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Effect of Suction and Discharge Line Evaporative Cooling on the Performance of VCRS

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Abstract: Refrigeration and air conditioning are one of the leading consumers of electric power in the world. Most of the refrigeration systems are based on simple vapor compression refrigeration cycle. This paper is concerned with evaluating and comparing the performance of VCRS with and without the use of evaporative cooling on the suction and discharge line. The system is evaluated on the basis of attaining same temperature drop in evaporator chamber with and without use of evaporative cooling and thus finding out the COP of both the arrangements respectively. Wood fiber is used as a porous pad which is wounded over the suction line. Cooling the suction line (line which comes out of evaporator and goes into compressor) will reduce the temperature of the refrigerant going into the compressor, thereby reducing its specific volume and hence the compressor work. Wood fiber and coconut coir is used in turn for cooling the discharge line (line which comes out of compressor and goes into condenser). This is supposed to reduce the load on the condenser and thus enhance the overall COP of the system. It is found that evaporative cooling system increases energy saving up to 14%. The COP of the system increased by 7.2% with the use of wood fiber as the evaporative cooling pad on both the suction and discharge line. Also the increase in COP of system by using wood fiber on the suction line and coco0nut coir on the discharge line is 6.5%.

Keywords: VCRS, Refrigerating Effect (RE), Coefficient of Performance (COP), R134a.

1. INTRODUCTION

1.1 VAPOR COMPRESSION REFRIGERATION SYSTEM (VCRS):

The term refrigeration could be defined as the process of removing heat from a substance under controlled conditions. It thus also includes the process of reducing and maintaining the temperature of body below the general temperature of its surrounding. In other words, refrigeration means a continued extraction of heat from the body whose temperature is already below the temperature of its surrounding. The vapor compression refrigeration cycle is used in most household refrigerators as well as in many large commercial and industrial refrigeration systems. The vapor compression refrigeration system consumes a massive amount of high grade energy and rejects the low grade energy to the surrounding which is in the form of waste heat. This has motivated researchers to focus on utilization of low grade heat that can be used for other useful purposes. This can be achieved by suction and discharge line evaporative cooling. In this work R134a, a halo carbon refrigerant is used of chemical formula is CF_3CH_2F that is Tetrafluroethane. It has high latent heat of vaporization. Its ODP is zero and GWP 65% less than other refrigerants.

1.2 EVAPORATIVE COOLING:

Evaporative cooling is a physical phenomenon in which the evaporation of liquid takes place by absorbing latent heat drawn from the air thus cooling a body in contact with it. Normally Porous materials are beneficial in this case because there permeability is large. It is the process by which the temperature of a substance is reduced due to the cooling effect from the evaporation of water. The conversion of sensible heat to latent heat causes a decrease in the ambient temperature as water is evaporated providing useful cooling. Evaporative cooling occurs when air, that is not too humid, passes over a wet surface; the faster the rate of evaporation the greater the cooling. When considering water evaporating into air, the wet-bulb temperature, as compared to the dry-bulb temperature of air, is a measure of the potential for evaporative cooling. The greater the difference between the two temperatures, greater the evaporative cooling effect. Evaporative coolers provide cool air by forcing hot dry air over a wetted pad. The water in the pad evaporates, removing heat from the air while adding moisture. When water evaporates it draws energy from its surroundings which produce a considerable cooling effect. The most common applications are domestic air coolers, earthen pot and perspiration (sweat). The cooling potential for evaporative cooling is dependent on the wet bulb depression (difference between dry-bulb temperature and wet-bulb temperature).

1.3 TYPES OF EVAPORATIVE COOLING SYSTEM:

1.3.1 Direct evaporative cooling

A direct evaporative cooling process is shown schematically in Figure 1. A porous medium is made into thin layers which are arranged in parallel. The process air flows across the surfaces of the layers at a particular velocity, which causes water inside the voids of the porous

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layers to evaporate. In this process, the energy (enthalpy) in the air remains the same as no external energy is supplied, so the heat required for evaporation must come from the air flow. As a result, warm dry air is changed to cool moist air in a quasi-adiabatic process. The cooling effectiveness of this type of direct evaporative system ranges from 70% to 95% in relation to the incoming air's wet-bulb temperature. However, it adds moisture to the air, making it only suitable for use in hot, dry climates or for spaces requiring humidification.

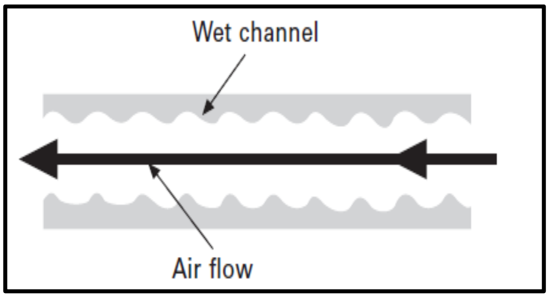

Fig. 1 Schematic of a direct evaporative cooling process

1.3.2 Indirect evaporative cooling

Indirect evaporative cooling lowers the air temperature without adding moisture to the air, making it more attractive than direct cooling, and is shown schematically in Figure 2. In an indirect evaporative air cooler, primary (product) air passes over the dry side of a heat exchanging wall, while secondary (working) air passes over its opposite, wet side. The wet side absorbs heat from, and therefore cools, the product air through evaporation of water, while the latent heat of evaporation is transferred to the working, wet side air. Under ideal operating conditions, i.e., the product air travels in a counter flow to the working air and the two airstreams have a good balance of flow rates and an infinite contact area, the product air temperature on the dry side of the heat exchanger would reach the wet-bulb temperature of the incoming working air and the temperature of the working air on the wet side of the sheet would increase from its incoming dry-bulb temperature to the incoming product air dry-bulb temperature and be saturated. However, practical systems are far from this ideal. It has been suggested that only 50% of the incoming working air wet-bulb temperature can be achieved for a typical indirect evaporative cooling system.

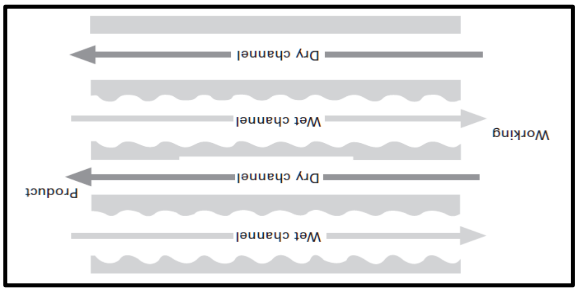

Fig. 2 Schematic of an indirect evaporative cooling process

2. EXPERIMENTAL SETUP

Figure 3 shows the schematic representation of a modified vapor compression refrigeration system with evaporative cooling of suction and discharge line. Evaporative cooling pads have been used for cooling suction and discharge line of the system. The experimental setup as shown in figure 4 consists of different components.

For the performance evaluation of the system, two different porous materials as evaporative cooling pads are used. Wood fibre and coconut coir have been used as the material for evaporative cooling pad. Water from an overhead tank is supplied to a pipeline stationed above the suction and discharge line.

The total mass flow rate of water from the pipe holes is 3.33×10^{-3} kg/s. Water falls on the porous pad from a plastic pipe which has evenly spaced holes of diameter 0.8mm. Suction line is 42 cm long and 1/4 inch in diameter and Discharge line is 55 cm long and 1/4 inch in diameter. The pipes are attached with overhead tank of 20 liter capacity. Pipes used in pipeline are of 12.5 mm in diameter and having 0.8 mm diameter holes on suction side (7 holes) and discharge side (9 holes).

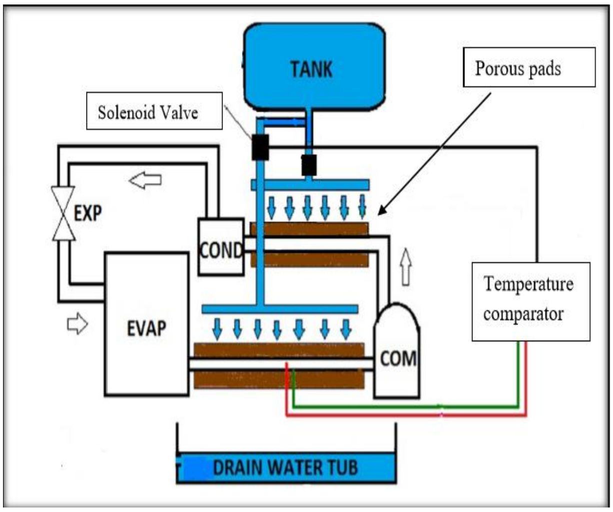

Fig. 3 Line diagram of VCRS system

Fig. 4 Experimental Setup

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The specification of different components are shown in table 1

Table 1 List of component

Compressor	KCE419HAG, hermetically sealed
Condenser	Air cooled
Evaporative cooling pad	1. Wood Fibre 2. Coconut coir
Capillary tubes	0.050”
Evaporator coil	5/16” (OD) x 30’ long
Low pressure gauge	0-250 psi,
High pressure gauge	0-500 psi
Rotameter	60 LPH
Refrigerant	R134a
Thermocouples	6
Charged mass	950 gm
Condenser fan and motor	9” (dia.) and 1/83 HP, 1350 RPM
Heater	1500 W
Condenser	9” x 9” x 2
Temperature comparator	1 no.
Solenoid valve	1 no.
Dimmerstat	1 no.

3. EXPERIMENTAL PROCEDURE

The suction line has been covered with wood fibre, which is an insulator as well as used for evaporative cooling due to its porous nature, so that the temperature of the refrigerant going to the compressor is reduced, thereby reducing its specific volume and hence the work required. Another evaporative cooling pad covers the discharge line coming out from the compressor in order to enhance condensation. Various porous materials have been used and its effect on the performance of the system has been analysed. The evaporative cooling pads get completely saturated in 20 seconds after the water from overhead tank falls on it. First of all the system was running as it is at pull down load condition, then with a load of 150, 300 and 450 W. Then the system was running with evaporative cooling using wood fiber at both the suction and discharge lines repeating the same procedure. Then for wood fiber on the suction side and coconut coir on the discharge side at the same conditions and its performance is evaluated.The water enters the porous pads and is evaporated there absorbing the heat and thus producing cooling effect. A temperature comparator unit is used to compare the temperatures of the refrigerant within the suction line and temperature of the cooling pad. Once the temperatures of both of them becomes same, or if the temperature of the refrigerant in suction line falls below that of the pad, a solenoid valve cuts off the supply of water to the tube which is placed above the suction line thereby stopping the cooling process. This is done until the time when the temperature of suction line fluid rises above that of the cooling pad temperature. Similarly, the discharge line was covered with wood fibre and coconut coir in turns and the same method was used to obtain cooling effect. No mechanism has been employed to cut off the water supply in the tube over the discharge line as the temperature of the refrigerant coming out the compressor is always at high temperature and pressure and needs to be cooled all the time. For obtaining results at load condition, the heater is provided inside the evaporator section of 1500 watt. Dimmerstat is provided to control the load by the heater.

3.1 OPERATING PARAMETERS:

Porous materials:

1) On both suction and discharge side, Wood Fiber having Porosity 50-60% and thermal conductivity = 0.043 W/m·K of thickness 4.5 mm is used.

2) On suction side a wood fiber and on discharge side a coconut coir (Porosity 26-37%) of thickness 4.5 mm is used.

3.2 Theoretical COP is calculated by formula:

Coefficient of performance (theoretical)

$$= \frac{\text{Refrigerating Effect (R.E.)}}{\text{Work Done (W.D.)}} = \frac{h_1 - h_4}{h_2 - h_1}$$

Where,

h_1 = Enthalpy at compressor inlet, kJ/kg

h_2 = Enthalpy at compressor outlet, kJ/kg

h_4 = Enthalpy at evaporator inlet, kJ/kg

3.3 Actual COP is calculated by formula:

$$\text{COP (actual)} = \frac{Refrigerating\ \ Effect}{Work\ \ Done}$$

Where,

$$\text{Refrigerating Effect (R.E.)} = \frac{m\ x\ c_p\ x\ (T_i - T_f)}{t}$$

Where,

m = Product mass (mass of water in evaporator tank)

c_p = Specific heat of water, kJ/kg-K

T_i = Initial temperature of water

T_f = Final temperature of water

t = Time required to lower product temperature, sec

$$\text{Compressor power} = \frac{N_c\ x\ 3600}{t_c\ x\ EMC_{com}}$$

Where,

EMC_{com} = Compressor energy meter constant = 3200 pulse/kW-hr

t_c = Time for 10 Pulse of compressor energy meter, sec

N_c = Number of pulses in compressor energy meter

4. RESULT AND DISCUSSION

The experimentation was carried out to compare the performance of vapor compression refrigeration system with and without evaporative cooling. Experimentation was carried out on designed and fabricated VCRS setup to get the performance at pull down load, partial loads and full load. Experiments were also carried out with and without evaporative cooling pads on suction and discharge lines to know the effect of cooling on the performance of VCRS. The experimental results are plotted for system performance in terms of COP. The variation of evaporator

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temperature with time is also plotted and discussed. The following cases were taken for experiments and compared with each other.

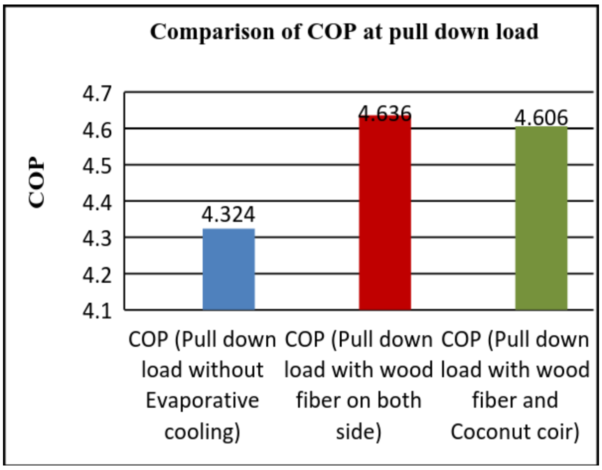

Fig. 5 Comparison of COP (theoretical) for various arrangements at pull down load

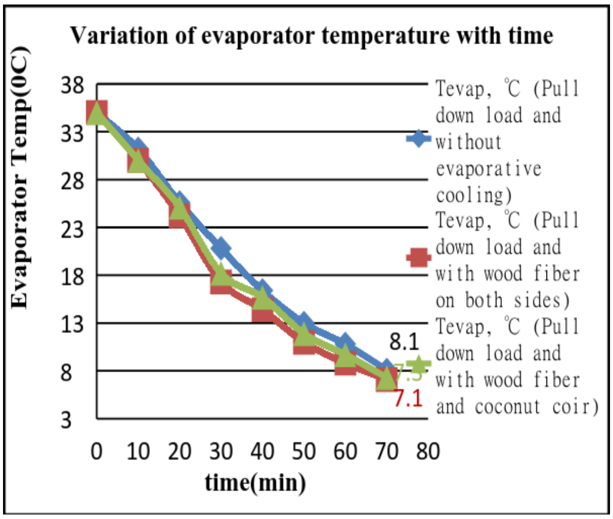

Fig. 6 Variation of evaporator temperature with time for pull down load

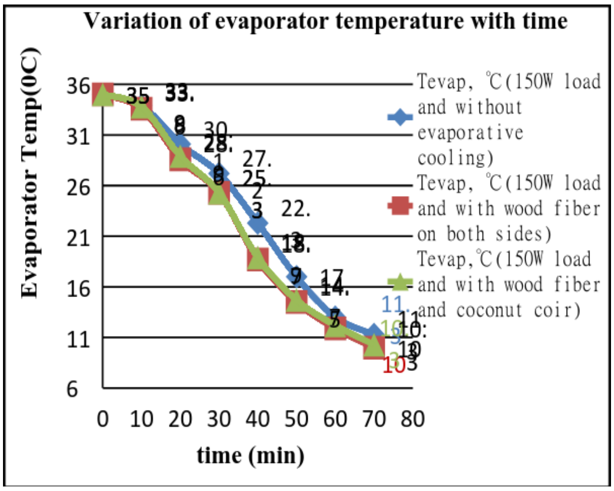

Fig. 7 Variation of evaporator temperature with time for 150W load

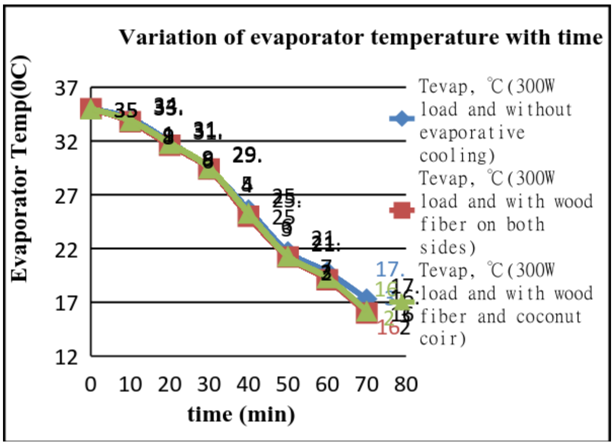

Fig. 8 Variation of evaporator temperature with time for 300W load

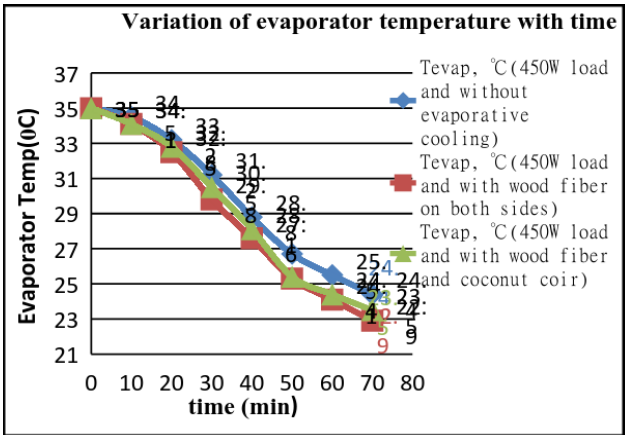

Fig. 9 Variation of evaporator temperature with time for 450W load

It is observed from the graph that the performance of system when wood fiber is used on both sides for evaporative cooling is effective than the other two arrangements. For the pull down time period of 70 minutes, lowest temperatures of 7.1^{0}C, 10^{0}C, 16^{0}C & 22.9^{0}C achieved which are shown in graph number 6, 7, 8 and 9 respectively when wood fiber is used on both sides as evaporative cooling pad at varying loads given in the system. Actual COP of system is 1.706 without evaporative cooling while it increases by 6.27% with evaporative cooling arrangement with wood fiber on both sides.

5. CONCLUSION

As a result of the current experimental study many conclusions can be drawn regarding the use of evaporative cooling on the performance of VCRS using porous materials. The performance of the VCRS was analyzed for a load of pull down, 150, 300 and 450 Watt with and without evaporative cooling of the suction and discharge line. It is found that the theoretical COP of VCRS increased by 7.22% with the use of wood fiber as the evaporative cooling pad on both the suction and discharge line. The increase in theoretical COP of VCRS by using wood fiber on the suction line and coconut coir on the discharge line is 6.52%. Wood fiber is better to use on both sides as the rate of cooling is faster as compared to the other two arrangements. An average of 12% time is saved due to evaporative cooling arrangement in the system. It is observed that the evaporative cooling system increases energy saving up to 14%.

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