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Performance Test of a Small Size LiBr-H_2O Absorption Chiller

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Abstract

This paper presents an experimental investigation on the performance of a small size absorption chiller which was renovated or developed from an old out-of-order commercial chiller. Its working fluid and controller circuit was replaced with the new one. The main objectives of this study are to gain the experience and know how to build the absorption chiller. The performance of this developed chiller was investigated under the local weather condition and the concentration of strong solution of 59% was used in this study. The experimental results show that the developed chiller can be operated at about 75% of nominal capacity and this cooling capacity satisfies the cooling load of the current conditioning room. The study results also demonstrate that, to obtain the high coefficient of performance, this chiller should be operated at 85°C of hot water temperature supplied to the generator.

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Keywords: Absorption chiller, Performance test, Crystallization, LiBr-water solution.

1. Introduction

Nowadays, all of natural resources are extravagantly used for the global development of human civilization. Among these, energy resources become the most important for human activities. It can be said that human society is seemed to be using more natural energy resources than nature is courteous. Consequently, the serious issues, e.g.: energy crisis, global warming and climate change, are occurred. To mitigate these serious problems, not only energy preservation and energy efficiency measures but renewable and waste energy utilizations should also be encouraged.

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One of the best technologies serving this idea is a thermal driven heating (as heat pump) and cooling (as refrigeration) systems. Among these systems, absorption cycle is popular and widely used due to it outperform the others in this class.

About 85% of the world's energy consumption is derived from the burning/combustion of fossil fuels as primary energy. In tropical countries, more than one third of the total electrical energy generated is consumed in commercial/residential buildings [1-3], and 70% of residential building energy consumption is used by air conditioning systems [3]. These are primarily by vapor compression systems. The use of renewable energy is one energy source option for such air conditioning system. Absorption chillers can be a key component in a building cooling system.

Currently, almost all current absorption systems are used for the waste heat recovery in industrial or large residential buildings. For such applications, systems are available in sizes range of 35 to 5,200 kW [4, 5] and they are equipped with gas or oil auxiliary/backup heat sources, [6-9, 10]. These systems still are fossil energy based cooling systems. To develop a renewable energy based air conditioner for residential application (low cooling capacity) a small scale of absorption chiller should be deeply studied.

This paper presents an experimental study on the performance of a small size (3.5 kW or 2 RT) LiBr-H_2O absorption chiller. The main objective of this study is to know how to develop the absorption chiller, especially working fluid blending and hot water temperature suitable for the developed chiller under local weather condition. Section 2 presents theory ragarding the absorption cycle. Section 3 details the experimental setup. The chiller performance evaluation and experimental results are described and discusses in section 4 and 5, respectively. Finally, the main conclusions and recommendations of the study presents in section 6.

Nomenclature

$\dot{m}_{ch}$	chilled water flow rate
$T_{ch,i}$	temperature of the chilled water entering the chiller
$T_{ch,o}$	temperature of the chilled water leaving the chiller
$\dot{m}_{ge}$	flow rate of the generator hot water
$T_{ge,i}$	hot water entering the generator temperature
$T_{ge,o}$	hot water leaving the generator temperature

2. Absorption refrigeration systems

Three main groups of active air conditioning systems are shown in Fig. 1. They are classified by the type of energy used- electrical, thermal and hybrid energy systems. Currently, almost all refrigeration systems are vapor compression systems [11] (the first group) which use electricity (high grade and expensive energy) as the input energy. Absorption is classified into the second group. The main advantage of this group is that they can be driven by many kinds of thermal energy (it can be the heat generated from low grade and cheap fuels or waste heat or renewable energy). In adsorption, the substance is sorbed at the surface of sorbent (called adsorbent), while in absorption, the sorbed substance diffuses in the volume of sorbent (called absorbent). Desiccant materials have a high capacity to keep water. They can be solid (e.g.: zeolites, silica gels) or liquid (e.g.: LiBr, LiCl, glycols, calcium chloride). They are classified as either absorbents or adsorbents. So, in desiccant cycle, air is used instead of water [12]. To increase the overall system efficiency and the balance of energy supply or increase the flexibility of energy utilization, the third group of active air conditioning system is attractive [12]. Absorption chillers are attractive for thermal and hybrid energy sources.

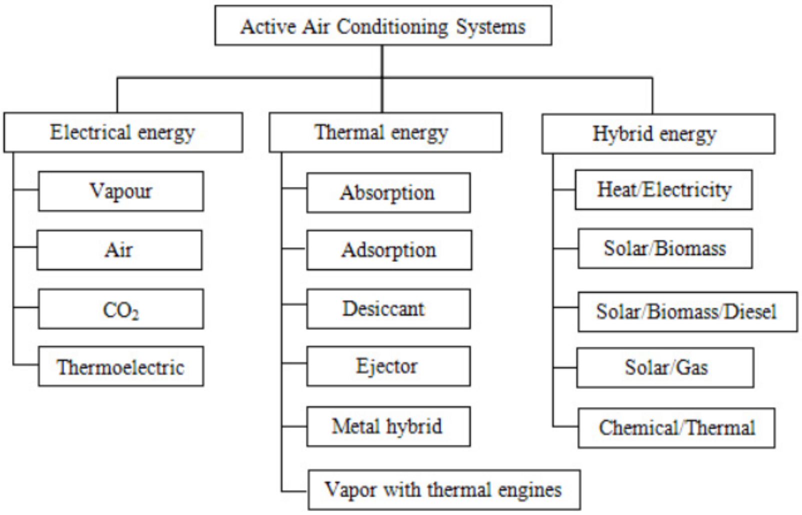

Fig.1. Active air conditioning system classification [14].

2.1. Basic Cycle of Absorption Chiller

In 1805, Oliver Evans theoretically proposed absorption cycle of sulphuric acid and water. Later on, in 1850, Edmond Carré developed the first absorption chiller using water and sulphuric acid. In 1859, his brother, Ferdinand Carré developed the first ammonia-H_2O refrigeration machine. Since 1945, LiBr-H_2O absorption chillers have widespread use. The trend reached its peak around 1960, and then diminished in 1970s with the development of low cost compressor and electrical motors [15]. As aforesaid, this kind of chillers are still used in the heat recovering systems and their main advantage is that they can utilize waste or renewable heat sources that currently would be otherwise be discarded. Due to environmental concerns and increase in energy prices, absorption cycle has received attention in recent years [16].

In absorption chillers, the absorbent is distilled (or the refrigerant, water, is evaporated) by heat at the generator. This is led to the condenser, where it rejects heat to the ambient and condenses. This is taken to the evaporator (through the expansion valve), where it receives heat from the space to be cooled and evaporates. The evaporated refrigerant (water) is absorbed by the weak solution in the absorber (from the generator). The absorption process also releases heat to the ambient, and the solution, now rich in water (strong solution) is taken to the generator (by a pump) to complete the cycle. The heat required for the generator is drawn from hot water or any other heat source. The condenser and absorber are cooled by cooling water pumped through a cooling tower. The chilled water produced from evaporator is pumped for cooling purpose. Absorption chillers can be classified as direct- or indirect-fired type. In direct-fired types, the heat source, e.g.: gas or fuel, is combusted inside the chiller. Indirect-fired types use hot fluid which brings heat from another source, such as solar water heating system, heat recovered from another process. In addition, absorption cycles are generally classified as single, double- or triple-effect when it has one, two or three generators, respectively [17]. Their thermodynamics cycles can be drawn as shown in Fig. 2 and 3, respectively.

Figure 4 shows a typical single-effect LiBr-H_2O absorption chiller. The process takes place in two vessels (shell). The upper vessel contains the condenser and generator; the lower vessel contains the evaporator and absorber.

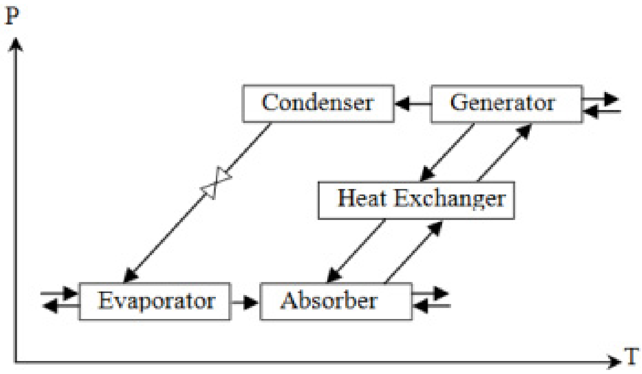

Fig.2. Single-effect absorption cycle.

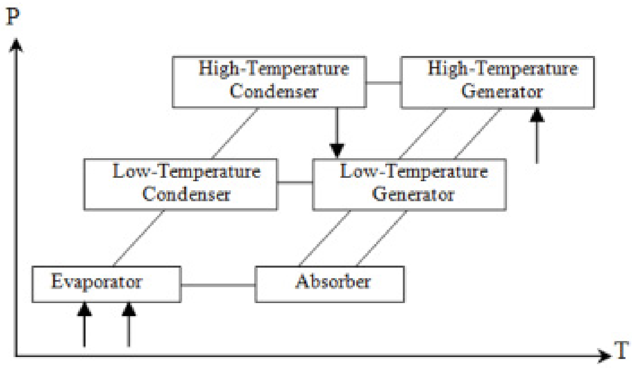

Fig.3. Double-effect absorption cycle.

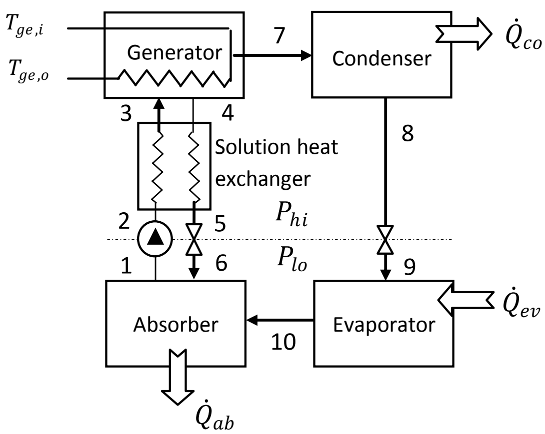

Fig.4. Schematic diagram of a single effect absorption chiller.

3. Experimental setup

The chiller used in this study (as shown in Fig. 5) was renovated from a very old commercial chiller which has not been operated for a long time. It is a water fired single-effect equipped with a cooling tower and a fan coil unit. This chiller (manufactured by Yazaki Company, model WFC-600S) has 7 kW nominal cooling capacity.

Without the data of working fluid (solution of LiBr as absorbent and water as refrigerant), its solution fluid and control circuit were replaced with the new one. After the renovation, the paramatric study regarding the main parameters, e.g.: concentration of solution, inside pressure and temperatures, was done for optimising their values.

Fig.5. Single-effect absorption chiller used in this study.

3.1. Blending of LiBr-water solution

The ratio of absorbent to refrigeration in the working solution can be determined using the chemical property chart of LiBr-water solution at any concentration under considering temperature and pressure as shown in Fig. 6. Each line shows the relationship between pressure and boiling point. The region on the left hand side of the curve presents liquid state and the right hand side, gaseous state (boiling point). The crystallization line drawn at the bottom portion of the graph shows the upper limit of the solution concentration. It is essential that these limits are not exceeded. Point A in the graph indicates a boiling point of 100 ˚C at 101.325 kPa. As shown by point B, 58% concentration solution produces a vapour pressure of 0.7 kPa at 40 ˚C. A decrease in concentration to 45% at 40 ˚C still retains a comparatively low vapour pressure of 2.3 kPa. Fifty eight percent (58%) solution will crystallize at point C (12 ˚C) [17]. Absorber inlet is the closest point to the crystallization line (Fig. 6), therefore the solidification may occur and the de-crystallization should be done at this point. At experimental site, there are some periods that the ambient temperature is lower than 20 ˚C. Hence, to prevent crystallization, the concentration of strong solution must be less than 59%. This value then has been used in this study.

This test aims at determining the chiller's performance and estimates its coefficient of performance (COP) under current modified condition. The test system set for this study consists of a chiller, cooling tower, fan coil unit, electrical boiler, pumps (hot water, chilled water and cooling water pumps), valves and other plumbing (as shown in Fig. 7). The original specification of this chiller (from the manufacturer before it was renovated) is given in Table 1.

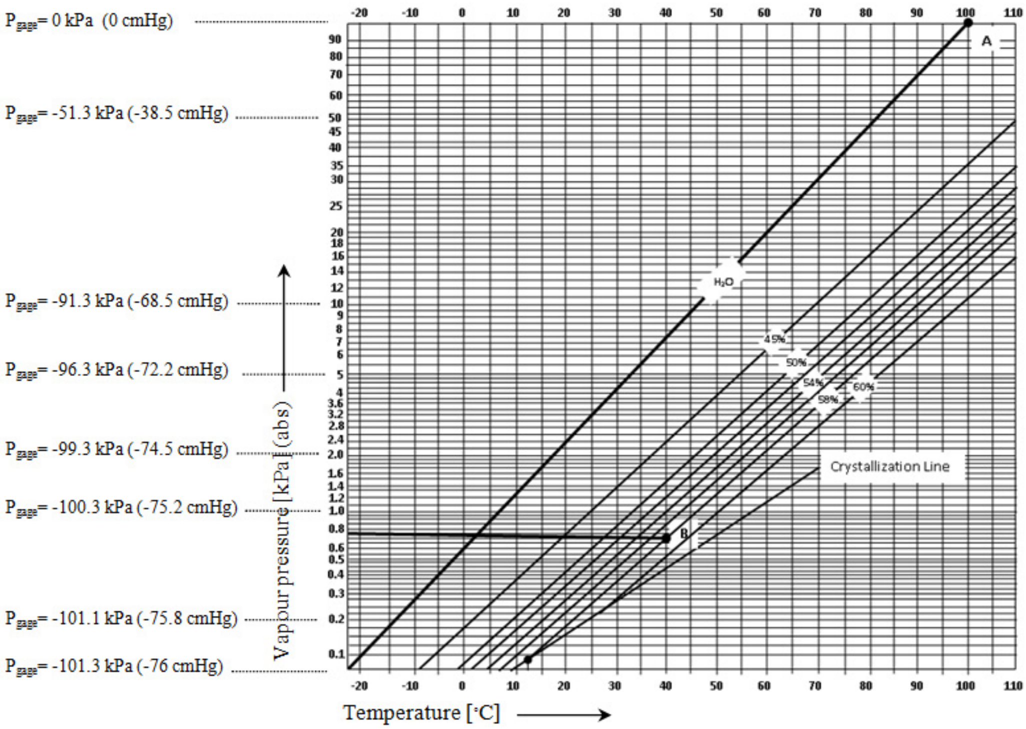

Fig.6. Chemical property chart of LiBr-water solution.

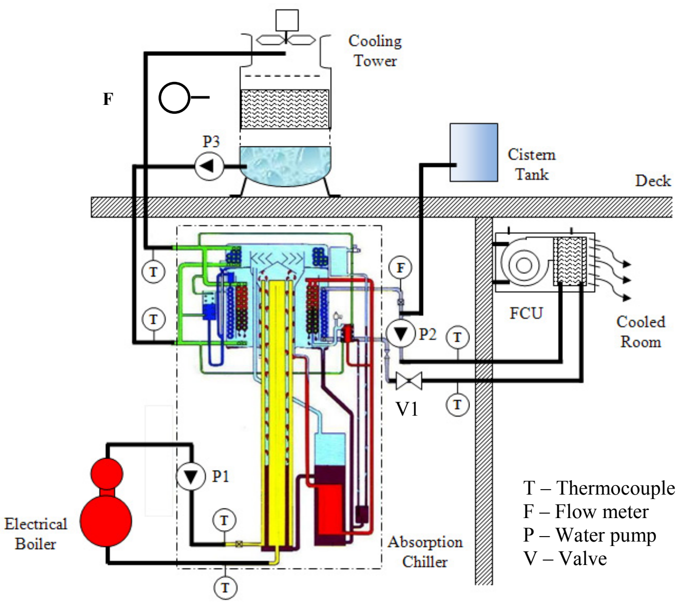

Fig.7. Schematic diagram of experimental setup.

3.2. Instruments and data acquisition system

To carry out the performance of the chiller system, all temperature and flow rate of working fluid of three loops: hot, cooling and chilled water loops, were measured. A data logger (Campbell Scientific Inc. model CR-10X) was used to record temperature from type-K thermocouples installed at different locations as shown in Fig. 7, and these data were recorded at every five-minute intervals.

3.3. Experimental procedure

The absorption chiller was tested under the design conditions indicated in Table 1. The cooling load calculation was first done and shows that the maximum cooling load of the test room is about 4.5 kW or 1.3 tons of refrigeration (TR) and occurs at around 16:00-17:00. A 20-kW electrical boiler was used to generate the hot water at any temperature for supplying to the chiller generator. To assure that the chiller is in good condition for use, a pressure gage is installed for measuring the chiller inside pressure. Regarding the chemical property (as shown in Fig. 6), if the solution pressure is higher than 2 mmHg, the chiller evacuation should be done using the vacuum pump.

As aforesaid, LiBr is a salt, it has a crystalline structure. The salt begins to leave the solution and crystallize below its minimum temperature. Crystallization may occur and interrupting the chiller operation if the concentration of solution is too high or the temperature is too low. When the crystallization is occurred, the solution temperature must to be raised above the saturation point, then the de-crystallization need to be done. To prevent this situation, the hot water should be heated to the set point temperature before supplied to the generator.

The steady state is defined by observing the constancy of mass flow rate and temperature at all components. The experiment results only in the steady state period will be used for experimental results analysis.

4. Evaluation of chiller performance

The chiller performance has been calculated on the basis of the resulting measurements and compared with the chiller specification data provided by the manufacture. The performance of the absorption chiller is determined by its cooling capacity, generator heat input and COP. These quantities are defined by the following equations.

The cooling capacity or chiller load can be calculated as:

$$\dot{Q}_{ev} = \dot{m}_{ch} C_p \left(T_{ch,i} - T_{ch,o}\right) \tag{1}$$

The heat supplied to generator is

$$\dot{Q}_{ge} = \dot{m}_{ge} C_p \left(T_{ge,i} - T_{ge,o}\right) \tag{2}$$

Finally, the instantaneous COP of chiller can be determined as:

$$COP = \dot{Q}_{ev} / \dot{Q}_{ge} \tag{3}$$

5. Results and discussion

The chiller was tested for three days at different hot water temperatures. Figure 8 shows the temperature profiles at inlet and outlet points of the chiller. This figure gives the supply and return temperatures in the three water loops: hot water supply, chilled water and cooling water. These figures show the test results of three hot water set point temperatures (it was set at the temperature controller) at 80, 85 and 90 ˚C, respectively. During steady state period, the average measured temperatures of supply hot water into the chiller generator were 81.3, 84.44 and 90 ˚C, respectively. The minimum chilled water temperature of 13.8 ˚C was achieved when the average supply hot water temperature was 84.4 ˚C (with set point temperature of 85 ˚C) and the average chilled water temperature of 14.6 ˚C was also achieved on this day.

Table 1. The specification of chiller used in this study (originally before renovated) [17].

Item		Specification	Unit
Refrigeration capacity		7.0	kW
Chilled water	Chilled water outlet temperature	9	C
	Chilled water inlet temperature	14	C
	Minimum chilled water outlet temperature	8	C
	Chilled water circulation volume	0.333	l/s
	Evaporator pressure loss	19.7	kPa
	Evaporator maximum pressure in ordinary use	295	kPa
COP		0.6	
Heat medium	Generator input	11.6	kW
	Generator inlet temperature range	75-100	C
	Generator circulation volume	0.463	l/s
	Generator pressure loss	12.8	kPa
	Generator maximum pressure in ordinary use	98	kPa
Cooling water	Heat rejection capacity	18.6	kW
	Cooling water inlet temperature	29.5	C
	Cooling water outlet temperature	34.5	C
	Cooling water circulation volume	0.888	l/s
	Condenser and absorber pressure loss	22.6	kPa
	Maximum pressure of condenser and absorber in ordinary use	295	kPa
Pump	Power supply	220, 110	V
	Electric motor rated output	100	W
	Electric motor rated input	195	W
	Electric motor rated current	2.2/2.0 (100V)	A
	Head x flow volume	76.8 x 0.333	kPa x l/s
Palladium cell heater (P.C.H.)		20	W

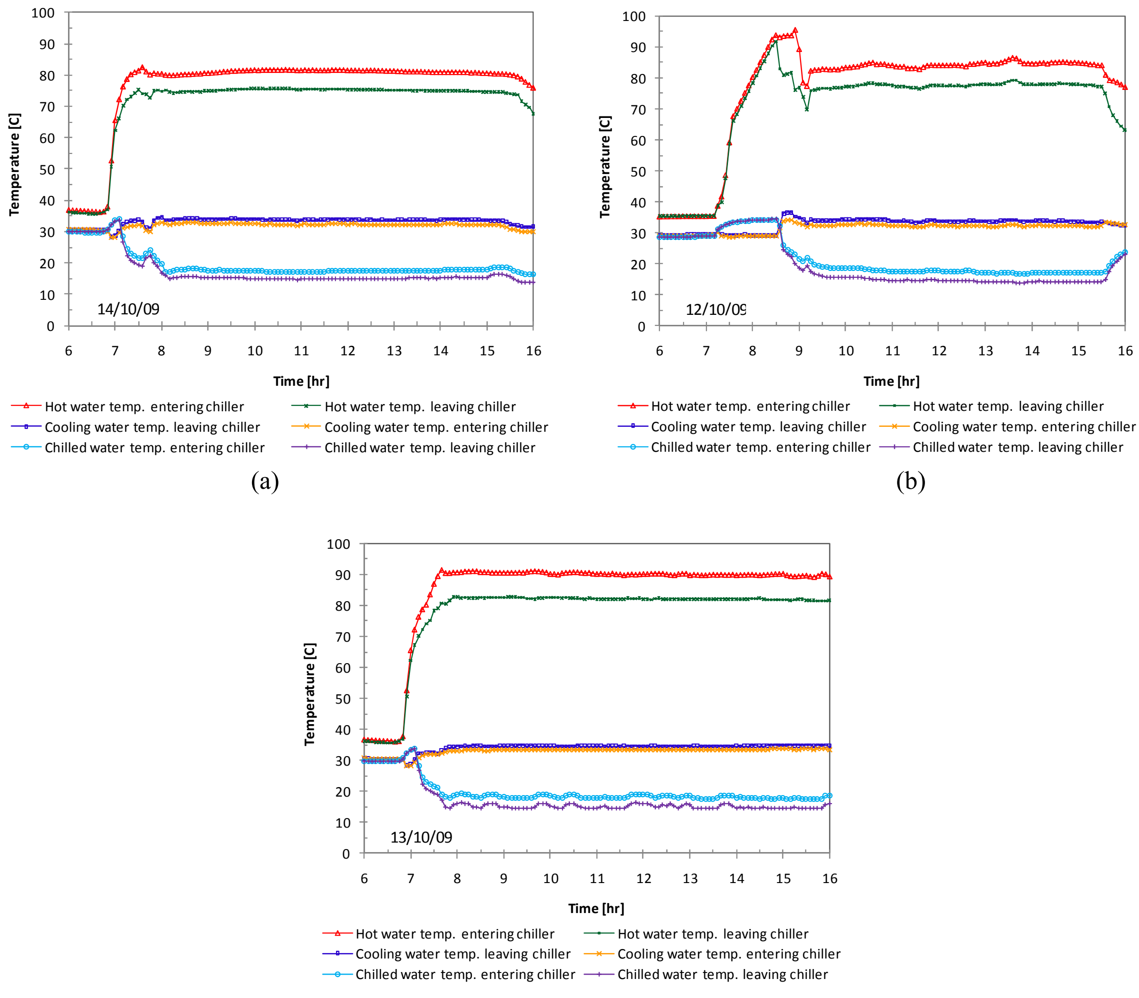

Fig.8. Temperature profiles when the hot water temperature was set at (a) 80 ˚C, (b) 85 ˚C and (c) 90 ˚C.

The data indicates that when the supply hot water temperature was set at 80 ˚C, its temperature profiles are the most stable compared to the others. The average difference between supply and return water temperature of three loops; hot, cooling and chilled water varied in the range of 6 to 8, 1 to 1.5 and 2 to 3 ˚C, respectively. In hot and chilled water loops, the higher set point temperature, the higher temperature difference occurs. In the cooling water loop, the temperature differences of each set point temperature are 1.49, 1.52 and 1.21 ˚C, respectively.

Figure 9 shows the chiller performance curves which calculated from the data shown in Fig. 8. This figure shows the input and output power in the heating, chilling (cooling capacity) and cooling water loops. During steady state, the average generator heat input for these three cases are 8 kW with a temperature difference of 6 ˚C, 8.8 kW with a temperature difference of 6.7 ˚C and 10 kW with a temperature difference of 10 ˚C, respectively. It can be observed that after an initial start-up period, the evaporator capacity reaches a constant level throughout the day.

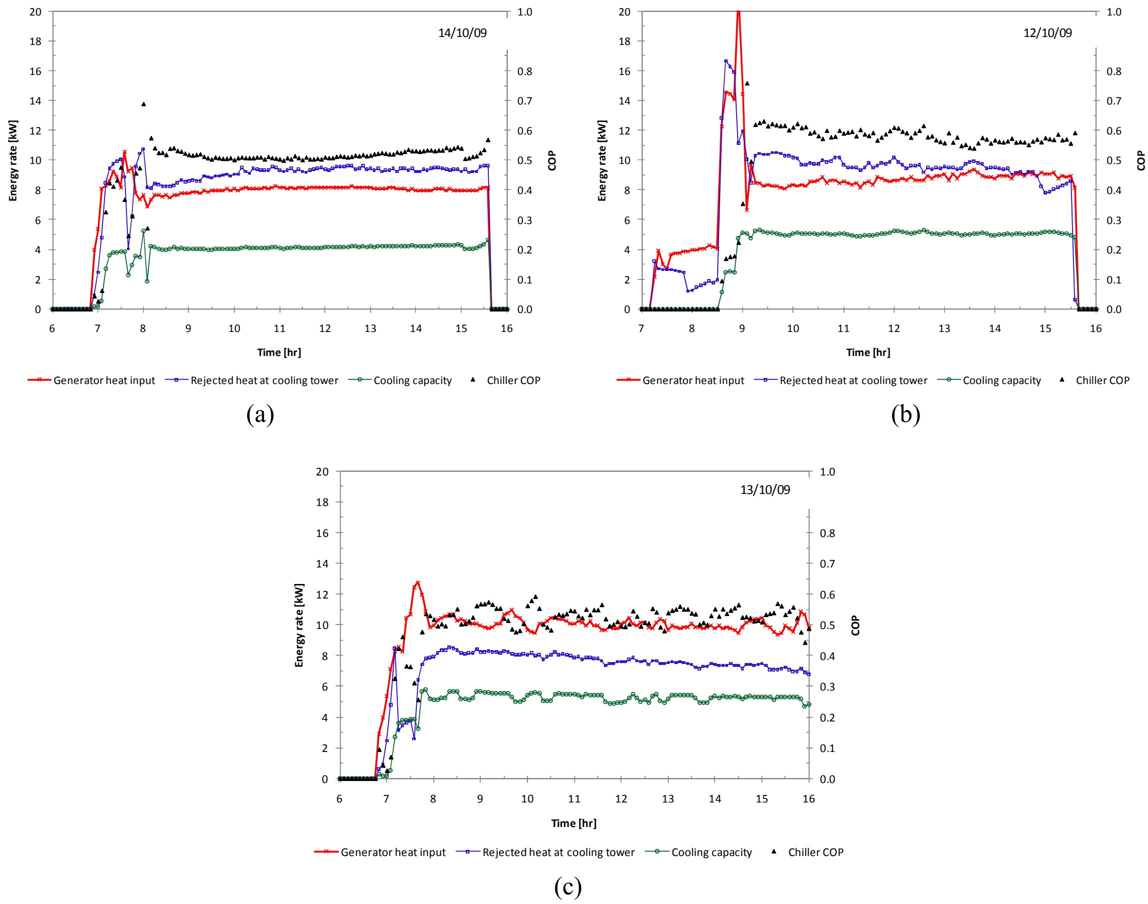

Fig.9. Chiller performance when the hot water temperature was set at (a) 80 ˚C, (b) 85 ˚C and (c) 90 ˚C.

The data indicates that the average cooling capacity of the chiller is stable at around 4.2 kW, 5.1 kW and 5.3 kW, for these three set point temperatures respectively. It can be observed that this absorption chiller runs at an average of 50, 72 and 75% of nominal refrigeration capacity when the supply hot water were set at 80 ˚C, 85 ˚C and 90˚C, respectively. The calculated COP directly depends on the supply hot water temperatures with the average values of 0.52, 0.58 and 0.53, respectively. Finally, because COP is an important thermal efficiency parameter of chiller, this chiller should be run at 85 ˚C supply hot water to obtain the maximum COP.

5. Conclusion

To gain the experience and know how to build the absorption chiller, an out-of-ordered chiller was renovated and setup for this current experimental study. The performance of this chiller was investigated under the local weather condition and the concentration of strong solution of 59% was used in this study. The developed chiller can be operated at about 75% of nominal capacity. The results show that the cooling capacity of this current chiller satisfies the cooling load of the conditioning room. To obtain the high coefficient of performance, this chiller should be operated at 85˚C of hot water temperature.

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