLERS(SINGLE-DOUBLE EFFECT COMBINED)

2.1 Use and Problem of Solar Heat

The system using solar hot water as driving source is applicable only to absorption chillers practically. The conventional air-conditioning system is shown in Figure 1. However, solar heat is unstable heat source which is easily influenced by weather and it is difficult to use it according to fluctuating air-conditioning loads. The points are shown as follows.

(1) In this system, the backup boiler is required, which causes the system to be complicated.
(2) It is difficult to control and establish an optimal control system.
(3) In case that the backup system functions, the efficiency is low because absorption chiller is single effect

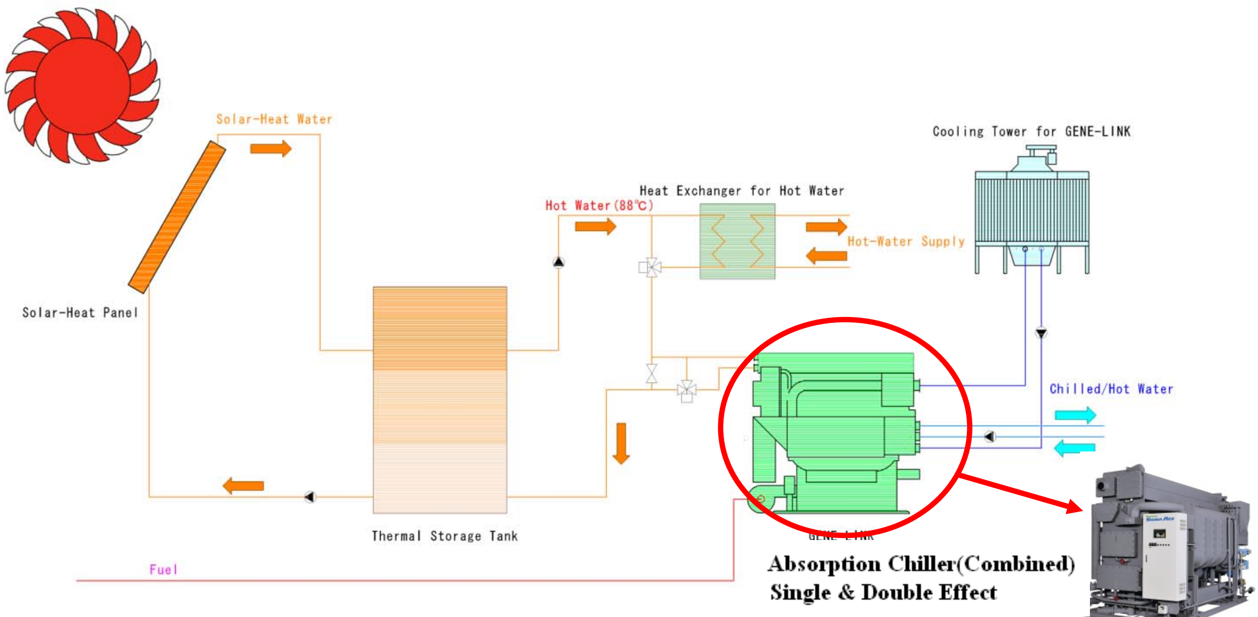


Figure 2:. Improved Solar Thermal Air-Conditioning System

2.2 Improvement from Conventional System

In consideration with the above problems, we developed single-double effect combined absorption chillers for using solar heat (hereinafter referred to as the Solar Absorption Chillers). The improved system using them is shown in Figure 2. The features are shown as follows.

(1) Since these solar absorption chillers are equipped with generators driven by solar hot water based on direct-fired absorption chillers, a backup system are unnecessary.
(2) These solar absorption chillers control so as to use solar hot water preferentially. In addition, control of loading is performed according to fluctuations in air-conditioning loading automatically.
(3) When driving by fuel, double-effect operation is performed, the high efficiency as absorption chillers which are currently diffused is obtained.

2.3 Performance of Solar Absorption Chillers

The performance of Solar Absorption Chillers is shown in Figure 3. Figure 3 shows the heat recovery amount in each cooling load factor and the combustion gas consumption amount in this case. The cooling water inlet temperature is set to 32ºC at 100% load and 27 ºC at 0%, and proportional values at 0 to 100%.

The heat recovery amount in case of hot water at 75ºC is 0.45kW/RT when the cooling load factor is 100 %, which increases as the load factor decreases, and reaches the maximum amount of 1.37kW/RT when the load factor is approx. 30% load factor where the heat recovery reaches the largest amount, cooling operation only by hot water without use of combustion gas is possible, therefore, the heat recovery amount in proportion to load is obtained in a loading area with approx. 30% and lower load factor.

Further, in case where the hot water is 90ºC, the heat recovery amount becomes 1.69kW/RT at 100% cooling load factor and reaches 2.42kW/RT at the most and the cooling load area operatable only by hot water is expanded to approx. 57%, therefore, it is found that heat amount can be more effectively used even if the temperature of hot water increases.

In case where the hot water is 75ºC, the combustion gas consumption amount can be reduced by approx. 9% at 100% cooling load factor compared to the case where hot water is not introduced. Since the above-mentioned decrease in combustion gas consumption amount has a proportional relationship with the heat recovery amount, it becomes larger as

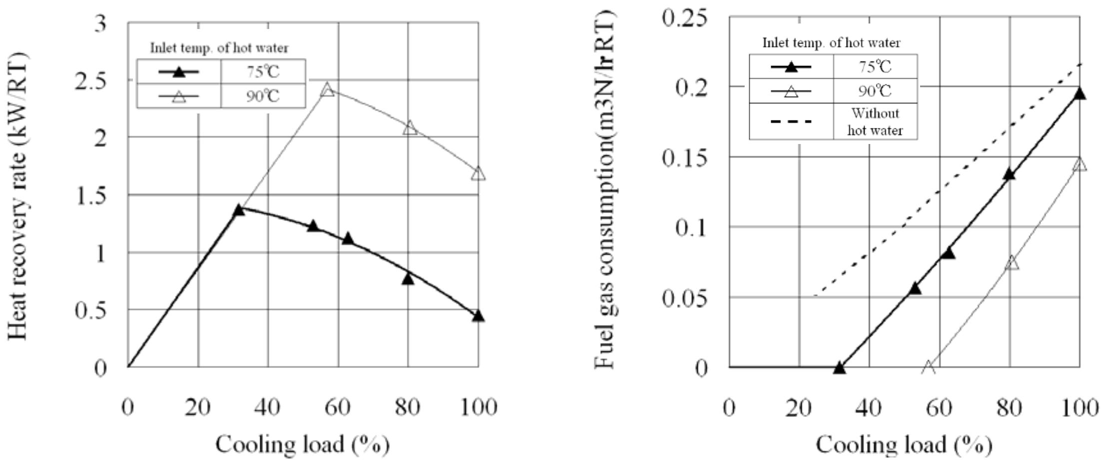


Figure 3: Heat recovery rate and Fuel gas consumption of Solar- driven Absorption Chillers

the load factor decreases, as mentioned above, combustion gas is not required in a area with 30% or less of load factor.

Further, it is found that in case where the hot water is 90ºC, the combustion gas consumption amount can be reduced by approx. 32% at 100% cooling load factor.

3 SOLAR COOLING SYSTEM IN JAPAN

3.1 Outline of Solar Cooling System

The demonstration plants are installed in our factory located in Kusatsu City of Shiga Prefecture, Japan. This system started to undergo full-sized verification test in Feb. 2011. The flow diagram of this system is shown in Figure 4.

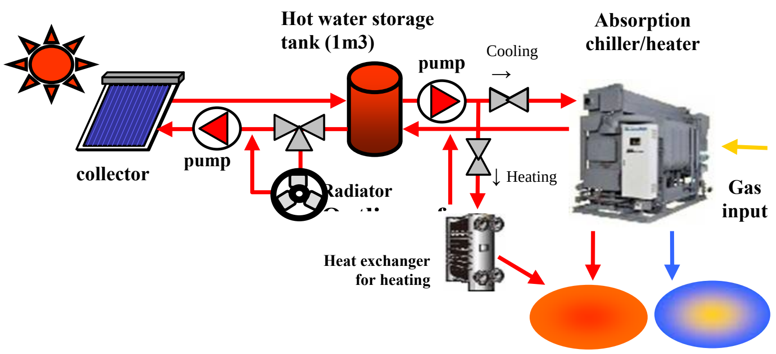


Figure 4: Schematic diagram of system

Figure 5: Aspect of Collector

Table 1: Specifications of system

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

Solar heat (hot water at 75ºC to 90ºC) is introduced into the Solar Absorption Chiller. 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 31ºC) during rated operation in case of solar heat hot water of Solar Absorption Chiller at 75ºC were installed on the roof of the office.

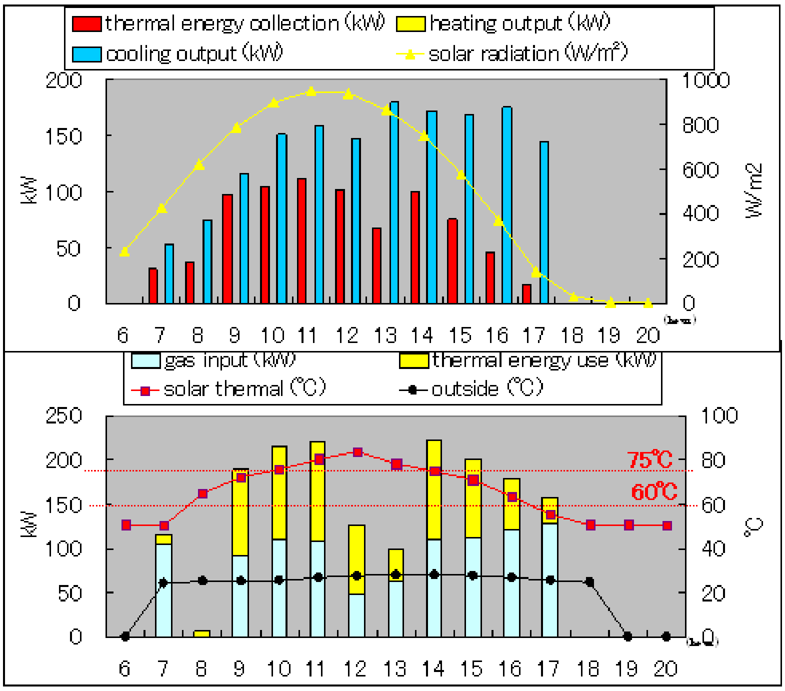


Figure 6: Operation data of cooling (20th May)

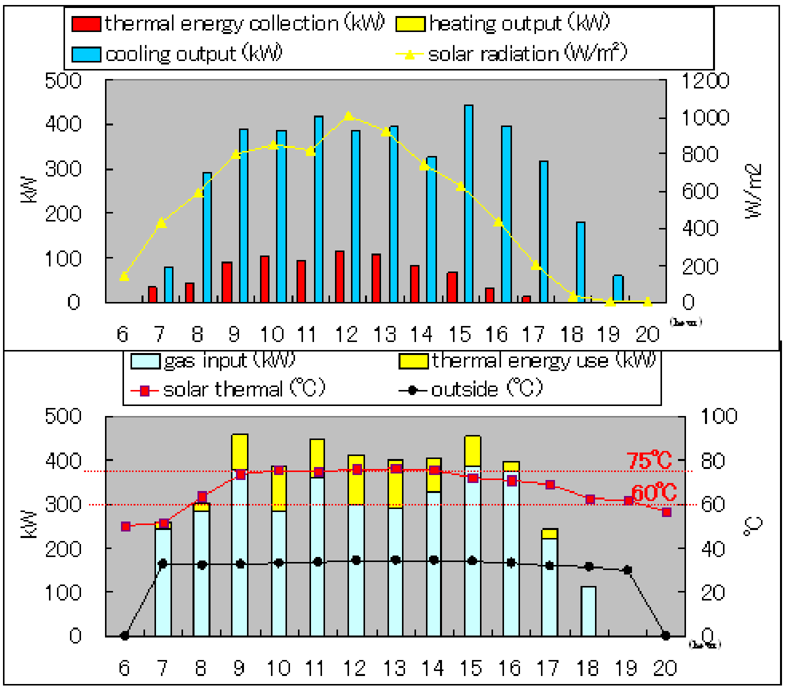


Figure 7: Operation data of cooling (28th July)

The hot water storage tank is provided to absorb the difference of flow rate between the solar energy collector and Solar Absorption Chiller and serves as a temporal cushion if solar radiation fluctuates suddenly. 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.

3.2 Evaluation status and results

3.2.1 Operation conditions

Figure 6 shows the operation data on May 20 and Figure 7 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.

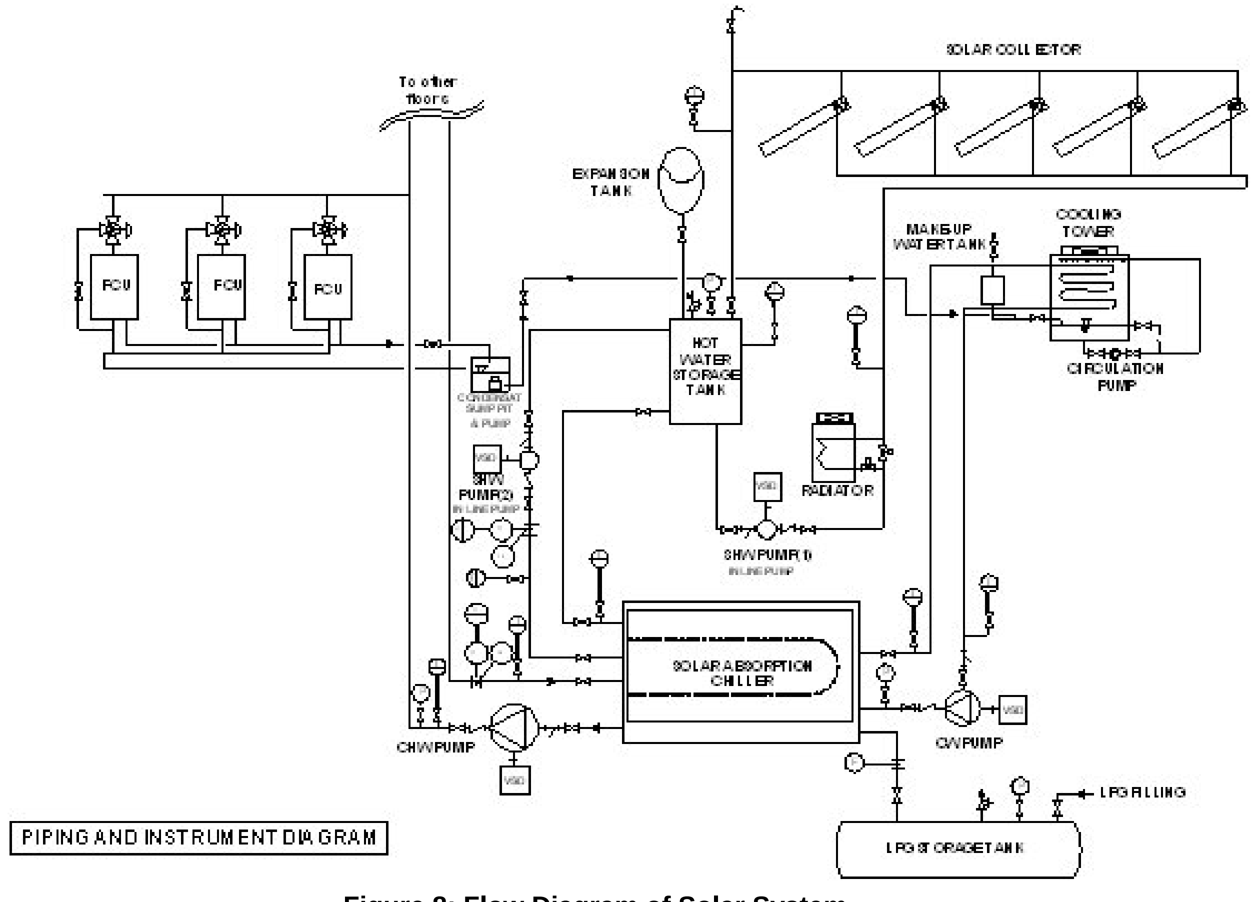


Figure 8: Flow Diagram of Solar System

3.2.2 Effect of Solar Absorption 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 Absorption Chiller developed exclusively for use of solar heat can reduce the hot water temperature from the solar energy collector more than use of conventional exhaust heat introduction type absorption chiller（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.

3.2.3 Improvement points

When changing to the low-load operation mode where the refrigerant pump of the chiller 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.

4 SOLAR COOLING SYSTEM IN INDONESIA

4.1 Outline of Solar Cooling System

The demonstration plants are installed in the building of University of Indonesia near Jakarta. The flow diagram of this system is shown in Figure 8. The basic specification of Solar Absorption Chillers is shown in Table 2. On this project, as a result of examining the air-conditioning load and the construction area of solar collectors, the cooling capacity is determined as 281 kW.

Table 2: Basic Specification of Solar Absorption Chiller

			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

COP = Cooling Capacity / HHV Heat Input

4.2 Greenhouse Gas Emission Reduction Effect

Based on the above system, we did a trial estimation by comparing with the conventional electric chiller. The comparison equipment specification is shown in Table 3. Cooling capacity of both equipment is the same as the above demonstration plant (281kW). COP of the electric chiller is 4.0 and electricity consumption is 70.25kW. Concerning the solar absorption chiller, it uses $20.5m3_N$/h of fuel natural gas when solar energy is not available and uses $14.0m3_N$/h when solar energy is available (Natural gas HHV=37.99kJ {9080kcal/$m3_N$}). Further, the solar absorption chiller consumes 2.25kW of electricity and it uses 3.75kW as Solar hot water pumps and a radiator.

Next, using “Average Hourly Statistics for Global Horizontal Solar Radiation” in Indonesia and annual “monthly operating condition and cooling load”, we calculate the annual electricity consumption and fuel natural gas consumption of both equipment.

Finally, we convert energy consumption to energy costs and CO2 emissions. We use 0.997kg-CO_2/kWh as CO2 emissions per operating electric energy and 0.051kg-CO_2/MJ as CO2 emissions per operating natural gas.

Comparison between solar absorption chiller and conventional chiller is shown in Table 4. Compared with conventional electric chiller, solar absorption chiller is possible reducing 43% CO2 emissions. And in case of 281kW cooling capacity, 77,999kgCO2/years are reducible. 277.6 kgCO2/years per 1kw cooling capacity are reducible.

4.3 Introductory Capacity Prediction of Solar Absorption Chiller in Indonesia

There are few absorption chillers in Indonesia, but, industrial sectors(plants) which are mostly provided with gas utilities and have sufficient infrastructures and commercial sectors,

Table 3: Comparison Equipment Specification

	Solar absorption chiller	Conventional electric chiller
Chiller	Solar absorption chiller x 1 Capacity 281kW Fuel gas consumption:(Hh=9080kcal/m^3_N) With solar using :14.0m^3_N/h Not solar using:20.5m^3_N/h Electricity consumption:2.25kW	Electric chiller x 1 Capacity 281kW Electricity consumption: 70.25kW(COP=4)
Facility	Solar hot water pump No.1:1.5kW Solar hot water pump No.2:0.75kW Radiator:1.5kW	

Table 4: Comparison between conventional chiller and solar absorption chiller【RP basis】

		Electric chiller	Solar absorption chiller
Amount of Energy	Electricity	183,600 kWh	16,369 kWh
	Fuel gas	− m^3_N	45,974 m^3_N
Energy cost	Electricity	181,257,972 RP	16,535,437 RP
	Fuel gas	− RP	96,085,660 RP
	Total	**181,257,972** RP	**112,621,097** RP
	Difference	−	−68,636,875 RP
	rate	100 %	62 %
CO_2emission	Electricity	183,049 kg-CO_2	16,320 kg-CO_2
	Fuel gas	− kg-CO_2	88,730 kg-CO_2
	Total	**183,049** kg-CO_2	**105,050** kg-CO_2
	Difference	−	−77,999 kg-CO_2
	rate	100 %	57 %

government and other public offices, hospitals, hotels, etc. are expectable as introduction sites of solar absorption chillers. The total air conditioning capacity in Indonesia in 2015 is presumed to be 1,130,000kW, and it is expected that 30% is occupied by solar absorption chillers.

In case of this assumption, air conditioning capacity of solar absorption chillers is 339,000kW. As CO2 reduction, 94,000tCO2 per year are expected.

339,000kW x 277.6kgCO2/years = 94,106.4tCO2

When assuming that the like quantity is introduced after year second, the effect triples in year third andten in year tenth, in ten years, it will increase 940,000tCO2.

5 CONCLUSION

(1) Solar absorption chillers enable the machines to be operatable even if the temperature decreases up to 75ºC and does not require the backup by combustion.

(2) In case where the temperature of hot water is 90 ºC, the reduction rate of combustion gas at 100% load factor becomes 32%.In addition, the cooling load area operatable only by hot water isexpanded to approx. 55%.

(3) From the estimation of effect by solar absorption chillers, in case of 281kW cooling capacity, 77,999kgCO2/years are reducible. 277.6 kgCO2/years per 1kw cooling capacity are reducible

6 ACKNOELEDGEMENT

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