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Performance Evaluation of Wick Cooled Condenser in Vapor Compression Refrigeration System

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ABSTRACT

Presently, the reduction in energy consumed by an air conditioner working on a vapor compression refrigeration cycle is a major issue. Application of evaporative cooling on a small-scale refrigeration and air conditioning system is limited due to its larger size and economy. In the present work, porous wick cloth is used on the condenser tube which is combined with direct evaporative cooling. Evaporation of fluid entrapped in the pore of wick cloth increase the heat transfer rate. The effect of evaporative cooling of the condenser on the performance of the air conditioner is experimentally investigated. The result shows about 32.4% enhancement in COP with a maximum ambient temperature of 35°C and 10-11% reduction in energy consumption and relative humidity about 21-26%. Refrigeration effect increased up to 30.6% with respect to the water cool condenser.

Keywords: *Compressor; Evaporator; COP; Wick Cooled.*

1.0 Introduction

With rapid grow in population, vast energy consumption has already put up its concerns world-wide.The global energy consumption of the buildings (residential or commercial) has been increased up to 20-40% in developed countries [1]. Refrigeration is a process of removing heat from a low-temperature reservoir and transferring it to a high-temperature reservoir. Refrigeration may be defined as lowering the temperature of an enclosed space by removing heat from that space and transferring it elsewhere. A device that performs this function may also be called an air conditioner, refrigerator, air source heat pump, geothermal heat pump or chiller (heat pump). HVAC systems account for significantly up to 50% of total building energy consumptions. Air-conditioners which are used on small scale and in houses have air cool condensers. Heat transfer from the condenser to surrounding varies throughout the year, especially in summers when ambient temperature is high. Chow et al. [2] mentioned that coefficient of performance (COP) of air-conditioner decreases about 2 to 4% for each degree increase in condenser temperature. Liu et al. [3] reported that increasing ambient dry bulb temperature and compressor frequency drops the COP. Liu et al. [3] studied the cooling performance of air conditioning system with dual independent evaporative condenser against variations between influencing factors, such as evaporator water inlet temperature, compressor frequency, air dry-bulb temperature, air velocity and water spray rate. They found increase in COP by 13.1% with a rising air velocity from 2.05 to 3.97ms-1 and elevation of 6.1% with increasing water spray rate from 0.03 to 0.05kgm-1s.The heat transfer co-efficient was in the range of 232-409 Wm-2K-1 under the condition such that velocity of air varies from 2.0 ms-1 to 4.0 ms-1 and water spray rate varies from 0.03 to 0.05kgm-1s.

Wang et al. [4] investigated the air-conditioning system with the help of evaporative cooling condenser where an evaporative cooling pad was made of porous cellulosic paper. This experiment was done to compare the effect of Directive evaporative cooled condenser with conventional air-cooled condenser, which resulted in temperature drop through the condenser from 2.4oC to 6.6oC resulting in rise of COP from 6.1% to 18%.

1.1 Working of theoretical vapor compression refrigeration system

It is a system in which the refrigerant undergoes phase changes on absorbing heat from the system in evaporator unit and on dissipating heat to

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the surrounding in condenser [5]. It is the most widely used method for air-conditioning of buildings and automobiles. It is used in domestic and commercial refrigerators, large-scale warehouses for chilled or frozen storage of foods and meats, refrigerated trucks and railroad cars, and a host of other commercial and industrial services. Oil refineries, petrochemical and chemical processing plants, and natural gas processing plants are among the many types of industrial plants that often utilize large vapor compression refrigeration systems. A simple vapor compression refrigeration system consists of the following components [6]:

i) Compressor
ii) Condenser
iii) Expansion valve
iv) Evaporator

The schematic diagram of the arrangement is as shown in Fig.2. The low temperature, low pressure vapor at state B is compressed by a compressor to high temperature and pressure vapor at state C. This vapor is condensed into high pressure vapor at state D in the condenser and then passes through the expansion valve. Here, the vapor is throttled down to a low-pressure liquid and passed on to an evaporator, where it absorbs heat from the surroundings from the circulating fluid (being refrigerated) and vaporizes into low pressure vapor at state B. The cycle then repeats. The exchange of energy is as follows:

a. Compressor requires work, δw. The work is supplied to the system from the surroundings.
b. During condensation, heat δQ1 the equivalent of latent heat of condensation is lost from the refrigerator.
c. During evaporation, heat δQ2 equivalent to latent heat of vaporization is absorbed by the refrigerant.

There is no exchange of heat during throttling process through the expansion valve as this process occurs at constant enthalpy.

1.2. Objectives and investigation

In the present work, an air-conditioner with an evaporative condenser was investigated which tube was covered using wick cloth. With the system having new evaporative cool condenser COP increases, whereas; average condensing temperature is lowered, which saves the electricity consumption. Annual saving from operational cost of the system satisfies the yearly maintenance cost. In the present work, our objectives were as follows:

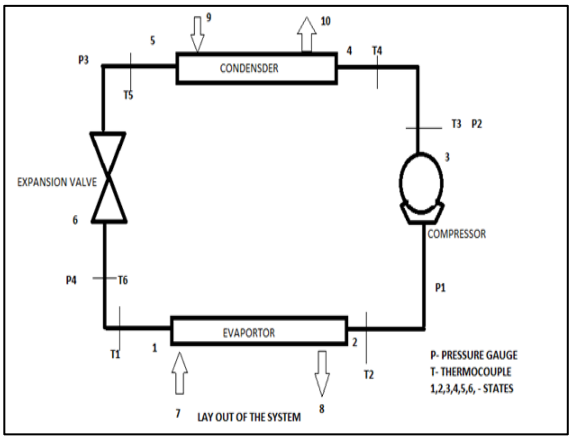
1. To study the working of Simple VCRS.
2. To study the importance of condenser cooling.
3. To compare the COP of Wick-cooled VCRS with Water-cooled VCRS.
4. To study the effects of condenser and evaporator temperatures on COP.

2.0 Experimental Setup

2.1 System description

A VOLTAS 1-ton window type Air conditioner was used to fabricate the experimental setup. Wick cloth as porous material having width 5 mm & thickness 2 mm was used on the condenser tube which was being wetted by the water droplet from the topside of the condenser circulated by a small fountain pump from a water tank using a flow control valve. The condensate collected from the indoor unit was also coupled with the water inlet point of the condenser which is generally, at a lower temperature than the tank water and boost the cooling effect. The schematic diagram is shown in Figure 2.

Fig 2: Schematic of Experimental Setup



Where
T1- Temperature at the inlet of the Evaporator
T2- Temperature at the outlet of the Evaporator
T3- Temperature at the outlet of the Compressor
T4- Temperature at the inlet of the Condenser
T5- Temperature at the outlet of the Condenser
T6- Temperature at the outlet of the Expansion Valve

P1- Pressure in the Suction Line
P2- Pressure in the Discharge Line
P3- Pressure in the Liquid Line
P4- Pressure in the Expansion Line

2.2 Fabrication method

After taking out the fins and application of wick cloth on condenser tube, cooling pad was used to cover the back side of the condenser but it was not completely wetted by the water. The pressure gauges and thermometers were attached with the system to examine the performance of system (Figure 3).

4 pressure gauges were placed while 8 thermometers were used in the setup to measure the temperature and pressures at various junctions and for plotting p-h curve purpose. The inner view of the condensing unit under operating condition of air conditioner can be seen from figure. Water flow rate was uniformly spread over the condenser tube and was controlled enough to properly wet the wick material.

Fig 3: Fabrication of Air-Conditioner

Experimental setup was fabricated and installed within the MAIT campus and experiment was conducted in 2 stages: first for water cooled condenser and second for newly made wick cool condenser in the mid-month of April which is the time of hot summer season in Delhi, India during the mid-day hours when the pick load condition in terms of temperature is available. The temperature was measured using J type thermocouple. Digital hygrometer meter was used for measurement of quality of air. Indoor unit temperature was set up to 16ºC.

2.3 Thermodynamic formulation

Pressure enthalpy diagram of a simple vapor compression refrigeration cycle can be shown in Figure 4.

Refrigeration effect in the evaporator:

$$Q_{ref} = m_R\,(h_1 - h_4) \quad (1)$$

Work done by the compressor:

$$W_c = m_R(h_2 - h_1) \quad (2)$$

COP of the system:

$$COP_{air-cool} = \frac{Q_{ref}}{W_c + W_f} \quad (3)$$

$$COP_{evap} = \frac{Q_{ref}}{W_c + W_f + W_p} \quad (4)$$

Heat lost by condenser:

$$Q_{cond} = m_R(h_2 - h_3) \quad (5)$$

This heat rejection from the evaporative cool condenser will be carried away by both water and air. The governing equation for heat transfer on water side accounted for the un-evaporated water can be written as:

$$Q_{water} = m_{w,out} c_{pw}(T_{wo} - T_{wi}) \quad (6)$$

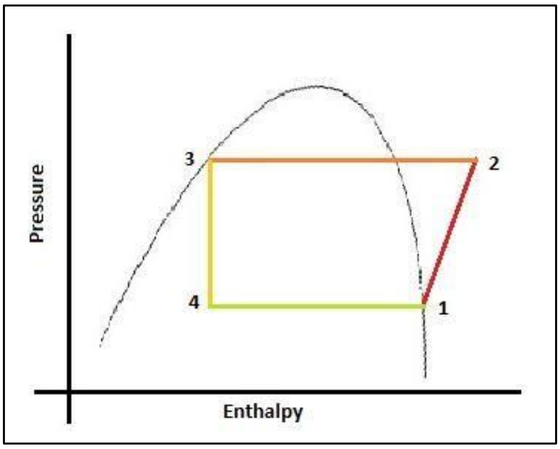
Heat transfer on air side will be addition of both sensible and latent heat transfer between air and water and will be given by:

$$Q_{air} = Q_{sensibleheattransfer} + Q_{latentheattransfer} \quad (7)$$

$$Q_{air} = m_a c_{pa}(T_{ao} - T_{ai}) + m_a h_{fg,water}(w_{ao} - w_{ai}) \quad (8)$$

This expression can be simplified even further

Fig.4: P-h Curve



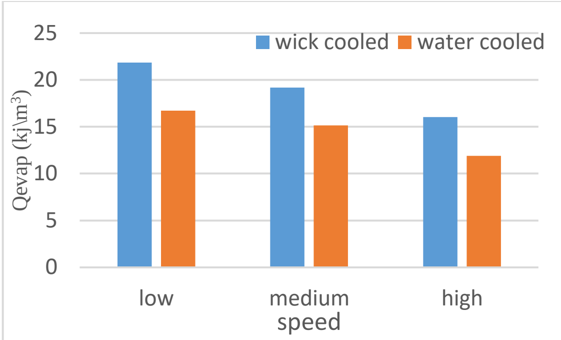
For calculation of mass flow rate of refrigerant, compressor frequency was assumed 70% and throttling process was assumed to be isenthalpic. Enthalpy and other attributes were calculated using engineering equation solver.

3.0 Results and Discussion

3.1 Variation of refrigeration effect

Due to lower condensing temperature and throttling, refrigerant get sub-cooled and heat carrying capacity of refrigerant increases in case of wick cooled condenser. Based on experimental result up to 30.6% refrigerant effect has been achieved using wick cooled condenser. Besides system possess more COP for the wick cooled run condenser despite of the ambient temperature which is comparatively high (Figure 5).

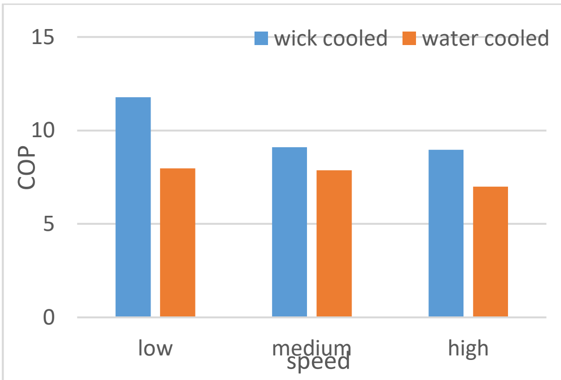
Fig 5: Comparison of Refrigeration Effect



3.2 Variation of COP

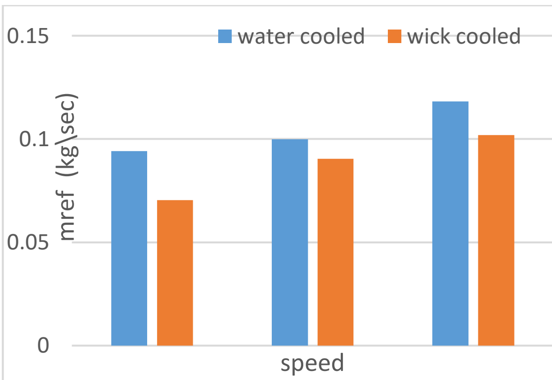
Due to more porosity in wick it retains more water and hence gives more cooling effect on evaporation and hence we get more COP in wick cooled condenser as compared to water cooled condenser. About 32.4% more COP of wick cooled condenser as compare to water cooled condenser (Figure 6).

Fig 6: Comparison of Mass Flow Rate



3.3 Variation in refrigerant mass flow rate

Fig 7: Comparison of Mass Flow Rate

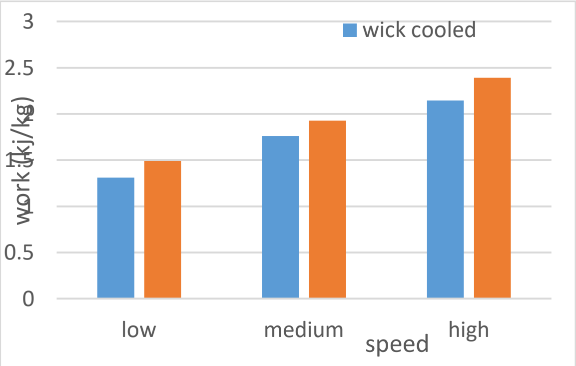


The reduction in mass flow rate of refrigerant is shown in Figure 7.

3.4 Variation in power consumption

Due to more COP in wick cooled condenser as compared to water cooled condenser and about 11.32% efficient in power consumption.

Fig 8: Comparison of Power Consumption



4.0 Conclusions

In the present work, an air-conditioner with a wick cooled condenser was investigated. With the system having new wick cool condenser COP increases up to 32.4% with a maximum ambient temperature of 34ºC and relative humidity about 21-26%. Refrigeration effect increased up to 30.6% with respect to the water cool condenser. Saving of 10-11% consumption in energy considering the pump power. No major scale formation was observed during the experiment over the wick cloth and on condenser tube.

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