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Prototype CO_2 Heat Pump and their Performance Analysis

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Abstract

Heat pumps are the most promising technologies to reduce global warming emissions and to more rationally use energy. In this experimental investigation Carbon Dioxide (CO_2) was used as refrigerant which is available in nature, eco friendly, economical, non toxic, non flammable and non corrosive. It is The performance evaluation of prototype vapor compression heat pump model was performed and evaluated the different parameters such as LMTD (Logarithmic Mean Temperature Difference), COP (Co-efficient of Performance) and heat transfer rate of condenser. This experiment is carried out by varying water mass flow rate, pressure and evaporator fan speed for two condensers of different dimensional specification. The water in the shell side was heated by absorbing heat from refrigerants in the tube side of condensers by counter flow heat exchanging method. The experimental results indicate fairly good COP with the use of CO_2. The advantages of CO_2 as refrigerant with zero ODP and minimum GWP.

Keywords: COP, Evaporator, Heat pump, LMTD, Ozone Depletion Potential

1. Introduction

A Heat Pump is an electrical device that extracts and transfer heat from one place to another. Refrigerators and air conditioners are examples of heat pumps. Heat pumps transfer heat by circulating a substance called a refrigerant through a cycle of alternating condensation and evaporation. A proto type heat pump system is a gadget which moves heat from refrigerant to water by an aid of electrical energy in condenser. It works on the principle of vapor compression refrigeration system. Presently used refrigerants globally are Tetra fluoro ethane (R-134a) and Dichloro Difluoro Methane (R22). These refrigerants consist of chlorofluorocarbons and hydro chlorofluorocarbons. Increase in the amount of chlorofluorocarbons components in the environment results in problems of ODP and GWP. Hence, carbon dioxide refrigerants should be used because of which have no ODP and less GWP[1] by replacing chlorofluorocarbon and hydro chlorofluorocarbon refrigerants. Therefore, CO_2 refrigerant naturally available may be used as a refrigerant in heat pumps[2]. The main advantages of CO_2 are eco friendly, non corrosive, low cost, non flammable, non toxic, stable and suitable for wide range of operating conditions[3]. The heat pump consists of compressor, condenser, evaporator and capillary tube[4] which is best suitable for domestic water heater[5].

In the present study the modification of heat exchanger and experimental performance evaluation of vapor compression prototype heat pump model was carried out. By

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modifying the heat exchanger, improvement in COP is observed[6]. The variation of speed of compressor and evaporator affect performance of the heat pump system[7]. The experiment was conducted to evaluate the different parameters like COP, LMTD and outlet temperature of water for different mass flow rate, pressure and evaporator fan speed.

2. Experimental Set Up

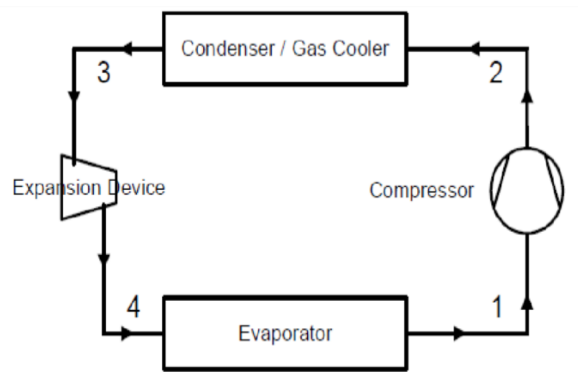

Figure 1. Heat pump cycle

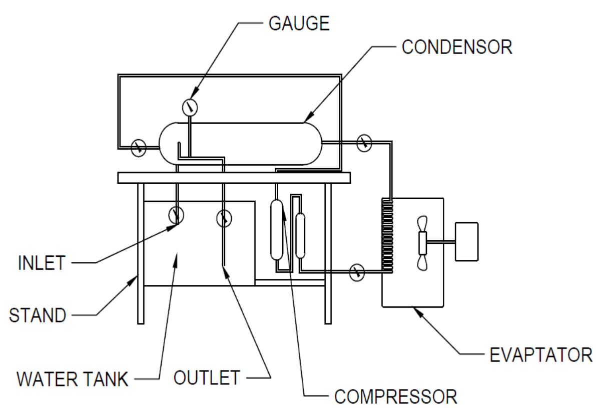

Figure 2. Line diagram of heat pump model

The heat pump cycle and line diagram of heat pump model as shown in Figure 1 and 2. The experimental set up of prototype heat pump model as shown in Figures 3 and 4. Mild steel angles fabrication used for supporting the heat pump structure. This heat pump proto type model consists of the components like two numbers of condensers, compressor, evaporator, Expansion device and water storage tank. The compressor is reciprocating type 1 ton capacity 250V, 50Hz which compresses to maximum pressure up to 280 PSI and temperature of 110^{0}C.

Figure 3. Heat pump experimental setup

Figure 4. Heat pump experimental setup

In this model, evaporator and condenser are the two heat exchangers used which work on counter flow heat exchanger method. Refrigerant working as hot working fluid flows in the tube and water as cold fluid flows in the shell of the condenser. The specification of heat pump evaporator and condenser are as follows.

Heat exchangers	Condenser 1	Condenser 2	Evaporator
Configuration of heat exchangers	Coaxial, single pass and counter flow	Coaxial, single pass and counter flow	Coaxial, single pass, 1/83 HPGW, 1200 rpm
Inner /outer tube diameters	8mm/6 inch	10mm/5inch	12mm/10inch, 3 rows (cooling coil)
Total length of tubes	20 inch	21 inch	13 inch

The expansion of refrigerant takes place in 18mm diameter tube.

3. Experimental Procedure

The experiment was conducted to measure the rate of increase in water temperature in the condenser outlet at different water mass flow rates and pressures. Refrigerant is filled to a pressure of 60PSI into the heat pump model. Initially, both pressures and temperatures values in the gauges are noted and inlet water temperature of condenser was also recorded. The heat pump is started and allowed to run for some time to reach steady state condition. The water is supplied to condenser from water tank through inlet valve using pump. After reaching the steady state condition, experiment is started by recording the pressure and temperature at different components of the heat pump system using temperature and pressure gauges. The outlet mass flow rate and temperature of water from condenser is recorded. The same procedure is repeated for 70PSI filling pressure of refrigerant and mass flow rate of water with constant time interval. Figure 1 show the refrigeration cycle. The parameters like LMTD, COP and heat transfer are calculated by using the recorded experimental values.

4. Result and Discussion

Condenser-1

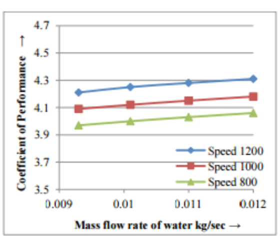

Fig 5: COP v/s Mass flow rate at 60psi

Condenser-2

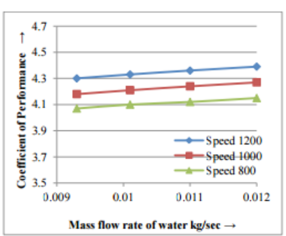

Fig 6: COP v/s Mass flow rate at 60psi

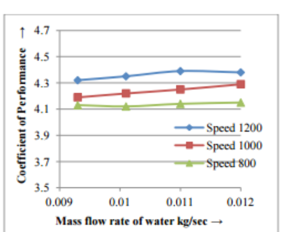

Fig 7: COP v/s Mass flow rate at 70PSI

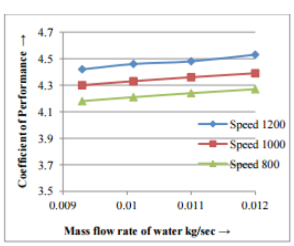

Fig 8: COP v/s Mass flow rate at 70PSI

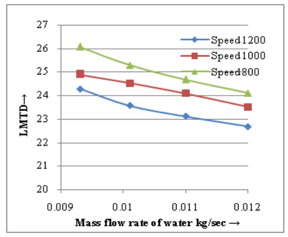

Fig 9. LMTD v/s Mass flow rate at 60PSI

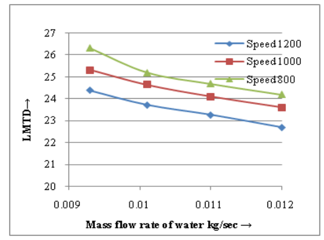

Fig 10. LMTD v/s Mass flow rate at 60PSI

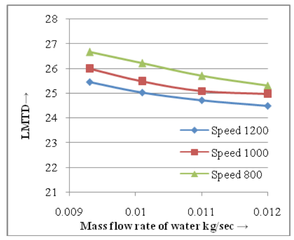

Fig 11. LMTD v/s Mass flow rate at 70PSI

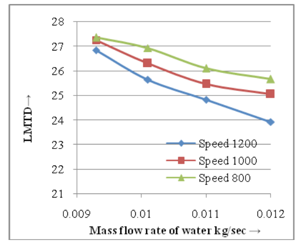

Fig 12. LMTD v/s Mass flow rate at 70PSI

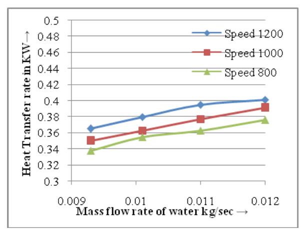

Fig 13. Heat transfer rate v/s Mass flow rate at 60PSI

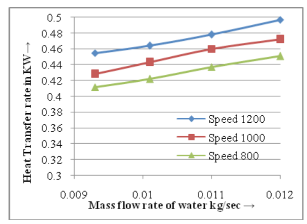

Fig 14. Heat transfer rate v/s Mass flow rate at 60PSI

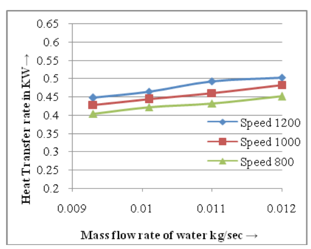

Fig 15. Heat transfer rate v/s Mass flow rate at 70PSI

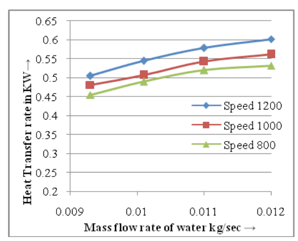

Fig 16. Heat transfer rate v/s Mass flow rate at 70PSI

Figures 5-12 shows the experimental results. Figure 5 and 6 shows a plot of COP versus mass flow rate of water for 60 PSI pressure of condenser1 and 2 respectively and Figure 7 and 8 shows a plot of COP versus mass flow rate of water for 70 PSI pressure of condenser1 and 2. From this graph it can be observed that, as mass flow rate of water increases value of COP also increases for different pressure and evaporator fan speed. The heat pump COP is more for refrigerant pressure of 70PSI and evaporator fan speed 1200rpm at condenser 2. The COP of system is improved by increasing the inlet temperature of water (preheating) which supplied to condenser. The condenser 2 is more economical as compared to condenser 1 by observing the COP of the two condensers 1 and 2. Figure 9 and 10 shows a plot of LMTD versus mass flow rate of water for 60PSI pressure of condenser1 and 2 respectively and figure 11 and 12 for 70PSI pressure. It is observed that as mass flow rate increases LMTD decrease slightly and maximum for 60PSI pressure and evaporator fan speed 800rpm at condenser1. More LMTD is observed, if the difference between the ends temperatures of counter flow heat exchanger (condenser) is more. Higher mass of the fluid at lower pressure has higher heat carrying capacity than the lower mass of the fluid at higher pressure. Thus LMTD decreases as the mass flow rate increases and pressure decreases. Figures 13 and 14 show plots of heat transfer rate versus mass flow rate of water at 60 PSI pressure for condenser1 and 2. Figure 15 and 16 shows the plot for 70 PSI pressure of condenser1 and 2 respectively. The heat transfer increases with increase in mass flow rate of water, increase in pressure and evaporator fan speed. The experimental results indicate better overall performance of condenser2 compared to condenser1. The heat transfer of condenser 2 (10 mm diameter tube used) at 1200 rpm is more compared to condenser 1 (8 mm diameter tube used) because of area of contact for heat transfer is more in condenser 2. Also heat transfer increases due to increases in evaporator fan speed (quick rate heat transfer between air and refrigerant in evaporator).

5. Conclusions

The experimental evaluation of prototype heat pump model using CO_2 as refrigerant to heat the water in the condenser was performed. The parameters like COP, LMTD and heat transfer for different mass flow rate and pressure were calculated from experimental values. From the results obtained the following conclusions can be drawn from the experiments.

- COP and heat transfer increases with respect to increases in water mass flow rate
- LMTD decreases as the mass flow rate increases and pressure decreases.
- As the refrigerant filled pressure increases, both COP and LMTD increase.
- As the refrigerant filled pressure increases the outlet water temperature and heat transfer of condenser increases.
- Maximum COP and heat transfer is achieved in condenser 2 at 70 PSI pressure and at 1200rpm fan speed.

6. References

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