Experimental Study on a Cold Storage System with a Variable Speed Compressor

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ABSTRACT

Selection of a compressor for a refrigeration system is generally done based on a peak load operating condition. The energy consumed by the compressor can potentially be reduced by regulating the compressor speed using an inverter. This experimental study investigates energy saving and performance enhancement potentials in an experimental cold-storage system when the electric frequency supply is reduced from 45 to 25 Hz, with a 5 Hz interval. The system is equipped with a compressor with a power rating of 3 HP (2.25 kW) and R22 was used as the refrigerant. The cooling load of the system was provided using an electric heater placed at the bottom of the cold storage chamber. Results show that the power input to the compressor was reduced when the electric frequency supply was decreased. The highest reduction in the compressor power input occurred when the electric frequency was decreased from 45Hz to 40Hz. The results also show that the coefficient of performance (COP) of the cold storage system was improved when the electric frequency supply was decreased. The largest COP improvement occurred when the frequency was decreased from 30 Hz to 25 Hz.

Keywords

Variable speed compressor, energy saving, inverter, cold storage system, COP

1. INTRODUCTION

There are four basic components in a vapor-compression refrigeration cycle (VCRC): a compressor, a condenser, an evaporator and an expansion device. In a small air-conditioning system the compressor typically consumes nearly 90% of total energy input while in a central-type system the compressor consumes approximately 72% of the total energy input [1, 2]. A thermostatic expansion valve (TXV) is traditionally used to regulate the degree of superheating and cooling capacity of the system [3]. The device also regulates the evaporating pressure and the refrigerant mass flow rate. The opening of the TXV depends on the cooling load demand. However, the degree of superheating and refrigerant mass flow rate cannot be controlled independently.

In a refrigeration system the compressor capacity is usually chosen to meet the peak cooling load demand, which is a combination of internal and external cooling load. The internal cooling load could reach the peak value at any time, but the external cooling load very rarely occurs because the sun position always change with time. Hence it is desirable to have a control strategy that can regulate the speed of the compressor so that the system is able to respond to partial load working conditions. Since a large portion of the energy supply is consumed by the compressor, regulating its speed could potentially lead to saving in energy consumption of the refrigeration system [4, 5].

At the peak load condition the compressor works at the nominal frequency of the electrical power supply. At part load conditions, the frequency of the electrical power supply to the compressor can be reduced, which in turn, would reduce the compressor speed. The aim of this experimental study is to investigate the energy saving and performance enhancement potentials of an experimental cold-storage system by regulating the electric frequency supply to the compressor.

2. EXPERIMENTAL APPARATUS

Figure 1 shows a schematic diagram of the experimental cold-storage system employed in this study. It comprises of a cooling compartment measuring 1.5m (L) x 1.5m (W) x 2.2m (H). The evaporator coil is located at the top of the cooling compartment while an electrical heater, which is used as a source of cooling load, is located near the bottom of the compartment.

The vapor-compression refrigeration system consists of a reciprocating compressor, an air-cooled condenser, a liquid receiver, an evaporator and a thermal expansion valve (TXV). Refrigerant-22 was used as the working fluid. The compressor has a nominal capacity of 3 HP (2.25 kW). The compressor speed was varied using a modulated source inverter by regulating the frequency of the electrical power supply, namely at, 25, 30, 35, 40 and 45 Hz. The three-phase main electrical power supply (380V, 50 Hz) was converted to DC voltage supply using an inverter. A schematic diagram of the inverter and the compressor is shown in Figure 2.

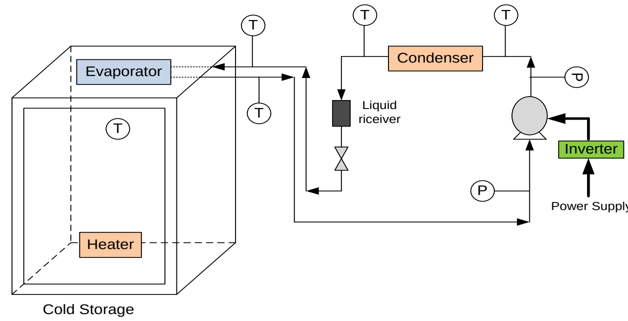

Figure 1: Schematic diagram of an experimental cold storage system.

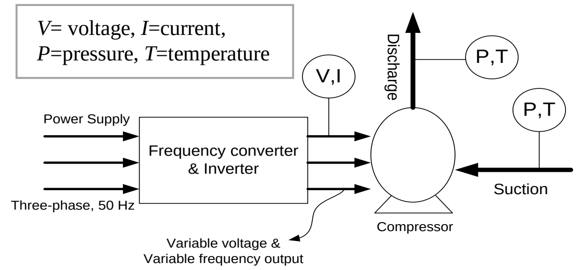

Figure 2: Schematic diagram of an experimental cold storage system.

To evaluate the performance of the cold storage system, four parameters were measured namely temperature (*T*), pressure (*P*), voltage (*V*) and electric current (*I*). The voltage and electric current were used to determine the power input of the compressor. The cooling load was provided by the electric heater with power rating of 1.5 kW. During the experiments the air temperature inside the cooling compartment was maintained at -5°C. The performance of the cold-storage system is expressed in terms of the coefficient of performance (COP), defined as,

$$\text{COP} = \frac{\text{Cooling capacity}}{\text{Compressor power input}} \tag{1}$$

The cooling capacity of the system was determined based on the enthalpy values at the inlet and outlet of the evaporator, which are obtained from the pressure-enthalpy (*p*-*h*) chart for R22 refrigerant. The input power reduction and COP improvement due to the variation in the electric frequency are determined using Eq. (2) and Eq. (3), respectively while the compression ratio (CR) is defined by Eq. (4), as follows:

$$P_{reduction} = \frac{P_n - P_{n-1}}{P_n} \tag{2}$$

$$COP_{improved} = \frac{COP_{n-1} - COP_n}{COP_{n-1}} \quad (3)$$

$$CR = \frac{P_{discharge}}{P_{suction}} \quad (4)$$

where P_n is the compressor input power at a given electric frequency supply and P_{n-1} is the input power at the reduced frequency. Similarly, COP_n is the coefficient of performance of the experimental cold-storage system at a given electric frequency and COP_{n-1} is the corresponding value at the reduced frequency. Also, $P_{discharge}$ is the discharge pressure while $P_{suction}$ is the suction pressure of the compressor.

3. RESULTS AND DISCUSSION

Figure 3 shows the variation of compressor suction pressure, discharge pressure and compression ratio of the cold storage system with the electric frequency supply. It is seen that the compressor discharge pressure continuously increases when the electric frequency was decreased from 45 Hz to 25 Hz. However, the magnitudes of the pressure increment can be considered small. Since temperature and pressure are dependent properties of the refrigerant, the increase in the compressor discharge pressure also causes the refrigerant temperature at the compressor exit to increase. The figure also shows that the suction pressure of the compressor continuously increases when the electric frequency supply was regulated from 45 Hz to 25 Hz. This leads to the superheating of the refrigerant at the evaporator outlet. To maintain the cooling load at a constant value, the mass flow rate of the refrigerant will have to be decreased. This can only be attained by reducing the compressor speed. Figure 3 also shows that, the compression ratio of the compressor also decreases when the electric frequency supply is reduced.

Figure 4 shows the variation of compressor power input and coefficient of performance (COP) of the cold-storage system with electric frequency supply. It can be observe that, the compressor input power decreases from 1.37 kW to 1.13 kW as the electric frequency supply was reduced from 45 Hz to 30 Hz. There are no changes in the compressor input power when the frequency supply was decreased from 30 Hz to 25 Hz. The highest reduction in the compressor power input, i.e. from 1.37 kW to 1.2 kW (about 12.4%) occurs when the electric frequency was reduced from 45 Hz to 40 Hz. The total reduction in the compressor input power is about 18%. The COP of the system is inversely proportional to the compressor power input. As the power input decreases as a result of reduction in electric frequency supply, the COP of the system increases. This finding agrees well with the results of a similar study reported by Aprea *et al.* [6]. The highest COP improvement occurs when the electric frequency supply was reduced from 30 Hz to 25 Hz.

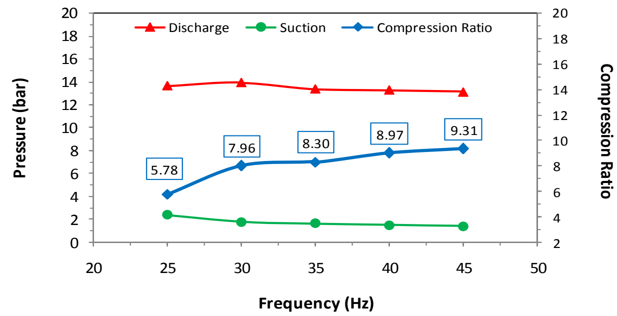

Figure 3: Variation of compressor suction pressure, discharge pressure and pressure ratio with electric frequency supply.

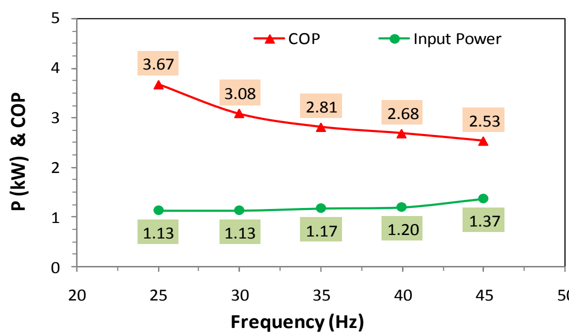

Figure 4: Variation of compressor power input and COP of the system with electric frequency supply.

Figure 5 shows the variation of percent reduction in the compressor power input and system COP with electric frequency supply. It can be observed that the COP of the system can potentially be improved by about 5.6% if the electric frequency supply was reduced from 45 to 40 Hz and by about 8.8% when the frequency supply was further reduced to 30 Hz. The highest COP improvement of 16% can be achieved when the frequency supply was reduced from 45 Hz to 25 Hz. It can also be observed that the largest reduction in compressor power input of about 12.4% can be achieved when the electric frequency supply was reduced from 45 Hz to 40 Hz.

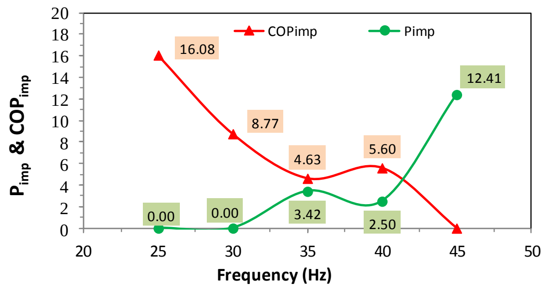

Figure 5: Variation of percentage reduction in compressor input power and system COP with electric frequency supply.

The percent power input reduction is only about 3.42 % when the electric frequency supply was reduced from 35 Hz to 30 Hz. The results also show that there is no further reduction on in the compressor power input when the frequency supply was further reduced to 25 Hz.

4. CONCLUSION

An experimental study on the effects of reducing electric frequency supply on the compressor power input and COP of a lab-scale cold storage system was presented. Results show that the compressor input power can be reduced by about 12% when the electric frequency was regulated from 45 Hz to 40 Hz. In addition, the COP of the system can potentially be increased by about 16% when the electric frequency was reduced to 25 Hz.

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