Experimental performance evaluation of heat pump by using CO_2 as a refrigerant

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Abstract. In this experiment the refrigerant used is CO_2 which is naturally available, eco friendly, economical, non toxic, non flammable and non corrosive. Its Ozone Depletion Potential (ODP) is zero and minimum Global Warming Potential (GWP). The performance evaluation of prototype vapor compression heat pump model was performed and evaluated the different parameters like COP (Co-efficient of performance), LMTD (Logarithmic mean temperature difference) and outlet water temperature of condenser. The experiment is carried out for two different condensers by varying mass flow rate and pressure. 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 result indicates fairly good COP with the use of CO2 refrigerant. These advantages of CO_2 as a refrigerant favors the replacement for globally used refrigerant with CO_2.

Key words: Heat pump, LMTD, COP and Ozone Depletion Potential.

1. Introduction:

A heat pump is a gadget which moves heat from warm body (refrigerant) to cold body (water) by an aid of electrical energy. It works on the principle of vapor compression refrigeration system. Heat pump is the best advanced technology and best solution to heat the water. Heat pump has reduced emissions and utilizes the maximum available energy. Presently used refrigerants in the world are Tetrafluoroethane (R-134a) and Dichlorodifluoromethane (R-22). These are made from the components of chlorofluorocarbons and Hydrochlorofluorocarbons. By increasing the amount of chlorofluorocarbons in the environment results in problems ODP and GWP. So, these refrigerants should be replaced by those which have no ODP and less GWP [1]. Therefore naturally available refrigerant like CO_2 is used as a refrigerant [2]. It has many advantages like eco friendly, low cost, non flammable, non corrosive, non toxic and suitable for almost all range of working situations [3]. The CO_2 is safe, recyclable, cost effective and stable refrigerant [4]. The main components of heat pump are compressor, condenser, evaporator and capillary tube [5]. The heat pump is best suitable for domestic water heating applications [6].

In the present study the modification of heat exchanger and experimental performance evaluation of vapor compression prototype heat pump model was carried out. By modifying the heat exchanges improvement in COP is observed [7]. The experiment was conducted to evaluate the different parameters like COP, LMTD and water outlet temperature for different mass flow rate and different pressure.

2. Experimental set up:

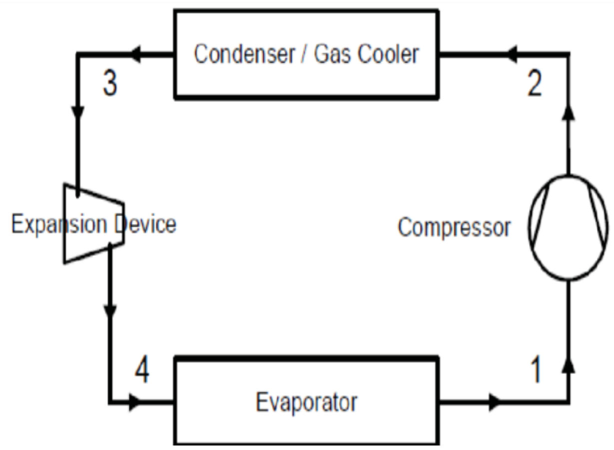

Figure 1. Heat pump cycle

The heat pump cycle and the line diagram of heat pump are shown in the figure 1. It shows the different components of the heat pump and the cycle. The cycle is opposite to the Rankine cycle. The supports are provided to fix the components of the heat pump. The figures 2 and 3 show the side view of heat pump setup. The supporting fabrication is done by using mild steel angles and plates. The condensers, compressor and evaporator were fixed by using clamps. The pressure gauges and temperature gauges are mounted at inlet and outlet of the components of heat pump. The flow regulating valve is connected to copper pipes to regulate the flow of refrigerant. The water regulating valves are connected to inlet and outlet pipes of condensers to regulate the mass flow rate of water.

The heat pump model consists of the components like 2 numbers of condensers, compressor, evaporator, capillary tube, energy meter, pump, water tank and fan. The specification of compressor are as follows, it is of 1 ton capacity reciprocating type, 240V, 50Hz, AC supply which compresses to up to of 300 psi pressure. The capillary tubes of diameter 2mm is used for expansion process. The refrigerant from 2mm tube is expanded in 18mm diameter tube. The pressure and temperature is reduced to lower extent. In this model condenser and evaporator are the two heat exchangers used which works on counter flow method. The condenser is a shell and tube heat exchanger where as evaporator is a cross flow heat exchanger. The fan is provided at the evaporator to increase the rate of heat transfer between the air and the refrigerant. The refrigerant (hot fluid) flows in the tube side and water (cold fluid) flows in the shell side of the condensers. The two condensers are of different specifications.

Figure 2. Left side view of experimental set up

Figure 3. Right side view of experimental set up

Table 1: The specification of evaporator and condenser

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

3. CO2 filling process

The CO_2 refrigerant is readily available in the any gas producing (O_2, CO_2) industries. The liquid CO_2 refrigerant is at a pressure of more than 8.5 bars (125 psi). The refrigerant is filled to the heat pump using regulator valve. A pressure gauge is brazed at the inlet of the valve to measure the pressure of CO_2 refrigerant. The regulator is opened, the liquid CO_2 refrigerant flows into the heat pump through the inlet valve because of pressure difference. When the pressure of CO_2 in the heat pump reaches 50psi the regulator valve is closed and the experiment is conducted. This process is repeated for 60 and 70 psi.

4. Experimental procedure:

The experiment was conducted to measure the rate of increase in water outlet temperature in the condenser at different pressures and mass flow rates. The heat pump is started and allowed to run for some time to reach steady state. The water is supplied from water tank to condenser through inlet valve using pump. The refrigerant is filled to a pressure of 50PSI into the heat pump model. Initial reading both pressures and temperatures in the gauges are tabulated and inlet water temperature of condenser also tabulated. After reaching the steady state experiment is started by taking the pressure and temperature at different components of the system using temperature gauges and pressure gauges. The outlet mass flow rate and temperature of water for the condenser-1 is noted for constant time intervals. This experimental procedure is repeated for the filling pressure of 60 PSI and 70 PSI and also the experiment is conducted by varying the mass flow rate of water (0.009, 0.01, 0.011 and 0.012 kg/sec). The parameters LMTD and

COP are calculated by using the noted experimental values. The figure 4 shows the end temperature for the hot and cold fluid of the condensers.

$$COP = T_2/(T_2 - T_1)$$

$$LMTD = \frac{(\theta 1 - \theta 2)}{\ln\left(\frac{\theta 1}{\theta 2}\right)}$$

Where $\theta_1 = T_{hi} - T_{co}$ and $\theta_2 = T_{ho} - T_{ci}$

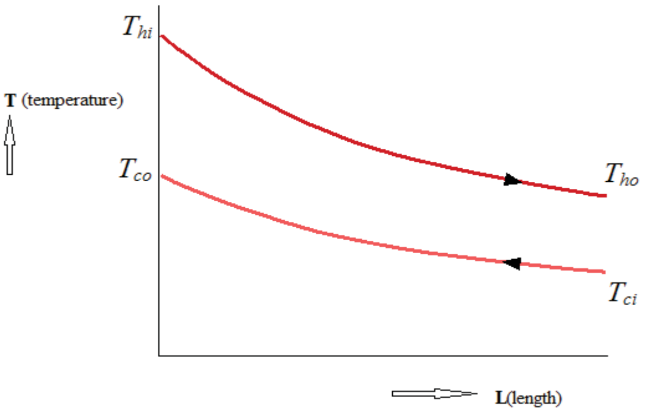

Figure 4. LMTD for counter flow heat exchanger

Result and discussion:

Condenser-1

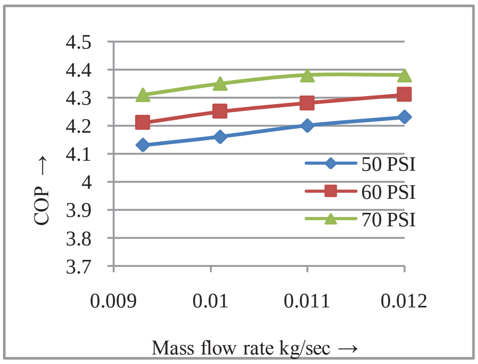

Figure 5. COP v/s Mass flow rate

Condenser-2

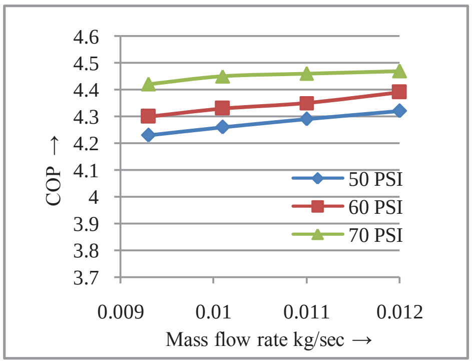

Figure 6. COP v/s Mass flow rate

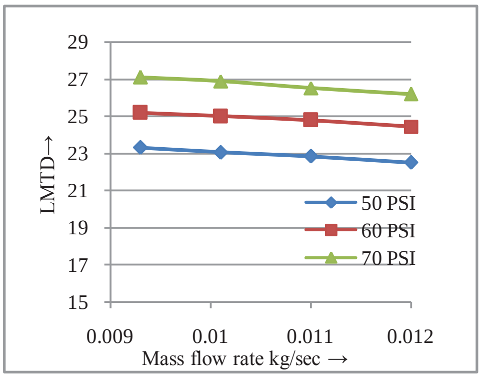

Figure 7. LMTD v/s Mass flow rate

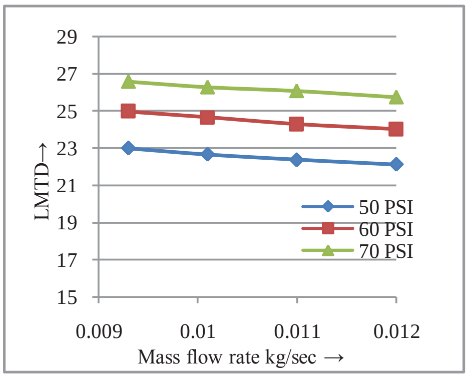

Figure 8.LMTD v/s Mass flow rate

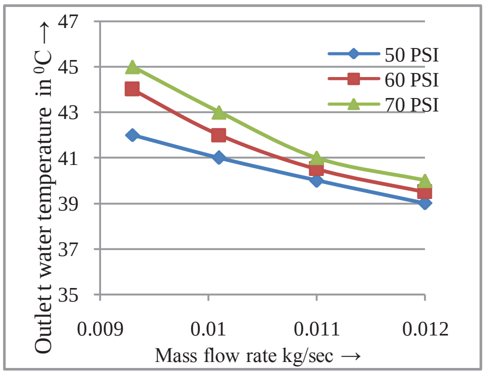

Figure 9. Outlet temp of water v/s Mass flow rate

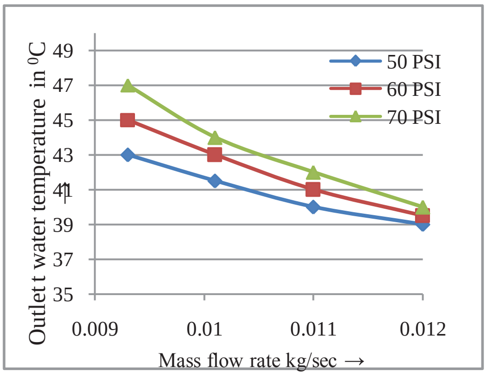

Figure 10. Outlet temp of water v/s Mass flow rate

The different graphs are plotted for the experimental results as shown above. The figure 5 and 6 shows a plot of COP versus mass flow rate of water for different pressure of condenser-1 and 2 respectively. From this graph it can be observed as mass flow rate increases COP also increases for different pressure. The COP is increases more for maximum refrigerant filled pressure 70PSI. The maximum COP is seen for condenser-2 at 70 PSI pressure because the heat transfer and difference in end temperatures are better in condenser-2 compared to condenser-1. The figures 7 and 8 shows a plot of LMTD versus mass flow rate of water for different pressure of condenser-1 and 2 respectively. It is observed that as mass flow rate increases LMTD decrease slightly and is minimum for 50 PSI refrigerant filled pressure. The figures 9 and 10 shows a plot of outlet temperature of water versus mass flow rate of water for different pressure of condenser-1 and 2 respectively. From the graph it is observed that as mass flow rate decrease, the outlet water temperature increases. The heat transfer is same for all the mass flow rate of water (0.009, 0.01, 0.011 and 0.012 kg/sec). If the less amount of water (0.009 kg/sec) supplied to the condensers, the rise in the temperature is more compared to more amount of water (0.012 kg/sec). So as mass flow rate of water increases the outlet temperature of water increases. The outlet temperature of water also increases as refrigerant filled pressure increases and it is maximum for condenser-2. As the mass flow rate of water increases the heat carrying capacity of water increases which increases the temperature difference between the hot and cold fluids of the heat exchanger. This is the main reason for the variation in COP, LMTD and outlet water temperature with the variation in mass flow rate of water.

Conclusion:

The experimental performance evaluation of CO_2 refrigerant heat pump model to heat water is performed. The heat pump provides an efficient solution for heating the water. The parameters like COP and LMTD for different mass flow rate and pressure are calculated from experimental values. The outlet temperature of water is measured. It is observed that as mass flow rate increases COP increases and LMTD decreases for different filled pressures. Also as the refrigerant filled pressure increase, both COP and LMTD increases. As the refrigerant filled pressure increases and mass flow rate decreases the outlet temperature of water increases for the condensers and is maximum for the condenser-2. The maximum COP and outlet temperature of water got in the experiments are 4.46 and 48^0C and it was got for the condenser-2. The CO_2 refrigerant performance shows better efficiency and reduced environmental impact. So, the CO_2 refrigerant is best replacement for globally used artificial refrigerants.

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