Study on Non-Freon Air Cooling System Using Water Refrigerant

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ABSTRACT

This paper aims for construction of a small, clean air cooling system using a water refrigerant and examines it experimentally. We offer a basic report for realization of the non-Freon air-cooling system using only water as a refrigerant. An experimental device consists of two groups, the first stage is composed a vacuum pump and a vacuum container of about 60 [liter] in volume, and the second stage has two heat exchangers (one is a heat load) and a water circulation pump. The variations of temperatures at each place are measured by thermocouples. An air-conditioner indoor unit or a heater as the heat load is used; the air conditioning measurement and the energy are measured, respectively. Consequently, in air-cooling system used only water refrigerant, the ability to cool a room air enough is provided. The development of a new vacuum pump which can exhaust a large amount of water vapor is introduced as an appendix.

Keywords: non-Freon, air-cooling system, water, vacuum pump, heat

1 INTRODUCTION

In recent years, global environment problems such as global warming and ozone depletion have been worried. The spread of air-conditioners contributes to an increase of work efficiency and improvement of comfortable living environment. On the other hand, alternatives, e.g. chlorofluorocarbon (HCFC, etc.), used for a refrigerant of air-conditioners don't destroy the ozone layer, but they are appointed as greenhouse gas, and the collection at the time of the disposal is obliged. However, it is difficult to collect all refrigerants.

Energy-saving product and non-Freon machinery have become active, and refrigerants using air-conditioners have zero or near to zero with ODP (an ozone destruction coefficient) and GWP (global warming potential). Interest in natural refrigerants like water, carbon dioxide, hydrocarbon, etc. has risen in the field of air conditioning. Water is superior for the cost and environment, and the handling is easy, too.

When water is located under vacuum, it boils till the pressure of saturation water vapor at the water temperature. The water temperature falls, since the boiling takes evaporative latent heat from water. In other words, we can get coldness by exhausting the vacuum container with water.

In food industry, there are some applications of water decompression cooling, e.g. moist lettuce or cut flowers, and decompression takes evaporation heat away from them rapidly [1], [2]. In resent years, Sanken Setsubi Kogyo Co. Ltd. (in Japan) and IDE technology Corporation (in Israeli) cooperated, and sell a water cooling system of the environment correspondence type that incorporated the steam turbo compressor [3]. This big cooling system which has freezing capacity of more than 350 [kW] is used in a gold mine in South Africa. In addition, there is absorption chiller of more than 100 [kW] using NH_3 or LiBr as the refrigerant. However, a small water decompression cooling system of several kW such as home use is not developed.

This paper aims for construction of a small, clean air cooling system using a water refrigerant and examines it experimentally. We offer a basic report for realization of the non-Freon air-cooling system using only water as a refrigerant.

2 WATER REFRIGERANT

There are some natural refrigerants, i.e. hydrocarbon (isobutane, propane), CO_2, ammonia, air, and water. Water exists in the natural world abundantly, has not the toxicity, burn ability, and is cheap. In addition, characteristics of water show the specific heat at constant pressure of 1.846 [kJ/(kg・K)], the latent heat of 2457 [kJ/kg] at 17.5 [℃], and water can remove large thermal energy by evaporation.

International Committee of Weights and Measures in 1990 was adopted an experimental formula which was reported about the saturated water vapor pressure P_s by D. Sonntag in 1986 [4]. The saturated water vapor pressure calculated by the experimental formula is shown in Fig. 1.

3 COEFFICIENT OF PERFORMANCE

Efficiency of the refrigerator is evaluated in COP (Coefficient of Performance). COP in the experiment that installed an air-conditioner indoor unit is calculated as follows.

First, the relative humidity Φ is measured. Using P_s, the relative humidity Φ is converted into the absolute humidity X.

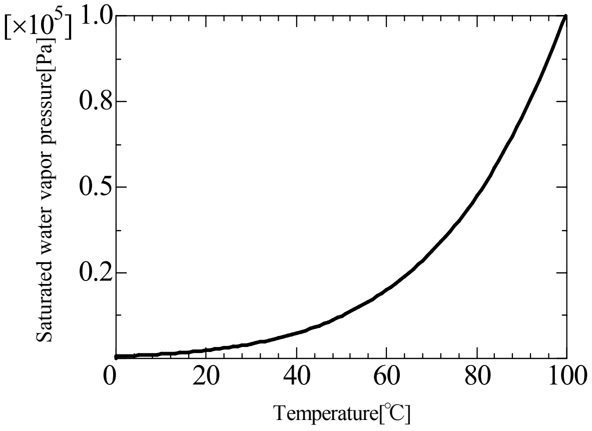

Fig. 1. A curve of the saturated water vapor pressure.

$$X = 0.622 \times \frac{\Phi P_s}{1.013 \times 10^5 - \Phi P_s} \tag{1}$$

where 0.622 is the ratio of molecular weight of steam/air.

Next, using Eq. (1), the ratio of enthalpy h is calculated by,

$$h[\text{kJ/kg}] = 1.005 \times T + (2447 + 1.846 \times T) \times X \tag{2}$$

where the specific heat at constant pressure of dehydration air is 1.005 [kJ/(kg(DA)・K)], T is the temperature [K], the evaporative latent heat of water is 2447 [kJ/kg] at 22.0 [℃], and the specific heat at constant pressure of water vapor is 1.846 [kJ/(kg・K)]. The specific volume V is calculated using the ideal gas equation by,

$$V[\text{m}^3/\text{kg}] = \frac{(287.13 + X \times 461.7) \times T}{(1 + X) \times 1.013 \times 10^5} \tag{3}$$

where the gas constants of dry air and water vapor are 287.13 [J/(kg・K)] and 461.7 [J/(kg・K)], respectively.

Therefore, the cooling capacity C_c at the quantity of wind 0.12 [m^3/s] is,

$$C_c[\text{kW}] = \frac{h_{inlet} - h_{outlet}}{V} \times 0.12 \tag{4}$$

Then, COP is obtained by,

$$\text{COP} = \frac{\text{Cooling capacity[kW]}}{\text{Integrated power[kW]}} \tag{5}$$

4 EXPERIMENTAL SETUP AND METHOD

4.1 Cooling experiment using air-conditioner indoor unit

Experimental setup is shown in Fig. 2. The experimental device consists of two groups, the first stage is composed a vacuum pump and a vacuum container of about 60 [liter] in volume, and the second stage has two heat exchangers (one is a heat load) and a water circulation pump.

In the first stage, the primary cooling water of 5 [liter] is located in a vacuum chamber. A heat exchanger is soaked in a plastic container which is thermally isolated with the stainless vacuum chamber. When the vacuum chamber is evacuated by a water ring vacuum pump, the temperature of the primary cooling water falls down so that thermal energy is taken as latent heat. In second stage, the cooled water by the heat exchanger inside the vacuum chamber is flowing into another heat exchanger of an air-conditioner indoor unit (product by Corona Co., CSH-ES282-W type) with flow speed of 2.6 [litter/min.] by the circulation pump. The amount of secondary circulating water is 5 [litter]. The room air as heat load exchanges the heat and becomes a cold wind from an outlet of the air-conditioner indoor unit. The cold wind isolates with a room air by a plastic sheet.

The variations of temperature at each place, i.e. primary cooling water temperature TCvw, air-conditioner indoor unit entrance water temperature TCci, the exit temperature TCco, room air temperature TCai, and the cold air TCao, are measured by thermocouples. In addition, the humidity of the room air and the exit from the air-conditioner indoor unit are measured by each humidity sensor. The absolute humidity and enthalpy characteristics are calculated using Eqs. (1) and (2). The power integrated by the water ring vacuum pump and the circulation water pump are measured by a wattmeter. The integrated power equals to the denominator in Eq. (5).

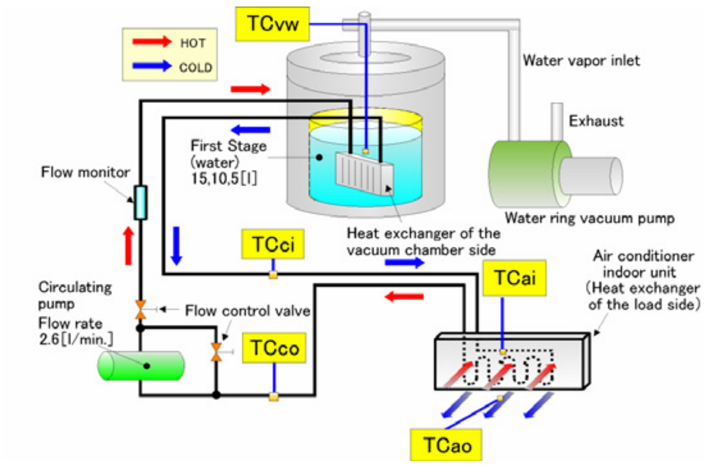

Fig. 2. Experimental setup.

4.2 Cooling experiment using heat load

As a heat load instead of the air-conditioner indoor unit, a heater of 0.24–1.33 [kW] is used. The quantity of the primary cooling water is 5 [liter], the secondary circulating water is 5 [litter] with flow speed of 3.0 [litter/min.]. Electric power consumption (a denominator of Eq. (5)) and each refrigerant water temperature in Fig. 2 are measured.

5 EXPERIMENTAL RESULTS AND DISCUSSIONS

5.1 Results for air-conditioner indoor unit

The variation of temperature at each place and the integrated power are shown in Fig. 3, respectively. During the experiment, TCai is kept at almost the constant temperature of 29 [℃]. Just after the experiment starts, TCvw decreases suddenly and the others also decrease gently. The experimental data shows a steady state in 20 minutes after the experiment starts. In the steady state during 30-45 [minute], the mean dry-bulb temperature difference between TCai and TCao is about 7.2 [℃].

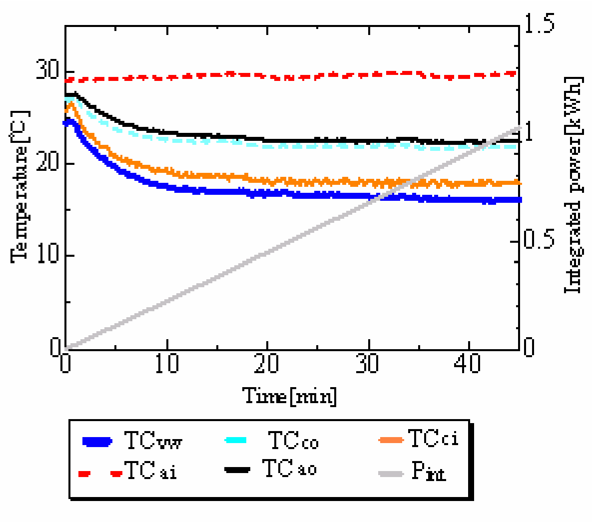

Fig. 3. Characteristics of temperature and integrated power.

The variations of relative humidity at the room air inlet and cold air outlet are shown in Fig. 4. The inlet relative humidity is approximately constant, but the outlet relative humidity increases, and the characteristic becomes approximately constant in 20 [minute] after the experiment starts. The reason seems that the relative humidity is defined as the quantity of water vapor for unit volume divided by the saturation steam density at the temperature. The saturation steam density depends on the temperature decreasing, but the quantity of water vapor is almost same.

The relative humidity is converted by Eq. (1) to the absolute humidity. Using Eq. (2), the enthalpy is calculated and the COP is depicted in Fig. 5. The COP shows low value at the time of the vacuum pump starting, but it shows about 1 for the steady state.

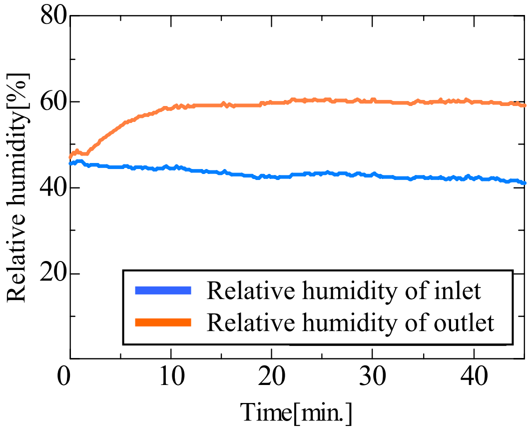

Fig. 4. Relative humidity (Primary cooling water of 5 [liter]).

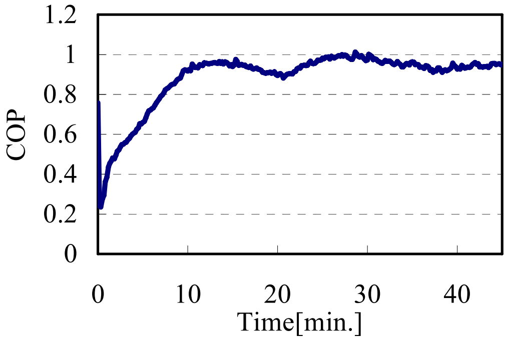

Fig. 5. COP （Primary cooling water of 5 [liter]）.

5.2 Results for heat load

The secondary circulating water is supplied a constant heat load (1.03 [kW]), and the characteristics are shown in Fig. 6. The experimental data shows a steady state in about 40 [minute] after the experiment starts. In the steady state during 50-70 [minute], the mean temperature difference ΔT between heater inlet and outlet is about 4.7 [℃]. The variation of the quantity of the primary cooling water is shown in Fig. 6 right axis. The primary cooling water of 15 [liter] at 25 [℃] decreases linearly and the rate of the quantity becomes 15 %.

The heat load supplied by the heater, i.e. the cooling capacity Cc, is given from the thermal balances Q_1 at the first stage and Q_2 at the second stage by

$$C_c = Q_1 = 2442 \times \Delta m \tag{6}$$

$$Q_2 = 4.2 \times \Delta T \times \Delta q \tag{7}$$

where the evaporative latent heat of water is 2442 [kJ/kg] at TCvw= 24 [℃], Δm [kg] is the quantity of evaporation, the specific heat of liquid water is 4.2 [kJ/(kg・K)], Δq

[kg/s] is the flow rate of the circulation water. The difference, i.e. Q_1 - Q_2, means the thermal leak from the vacuum chamber and depends on the temperature difference between the room temperature and the primary cooling water. COP is about 1.2 for the steady state as an average of Δm for 10 [s] substituting the electric power of about 1.3 [kW] and Eq. (6) to Eq. (5).

Consequently, in air-cooling system used only water refrigerant, the ability to cool a room air enough was provided.

However, the vacuum pump in this study is a water ring vacuum pump. Since this vacuum pump can't evacuate over the pressure of saturation water vapor of the water seal, the vacuum pump needs a lot of water seal with about 2 [℃]. We considered using oil-sealed rotary pump, oil free vacuum pump and etc., but there is no ability to exhaust a large amount of water vapor. Therefore, the development of a new vacuum pump which can exhaust a large amount of water vapor and can evacuate up to 1/100 of atmospheric pressure will be needed.

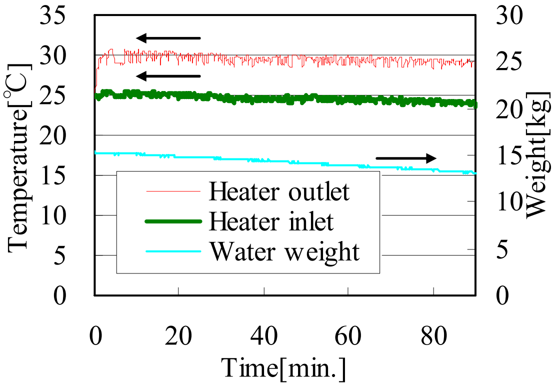

Fig. 6. Experimental results for heat load.

6 CONCLUSIONS

A small air-cooling system of around several kW using only water refrigerant as a non-Freon technology was examined. The vacuum-cooling could cool down the room air about 22 [℃] for the ambient temperature of 29 [℃]. The COP was about 1.0.

Consequently, cooled water was made by vacuum-cooling and the circulating exchanged cold energy to the room air. The non-Freon air-cooling system using only water refrigerant will be realized.

APPENDIX

The engine vacuum pump has the following characteristics. An engine of a car is used as it is, and the modified cylinder head which has some reverse-check valves made by FRP sheet of 0.3 mm in thickness can exhaust gas by the pressure difference between the internal and external automatically (see Fig. 7). The new vacuum is simple structure, cheap, and easy construction. The water temperature characteristics exhausting water vapor for 3 [liter] of this vacuum pump (400 [rpm]) were measured (see Fig. 8). Consequently, it is cleared that the new vacuum pump can work enough for the air cooling system using water refrigerant.

Fig. 7 Engine vacuum pump.

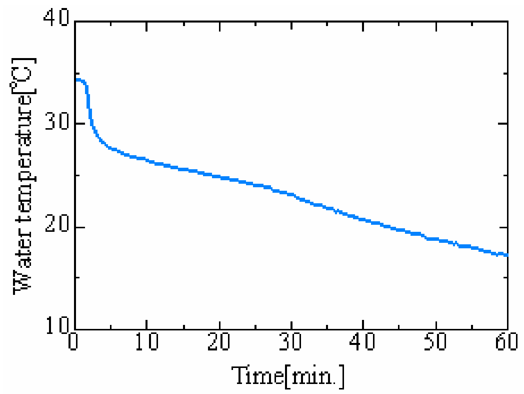

Fig. 8. Vacuum-cooling by engine vacuum pump (No heat load).

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