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EXPERIMENTAL ASSESMENT OF REFRIGERATION SYSTEM CHARACTERISTICS WITH SCROLL COMPRESSOR

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Abstract: In this study, characteristics of a chiller system are investigated. The experimental setup consist of an air cooled condenser, a liquid type shell-tube evaporator, and a scroll compressor. Compressor speed is changed between 30-60 Hz via PWM type frequency inverter. Mass flow rate of the refrigerant R134a is controlled by an electronic expansion valve (EEV) and a thermostatic expansion valve (TXV) in the system. The cooling capacity of the chiller system is about 3 kW. For determining the performance characteristics of the system eight parameters are considered. These are the EEV opening, superheating, subcooling, evaporation/condensing temperatures, and refrigerant flow rate. It is found that the COP decreased to its half and cooling capacity increased 37% by increasing the frequency from 30 Hz to 60 Hz. According to analysis, superheating changing affects various parameters in the system and also it is important to monitor this parameters.
Keywords: Chiller, cooling performance, superheating, subcooling,

SARMAL KOMPRESÖRLÜ BİR SOĞUTMA SİSTEMİ KARAKTERİSTİKLERİNİN DENEYSEL İNCELENMESİ

Özet: Bu çalışmada, bir su soğutma grubunda sistem performansını etkileyen parametreler analiz edilmiştir. Deneyler, yaklaşık 3 kW kapasiteli bir su soğutma grubunda gerçekleştirilmiştir. Deney düzeneğinde, scroll tip kompresör, elektronik tip genleşme vanası (EGV), sıcaklık kontrollu genleşme vanası (TGV), su soğutan bir buharlaştırıcı ve hava soğutmalı yogusturucu kullanılmıştır. Kompresör hızı PWM tipi bir frekans invertörü kullanılarak 30-60 Hz arası değitirilmiştir. Yoğuşturucu izole edilmiş bir hava kanalı içerisine yerleştirilmiştir. Deneyler sırasında kompresör hızı ve EGV açıklık miktarı bulanık mantık algoritma ile kontrol edilmiştir. Yapılan çalışmada,EGV açıklık oranı, kızgınlık miktarı, aşırı soğutma miktarı, buharlaşma ve yoğuşma sıcaklığıile soğutucu akışkan debisi gibi sekiz farklı parametrenin soğutma çevrimine etkileri ayrı ayrı incelenmiştir. Sonuçlara göre, kompresör frekansının 30 Hz den 60 Hz'e çıkarılması ile COP değerinin yarıya düştüğü, soğutma kapasitesinin %37 arttığı gözlenmiştir.Sonuçlara göre, kızgınlık değerindeki değişimin bir çok büyüklüğü etkilediği görülmüştür. Bu nedenle kızgınlık değerinin soğutma sistemlerinde mutlaka izlenmesi gerektiği soncuna ulaşılmıştır.
Anahtar kelimeler: Su soğutma grubu, soğutma performansı, aşırı ısıtma, aşırı soğutma

NOMENCLATURE

COP	Coefficient of Performance [-]
c_p	Specific heat [J kg^{-1} K^{-1}]
EEV	Electronic expansion valve [-]
f	Compressor frequency [Hz]
H	Enthalpy [J kg^{-1}]
$\dot{m}$	Mass flow rate [kg s^{-1}]
P	Pressure [Pa]
$\dot{Q}$	Heat transfer amount [J s^{-1}]
SC	Subcooling [˚C]
SH	Superheating [˚C]
T	Temperature [˚C]
TXV	Thermostatic expansion valve [-]
$\dot{W}$	Power [W]
UA	Total heat transfer coefficient [kW/K]

Subscripts

A	Air
C	Condensing
COMP	Compressor
CON	Condenser
E	Evaporating
EV	Evaporator
IN	Inlet
OUT	Outlet
R	Refrigerant
W	Water
LM	Logarithmic
1	Inlet of the evaporator
2	Outlet of the evaporator

INTRODUCTION

There are various studies in the literature that investigate to improve efficiency in the refrigeration systems. Qureshi and Tassou (1996) investigated variable speed capacity modulation of domestic size heat pumps. In this study, the author focused on different topics with alternative current (AC) compressors. These topics were energy conservation by using capacity modulation, performance comparison with conventional systems, and mathematical modeling of variable speed systems. Results showed that a variable speed capacity modulation method can yield 15% improvement on energy consumption compared to a conventional system. Larsen and Thybo (2004) studied energy savings in a refrigeration system by setting the optimum points of the working conditions. They revealed that a significant amount of energy can be saved by using an optimal control strategy. Also, the authors showed that it is possible to decrease the energy consumption, especially in the cold season where the ambient temperature is low by finding an optimal condenser pressure, without changing the cycling capacity. Björk and Palm (2006) experımentally investigated effect of on/off cycling in domestic refrigerator at different expansion valve capacity, quantity of charge, and ambient temperature. Aprea et al. (2006) compared an EEV and a TXV with respect to energy consumption in a vapor compression plant subjected to a cold store. A fuzzy logic algorithm was used to control refrigeration system capacity. Results showed that EEV reduces energy consumption in refrigeration system. In another study Aprea et al. (2009) investigated optimal working conditions of AC compressors. The authors identified the compressor frequency that optimizes energy, exergy, and economy. A reciprocating and a scroll type AC compressor were compared. It is resulted that reciprocating and scroll compressors provided 15% and 25% energy savings, respectively. Cecchinato et al. (2010) investigated partial load efficiency of an air-cooled water chiller with variable speed compressor. Different operating modes of the compressor were experimentally analyzed point of view energy efficiency. Experimental study revealed that cooling capacity control by means of compressor speed change was a suitable solution to improve partial load efficiency. Ekren and Küçüka (2010) investigated effects of fuzzy logic control in a variable speed scroll compressor and an EEV. This study showed that a considerable performance improvement such as 17% can be obtained based on fuzzy controlled compressor and EEV in comparison with on/off controlled compressor.

A refrigeration system has four main components such as compressor, condenser, evaporator, and expansion device. In this system, a serial of process takes place called refrigeration cycle. The first step to design a refrigeration system is to calculate cooling load then to define system type and refrigerant type. Afterwards, sizing can be realized for the system components. Sizing is important to have exact amount of cooling capacity and high cooling performance from the system. For instance refrigeration systems may not able to provide right cooling capacity because of the improper design parameters and higher outdoor air temperatures. Recently, outdoor air temperatures are getting higher at summer period because of the global warming. Refrigeration capacity modulation, cool storage can be used to reduce peak time electricity consumption and to improve refrigeration system efficiency for the summer period. Also these methods may reduce initial investment and operation costs (Qureshi and Tassou, 1996; Ozkol, 1997; Lazzarin and Noro, 2008). Different softwares for the cooling load, thermodynamic analysis, equipment sizing and simulation are used to decrease calculation failure. On the other hand, refrigeration system behaviors have to be known to use these softwares effectively. Since interaction of each parameters effects result of the analysis.

The main aim of this study is to investigate effects of some parameters such as superheating, subcooling, evaporation and condensing temperature, refrigerant flow rate in the refrigeration cycle. In addition to this, effect of these parameters on the compressor speed and EEV opening amount is investigated. Another important point of this study is to analyze variation of coefficient of performance (COP), condenser, evaporator and compressor capacities at different compressor speeds and EEV opening amounts. It is also aimed to understand the refrigeration system behavior by using system characteristics. Experimental setup is given schematically in the Fig.1

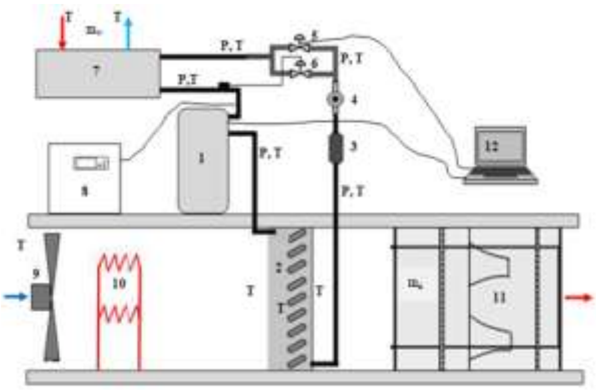

Figure 1. The main components of experimental setup

The experimental chiller system about 3 kW in cooling capacity consists of a scroll compressor, a liquid type shell–tube evaporator, and an air-cooled condenser which is placed in a thermally insulated air channel. To simulate external conditions air flow rate and temperature can be changed by using a fan and an electrical heater, respectively. Chilled water which exits from the evaporator is sent to the water tank to be heated up. Heating chilled water in the tank simulates load. The water tank has 1 m^3 volumetric capacity. During the experiments, in order to obtain constant cooling load in the evaporator, two electrical heaters are used in the water tank. Experimental conditions are given in Table 1.

Table 1 Experimental conditions

Exp.	Compressor	Expansion Valve
m_W= 0.496 decreased to 0.100 kg/s ($T_{A,IN}$= 30 °C, $T_{W,IN}$ =13 °C)		
1	Fixed Frequency *(f= 50 Hz)*	EEV fuzzy logic controlled *(SH=8°C)*
2	Fixed Frequency *(f= 50 Hz)*	TXV *(SH=8°C)*
m_W= 0.496 decreased to 0.100 kg/s ($T_{A,IN}$= 30 °C, $T_{W,IN}$ = 13 °C)		
3	Fuzzy Logic Controlled *($T_{W,OUT}$ =9 °C)*	TXV *(SH=8°C)*
4	Fuzzy Logic Controlled *($T_{W,OUT}$ =9 °C)*	EEV fuzzy logic controlled *(SH=8°C)*
m_W=0.100 kg/s ($T_{A,IN}$= 30°C $T_{W,IN}$ = 13 °C)		
5	Fuzzy Logic Controlled *($T_{W,OUT}$ =9 °C)*	EEV Fuzzy Logic Controlled *(SH=8°C)*
6	Fixed Frequency *(f= 50 Hz)*	EEV Fuzzy Logic controlled *(SH=8°C)*
7	ON/OFF control Fixed Frequency *(f=50 Hz, $T_{W,OUT}$ = 9°C)*	TXV *(SH=8°C)*

THERMODYNAMIC ANALYSIS

Temperature, pressure, and mass flow rate of refrigerant should be known for thermodynamic analysis of the cooling cycle. Hence, temperatures are measured at different points over the cooling cycle by 'T'-type thermocouples. Additionally, gauge pressures are measured by ratio metric type pressure transducers in the cooling cycle at inlet and outlet of the evaporator, condenser, and the compressor. The other measurements during the experiments are power consumption of the compressor which is measured by a wattmeter. Electricity consumption of the PWM inverter is not taken into account. By using these measurements evaporator capacity or cooling capacity ($\dot{Q}_{EV}$) is calculated in Eq.1

$$\dot{Q}_{EV} = \dot{m}_W c_{p,W} \Delta T \tag{1}$$

where $\dot{m}_W$ is water flow rate, $c_{p,W}$ is specific heat and ΔT is water temperature difference. Refrigerant flow rate $\dot{m}_R$ is calculated by Eq.2

$$\dot{m}_r = \frac{\dot{Q}_{EV}}{(h_1 - h_2)} \tag{2}$$

Where, h denotes enthalpy and subscripts $_1$ and $_2$ denotes inlet and outlet of evaporator. *COP* is calculated by Eq.3. Where, $\dot{W}_{comp}$ is compressor capacity.

$$COP = \frac{\dot{Q}_{EV}}{\dot{W}_{COMP}} \tag{3}$$

Total heat transfer capacity of the evaporator and condenser calculated by Eq.4. Where, $\dot{Q}$ is heat transfer amount in the evaporator or condenser and ΔT_{LM} is logarithmic temperature difference. Where, evaporation temperature of refrigerant was used to calculate ΔT_{LM}

$$UA = \frac{\dot{Q}}{\Delta T_{LM}} \tag{4}$$

RESULT AND DISCUSSION

In this part of the study, variation of COP, condenser capacity ($\dot{Q}_{CON}$), evaporator capacity ($\dot{Q}_{EV}$), compressor capacity ($\dot{W}_{COMP}$), superheating (*SH*), sub-cooling (*SC*), evaporation temperature (T_E), condensing temperature (T_C), refrigerant flow rate ($\dot{m}_R$), and total heat transfer coefficient (*UA*) with compressor speed and EEV opening are evaluated.

Evaporation Temperature

In the evaporator, heat absorbed from the environment depends on total convection coefficient, surface area of evaporator and temperature difference between the cooled environment and the evaporator. When surface area and total heat transfer coefficient remains constant, evaporation capacity changes by temperature difference. Generally, temperature difference between the cooled environment and evaporation temperature changes according to forced or naturally convection and it can be assumed as 10-15°C (Ozkol, 1997). On the other hand, increasing superheating of refrigerant at the evaporator outlet, decreases evaporator capacity. This is due to the big temperature difference between the evaporator surface and the environment temperature in dry gas flow area and also decreasing coefficient of heat convection. While other conditions are constant, and EEV opening increases, more refrigerant flows into the evaporator, superheat decreases, heat transfer gets better and evaporation temperature increases (see Fig. 2).

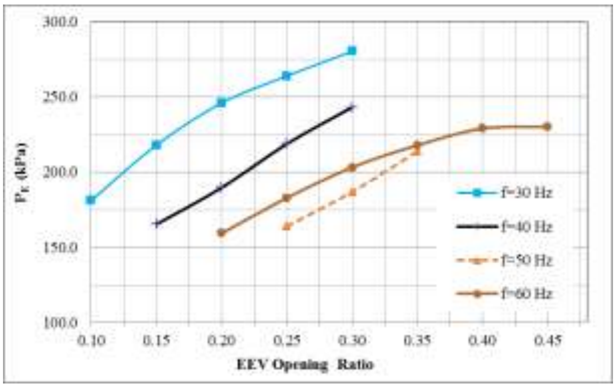

Figure 2. Variation of evaporation pressure with EEV opening

On the other hand, by increasing EEV opening increases evaporation pressure and temperature also more refrigerant takes place in the evaporator. As a result mass flow rate of refrigerant in the condenser and rate of subcooling decreases (see Fig. 3).

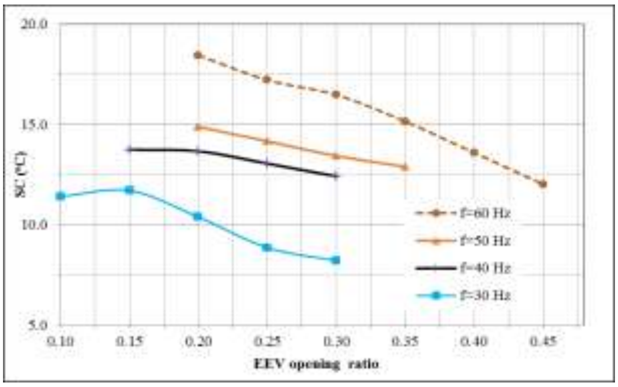

Figure 3. Variation of subcooling rate with EEV opening

Condensing temperature is another important parameter which changes by evaporation temperature. For the convenient condenser design, temperature difference between secondary fluid and condensing temperature can be considered approximately as 15°C (Ozkol, 1997). While evaporation temperature increases, condensing temperature also increases depending on cooling capacity (see Fig. 4).

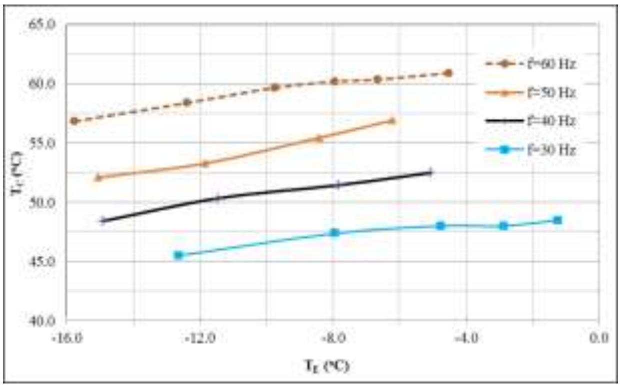

Figure 4. Variation of condensation temperature with evaporation temperature

The result of increasing evaporation temperature and pressure provides higher amount of refrigerant flows through the compressor and also cooling capacity increases (see Fig. 5). As seen in Fig. 5, at higher level of evaporation temperature, cooling capacity doesn't change any more. The reason of this is decreasing cooling capacity of unit refrigerant amount at higher condensation pressure.

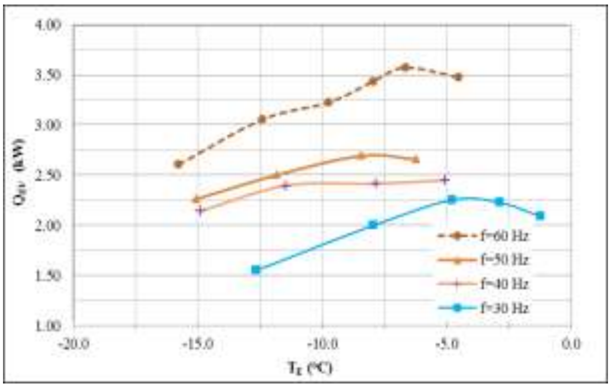

Figure 5. Variation of cooling capacity with evaporation temperature.

Furthermore, when evaporation temperature increases, COP also increases. Evaporation temperature versus COP graphic based on various compressor frequencies is given in Fig. 6. This figure shows that after a certain point of evaporation temperature COP decreases as similar cooling capacity change in previous figure.

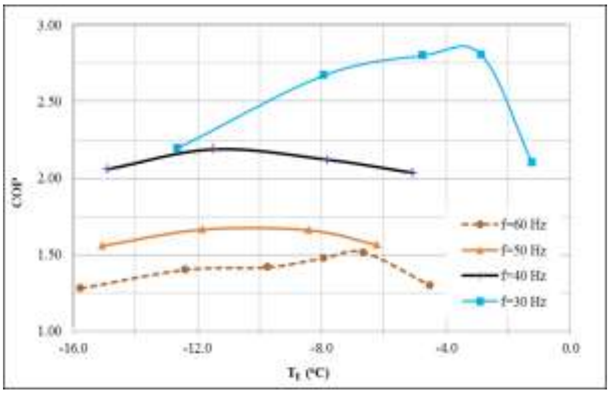

Figure 6. Variation of COP with evaporation temperature

Superheating

Preventing liquid suction into the compressor, EEV opening is adjusted to maintain 5-10°C of superheating amount at the outlet of the evaporator. When EEV opening increases, amount of refrigerant flow also increases in the evaporator. Under this condition, pressure and saturation temperature in the evaporator increases and temperature at the evaporator outlet decreases. Superheating is an important control parameter since it gives information about the evaporator's refrigerant demand in a variable speed refrigerant system. In the variable speed refrigerant systems, especially at partial loads to be able to provide a stable refrigerant flow EEV opening and superheating must be controlled. These values are inversely proportional (see Fig. 7).

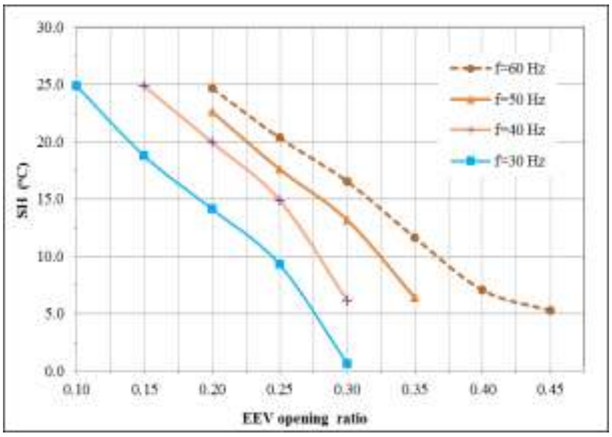

Figure 7. Variation of superheating rate with EEV opening

While EEV opening percentage is increasing, evaporating temperature also increases. On the other hand superheating is decreasing. At constant suction pressure, if superheat keeps on increasing specific volume also increases at the compressor inlet and for the same refrigerant process more refrigerant amount needs to be compressed. The Fig. 8 shows superheat versus cooling capacity.

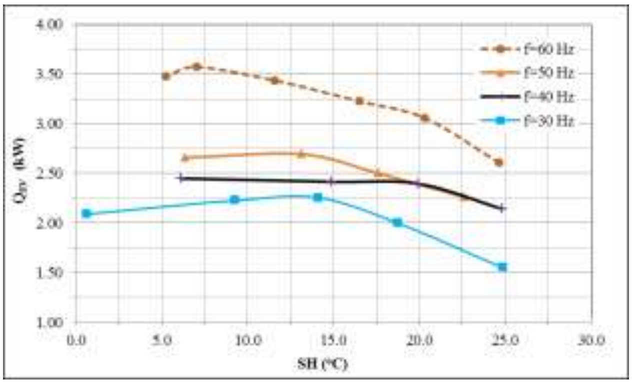

Figure 8. Cooling capacity with superheating

Heat Transfer Change

In a refrigeration system, there are two reasons for irregularity and unstable flow. Variability of heat transfer is the first reason and evaporator's feeding is the second reason.(Lazzarin and Noro, 2008). In an evaporator, heat transfer realizes by nucleus boiling unlike convective heat transfer and also heat transfer coefficient is larger than the single phase forced convection. With an increasing superheating rate, bigger portion of evaporator is filled by gas refrigerant and heat transfer coefficient decreases. Conversely, when EEV opening increases, flow rate of refrigerant and total heat transfer coefficient in the evaporator and the condenser increases. As seen in Fig. 9, when compressor frequency increases UA value also increases. Superheating value which is one of the important parameters in a refrigeration system is affected by heat transfer amount between secondary fluid and refrigerant. When EEV opening increases, refrigerant flow rate that is sent into the evaporator also increases. In the condenser and the evaporator, total heat transfer coefficient increases by increasing amount of refrigerant flow. While EEV opening percentage increases superheating decreases on the other hand total heat transfer capacity increases. As seen in the Fig. 9 when compressor frequency increases UA value also increases.

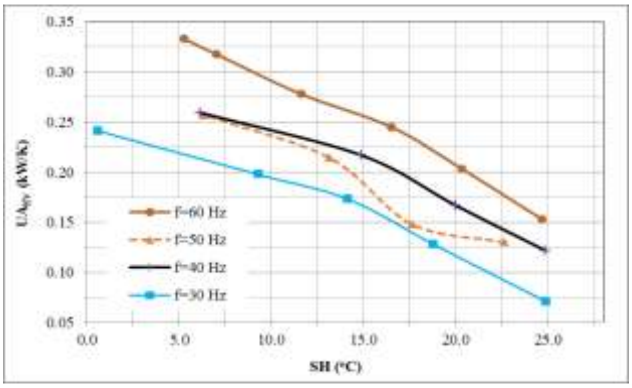

Figure 9. Variation of evaporator heat transfer coefficient with superheating rate

Refrigerant Mass Flow Rate

Changing of cooling capacity is proportional to amount of refrigerant flow. Variable speed systems also adjust their capacity modulation by adjusting amount of refrigerant flow in the cycle. The more refrigerant flow rate means the more cooling effect. EEV opening amount, subcooling, compressor frequency, and evaporation temperature changing affect amount of refrigerant flow in the cooling cycle directly. The increase of superheating rate in the system also increases refrigerant specific volume at the compressor suction. This result means that decrease in mass flow rate for the same suction volume (see Fig. 10).

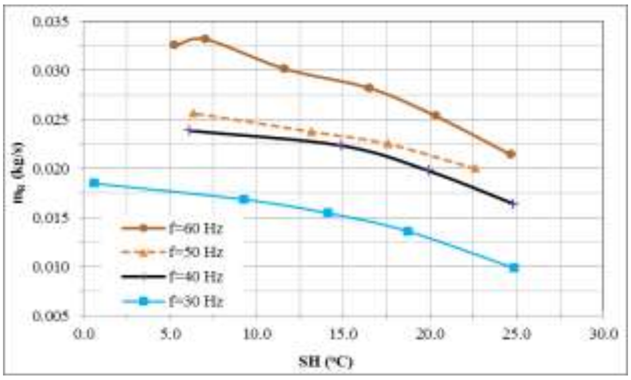

Figure 10. Variation of superheating rate with refrigerant mass flow rate

Effect of Compressor Speed

In this study, compressor speed is changed via compressor frequency in the range of 30 to 60 Hz. Fig.11 shows that cooling capacity and COP based on compressor frequency. With increasing of compressor frequency, condenser pressure increases and evaporation pressure decreases. Since capacity increasing is limited by decreasing evaporation pressure.

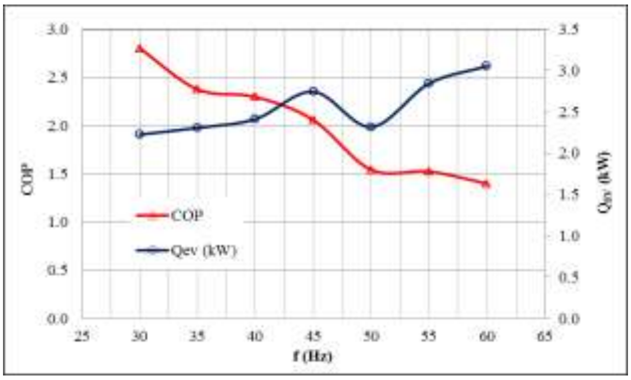

Figure 11. Variation of COP and cooling capacity with compressor frequency

In this study, by increasing compressor frequency from 30 Hz to 60 Hz, cooling capacity increases 37% and COP decreases to its half. However, by an enlarging of condenser and evaporator surface areas, it should be expected that cooling capacity much more increases with less decreasing in COP.

CONCLUSION

In this study, various parameters and their effects in a chiller is investigated. Among these parameters it is resulted that superheating changing affects various parameters in the system and it is strictly important to monitor this parameters. Superheating decreases when EEV opening amount increases and superheating increases when compressor frequency increases. The increase of superheating causes decreasing refrigerant density and flow rate at the compressor suction. In this study, by increasing compressor frequency from 30 Hz to 60 Hz, cooling capacity increases 37% and COP decreases to its half. However, by an enlarging of condenser and evaporator surface areas, it should be expected that cooling capacity much more increases with less decreasing in COP. As a result, it is important to consider various parameters that affect the system's performance while designing a cooling system. By considering system characteristics, an efficient system can be obtained even it works at variable environment.

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