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Effect of Humidity on Condensation in Vapour Compression Refrigeration System for Fresh Food Transport Vehicles

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ABSTRACT:

In today's world the developed countries rely on the refrigerated container (reefer) vehicles for the transportation of cold chain products such as fresh foods. In India this technology was introduced in late 1980s but the growth was very slow compared to other countries and failed to match the international trends. However recently, with fast development of roadways, urbanisation and connectivity the reefers get a massive response. The reefers have several advantages but they consume considerable amount of electrical energy to operate. Reefer works based on vapour compression refrigeration cycle in which condenser is an important device. This condenser uses fan-blown atmospheric air over it to remove vaporization heat from refrigerant. The temperature of refrigerant after condensation has effects on Coefficient of performance (COP) of the refrigeration system. This temperature can be altered by the relative humidity of air. The result of our project shows that the increase in air humidity by 18.60% increases the COP by 11.37% and also it reduces the power consumption.

KEYWORDS:

Refrigerated container vehicles; Relative humidity; Refrigeration; Condenser; Dry-bulb temperature

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ACRONYMS AND NOMENCLATURE:

COP	Coefficient of performance
DBT	Dry-bulb temperature
Q	Heat exchanged
Q_{ev}	Cooling effect
W_{com}	Compressor work

1. Introduction

Energy is a very important factor in driving strong economic development and growth of any country. With the increasing demand for energy, the research on conservation of energy and its efficient use is turning out to be one of the important topics. Reduction of energy consumption through efficient energy use or by reducing the consumption of energy services is a goal in all engineering fields. Saving energy will decrease the dependence on fossil fuel, and this is an essential contributor in the measure and gross of the economy in any country due to the high prices of fossil fuel. This saving and reduction in energy consumption, in addition helps in decreasing global warming [1]. Increasing living standards and demand for human comfort have caused an increase in energy consumption [2]. The amount of energy consumed by air conditioners, refrigerators, and water heaters is increasing rapidly, and occupies about 30% of the total power consumption. Therefore, any attempt to decrease the energy consumption of cooling systems as a whole will contribute to large-scale energy savings at the international level. Reduction of energy consumption of cooling units can be achieved by improving the performance. This can be done by lowering the compressor power consumption, increasing the condenser heat rejection capacity, or reducing the difference between condenser and evaporator pressures.

The refrigeration is considered a branch of science which deals with the processes of heat transfer and conservation to reduce the temperature of a given volume control below the temperature of the surroundings [3] and therefore falls within the activities that allow reducing the energy consumption. Refrigerated transport of fresh foods requires temperature control in special vehicles' containers [4]. Refrigerator includes compressor, condenser, expansion valve, and evaporator. The process of condensation is encountered in many engineering installations, for example in steam power plants, refrigeration and air conditioning equipment, heat pumps, other unconventional energy devices, chemical and process engineering installations. In refrigeration units and heat pumps, the processes of condensation (besides the boiling processes) take the fundamental role in the heat transport [5-8]. The utilization of phase changes of refrigeration media became a principle of operation of devices that accomplish the left-running thermodynamic cycle. The high efficiency of refrigeration units relies not only on thermodynamic parameters of the cycle, but also on their technical state and technological conditions of operation. The operational efficiency of the whole unit is affected by the efficiencies of particular processes that take place in the component apparatuses.

An important question is appropriate realisation of high-efficiency phase-change processes in heat exchangers. Among other issues, the processes of condensation need to be characterized by high intensity of heat transfer and high efficiency [9]. The intensity of heat exchange during the condensation of the refrigerant depends on many factors, including geometrical dimensions of the condenser, thermal and flow parameters (pressure, temperature, heat flux density, mass flux density, refrigerant velocity, etc.). An important factor can be the interaction of mass fields, where the condensation takes place, that is the gravitational, electric or magnetic field. Also admixtures of other substances in the condensing two-phase medium can have a great effect on the condensation process [10].

The air cooled condensers (fin and tube heat exchangers) are the most widespread category for low and average refrigeration capacities because the cooling medium (air) is a natural and free source. They are dimensioned from the air average temperature, therefore leading to high condensing pressures. Their energy performances are governed by the thermodynamic properties, e.g. heat capacity and heat transfer. A lower refrigerating efficiency or a dysfunction of the system can occur when the difference between the nominal and outside temperature is high, especially in hot summer periods [11]. It is found that pre cooling the air by about 4°C before entering the condenser reduce the discharge pressure and increase the cooling effect thus increases the coefficient of performance (COP) and second law of efficiency of the system by about 21.4% and 20.5% respectively [12]. Based on the literature survey it was clear that the authors focussed to improve the COP and to decrease the energy consumption by altering the condenser. In this study, authors consider dry cooling technique for improving the humidity of air before entering the condenser of a vapour compression refrigeration system using water sprayer.

2. Experimental setup

The experimental setup consists of a basic vapour compression refrigeration system, water sprayer along with storage tank and digital thermometers as shown in Fig. 1. The technical specification of basic vapour compression refrigeration is given in Table 1. The basic components of the conventional vapour compression refrigeration system are illustrated in Fig. 2. The water sprayer was used to control the air temperature and relative humidity before entering the condenser. It consists of tray, thread and stand. The tray has the dimensions of 30cm×10cm with the height of 5 cm and made up of Galvanised Iron sheet. The thread has the length of 27cm and made of pure cotton. Then the thread was knotted on to the surface of the tray which has several holes for the purpose of transferring the water from tray to the storage tank. The flow rate of water can be regulated by the potential energy of the water stored in the tray. The temperature measuring device used in this process was TPM-10 type digital thermometer. They were located at various stages of condensation to measure its temperature.

Table 1: Specifications of a base refrigeration system

Parameters	Value
Cooling capacity	1058 Kcal/h
Power input	850 W
Current input	2.00 A
Refrigerant used	Freon-12
Compressor type	Reciprocating
Expansion device	TXV
Condenser face area	0.069 m2

Fig. 1: Experimental setup

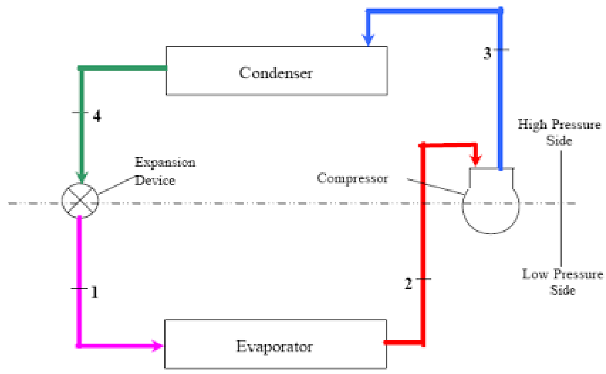

Fig. 2: Block diagram of refrigerator

3. Methodology

Experiments were conducted in Tamil Nadu, India during ambient temperatures (26-34°C). The water was stored in the sprayer tray before the start of the experiment as shown in Fig. 3. The first experiment was conducted without operating the sprayer (base system) while the second with the sprayer under the same conditions for comparison. Experimental data were recorded at regular intervals. Temperatures of air and refrigerant were measured using TPM-10 digital thermometer at points i.e. 1-4 as shown in Fig. 2. The discharge pressures were measured using pressure gauges of range (0-35 kg/cm^2). The relative humidity of the air was measured using the dry bulb (DBT) and wet bulb temperature (WBT) of the air with the help of psychometric chart. The goal of the experiment was to determine the COP of the refrigerator while pre cooling the air before entering the condenser. The COP of the refrigerator was calculated from the measured parameters as the cooling effect produced per unit work input using,

$$\mathrm{COP} = Q_{ev}/W_{com} \quad (1)$$

The heat exchanged in the condenser and the cooling effect of the refrigerator were calculated using the measured parameters as,

$$\mathrm{Q} = \mathrm{FUA}(\Delta T)^{*}_{1m} \quad (2)$$

$$\mathrm{Q}_{ev} = h_1 - h_4 \quad (3)$$

Fig. 3: Water sprayer ahead of condenser

4. Results and discussion

The experimental results are presented in Figs. 4 to 10. In all figures, the blue diamond points represent the base system and the orange square points represent the system with sprayer. The relative humidity decreases with increase in time until 3pm after that it keeps increasing for both the cases (see Fig. 4). The average percentage increase in relative humidity during the entire experimental period was 18.60% with the help of sprayer. The COP decreases with increase in time until 3pm after that it keeps increasing for both the cases (see Fig. 5). The average percentage increase in COP during the entire experimental period was 11.19% with the help of sprayer. The COP increases with increase in relative humidity for both the cases (see Fig. 6). The average percentage increase in COP during the entire experimental period was 11.37% with the help of sprayer while varying relative humidity

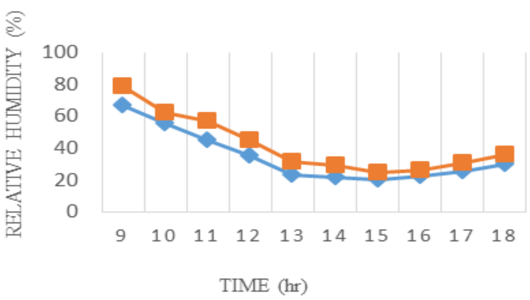

Fig. 4: Time vs. Relative humidity

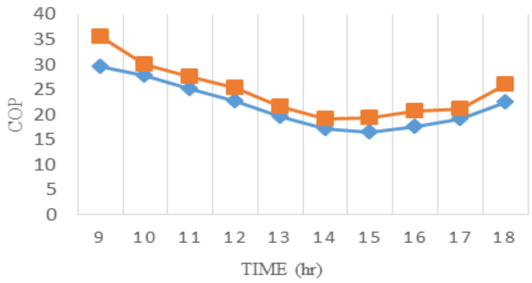

Fig. 5: Time vs. COP

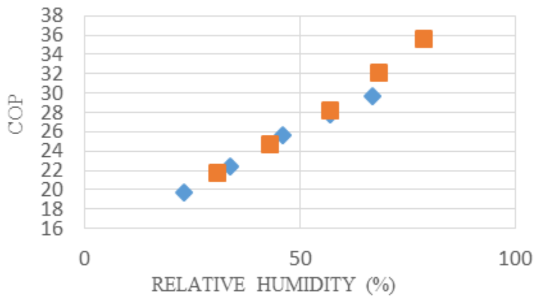

Fig. 6: Relative humidity vs. COP

The cooling effect increases with increase in relative humidity for both the cases (see Fig. 7). The average percentage increase in cooling effect during the entire experimental period was 11.06% with the help of sprayer while varying relative humidity. The heat exchanged decreases with increase in relative humidity for both the cases (Fig. 8). The average percentage increase in heat exchanged during the entire experimental period was 18.14% with the help of sprayer while varying relative humidity. The COP decreases with increase in DBT of air for both the cases. The average percentage increase in COP during the entire experimental period was 11.24% with the help of sprayer while varying the DBT of air. The COP decreases with increase in condensed temperature difference for both the cases. The average percentage increase in COP during the entire experimental period was 11.91% with the help of sprayer while varying the condensed temperature difference.

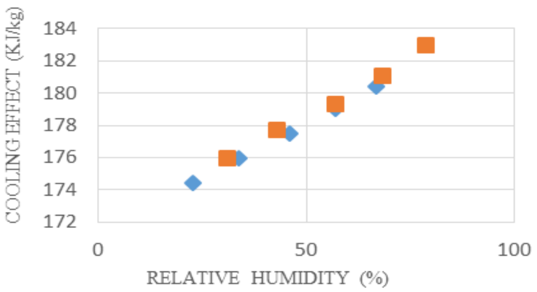

Fig. 7: Relative humidity vs. Cooling effect

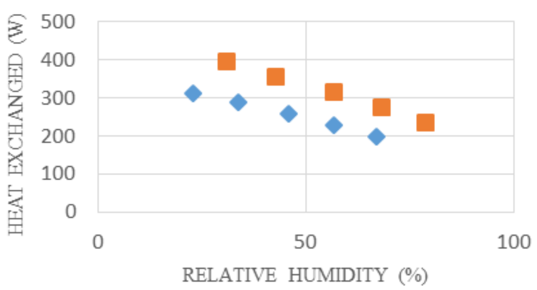

Fig. 8: Relative humidity vs. Heat exchanged

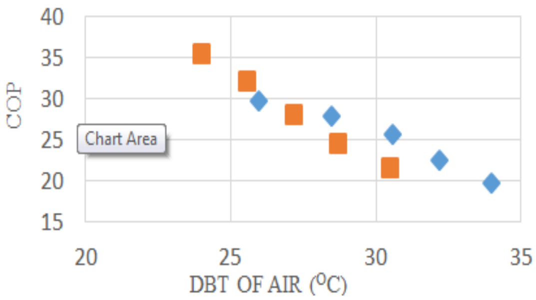

Fig. 9: DBT of air vs. COP

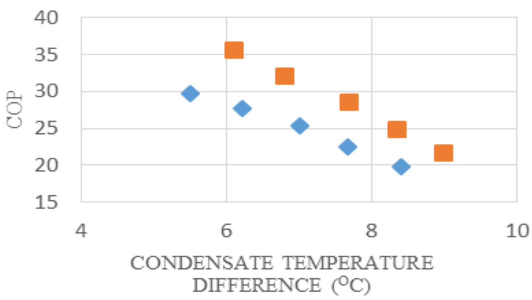

Fig. 10: Condensate temperature difference vs. COP

5. Conclusion

Performance of a vapour compression refrigeration system while pre-cooling the air which is flowing over the condenser tubes was presented in this paper. As we discussed the experiment was carried out in Tamil Nadu, India where nearly 8 months of summer which has low humidity condition that directly affects the COP of the refrigerated container (reefer) vehicles. These low humidity conditions enhances the condenser temperature which increases the power consumption. The experimentation was done to reduce the condenser temperature by improving the humidity. The results show that the COP was improved by 11.37% while increasing the air humidity by 18.60%. It also reduces the discharge pressure which in turns reduces the power consumption.

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