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Experimental study of the split-type air conditioner with the variable-speed compressor, variable-speed supply fan, and electronic expansion valve

Amani D. Salman [1*], Alaa R. Al-Badri [1], Ahmed H. Al-Hassani [2]

Affiliations
[1]Department of Mechanical Engineering,
Wasit University,
Wasit, Iraq.

[2]Ministry of Electricity, Iraq

Correspondence
Amani D. Salman
amanydhi301@uowasit.edu.iq

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Abstract

Air conditioning systems consume more energy due to the use of fixed-speed devices, including the fixed-speed compressor, which is the main part of cooling systems and consumes the largest portion of energy. In this study, a split-type air conditioning system with a capacity of 1 ton (12,000 BTU/hr, 3.5 KW) of refrigeration was tested using R410A as the working fluid under different operating conditions. The system consists of a VSC, an air-cooled condenser, an electronic expansion valve (EEV), and a direct expansion evaporator (DX) with a variable-speed fan. The effect of compressor speed, degree of superheating, EEV opening, and supply fan speed on system performance was considered. Through experiments, concluded several points. First of all, the highest superheat was 20 ℃ at constant compressor speed. On the other hand, the smallest superheat was 10 ℃ at constant compressor speed. The performance coefficient increases when the compressor speed decreases. The highest value of the COP is 4.71, which can be obtained at the compressor speed of 3000 rpm and DS is 20 ℃, while the lowest value of the COP is 1.74 at the compressor speed of 5000 rpm and DS is 10 ℃ because of the increasing the compressor speed leads to an increase in energy consumption and a decrease in the COP, increasing the closing of the expansion valve opening leads to an increase in DS because of a decrease in the flow rate of the refrigerant to the evaporator. In addition, the coefficient of performance (COP) increases with the increase in temperature of the air leaving the evaporator due to the heat exchange process.

Keywords: Variable speed compressor, DX A/C, EEV, R-410A, Degree of super heat

الخلاصة: تستهلك انظمة تكييف الهواء المزيد من الطاقة بسبب استخدام الاجهزة التي سرعتها ثابتة ومنها الضاغط الثابت السرعة حيث يعد الجزء الرئيسي في انظمة التبريد ويستهلك الجزء الاكبر من الطاقة الكهربائية. في هذه الدراسة، تم اختبار نظام تكييف الهواء من النوع المنفصل بسعة 1 طن (12000 وحدة حرارية بريطانية / ساعة) من التبريد باستخدام R410A كسائل عمل في ظل ظروف تشغيل مختلفة. يتكون النظام من VSC ومكثف مبرد بالهواء وصمام تمدد إلكتروني (EEV) ومبخر تمدد مباشر (DX) بمروحة متغيرة السرعة. تم النظر في تأثير سرعة الضاغط، ودرجة الحرارة الزائدة، وفتح EEV، وسرعة مروحة الإمداد على أداء النظام. من خلال التجارب توصلنا إلى عدة نقاط. أولا، أعلى درجة حرارة كانت 20 °C عند سرعة الضاغط الثابتة. من ناحية أخرى، كانت أصغر درجة حرارة فائقة 10 °C عند سرعة ضاغط ثابتة. يزيد معامل الأداء عندما تقل سرعة الضاغط. أعلى قيمة لـ COP هي 4.71، والتي يمكن الحصول عليها عند سرعة الضاغط 3000 دورة في الدقيقة وDS هي 20°C ، بينما أقل قيمة لـ COP هي 1.74 عند سرعة الضاغط البالغة 5000 دورة في الدقيقة وDS هي10°C بسبب سرعة الضاغط. تؤدي زيادة سرعة الضاغط إلى زيادة استهلاك الطاقة وانخفاض في COP، وزيادة إغلاق فتحة صمام التمدد تؤدي إلى زيادة DS بسبب انخفاض معدل تدفق المبرد إلى المبخر. بالاضافة الى دلك يزداد معامل الاداء مع زيادة درجة حرارة الهواء الخارج من المبخر بسبب عملية التبادل الحراري.

1. 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 and 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 39.9% [3]. Watcharapongvinij et al. [4] The experimental results showed that the variable-speed compressor, in the presence of a cooling load, is more efficient during the day than it is at night and without a load. This is because it changes its speed to increase the flow of refrigerant to match the thermal load. [5], the fan speed changes to affect the sensible and latent heat, as for the expansion valve, which is manually controlled, works to regulate the flow of the refrigerant and regulate the DS at the exit from the evaporator [6], as well as improve the operational efficiency that is directly related to its operation [7]. Li et al. [8] 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. To demonstrate the effect of EEV on system efficiency and energy consumption, Xia et al. [9] 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 led to system instability, as well as the catch resulting from changing the opening of the EEV as it works to increase energy consumption. In addition to reducing energy consumption, variable-speed refrigeration systems can control the temperature and humidity, with the presence of an electronic expansion valve and FLC control units [10] developed a fuzzy logic controller to regulate the supply fan and compressor speeds in the air conditioning system. The control system was simulated using Mat lab software to manage the compressor and fan speed using humidity and temperature sensors. The simulation results indicate that the fuzzy logic controller could indeed control the A/C system's operating point to cool the indoor environment quickly, which continues to improve the humidity condition in the room and then also allows the controller to guide the fin towards the consumer to cool it, provide healthy oxygen, and increase the system's efficiency. To control the temperature and humidity in air conditioning systems that contain a variable speed compressor and a variable speed supply fan, a controlled study was presented by Saikee et al. [11] using a PID controller and an electronic expansion valve by changing both the speed of the compressor and the supply fan, which showed good results in control and energy savings. 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 [12]. This was shown by the study by Chia et al. [13], 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.

2. LITERATURE REVIEW

It has been shown through previous studies that it is possible to save energy and improve room temperature control by using a method to control the compressor speed, supply fan speed, and EEV opening, which may be manual or automatic control. review some of them, Tu et al. [14] studied the effect of coupling between the compressor speed and the electronic expansion valve opening on the performance and stability of the cooling system and used a dynamic model to control the refrigerant flow system. The result showed an increase in energy efficiency. In addition to that, closing the EEV orifice at a constant compressor speed increases the cooling capacity. Ahmed et al. [15] used a fuzzy logic controller to regulate the supply fan and compressor speeds in the air conditioning system. The suggested controller's objective is to manage the operating conditions while keeping the oxygen level and indoor room humidity low while lowering energy consumption. The control system was simulated using Mat lab software to manage the compressor and fan speed using humidity and temperature sensors. The simulation results indicate that the fuzzy logic controller could indeed control the (A/C) system's operating point to cool the indoor environment quickly, which continues to improve the humidity condition in the room and then also allows the controller to guide the fin towards the consumer to cool it, provide healthy oxygen, and increase the system's efficiency.

In this research, the effect of changing DS on the COP of a 1-ton variable speed air conditioning system with working fluid was studied, taking into account the change in compressor speed, supply fan speed, and EEV opening and their effect on the evaporator and condenser. The condenser pressure must not exceed 33 bar and the temperature must not exceed 80 ℃, whereas closing EEV led to increasing condenser pressures that achieved refrigerant subcooled, where energy consumption increases and COP decreases with increasing compressor speed, as well as how EEV opening affects the condenser pressure. Closing the EEV leads to a decrease in the evaporator temperature.

Nomenclature:	**Subscripts**
VSC: Variable speed Compressor (rpm)	L: Length(m)
EEV: Electronic expansion valve	H: Hight (m)
VSD: Variable speed drive.	W: Width (m)
DS: Degree of superheat (℃).	c: Condenser
W: Power consumption (w)	e: Evaporator
Ta: Temperature of air. (℃)	i: Inlet
A/C: Air conditioning system.	o: Outlet
$\dot{m}$: mass flow rate (kg/s)	a: Air
COP: Coefficient of Performance.	P: Pressure inductor
h: Specific enthalpy	**Greek symbols**
NTC: Negative temperature coefficient.	∂: Standard deviation
DHT: Digital humidity and temperature.	ϑ: Evaporator air flow velocity(m/s)
FLC: Fuzzy Logic Control.	ρ: Density (kg/m^3)
Comp. speed: Compressor speed (rpm)	

2. EXPERIMENTAL SETUP

The experimental rig was a split-type air conditioner with a refrigeration capacity of one ton and R-410a working fluid. It consists of two parts shown in Figure 1: 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 air conditioning device is a ready-made split type, meaning it consists of ready-made, not manufactured, parts. The compressor speed is regulated from 3,000 to 5,000 rpm by the variable frequency drive of brushless DC motors, which is controlled by a 0–5-volt signal. Data acquisition using the Lab View 2018 Program was used to record sensor data, including temperature, humidity, and pressure, and to control compressor speed, supply fan speed, and EEV opening. The airflow rates and temperatures are taken at the entry and exit of the evaporator and condenser. The experiments were conducted in the spring season, where the air conditioning device, i.e., the internal part that contains the DX evaporator, was placed inside a room whose dimensions were $(3(L) \times 2(w) \times 3.5(H))$ insulated with cork, with the thickness of the insulation ranging from 5 Cooling loads are placed inside the room. The sensible load capacity is 700 watts, and the latent load is 500 watts, as shown in Figure 2. At the beginning of the control, the temperature is set at 25°C, and then manual control of the compressor speed begins to regulate and adjust the temperature, as well as increase the flow rate of the refrigerant. The electronic expansion valve is also controlled to regulate the DS outlet from the evaporator.

The assumption of this work

• The test room was set in an open location at Wasit University.

• The tests were conducted in the summer. The test began at 7 a.m. and ended after 24 hours at steady state condition.

• The test was performed in clear weather.

• The room temperature is set at 25°C.

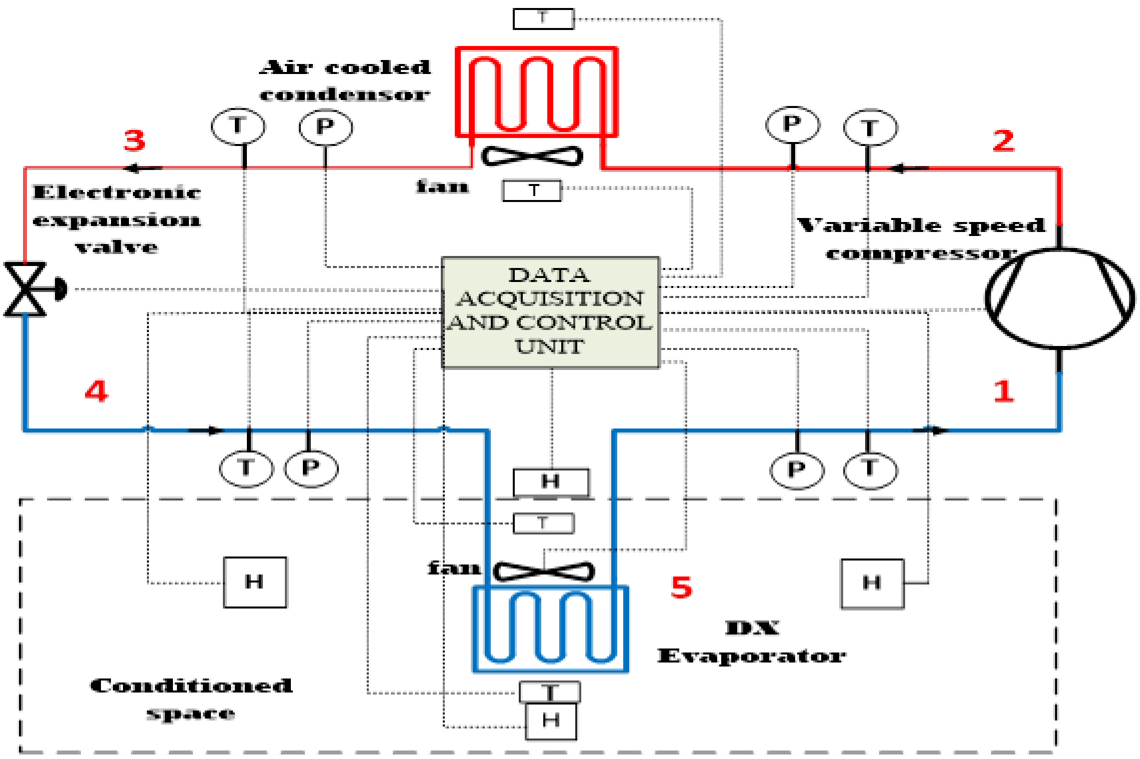

Fig. 1 Schematic diagram of the experimental setup

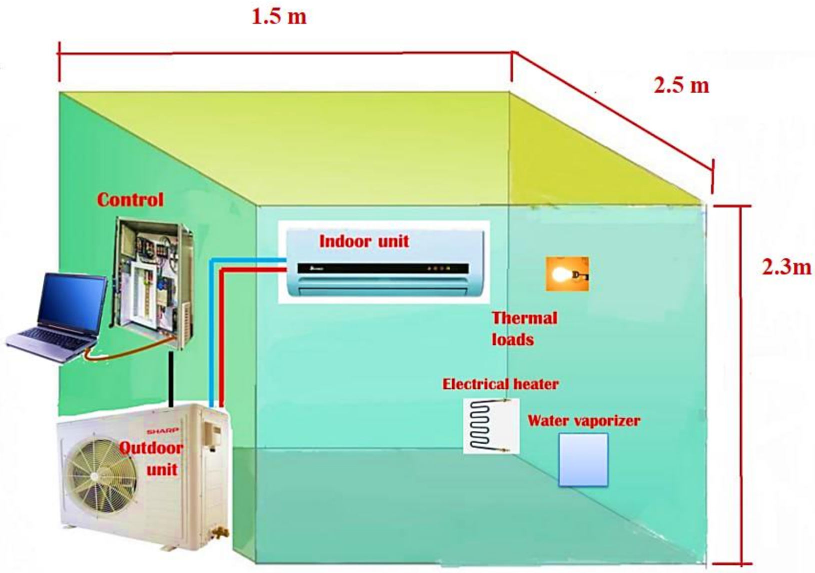

Fig.2: Image of experiment setup with conditioned space

2.1 Measuring instrument

There are 12 sets of sensors to measure air temperature and humidity in the air distribution subsystem of the DX evaporator air conditioning system. The humidity inside the room is measured directly using DHT-22 humidity sensors(H) placed inside the room. As shown in Figure.1, There are eight commercial-type NTC-10 temperature sensors (T) with a total error of ±0.3°C, four of which measure refrigerant temperatures at the DX station where they are inserted into the refrigerant circuit to be in direct contact with the R-410A refrigerant. Another is to measure the temperature of the flowing air, as it is placed in direct contact with the air coming out of the condenser and the supply fan, where the results of the sensor readings are displayed on the front panel of the Lab View program. Sensor data is transmitted to the Lab View software using the Labjak-T7 Pro data acquisition device. Four pressure transducers are used to measure the inlet and outlet pressures of the evaporator and condenser. The pressure value of the system is recorded directly on the front panel of LabVIEW. The airflow rate exiting the evaporator and condenser is measured using a GM8903 hot-wire anemometer. The energy consumption of a variable speed air conditioning system is measured using a digital meter, and the three-phase digital counter YG889-95Y is shown in Figure (3). The power input value of the system is recorded directly on the front panel of LabVIEW. All sensors are connected to the LabVIEW software installed on the laptop, using a USB cable.

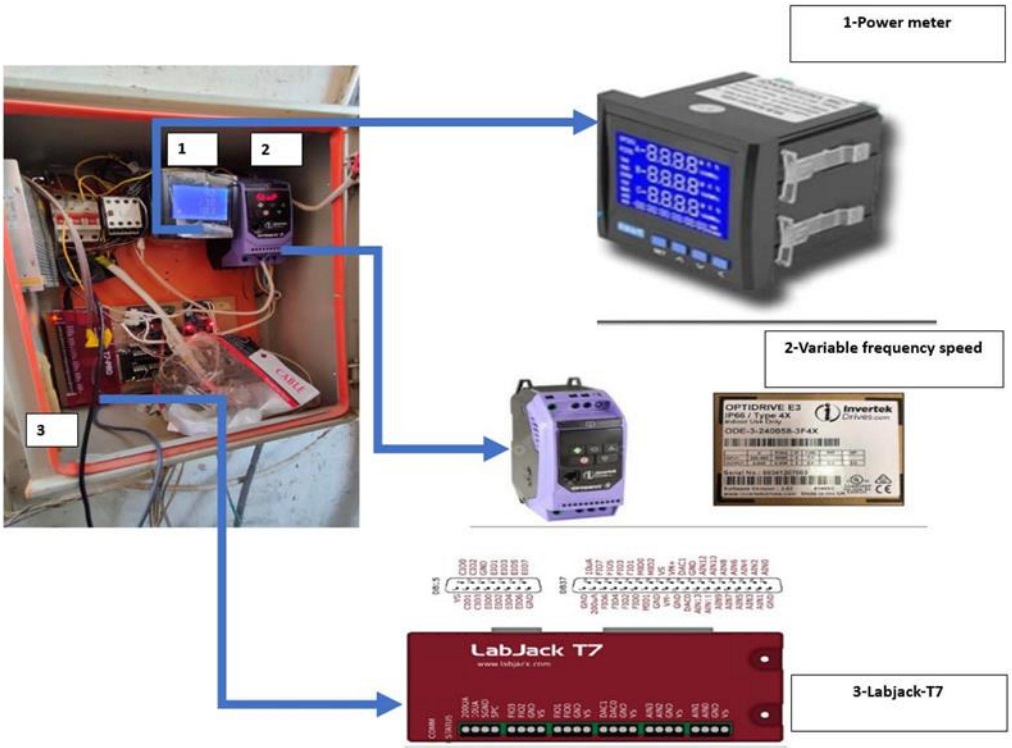

Fig. 3 Types of steel fibers

The performance of the system was examined under manual operation and by conducting 17 tests. The compressor speed, the supply fan speed, and the EEV opening were controlled manually. In addition to this, the effect of the compressor speed, the increase in the evaporator temperature, and the evaporator fan speed on the COP were studied.

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

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

Where (W) is the total power consumed. (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)

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

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

$$h_{aei} = f(T_{aei}, RH_{aei}) \quad (3)$$

$$h_{aeo} = f(T_{aeo}, RH_{aeo}) \quad (4)$$

Where as respectively (T_{aei}) and (T_{aeo}) is dry temperature at inlet and outlet to evaporator measured in (°C), (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).

$$\dot{m}_a = \rho \times A \times \vartheta \tag{5}$$

Where (ρ) is density measured of air measured in (kg/m^3), (A) is the cross-sectional area of the duct exposed to the airflow is obtained by multiplying the duct length by the duct width as shown in $Eq.$ (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).

$$A = L \times W \tag{6}$$

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

3. RESULTS AND DISCUSSIONS

This research presents an experimental study on a variable-speed direct-expansion air conditioning system that contains a variable-speed compressor and an electronic expansion valve (EEV). The effect of compressor speed, fan speed, and valve opening on COP was presented as follows.

3.1 Effect of EEV opening on the COP

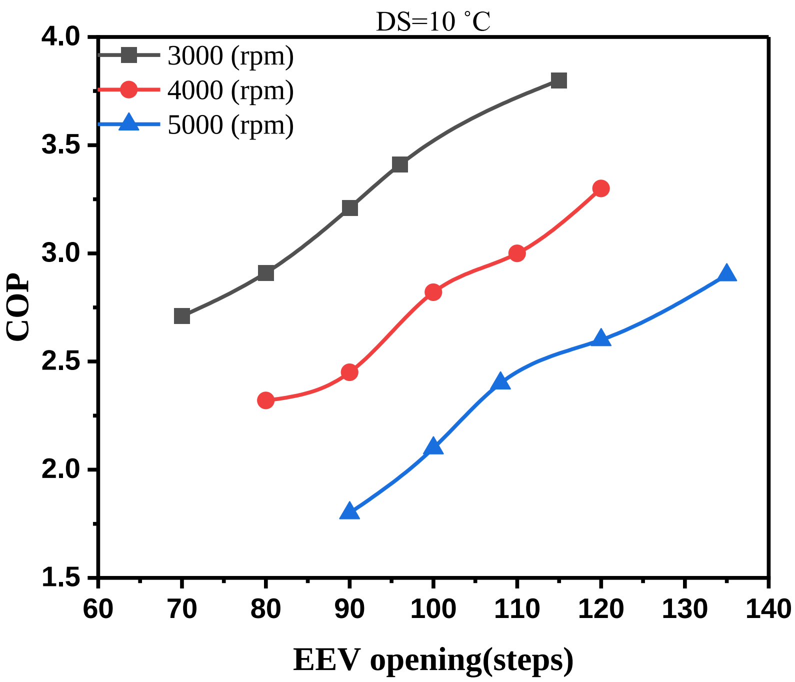

Fig. 4: Effect of EEV opening and Compressor speed on COP at DS=10 ℃

The figure shows the relationship between EEV opening and the coefficient of performance (COP) when DS is constant, its value is 10, and the compressor speed ranges from 3000 to 5000 rpm. The results showed that at a constant compressor speed, the COP increases with the increase in EEV opening due to the increase in the refrigerant flow rate, which leads to an increase in cooling capacity.

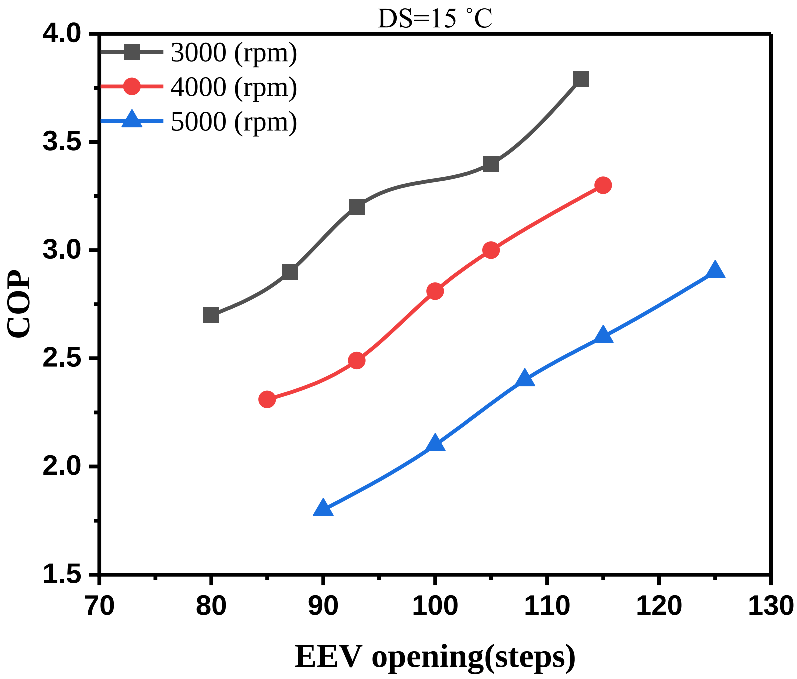

Fig.5: Effect of EEV opening and Compressor speed on COP at DS=15 ℃.

The figure shows the effect of EEV opening on COP at DS = 15 °C. Notice that with the increase in the compressor speed, the valve opening increases because the compressor speed is directly proportional to the valve opening at the sub-cooling limits, as well as the coefficient of the performance is higher than in Figure (4) due to the increase in DS.

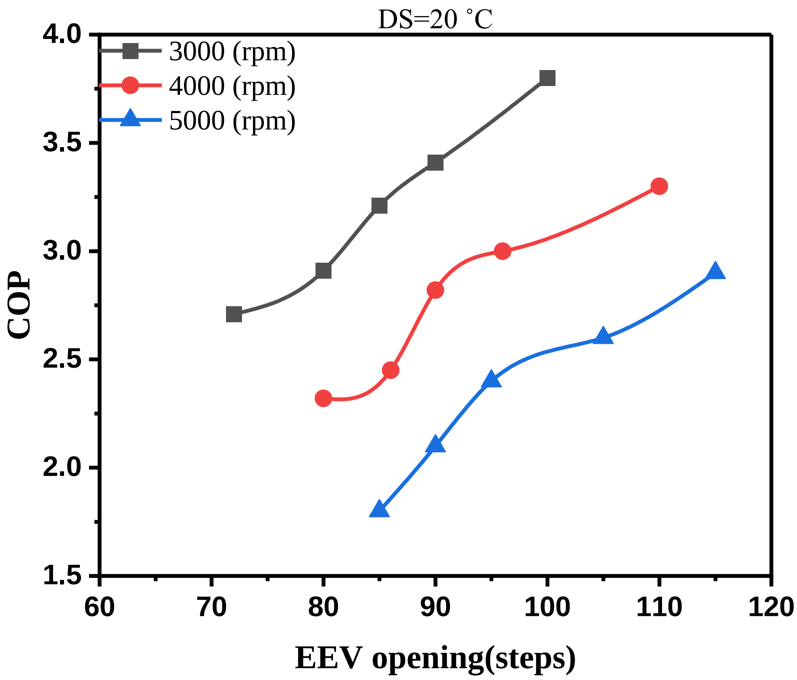

Fig.6 Effect of EEV opening and Compressor speed on COP at DS=20 ℃

The EEV opening is regulated to maintain the overheating temperature at 20°C. Through the figure, which shows the relationship between EEV opening and COP.The results show the COP increases at low compressor speeds due to decreasing compressor frictional losses and the pressure ratio between condenser pressure and evaporator pressure, which leads to a decrease in compressor power consumption. The COP increases by decreasing the EEV opening at each speed due to the increase in refrigerant liquid sub-cooling outlet from the condenser.

3.2 Effect of Evaporator Fan speed on COP

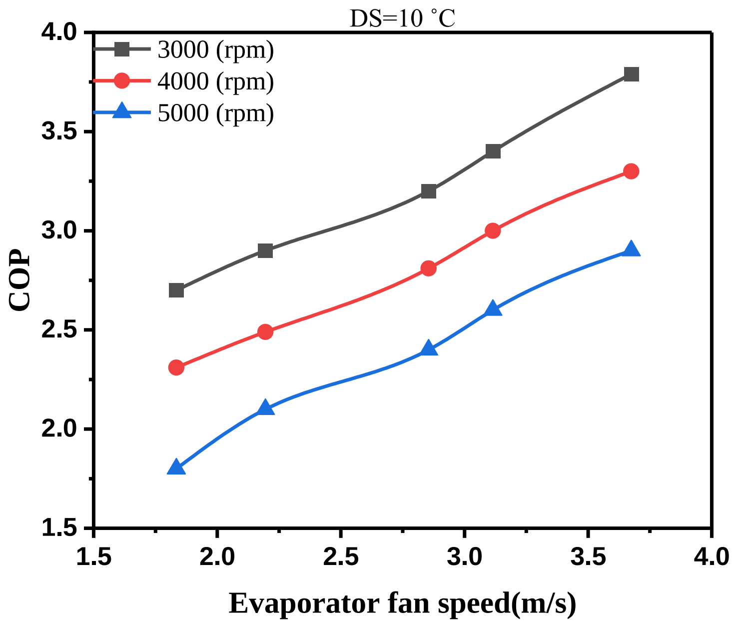

Fig.7**:** Effect of Evaporator air velocity on COP at DS=10 ℃

conclude from the figure that shows the relationship between the evaporator fan speed and COP. When DS is constant, as the supply fan speed increases, the coefficient of performance increases at a fixed compressor speed. Whereas, at the compressor speed of 3000 RPM and the evaporator fan speed of 3 m/s, the performance factor is 3.3. The reason is due to the heat exchange process.

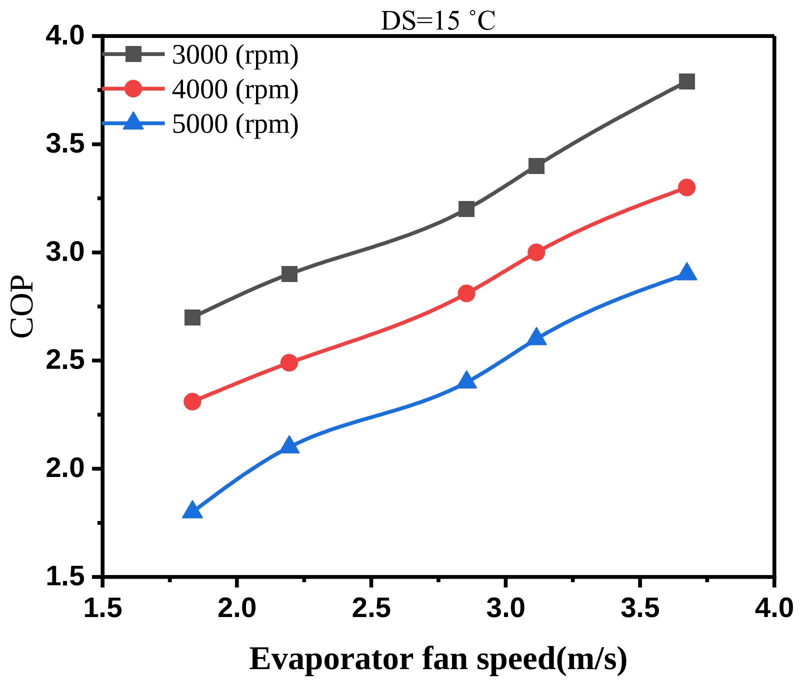

Fig. 8 Effect of Evaporator air velocity on COP at DS=15 ℃

Notice the effect of the evaporator Fan speed and changing the compressor speed on the COP. It is shown in the figure that increasing the evaporator fan speed leads to an increase in COP at a constant compressor speed and is greater than it is in Fig. 7, and the reason is that with increasing DS, the EEV opening decreases, which leads to an increase in energy efficiency as well as the COP at the compressor speed of 3000 rpm, which is greater than 5000 revolutions per minute, because the higher the compressor speed, the higher the energy consumption, which negatively affects the performance coefficient.

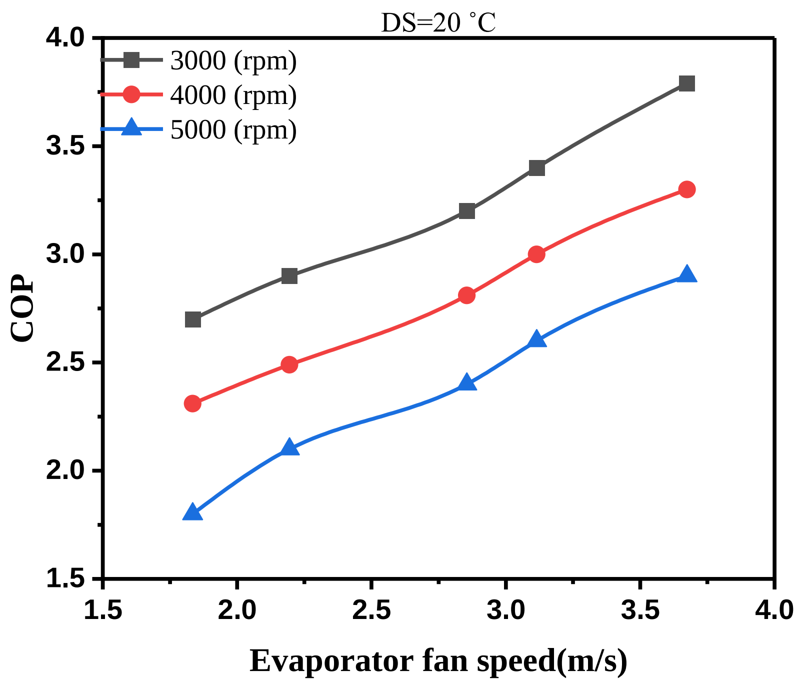

Fig 9 Effect of Evaporator air velocity on COP at DS=20 ℃

In the figure, it can be seen that the amount of COP increases significantly with the increase in evaporator fan speed from 1.8 to 3.5 m/s. The amount of COP increased by about 3%. The reason is that with the increase in fan speed, the temperature and pressure of the condenser increase and the temperature of the evaporator decreases, which leads to an increase in the heat exchange process.

3.3 Effect of T_{aeout} on the Evaporator air flow velocity

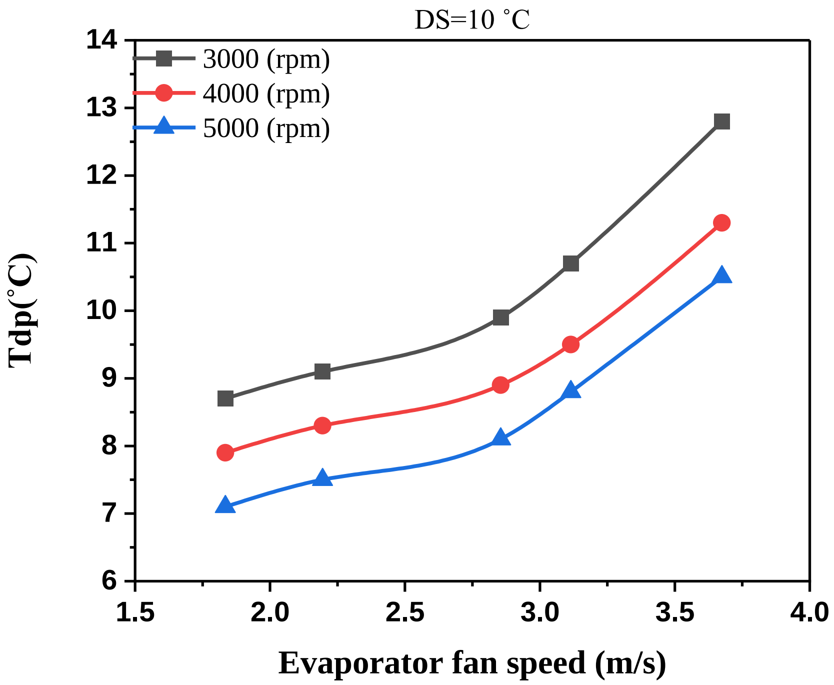

Fig. 10 Effect of Evaporator Fan speed on T_{aeo} at DS=10 ℃

The figure shows the direct relationship between evaporator fan speed and air temperature when DS is constant. As seen in the figure, as the compressor speed increases, the temperature of the air leaving the evaporator decreases, and at a constant DS and a constant supply fan speed, the reason is that as the airflow speed increases, the evaporator pressure decreases.

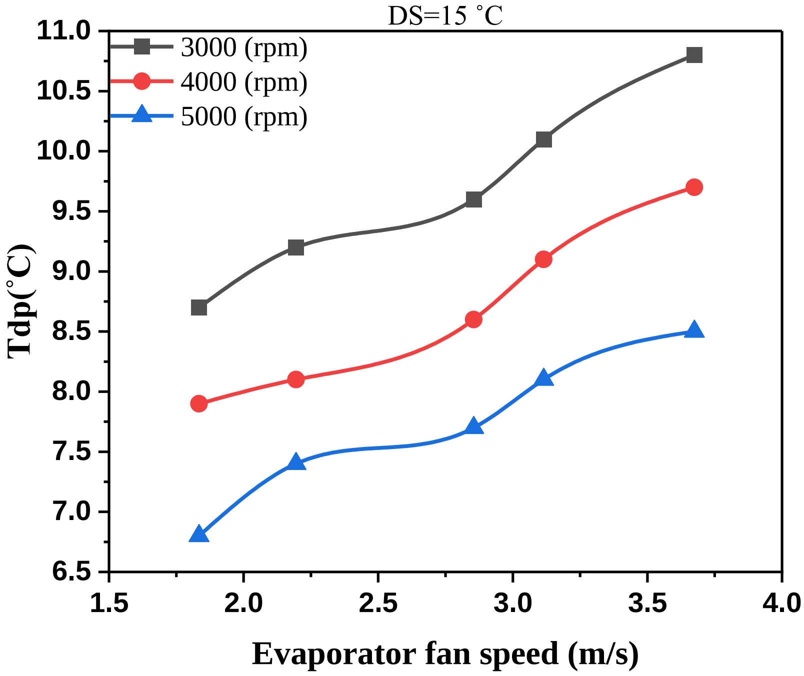

Fig. 11: Effect of Evaporator Fan speed on T_{aeo}at DS=15 ℃

From the figure, the effect of the evaporator fan speed on the air temperature is seen at compressor speeds ranging from 3000 to 5000 rpm. Notice that as the evaporator fan speed increases, the air temperature increases, and the reason is due to the heat exchange process; that is, when the air temperature increases, the condenser pressure and temperature increase.

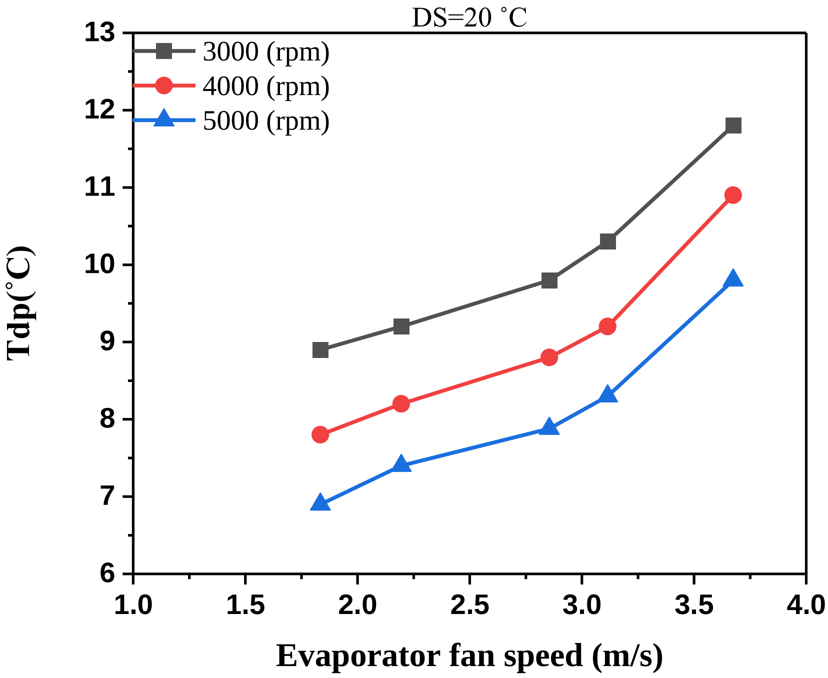

Fig. 12: Effect of Evaporator Fan speed on T_{aeo} at DS=20 ℃.

The figure shows that the air temperature increases with the increase in the evaporator Fan speed and at a constant compressor speed, as the cooling capacity COP increases linearly with the increase in the evaporator temperature and because of the increase in the flow rate with the evaporator pressure and the decrease in the condenser temperature. DS increases as the valve opening increases due to a lower flow rate of the refrigerant to the evaporator.

4. CONCLUSIONS

1. In this study, a split-type air conditioning system having a capacity of 1 tonne (3.5 KW) of refrigeration with R410A as the working fluid was tested under various operating conditions. The system consists of a VSC, an air-cooled condenser, an electronic expansion valve (EEV), and a direct expansion (DX) evaporator with a variable speed fan. The effect of compressor speed, electronic expansion valve opening, and supply fan speed on COP was tested in three cases of DS. Display, as shown by the following details:
2. The degree of superheat increases with the increase in closing EEV and at a constant compressor speed.
3. The coefficient of performance increases from 2.8 to 4.1 as the compressor speed decreases from 5000 to 3000 rpm.
4. Increasing the evaporator fan speed from 2 m/s to 4 m/s leads to an increase in the air temperature from 8 to 12 due to the heat exchange process, which leads to increased energy efficiency.
5. Increasing the evaporator fan speed from 2 to 4 m/s improves the COP by 4%.
6. The cooling rate increases with increasing air temperature, resulting in an increased heat absorption rate and a higher flow rate of refrigerant R-410A.
7. The EEV opening is regulated by manual control to obtain a constant DS at the desired values.

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