Pengaruh Umpan Air Laut dan Suhu Udara terhadap Kinerja Unit Desalinasi Pompa Panas Dengan Humidifikasi dan Dehumidifikasi

by Tri Istanto

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The Effect of Feed Seawater and Air Temperatures on Performance of A Desalination Unit of Heat Pump With Humidification and Dehumidification

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Abstract

The use of heat pump could make the desalination unit structure compact and could be combined with the solar energy as renewable energy source make desalination cost less and protect environment. Desalination with humidification and dehumidification process was deemed as an efficient and promising means of utilizing the condenser and evaporator of heat pump to produce freshwater from seawater. This paper present a desalination unit driven by mechanical vapor compression pump, which it utilized the heat from condenser and the cold from evaporator of heat pump adequately, and reclaimed most latent heat. The air, firstly, was humidified in the humidifier and then was cooled in the evaporator to produce freshwater. The effects of the operation such as feed seawater and air temperatures on the performance of this unit were examined. In this research the effect of feed seawater temperature on the performance of this unit was examined at 28°C, 30°C, 45°C, and 60°C. The addition of electric air heater was used to vary the air temperature to the humidifier on this system. In this research the air temperature was varied at 35°C, 45°C, 55°C, and 65°C. The seawater volumetric flow rate was kept at 300 l/h, and seawater in this system was recirculated. The result of this research showed that the volume of fresh water production increase with increasing both of the inlet of the feed seawater temperature and the inlet air temperature to the humidifier on this desalination unit.

Keywords: Dehumidification, Desalination, Heat Pump, Humidification.

Nomenclature

A	*sectional area of duct*……………………….....m^2
COP	*coefficient of performance*
h_1	*refrigerant enthalpy at evaporator exit* .....kJ/kg
h_2	*refrigerant enthalpy at compressor exit, refrigerant enthalpy at humidifier exit*.......kJ/kg
h_{2a}	*refrigerant enthalpy at condenser inlet*.....kJ/kg
h_3	*refrigerant enthalpy at condenser exit,*
	refrigerant enthalpy at dehumidifier exit ...kJ/kg
$\dot{m}_a$	*mass flow rate of air*……………………...kg/s
$\dot{m}_{a1}$	*mass flow rate of air at humidifier inlet*.......kg/s
$\dot{m}_{a2}$	*mass flow rate of air at dehumidifier inlet*...kg/s
$\dot{m}_{ref}$	*mass flow rate of refrigerant*..……………..kg/s
m_w	*mass of freshwater*.......................................kg
W_{comp}	*compressor power*…………………………..W
Q_{ref}	*volumetric flow rate of refrigerant*………..m^3/s
Q_{cond}	*heat released by condenser*…………………..W
v	*air velocity*……………………………………..m/s
w_1	*humidity ratio of air at humidifier inlet*....kg/kg
w_2	*humidity ratio of air at humidifier exit*......kg/kg
w_3	*humidity ratio of air at dehumidifier exit*..kg/kg
ρ_a	*density of air*………………………………..kg/m^3
ρ_{ref}	*density of refrigerant*…………………….kg/m^3
ΔW_1	*the addition of the total mass of water vapor after the humidifier*………………………….kg/s
ΔW_2	*the addition of the total mass of water vapor after the dehumidifier*...............................kg/s
τ	*period*…………………………………….(h/day)

1. Introduction

The amount of fresh water resources is nearly constant since the start of life on earth. On the other hand, the world population has increased more rapidly over a period of less than 200 years. This is offset by an increase in water consumption in the world, which has doubled every 20 years exceeds two times the rate of population growth. At present, about 40% of the world's population is suffering from serious water shortages. By the year 2025, this percentage is expected to increase to more than 60% (El-Dessouky. H T. and Ettouney,H.M., 2002). This is because of the rapid increase of population, changes in the life-style, increased economic activities, and pollution that limit the use of fresh water resources. So the availability of fresh water will decrease. This fresh water shortages could threaten the livelihood of many people in the world, because water is one of the primary needs. Moreover, common use of unhealthy water in developing countries causes 80-90% of all diseases and 30% of all deaths (El-Dessouky. H T. and Ettouney,H.M., 2002). According to a recent report of the International Atomic Energy Agency (IAEA), estimated 1.1 billion people have no access to safe drinking water and more than 5 million die from water borne diseases each year (Fath, H.E.S., 2005). Mainly the rural population suffers from a shortage of drinking water. Especially in remote areas, the infrastructure for water and energy is poorly developed. Besides the lack of water, the content of total dissolved solids in the water that's available in these areas is often too high. Therefore it is not suitable for human consumption.

Water is one of the most abundant resources on earth, covering three fourths of the planet's surface. About 97% of the earth's water is saltwater in the oceans and 3% (about 36 million km^3) is freshwater contained in the poles (in the form of ice), ground water, lakes, and rivers, which supply most human and animal needs. Nearly 70% from this tiny 3% of the world's freshwater is frozen in glaciers, permanent snow cover, ice, and permafrost. Thirty percent of all freshwater is underground, most of it in deep, hard-to-reach aquifers (Kalogirou,S.A., 2005). Lakes and rivers together contain just a little more than 0.25% of all freshwater; lakes contain most of it. Of the total water consumption, about 70% is used by agriculture, 20% is used by the industry, and only 10% of the water consumed worldwide is used for household needs (Kalogirou,S.A., 2005). The only nearly inexhaustible sources of water are the oceans. Their main drawback, however, is their high salinity. Therefore, it would be attractive to tackle the water-shortage problem with desalination of this water. Desalinize in general means to remove salt from seawater or generally saline water. According to World Health Organization (WHO), the permissible limit of salinity in water is 500 parts per million (ppm) and for special cases up to 1000 ppm, while most of the water available on earth has salinity up to 10,000 ppm, and seawater normally has salinity in the range of 35,000– 45,000 ppm in the form of total dissolved salts (Tiwari,N.G., 2003). Excess brackishness causes the problem of taste, stomach problems and laxative effects. The purpose of a desalination system is to clean or purify brackish water or seawater and supply water with total dissolved solids within the permissible limit of 500 ppm or less.

Desalination can be achieved using a number of techniques. The desalination system that utilizes the "heat pump" is already applied prevalently, which is a concept of the energy utilization. The use of heat pump could make the desalination unit structure compact and the solar energy as renewable energy source make desalination cost less and protect environment. By virtue of using the heat pump and solar energy, the system in this work can reduce operating costs and its maintenance is simple and convenient. Desalination with humidification and dehumidification process is deemed as an efficient and promising means of utilizing the condenser and evaporator of heat pump to produce freshwater from seawater. Humidification and dehumidification desalination process is viewed as a promising technique for small capacity production plants (Ettouney, H.,2005). The process has several attractive features, which includes operation at low temperature, ability to combine with sustainable energy sources, i.e., solar, geothermal, and requirements of low level of technical features. Performance of the desalination unit of heat pump with humidification and dehumidifikasi to enhance production of freshwater depends on the temperature of seawater input to the humidifier, the air temperature inside the duct, the mass flow of seawater, air mass flow rate, solar radiation intensity, and type of solar collector.

Dai,Y.J., (2000) studied solar desalination with humidification and dehumidification, where it was found that the performance of the system was strongly dependent on the temperature of inlet salt water to the humidifier, the mass flow rate of salt water, and the mass flow rate of the process air. Slesarenko (2001) studied the using state of heat pump in desalination plants. Orfi,J., (2004) studied a water desalination system by solar energy using the humidification-dehumidification principle. Hawlader, M.N.A., (2004) analyzed the performance of a novel solar-assisted system by heat pump and obtained good water production. A theoretical and experimental investigation of humidification–dehumidification desalination system is studied by Yamali (2008) and Amer,E.H., (2009). Penghui Gao (2008) analyzed the performance of a new type desalination unit of heat pump with humidification and dehumidification, and presented a mathematical model of the unit.

2. Methodology

The system is diagrammatically shown in Fig. 1. It consisted of three parts. One part is air heater; the other is humidification–dehumidification portion including alveolate humidifier, and the dehumidifier (evaporator); and another part is heat pump component which comprises compressor, condenser, expansion valve, and evaporator. In the system, the air is heated through the electric air heater, and then humidified in the alveolate humidifier which is driven by the fan. Subsequently the humid air is cooled when passing through the dehumidifier/evaporator, and the freshwater is obtained. The feed seawater is sprayed by sprinkler into the alveolate humidifier to humidify air and the remains of seawater is recirculated. The condenser gives out quantity of heat to the air. The direction of air flow, refrigerant flow, and seawater flow are shown in Fig. 1. The effects of feed seawater and air temperatures on the performance of this unit were examined. In this research the effect of feed seawater temperature on the performance of this unit was examined at 28°C, 30°C, 45°C and 60°C.

The electric air heater was used to vary the air temperature to the humidifier on this system. In this research the air temperature was varied at 35ºC, 45ºC, 55ºC, and 65ºC.

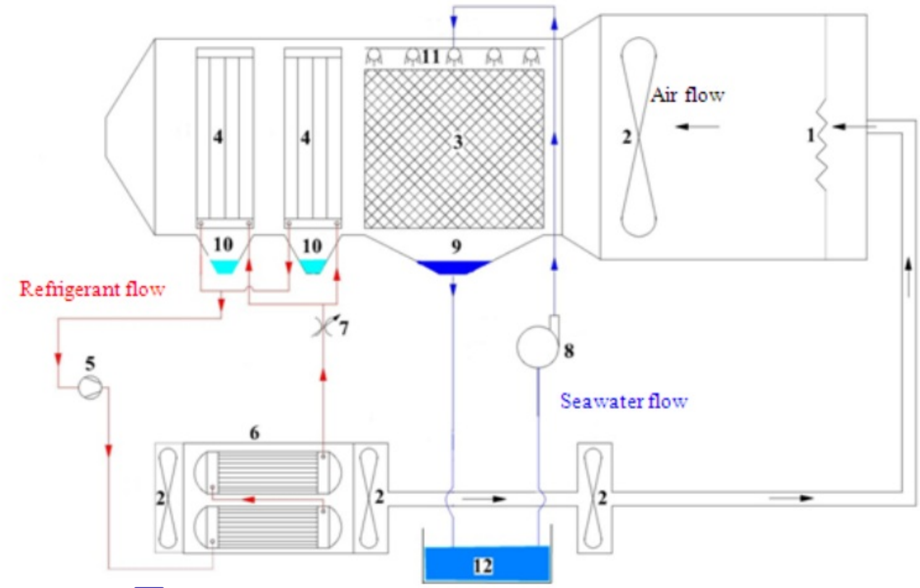

Figure 1. Schematic sketch of desalination system. 1.air heater; 2. fan; 3. alveolate humidifier; 4. dehumidifier/evaporator; 5. compressor ; 6. condenser; 7. expansion valve; 8. centrifugal pump; 9. brine drainer; 10. freshwater box; 11. sprinkler; 12. brine box.

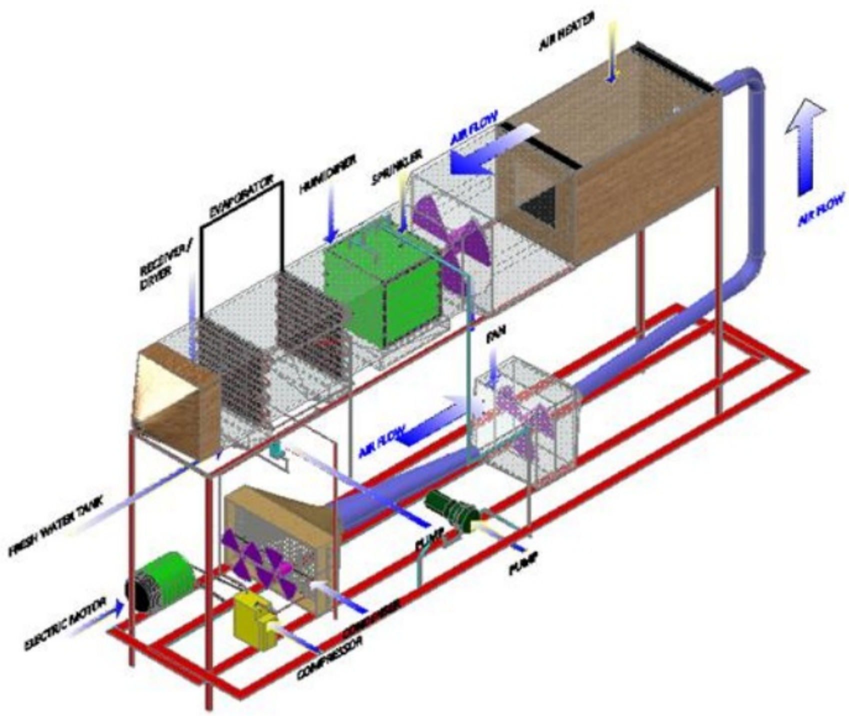

Figure 2. Schematic diagram of the experimental rig

The related parameters of the desalination unit are as follow. Refrigerants used in heat pump systems is HFC 134-a, with the type of compressor used is a 2-cylinder reciprocating compressor. Condenser used 2 pieces with dimensions 58 cm x 36 cm x 1.5 cm for each condenser. Evaporator used 2 pieces mounted in parallel. The alveolate humidifier used is made of aluminum with dimensions of 30 cm x 37 cm x 35 cm. Sprinkler used 5 pieces mounted on the humidifier. Thermocouples used in this study were T-type thermocouples with a diameter of 0.1 mm. Flowmeter used is flowmeter Dwyer VA20440-type. Seawater used in this study had a salinity of 31,342 ppm.

The equation for calculating the standard heat pump COP :

$$COP_{HP,standard} = \frac{Q_{cond}}{W_{comp}} = \frac{\dot{m}_{ref}.(h_2 - h_3)}{\dot{m}_{ref}.(h_2 - h_1)} \quad (1)$$

The actual heat pump COP can be calculated by the following equation :

$$COP_{HP,actual} = \frac{Q_{cond}}{W_{comp}} = \frac{\dot{m}_{ref}.(h_{2a} - h_3)}{\dot{m}_{ref}.(h_{2a} - h_1)} \quad (2)$$

The refrigerant mass flow rate can be calculated by the following equation :

$$\dot{m}_{ref} = \rho_{ref}.Q_{ref} \quad (3)$$

The amount of heat released by the condenser is calculated by the following equation :

$$Q_{cond} = \dot{m}_{ref}.(h_{2a} - h_3) \quad (4)$$

Air mass flow rate in duct is calculated by the following equation :

$$\dot{m}_a = \rho_a.V_a.A \quad (5)$$

The addition of the total mass of water vapor after the humidifier is calculated by the following equation :

$$\Delta W_1 = \dot{m}_{a1}\,(w_2 - w_1) \quad (6)$$

The addition of the total mass of water vapor after the dehumidifier is calculated by the following equation :

$$\Delta W_2 = \dot{m}_{a2}\,(w_2 - w_3) \quad (7)$$

Mass of freshwater produced during the process (theoretically result) can be calculated by the following equation

$$m_w = \int_0^{\tau} \dot{m}_a\,(w_i - w_o)\,dt \quad (8)$$

In the study of effect of air temperature on the production of freshwater, feed seawater temperature is kept at a constant temperature of 35°C, the compressor operated at a constant rotation of 1,200 rpm, the volumetric flow rate of seawater constant at 300 l/h , and seawater in the this system recirculated. While on the study of effect of feed seawater temperature on the production of freshwater, the temperature is kept at a constant temperature of 30°C, compressor speed, the volumetric flow rate of seawater, and seawater circulation in the system is the same as testing the effect of air temperature. Data taken in this test is the pressures and temperature on heat pumps, pressure and temperature (dry and wet bulb temperatures) in the duct, and the capacity of freshwater produced. Desalination system is run for 180 minutes at each test variation and retrieval of data every 20 minutes.

3. Results and Discussion

a. Effect of air temperature on freshwater production

Figure 3 shows the accumulation of fresh water production over time with variations in air temperature. From Fig. 3 can be seen that the production of fresh water increases with time and air temperature. This is because the higher the air temperature then the ability to absorb water vapor is also higher. This is shown in Fig. 4, where the higher air temperatures, so the addition of the total water mass in the air after passing through the humidifier also higher. This is because air at higher temperatures have a lower relative humidity than the air at low temperatures, so the ability to absorb water vapor is become higher. The average volume of fresh water produced every 20 minutes was 200 ml , 240 ml , 280 ml and 300 ml for the air temperature 35°C, 45°C, 55°C, and 65°C, respectively. The volume of freshwater that resulted every 20 minutes for each variation of air temperature is relatively equal. This happens because the air temperature, volumetric flow rate of seawater, seawater temperature and air velocity entering into the system during the time of testing for each variation is relatively equal. Production of fresh water produced on testing for 180 minutes as follows : 1,189 ml, 2,180 ml, 2,550 ml and 2,900 ml for the air temperature 35°C, 45°C, 55°C, and 60°C, respectively

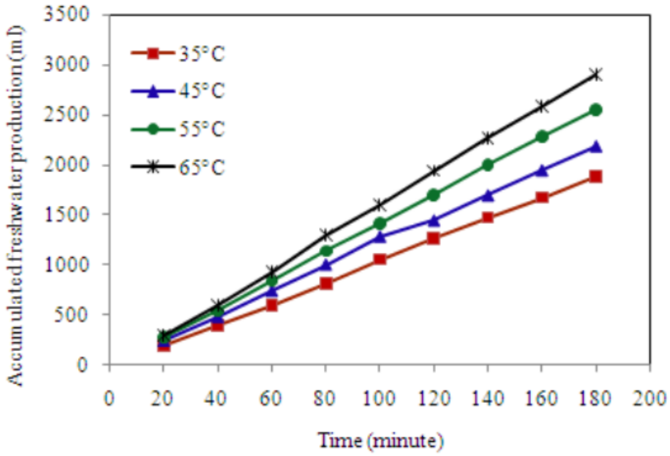

Figure 3. Effect of air temperature on freshwater production

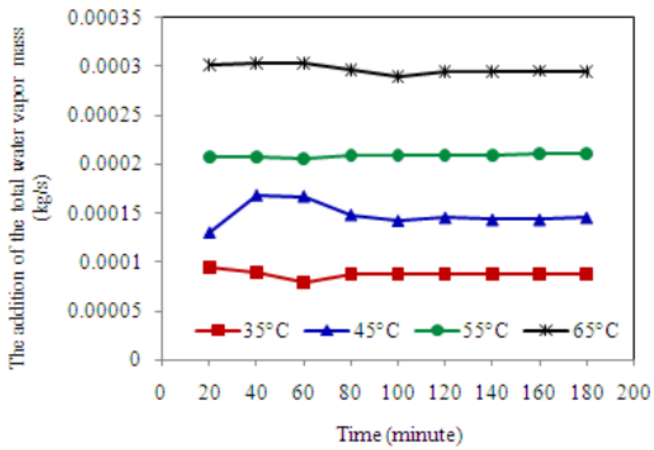

Figure 4. Effect of air temperature on the addition of the total water vapor mass in air

b. Effect of air temperature on COP of heat pump

Figure 5 shows the relationship between the actual heat pump COP with the air temperature. From Fig. 5 can be seen the value of the actual heat pump COP decreases with increasing air temperature. The values of the actual heat pump COP ranged from 5.99 to 6.67. The highest COP of heat pump occurs at air temperatures of 35°C. This is because at the air temperature 35°C, heat pump system has the lowest cooling load compared to other air temperature. Cooling load of heat pump system will increase with increase in air temperature entering into the system. COP of heat pump at certain air temperatures are relatively similar with respect to time. This is because the cooling load of heat pump relatively similar during operated at the certain constant air temperature.

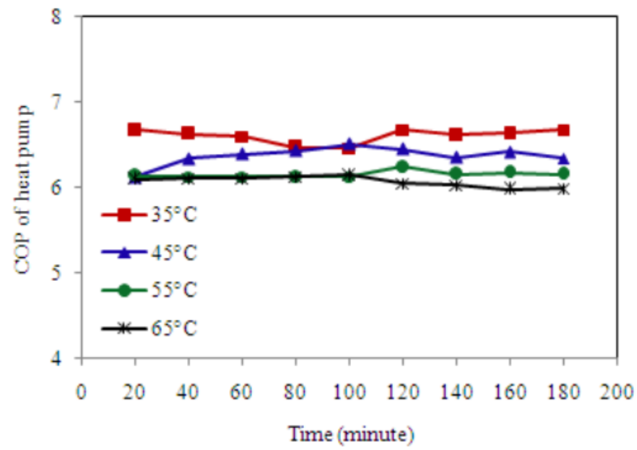

Figure 5. Effect of air temperature on COP of heat pump

c. Effect of feed seawater temperature on freshwater production

Figure 6 shows the accumulation of freshwater production over time with variations in feed seawater temperature. From Fig. 6 can be seen that the amount of freshwater produced increased with time and feed seawater temperature. This is because the humidity ratio of seawater from temperature of 28°C up to 60°C increased after going through the process of humidification in the humidifier, so that the water vapor content of air-borne to the process of condensation increases. With the increase in humidity ratio, then the addition of the total mass of water vapor increases, as shown in Fig. 7, where the condensation result into fresh water will increase. Production of fresh water produced on testing for 180 minutes as follows : 1,120 ml, 1,350 ml, 3,540 ml, and 4,820 ml for the feed seawater temperature 28°C, 30°C, 45°C, and 60°C, respectively

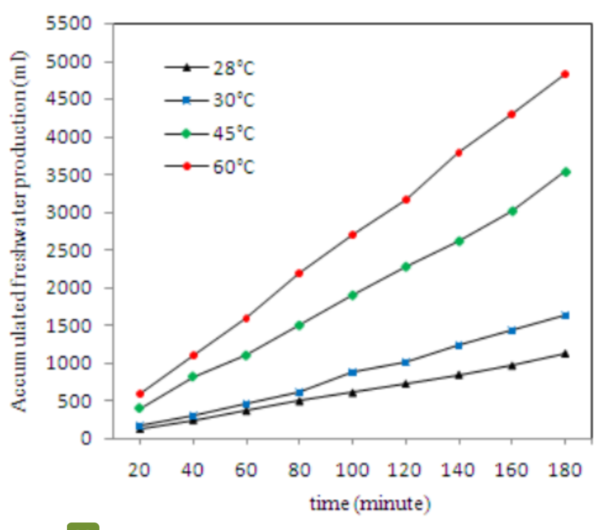

Figure 6. Effect of feed seawater temperature on freshwater production

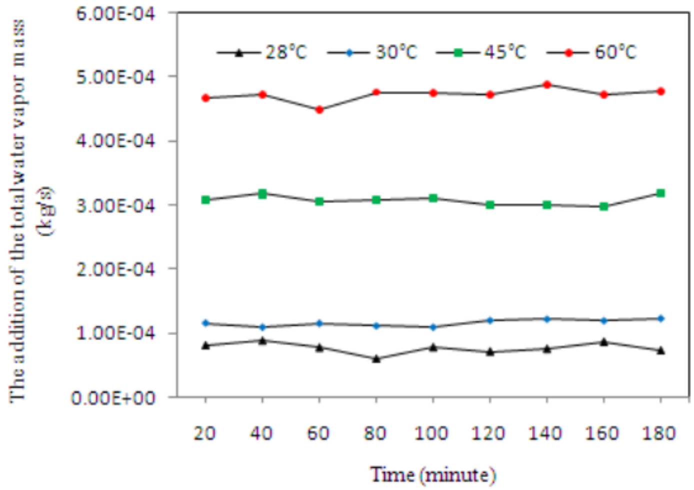

Figure 7 . Effect of feed seawater temperature on the addition of the total water vapor mass in air

d. Effect of feed seawater temperature on COP of heat pump

Figure 8 shows the relationship between the actual heat pump COP with variations in feed seawater temperature. From Fig. 8 can be seen the value of the actual heat pump COP decreases with increasing feed seawater temperature. This happens because the higher feed seawater temperature entering the desalination unit, the higher the compressor work, where COP is inversely proportional to the compressor work. The values of the actual heat pump COP ranged from 4.77 to 5.50.

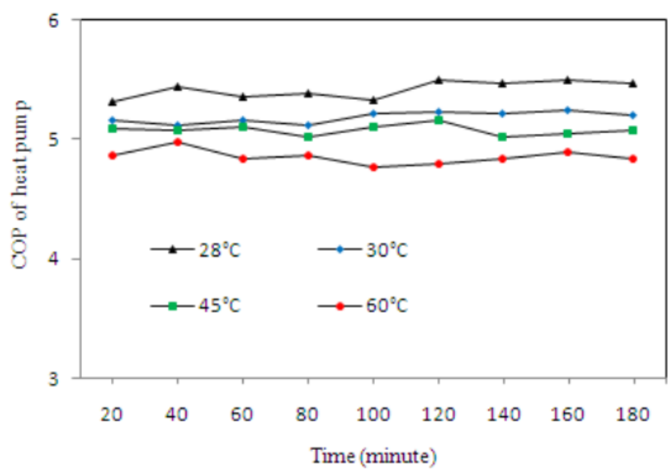

Figure 8. Effect of feed seawater temperature on COP of heat pump

Fresh water that produced from this desalination process has a salinity 715 ppm. This means that fresh water produced from desalination process is in compliance with water standards that can be used for drinking , household needs (cooking, washing, gardening, etc.) and some industrial purposes (El-Dessouky. H T. and Ettouney,H.M., 2002).

4. Conclusions

The results of this study indicate that the air temperature and feed seawater temperature entering to humidifier have the apparent effect on the freshwater yield of the desalination system. The volume of fresh water production increase with increasing both of the feed seawater temperature and the air temperature entering to the humidifier on this desalination unit. COP of heat pump decrease with increasing both of the feed seawater temperature and the air temperature entering to the humidifier on this desalination unit.

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