Performance of non-CFC refrigerator driven by chilled water from 35 kW $LiBr/H_2O$ solar absorption cooling system

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Abstract

In this study, the temperature profiles inside the refrigerated space and loads of a non-CFC refrigerator driven by chilled water from 35 kW $LiBr/H_2O$ solar absorption cooling system (SACS) was investigated. Furthermore, the performance of this system in terms of the coefficient of performance (COP) and energy efficiency ratio (EER) was evaluated in order to compare with commercial refrigerator. A 0.14 m^2 commercial fridge was converted and used as the main body, in which a cooling coil unit with the surface area of heat exchange of 1.06 m^2, a fan of 0.08 kW for forced air circulation, and a pump of 0.1 kW for chilled water circulation were installed. Thirty-eight 500 cm^3 bottles of drinking water resulting in 18.39 kgs of weight were put into the prototype refrigerator as the load. The results showed that during a 700 min fully operational test, the inlet chilled water (refrigerant) was maintained in the range of 7-10°C and circulated to the evaporator (cooling coil) by the pump. After applying the refrigerant to the refrigerated space, the space temperature decreased and kept constant at about 7.58°C within 350 mins, corresponding to load temperatures decreased from 21.88°C to 11.10°C. The COP and EER of this refrigerator were found to be 0.76 and 2.39, respectively. The experimental results indicate that the proposed non-CFC refrigerator can be used to preserve food and beverages. This can be applied in an industry where excess cold water is available.

Keywords: *Refrigerant, refrigerator, solar absorption cooling, coefficient of performance (COP), energy efficiency ratio (EER)*

1. Introduction

Cooling technologies play a vital role in everyday life. However, these cooling systems and refrigerators consume a large amount of electricity. Thus, solar-driven cooling systems have been installed to reduce such electricity consumption [1,2]. Absorption cooling systems (ACSs) are widely adopted among solar cooling techniques because they are compatible with a low temperature heat source at a lower cost of thermal energy. In addition, an environmental friendly non-CFC refrigerant can be used. A 35 kW (10 ton of refrigeration) single-effect solar absorption cooling system (SACS) based on water-lithium bromide ($LiBr/H_2O$) working fluids was installed in the School of Renewable Energy Technology, Naresuan University, Phitsanulok, Thailand, in 2006. The SACS produces chilled water (7-10°C) of 0.2 m^3 to supply to air-conditioners located in the testing building. There is excess chilled water, which has a potential for other cooling applications.

A non-CFC refrigerator was designed and constructed by using the excess chilled water from the SACS as the refrigerant, as described in a previous study [3]. In the present study, therefore, the temperature profile inside the non-CFC refrigerator was measured, in order to the evaluation of coefficient of performance (COP) and energy efficiency ratio (EER) of this system.

2. Description of the experimental absorption and refrigeration system

The 35 kW (10 ton of refrigeration) SACS is shown in Fig. 1. This cooling system is thermally driven by a 72 m^2 evacuated tube solar collector with an LPG-fired backup heating system. The absorption chiller uses a single effect absorption model: WFC SC-10, from Yazaki Company. The chiller has a maximum cooling capacity of 35 kW. Normally, the driven temperature of SACS cycle varies typically between 70°C to 95°C and the practical COP varies between 0.2 and 0.7 with a cooling capacity of 20-35 kW. Generally, the water-lithium bromide ($LiBr/H_2O$) is used as working pair fluids where water is the refrigerant and lithium bromide as the absorbent [4-6]. The prototype of non-CFC refrigerator has been connected to the chilled water tank of the SACS system, as shown in Fig. 1.

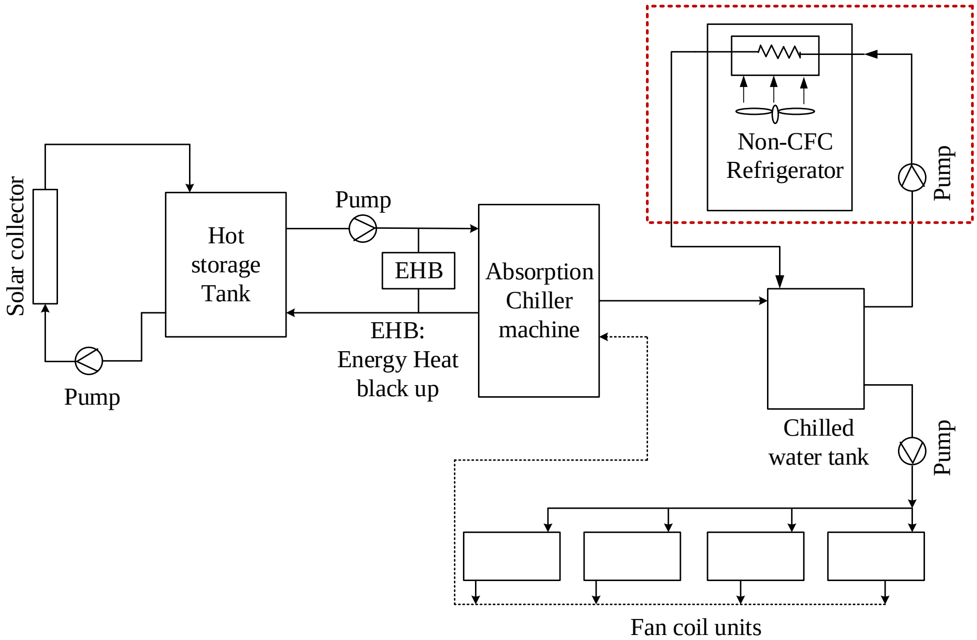

Figure 1. Schematic diagram of 35 kW (10 ton of refrigeration) single-effect solar absorption cooling system (SACS) combined with a non-CFC refrigerator.

Table 1. Characteristics of the components fabricated as the non-CFC refrigeration.

Characteristics	Size	Unit
Refrigerator Volume	0.14	m^3
Pump power	0.10	kW
Fan power: (270 x 27 x 65 mm)	0.08	kW
Chilled water	7-10	°C
Area of cooling coil (evaporator)	1.06	m^2
Chill water storage tank	0.2	m^3

3. Experimental setup

Fig. 2(a) shows the testing diagram of the non-CFC refrigerator driven by chilled water as cooling fluid. A 0.14 m^3 commercial refrigerator was modified by inserting an evaporator (cooling coil) in which the excess chilled water from the SACS flowed through. An electric fan of 80 W was used to circulate the air inside the refrigerator. In order to verify the operation of this prototype refrigerator, chilled water, as cooling fluid is stored in a 0.1 m^3 tank, was fed into the system, using pump no. 2 to the 0.2 m^3 chilled water storage tank where the temperature was maintained in the range of 7°C - 10°C. Note that the chilled water in the 0.2 m^3 tank was assumed as the chilled water from the SACS. The chilled water used as cooling fluid, was made from ice. The chilled water was drawn by pump no.1 into the evaporator (cooling coil) with a mass flow rate of 9×10^{-2} kg/s. The heat exchange process was occurred in the evaporator and gradually distributed the low temperature air in the refrigerated space. As a result, the heat energy of the loads was picked up by the chilled water served as the evaporator. Characteristics of the components fabricated as the prototype non-CFC refrigerator are summarized in Table 1.

Thirty-eight 500 cm^3 bottles of drinking water resulting in 18.39 kgs of weight were put into the refrigerated space as the load. Thermocouple sensors type T connected to a Graphtec-data recorder (GL820) were attached inside the refrigerated space and the load for measuring temperature at different locations inside the refrigerated space of the non-CFC refrigerator, as illustrated in Fig. 2. T_{CT} and T_{CB} are the temperature at the top and bottom surface area of the cooling coil, respectively. T_{R1} to T_{R4} are the temperatures inside the refrigerated space, and T_{L1} to T_{L4} are the load temperatures measured inside the bottles.

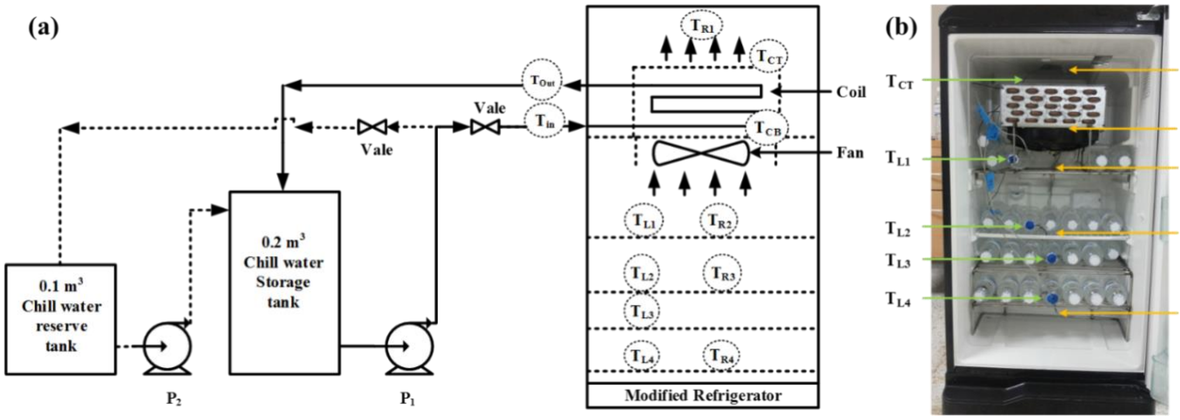

Figure 2 Non-CFC refrigerator: (a) schematic testing diagram, and (b) photograph of the positions of the installed thermocouple sensors.

The performance of the non-CFC refrigerator was evaluated by the coefficient of performance (COP) given as:

$$COP = \frac{Q_{evp}}{W_e} \qquad (1)$$

where Q_{evp} is the magnitude of the heat removed from the refrigerated space (kW) and W_e is the work input consumed by the electric pumps. The Q_{evp} can be determined from the sensible heat which is defined as:

$$Q_{evp} = \dot{m}C_P(T_{out} - T_{in}) \qquad (2)$$

where $\dot{m}$ is the mass flow rate of chilled water (9×10^{-2} kg/s), C_P is the specific heat of chilled water (4.187 kJ/kg·C), T_{in} and T_{out} are the inlet and outlet temperature of chilled water flowing through the evaporator, respectively.

In order to compare with commercial refrigerators, the energy efficiency ratio (EER) was also determined, based on the ratio of the rate of total heat removal from the cooled space by the refrigerator (BTU) to the rate of electricity consumption (Wh). Therefore, EER have the unit BTU/Wh.

$$EER = 3.412 \times COP \qquad (3)$$

4. Results and Discussion

The initial temperatures of refrigerated space in the non-CFC refrigerator, loads and chilled water were 23.8°C, 23.58°C and 8.70°C, respectively and, the ambient temperature was measured as 24.60°C as well. Fig. 3(a) shows the temperature profile inside the refrigerated space of non-CFC refrigerator at different locations flowed by T_{R1} to T_{R4}, compared with a temperature of chilled water entering (T_{in}) the cooling coil. It may be observed that the temperatures inside the refrigerated space significantly decreased with time until a constant of 9°C-10°C was reached at around 300 min-700 min after which the test was stopped. The refrigerated space had a similar temperature after operating this system for 300 min. In addition, T_{R1} was close to T_{in} over the testing time due to the tri T_{R1} thermocouple sensor being located at the top position of refrigerated space where cooling air was leaving the evaporator (Fig. 2). The temperature profiles of the load (T_{L1} to T_{L4}) inside the refrigerated space together with T_{in}, is shown in Fig. 3(b). The load temperatures decreased with time and maintained a constant temperature for 300 min 700 min, when the test was stopped. It was noted that the load temperature profiles corresponded to the temperature profiles of the refrigerated space. According to Fig. 3, the loads had higher temperatures than the refrigerated space. The load temperature of T_{L1} was similar to that of T_{in} because the T_{L1} thermocouple sensor was attached the load next to the evaporator (Fig. 2). However, the temperature of the refrigerated space and loads were higher than the temperature of a commercial refrigerator, which is maintained at 0-5°C. The inlet temperature of the chilled water (cooling fluid) significantly affected the temperature profile of the refrigerated space and loads because the cooling coil unit absorbed heat from the refrigerated space and loads, because of the circulation of the chilled water. Fundamentally, the rate of heat transfer inside the evaporator is a function of the mass flow rate of the chilled water, which is depended on the power of a pump, and the warm air velocity distributed by a fan.

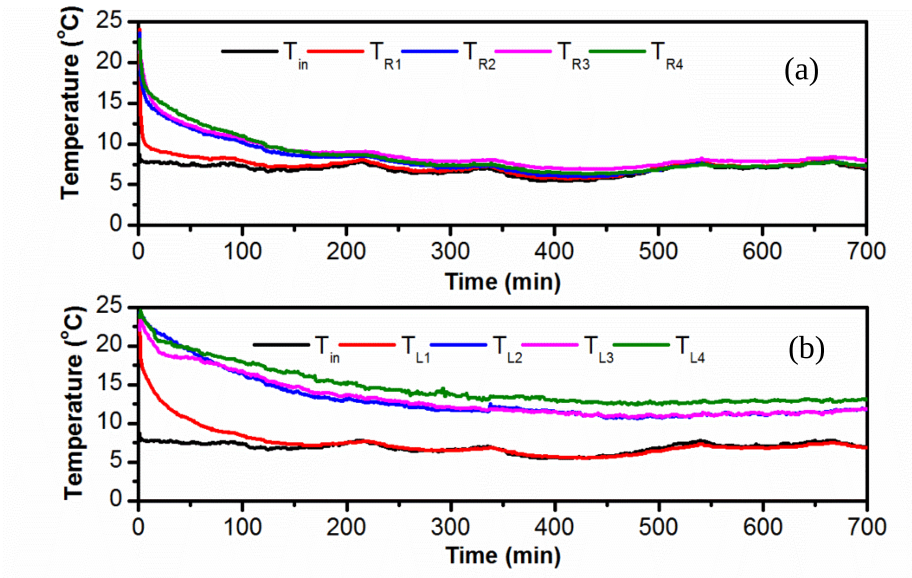

Figure 3. Temperature profiles of (a) the refrigerated spaces and (b) loads.

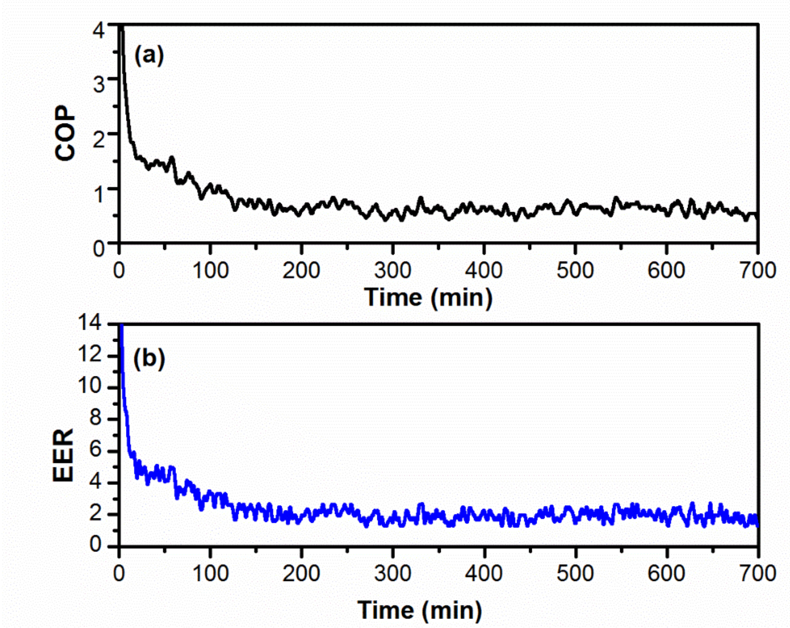

Figure 4.The performance of non-CFC refrigerator: (a) coefficient of performance (COP) and (b) Energy efficient ratio (EER).

The performance of the non-CFC refrigerator was evaluated in terms of the coefficient of performance (COP) as shown in Fig. 4 (a). The COP steadily decreased with time, from 0-200 min and then remained constant afterwards. The average COP was 0.76 over the whole testing time. Fig. 4(b) presents the energy efficiency ratio (EER) of the non-CFC refrigeration system. It may be seen that the time dependents of the EER correspond with the time dependents of COP because EER was evaluated according to the relationship followed in Equation 3. The average EER of this system was 2.39. The COP and EER have shown dependency on the temperature gradients between the chilled water temperature entering and leaving the cooling coil unit, according to Equation 2. Compared with commercial refrigerators (Green label for refrigerators, Thailand: EER > 3.1 or COP > 0.91), the non-CFC-refrigerator not only had lower COP but also had lower EER. These were because the pumps and fan were continuously running during testing time to circulate the chilled water and air inside the refrigerated space and also the limitations of temperature and capacity of chilled water. However, water is non-toxic, noncorrosive, nonflammable, chemically stable, and of low cost. Therefore, the results in this study can be a guideline for non-CFC refrigerator design in an industry where excess water is available.

5. Conclusions

In the present study, temperature profiles and performance in term of the coefficient of performance (COP) and energy efficiency ratio (EER) of the non-CFC refrigeration was successfully measured and evaluated over the testing time of 700 min. As results, the inlet temperature of chilled water had significantly affected the temperature profile of the refrigerated space and loads due to the evaporator unit absorbing heat from the refrigeration space and loads, using chilled water. The COP and EER of this system decreased with time, corresponding to the temperature profile. Compared with commercial refrigerators, the non-CFC-refrigerator had lower COP and EER due to requiring power for a pump and fan throughout the operating time, in order to maintain the temperature within the refrigerated space and loads, including the limitations of temperature, and lower-capacity and transport properties of chilled water.

Acknowledgements

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