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STUDY THE EFFECT CHANGE IN DS OF A DX-EVAPORATOR AIR CONDITIONING SYSTEM USING MANUAL CONTROL

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Abstract:
Air conditioning systems consume high rates of energy, with the compressor consuming the largest portion of this energy. In this study, the performance of a variable-speed air conditioning system with a capacity of one ton was tested, which contains a compressor, a variable-speed supply fan, an electronic expansion valve, and a DX evaporator with R-410A refrigerant. The results showed that increasing DS does not affect the performance coefficient at a fixed compressor speed. Moreover, when the compressor speed increases, the performance factor decreases from 4.2 to 3.5 due to increased energy consumption.

Keywords: DX A/C system, VSRS, EEV , DS

INTRODUCTION

The demand for electrical energy is increasing due to the spread of air conditioners, which are among the most important systems in cooling systems because they consume a lot of energy, i.e., about 10–20% in the United States and Japan. For this reason, air conditioners must be controlled to reduce energy consumption as well as provide temperature and humidity. An experimental investigation on variable-speed compressors (VSC) with an electronic expansion valve (EEV) in refrigeration systems [1] The cooling system must be controlled to reduce energy consumption and increase efficiency, as it is important to control the internal temperature and humidity, which affect thermal comfort and air quality[2]. In recent years, inverter technology has appeared, which means that the compressor has a variable speed, and the supply fan has a variable speed, which improves thermal control and efficiency by up to 40% compared to the compressor and the supply fan with a fixed speed[3]. the fan speed changes to affect the sensible and latent heat. As for the expansion valve, which is manually controlled, it works to regulate the flow of the refrigerant and regulate the DS at the exit from the evaporator[4], as well as improve the operational efficiency that is directly related to its operation [5]. Li et al.[6] presented a study on controlling DS at the evaporator outlet and increasing refrigerant flow in air conditioning systems using EEV, where valve opening is controlled by receiving the input signal and generating the output signal. The results showed that this method could feed the evaporator with refrigerant liquid in different operating conditions, in addition to the low temperature of the air leaving the evaporator [7], compared the refrigerants (R-22, R32, and R-410). A thermodynamic analysis was performed to show the effect of sub-cooling and DS on system performance. The results of the analysis showed that as the DS increases, COP increases with increasing DS using R-32; as for R-22, the COP decreases with increasing DS; while using R-410A refrigerant, the change in DS value does not affect the COP of the system. To demonstrate the effect of EEV on system efficiency and energy consumption, Xia et al. [8] presented a study on the effect of EEV and high DS and its impact on the stability of the system, where he explained that increasing DS and changing the opening of the electronic expansion valve lead to system instability, as well as the catch resulting from changing the opening of the EEV as it works to increase energy consumption. Variable-speed refrigeration systems can control the temperature and humidity, in addition to reducing energy consumption, with the presence of an electronic expansion valve. Through studies, the importance of the EEV has been shown in regulating the flow rate, as it is more responsive and has high stability compared to the capillary tube, which is slow in response in addition to instability. This was shown by the study by Chia et al.[9], which presented an experimental study to control the DS in a container cooling system and compared the operating performance between the EEV and the thermal expansion valve (TEV), where the results proved that the efficiency of the cooling system in the container increased by 15% using the EEV compared to the TEV.

For the purpose of this research, we examine the effect of a change in DS on the performance of a variable-speed air conditioning system that contains a variable-speed rotary compressor and an electronic expansion valve.

2. Experimental set up

The experimental rig, as shown in Figure.1, used a split-type air conditioner with a refrigeration capacity of one ton and R-410a working fluid. It consists of two parts: the refrigeration station and an air distribution subsystem. The main components of the refrigeration station include a DX evaporator, an electronic expansion valve, and a variable-speed rotary compressor. The air side includes ducts for air distribution, a condenser containing air-cooled tubes, and a variable-speed supply fan.

The compressor speed is regulated from 3000 to 5000 rpm by the variable-frequency drive of the brushless DC motor, which is controlled by a 0–5V signal. Data acquisition using the Lab View 2018 program was used to record sensor data, including temperature, humidity, and pressure sensors, which are used to sense the temperature of the air and coolant and are of the commercial type NTC (10 $k\Omega$). As for the humidity sensors, they are placed inside the experiment room as well as for manual control of the compressor speed. Supply fan speed and EEV opening. The air flow rates at the entry and exit of the evaporator and condenser are taken, as well as the temperatures at the entrance and exit.

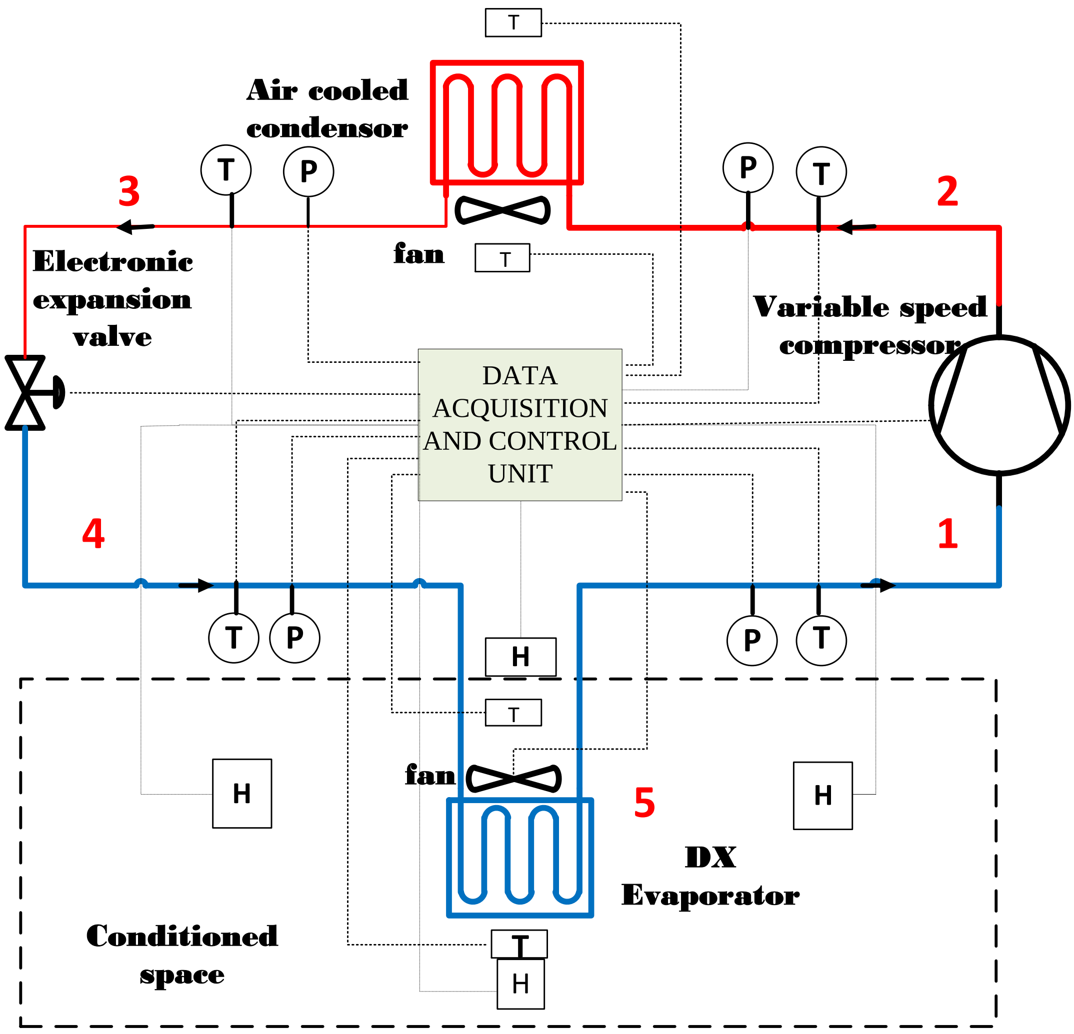

Fig.1: The sketch of experimental rig.

The experiments were conducted in the spring, where the air conditioning device was placed in a completely insulated room with cork, where the thickness of the piece ranged from 5 cm and the dimensions of the room were ($3.5\,\mathrm{h} \times 3\,\mathrm{L} \times 2.5\,\mathrm{w}$). Cooling loads are placed inside the room: an electric heater to generate a sensible load, with a capacity of 700 watts of sensible load, and a water vaporizer to generate a latent load, with a capacity of 500 watts, as shown in Figure .2.

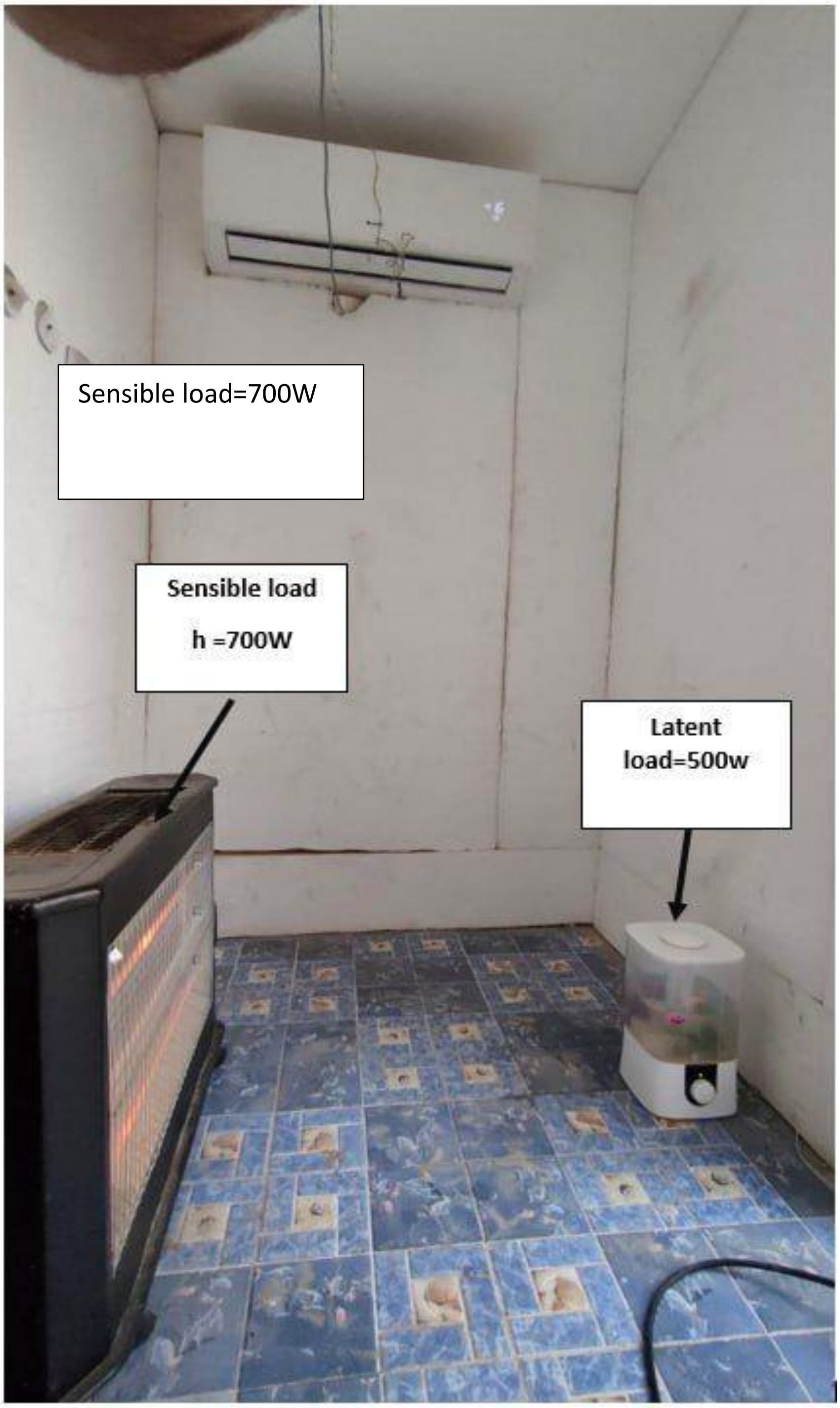

Fig.2: Experimental room.

In this study, at the beginning of the manual control, the temperature is set at 25 °C, and then the compressor speed, supply fan speed, and EEV opening are controlled as shown in Figure 3. Where the speed of the compressor is manually controlled to adjust the room temperature based on the difference between the sensor temperature and the required temperature, the speed of the supply fan is controlled to adjust and reduce humidity by increasing the air flow, while the EEV opening regulates the DS through the flow of refrigerant.

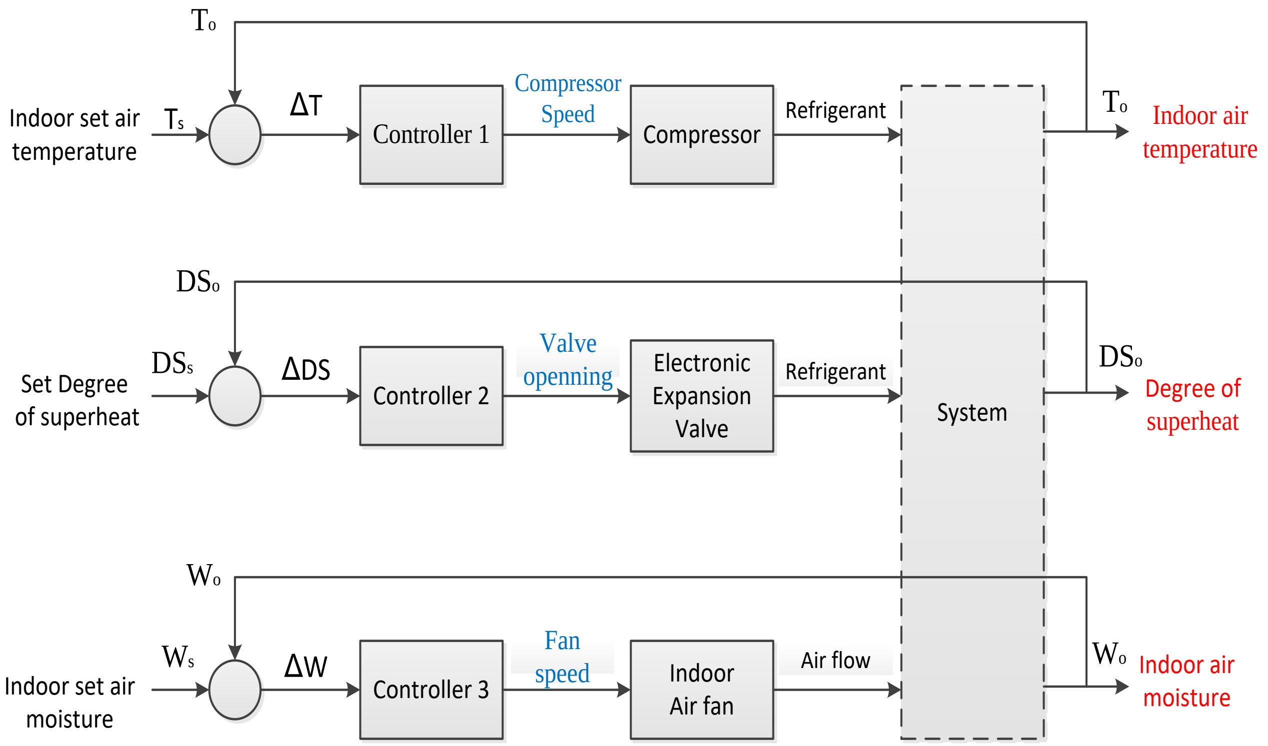

Figure.3: Control loops in DX air condition system.

The coefficient of performance (COP) was calculated depending on the output cooling rate from the evaporator as shown in Eq. (1).

$$COP = \frac{Q_e}{W} \qquad (1)$$

Where (W) is the total power consumption, it is measured in watts, (Q_e) is cooling rate, measured in (W).

(Q_e) depended on the mass air flow rate and the difference between the enthalpy of air at the entry and exit of the evaporator. as shown in Eq. (2)

$$Q_{e=}\dot{m}_a \times (h_{aei} - h_{aeo}) \qquad (2)$$

Where (h_{aei}) and (h_{aeo}) is the enthalpy of air entering and leaving the evaporator, and its unit is (kJ/kg), which can be determine from the psychrometric chart through the evaporator temperature and relative humidity, as shown in Eq. (3) & (4)

$$h_{aei} = f(T_{aei}, RH_{aei}) \qquad (3)$$
$$h_{aeo} = f(T_{aeo}, RH_{aeo}) \qquad (4)$$

Whereas respectively (T_{aei}) and (T_{aeo}) is dry temperature at inlet and outlet to evaporator measured in (℃), (RH_{aei}) and (RH_{aeo}) represent relative humidity found in Psychometric chart.

As for $\dot{m}_a$ it represents the mass flow rate of air measured in units of (kg/s), which can be obtained by multiplying the density by the area. The evaporator is at air velocity, as shown in Eq. (5).

$$\dot{m}_a = \rho \times A \times \vartheta \qquad (5)$$

Where (ρ) stands for density it is determine from the psychrometric chart at a specified temperature and relative humidity and is measured in (kg/m^3). (A) stands for cross-sectional area of the duct exposed to the air flow is obtained by multiplying the duct length by the duct width as shown in the Eq. (6) and is measured in (m^2), and(ϑ) is the evaporator air flow velocity obtained by a Hot wire anemometer and is measured in (m/s).

$$A = L \times W \qquad (6)$$

Where (L) is the length of the duct and measured in (m), (W) is the width of the duct and measured in (m).

Uncertainty was used in the performance coefficient(U_{COP}), based on the multi-sample analysis method, which depends on the constant error and randomness in each variable, as shown in Eq.(7)

$$\delta U = \left[\sum_{i=1}^{n}\left(\frac{\delta U}{\delta X_i}\delta X_{i,f}\right)^2 + \sum_{i=1}^{n}\left(\frac{\delta U}{\delta X_i}\delta X_{i,r}\right)^2\right]^{\frac{1}{2}} \qquad (7)$$

Where the two terms indicate fixed and random errors, (n) is the measured number, (δX_i) is the value of fixed error, (δX_r) the value of random error and calculated from equation (8).

$$\delta X_{i,r} = \frac{t \times \sigma_i}{\sqrt{N}} \qquad (8)$$

The uncertainty of the coefficient of performance (U_{COP}), which depends on the temperature sensors, air flow rate, and Power consumption meter reading. The uncertainty limits of the COP were 4 to 6.2%.

3.Result and Desiccation

Compressor speed and supply fan speed are an essential part of variable-speed air cooling systems, as changing the compressor speed affects the flow rate of the refrigerant and thus the cooling capacity. In addition, the electronic expansion valve regulates (DS) at the required value and maintains the pressure ratio between the evaporator and condenser at optimal levels. Closing the EEV opening leads to increased condenser pressure, which achieves subcooling. In this research, the performance of a variable-speed air conditioning system under manual control is examined to determine the effect of changing DS, compressor speed, and EEV opening.

3.1 The effect of DS and fan speed on COP at each compressor speed.

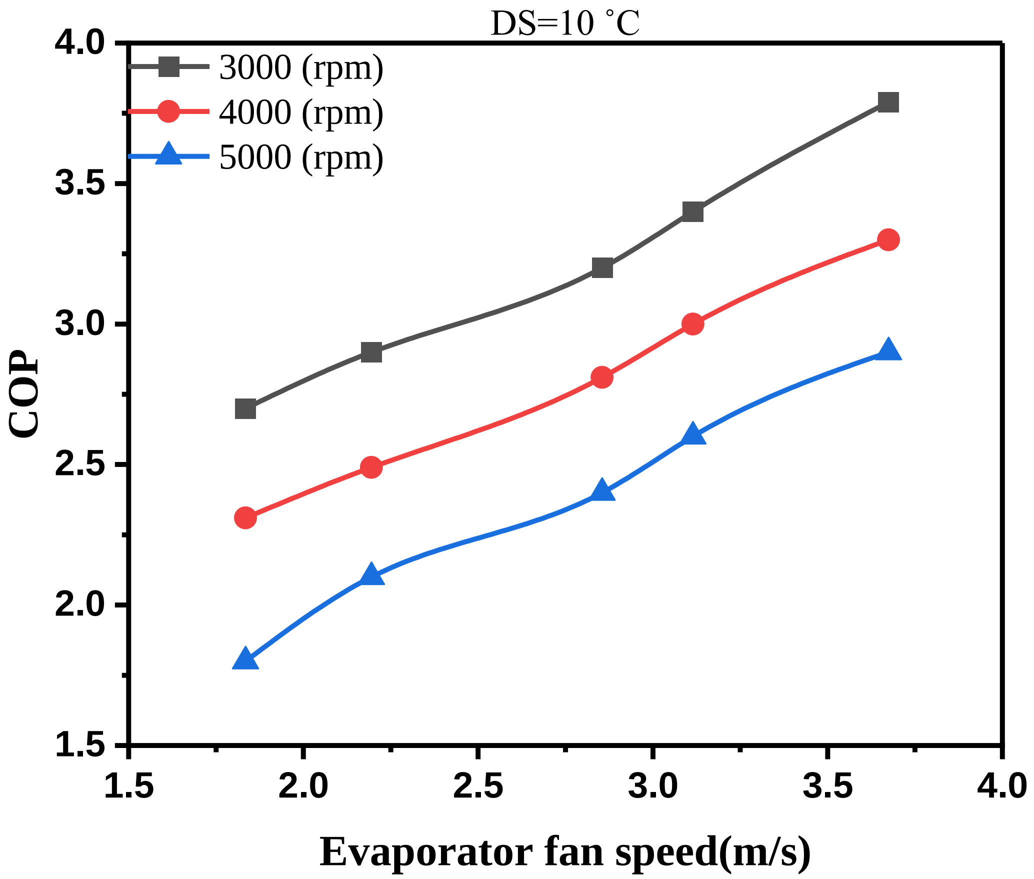

Fig.3: Effect of evaporator fan speed on COP at DS=10 °C.

The figure shows the effect of evaporator fan speed on COP at 3000, 4000, and 5000 rpm compressor speeds, where the EEV is controlled to reach a steady state while maintaining the value of DS = 10°C. Notice that the COP increases as the fan speed increases. This is because the heat exchange process between the evaporator and the condenser increases and the condenser pressure decreases.

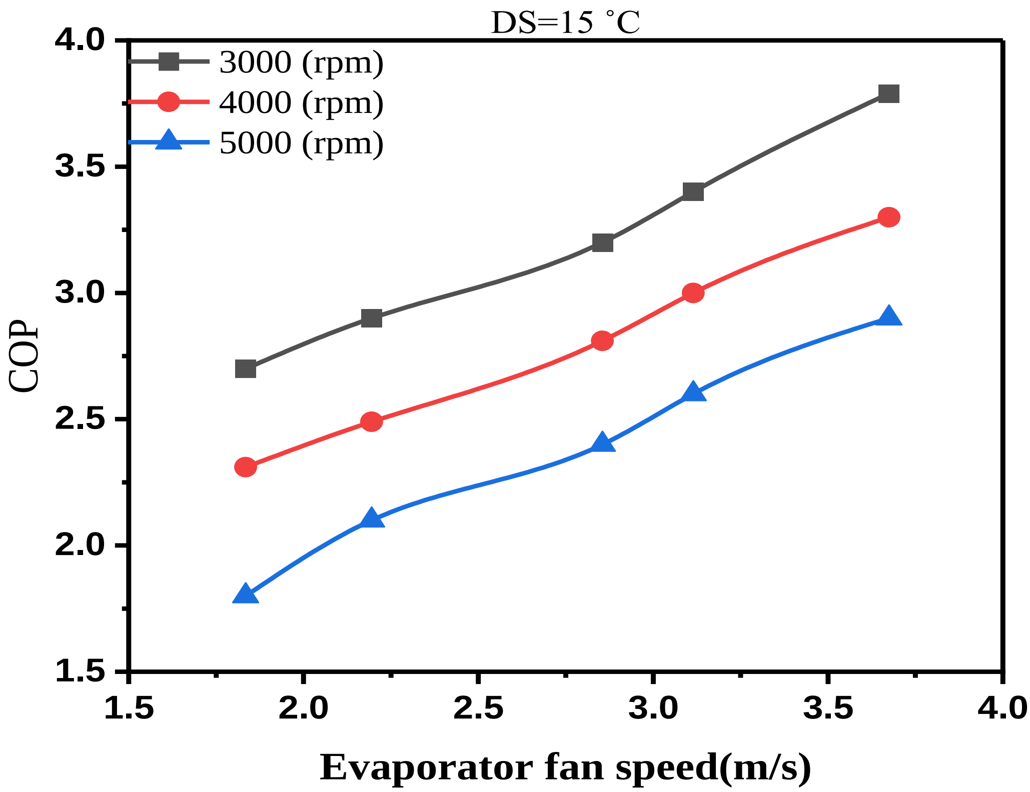

Fig.4: Effect of evaporator fan speed on COP at DS=15 °C.

It should be noted here that at a constant compressor speed and evaporator fan speed of 2 m/s, the COP value is 1.8, while when the fan speed is increased to 4 m/s, the COP value increases by 2.9 due to the heat exchange process that leads to an increase in the cooling rate.

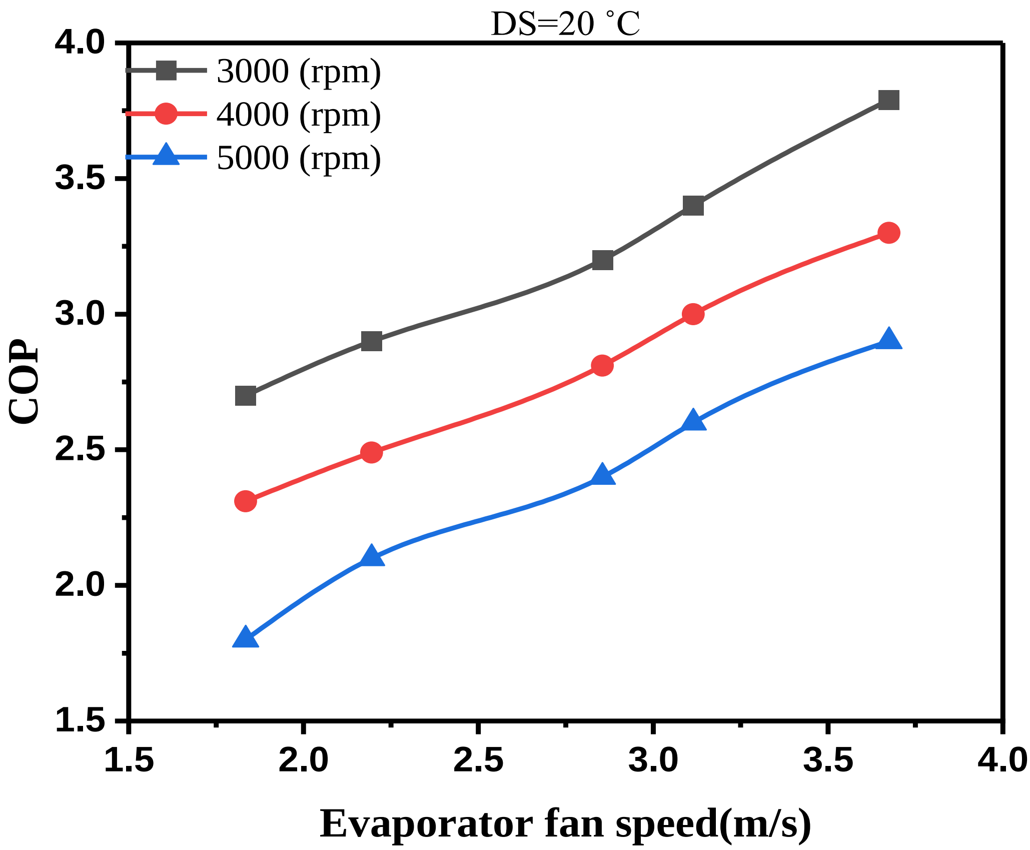

Fig.5: Effect of evaporator fan speed on COP at DS=20 °C.

the effect of compressor speed on the COP at a compressor speed ranging from 3000-5000 rpm while maintaining a constant DS of 20 °C by adjusting the valve opening at each of the supply fan speeds, and the EEV opening increases with the increase in the supply fan speed. It should be noted here that at the evaporator air speed of 2 m/s, the COP value is low at 2.9, while when the fan speed is increased to 2.8 m/s, the COP increases by 3.99 at a constant compressor speed. This is because decreasing the fan speed results in less refrigerant evaporation and a sudden change in the EEV opening, which exposes the system to hunting.

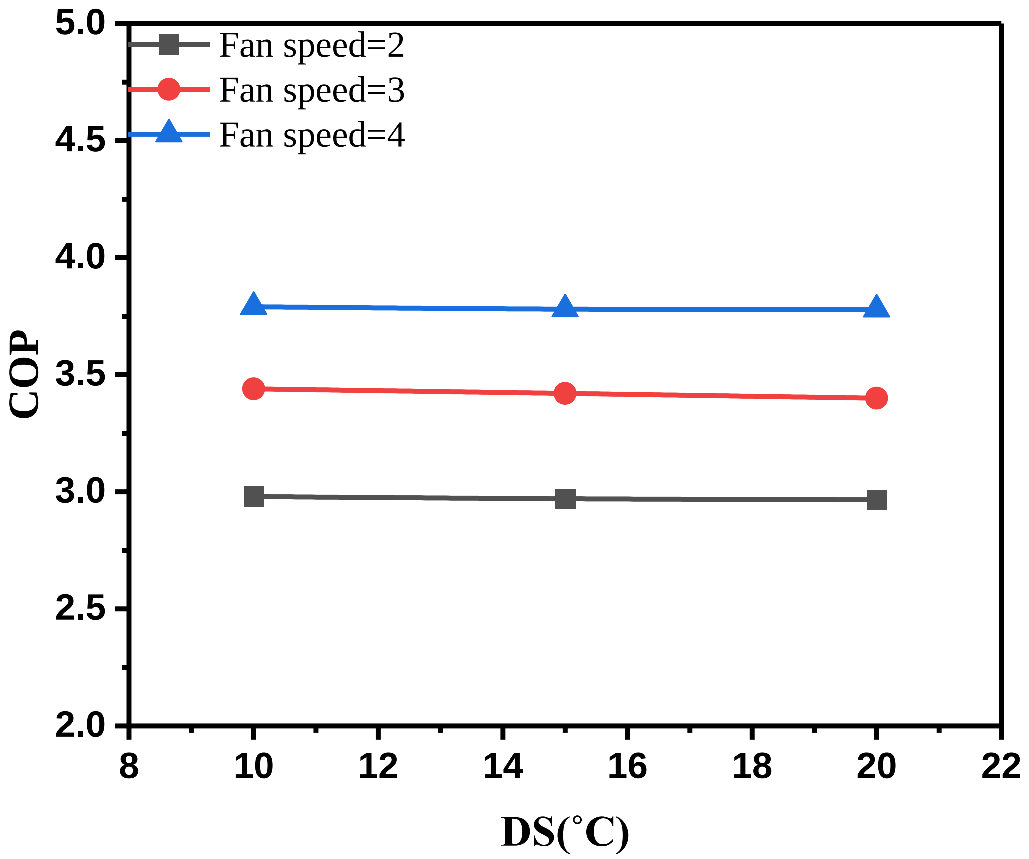

Fig.6: The effect of change in DS on COP at constant compressor speed.

Notice from the figure that when the compressor speed is constant, the change in ds does not affect the coefficient of performance (COP) when using R-410A refrigerant fluid.

4. CONCLUSION

The performance of a 1-ton variable-speed air conditioning system was experimentally studied using R-410A as the refrigerant. The effect of compressor speed and EEV opening on system operation was taken into account. The results showed that as the compressor speed increased from 3000 to 5000 rpm, the coefficient of performance decreased from 4.1to 3.2 due to the increase in energy consumption consumed by the compressor. As the degree of superheating increases at a fixed compressor speed and a fixed supply fan, the COP is not affected by the increase in DS but rather remains constant due to the use of R-410A refrigerant.

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