The investigation of mass flow rate and inlet fluid temperature effect on the boosted heat pump performance

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Abstract

The aim of this research is to study the mass flow rate and inlet water temperature effect of hot water that fed to evaporator section of the boosted heat pump comparing the case study of using air source. Both heat pumps were test under the hot water temperature condition of 35-65 $^{\circ}$C that produced hot water of 100 liter storage tank. For methodology, the boosted heat pump was adapted with the water box installed at the evaporator section and the variation of hot water temperature was controlled by the electric heater and then fed the hot water into the evaporator section at the mass flow rate of 1 kg/min, 2 kg/min, and 3 kg/min under the inlet temperature variation of 35 $^{\circ}$C, 40 $^{\circ}$C, 45 $^{\circ}$C, 50 $^{\circ}$C, 55 $^{\circ}$C, 60 $^{\circ}$C, and 65 $^{\circ}$C, respectively. While the conventional heat pump, the fan blown the ambient air into evaporator section. The coefficient of performance (COP) of both heat pumps were calculated and it was found COP of the boosted heat pump was higher than the conventional heat pump at every the mass flow rate, moreover, COP would be decreased when the water temperature in storage tank increased because the power of heat pump increased. The suitable of mass flow rate was clearly at 2 kg/min and the hot water temperature that fed to the evaporation section of boosted heat pump was equal to 45 $^{\circ}$C. COP of boosted heat pump could be raise the highest value of 3.69 while COP of conventional heat pump was equal to 2.51.

Keywords: *Boosted heat pump, Hot water mass flow rate, Cofficient of Performance (COP).*

1. Introduction

Currently, the demand of hot water using in residence home, hotels, hospitals and various industrial sectors is growing. The conventional hot water production is commonly used the electric heater because its investment is cheap and easy installation. However, the disadvantage of electric hot water heater is mainly to use a high power consumption about 3.5-4.5 kW, which is a huge waste of energy. Heat pump is an alternative method for hot water production instead of electric heater using that uses an electricity less than electric heater about 3-4 times (Techato, 2012). The coefficient of performance (COP) the heat pump is approximately 3.00. Heat pump can classify of four types such as Ground Source Heat Pumps (GSHPs), Air Source Heat Pumps (ASHPs), Solar Assisted HPs (SAHP) and Gas-Engine Driven Heat Pumps (GEHPs). The heat resource for evaporator of each type is different for example; ground source, ambient air, solar heat source, and gas source while the condenser of all type is the hot water storage tank (Hepbasli & Kalinci, 2009). The efficient improvement of heat pump systems, together with the their cost reduction, has led to publish not only use in air-conditioning , but also widely uses in other applications such as drying or hot water production (Daghigh, Ruslan, Sulaiman, Sopian et al, 2010). During the whole heating process, it noted that the condensation temperature of heat pump unit varied with the change of water temperature in the water tank load (Shiyu et al, 2007). Heat pump performance is studied in many case studies. (Morrison, Anderson, Behnia, 2004) studied Seasonal performance rating of heat pump water heaters in Sydney, Australia. The results found that the coefficient of performance (COP) was 2.3 for a heat pump system in a laboratory situation with an integral condenser and COP of 1.8 for systems with an external condenser. (Pramote, 1999) studied the hot water system of vapor compression heat pump, which the system had the highest COP value about 4.0-4.2 and was able to produce the hot water with a maximum temperature of 41.7 °C at the mass flow rate of 3 kg/min. (Huang & Lin, 1997) studied the hot water heater production by using a small heat pump that used R22 as a working fluid and 100 liters of hot water tank. The hot water temperature was up to 54 °C, which COP was in the range of 2.0-3.0. (Wang et al, 2017) studied the coefficient of performance (COP) of air source heat pump by using R22 as a working fluid. The hot water

of 300 liters was produced from 30-54.2 °C under the variation of ambient air temperature at -7 °C, 2 °C, 7 °C, 20 °C, and 30 °C, respectively. The experimental results investigated that when the water temperature increased, the power consumption would be increased of 56 %, 48 %, 42 %, 39%, and 34% respectively and the COP decreased 43 %, 48 %, 51 %, 64 %, 48 %, respectively.

From the previous research, that shows heat pump systems can work with solar heat from solar hot water production. Anyway, the effect mass flow rate is lack therefore in this study need to investigate the effect from the hot water mass flow rate in evaporator section of the boosted heat pump comparing with the conventional heat pump (an air source heat pump type) by using R22 as a working fluid. The both heat pumps was test under the condition of hot water temperature in the 100 liters storage tank from 35 °C to 65 °C, By changing the flow rate of 3 values under the inlet temperature condition evaporator of 35 °C, 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, and 65 °C, respectively.

2. Objectives

To study the effect of hot water mass flow rate and inlet water temperature on boosted heat pump performance.

3. Materials and Methods

3.1 Boosted heat pump concept

The boosted heat pump has the similar equipment like a conventional heat pump. The equipment consists of compressor, condenser, expansion valve and evaporator. But inside the evaporator section will feed the hot water instead of air. The boosted heat pump working principle is shown in Figure 1. At the evaporator section, the refrigerant R22 (a working fluid) absorbs heat from the hot water and change from fluid to vapor, then the refrigerant vapor will flow to the compressor and is pressed up to high temperature and pressure before high pressure vapor transfers to condenser section. At this section, the high pressure vapor is reduced temperature so the vapor reforms to liquid and flows to the expansion valve. When the refrigerant liquid passes through the expansion valve, the pressure is reduced and the state of refrigerant is a mixture between liquid and vapor and then be continue to receive heat at the evaporator, (Pramote, 1999).
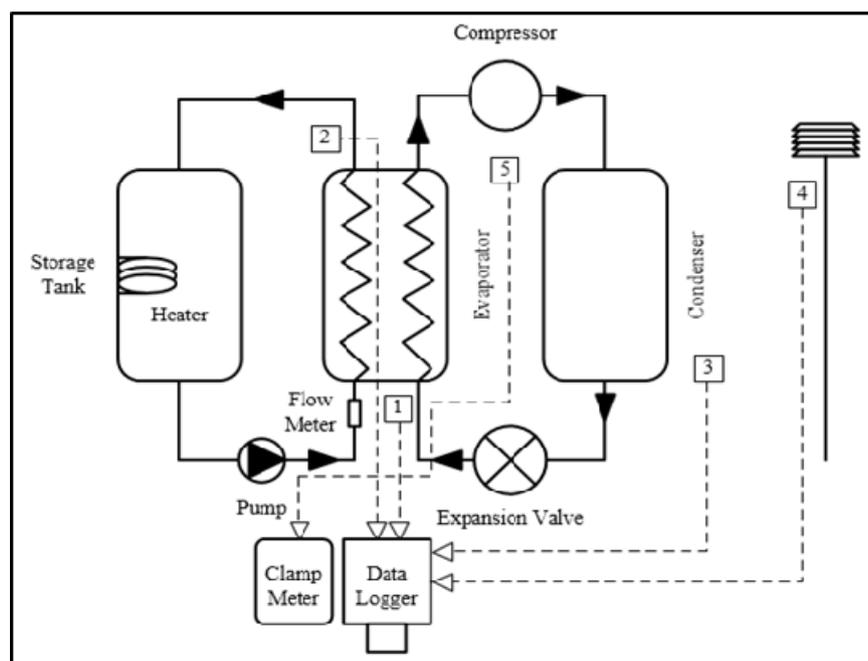

Figure 1 Boosted heat pump working principle

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3.2 Experiment Method

In Figure 2(a) shows the boosted heat pump experiment setting. The boosted heat pump by using R22 as a working fluid was adapted with the water box that installed at the evaporator section as shown in Figure 2(b). The flow rate variation of hot water temperature was controlled by the electric heater and fed the hot water into the evaporator section at the mass flow rate of 1 kg/min, 2 kg/min, and 3 kg/min under the inlet temperature condition of 35 °C, 40 °C, 45 °C, 50 °C, 55 °C, 60 °C, and 65 °C, respectively. Hot water would be supplied to the evaporator using water pump Green-03 DC 12 V. The experiment consisted of two cases; using hot water in evaporator and using air source (a conventional heat pump).

| (a) Boosted heat pump | (b) The water box that installed at the evaporator section |

For data collection, thermocouples type K were used to measure temperature in various points as shown in Figure 1, namely point 1 the inlet water temperature to evaporator, point 2 the outlet water temperature to evaporator, point 3 the temperature of hot water in a condenser tank, point 4 the ambient temperature. All of measured temperature were recorded in the multi-channel data logger (Model; Lutron TM-1947SD). For the compressor power of heat pump (point 5) was used clamp meter (Model; Mastech MS2203). The mass flow rate of hot water was measured by flow meter (Model; Treaton Z-4001). After that, the test was conducted to collect data every 5 minutes for coefficient performance (COP) that can be calculated following equation (1) and equation (2).

Coefficient of performance (COP) of heat pump can be calculated from the useful heat from the condenser divided by the power input the compressor.

$$COP_{Heatpump} = \frac{Q_{Cond}}{W_{Comp}} \qquad (1)$$

Where $COP_{Heatpump}$ is coefficient of performance of heat pump. Q_{Cond} is useful heat from the condenser. W_{Comp} is power consumption of compressor.

The heat removal from condenser, can be calculated from the equation (2)

$$Q_{Cond} = \frac{M_S C_P \left(T_S^{t+\Delta t} - T_S\right)}{\Delta t} \qquad (2)$$

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Where M_S is the amount of water in the hot water tank (kg). C_P is specific heat capacity of water (J/kg·K). $T_S^{t+\Delta t}$ is the water temperature in the hot water tank when the time is changing (°C). T_S is the water temperature in the hot water storage tank (°C) and Δt is time (s).

4. Results and Discussion
4.1 Compresser Power
Figure 3, shows the changing compressor power at various mass flow rate and various hot water temperatures condition that supplied to the evaporator section. At the mass flow rate of 1 kg/min, 2 kg/min and 3 kg/min, the compressor power of boosted heat pump in each average period was in the range of 0.251 - 0.404 kW_e, 0.235 - 0.379 kW_e and 0.238 - 0.399 kW_e, respectively. While the compressor of conventional heat pump that used air source in evaporator section use the power approximately 0.297 - 0.462 kW_e.
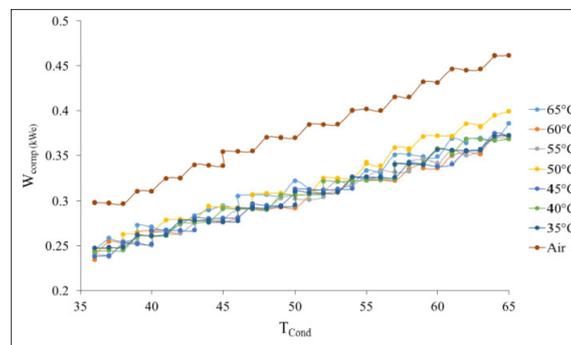
(a) At mass flow rate of 1 kg/min
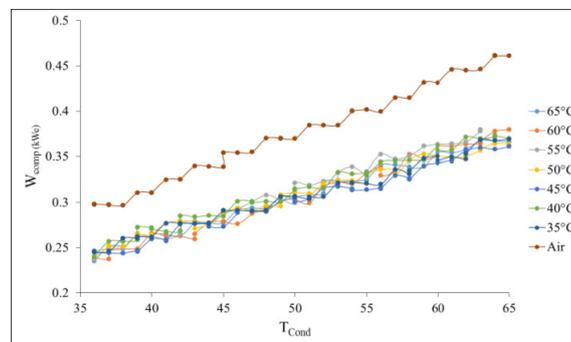
(b) At mass flow rate of 2 kg/min
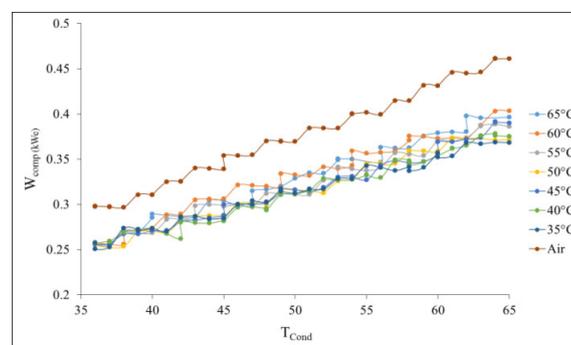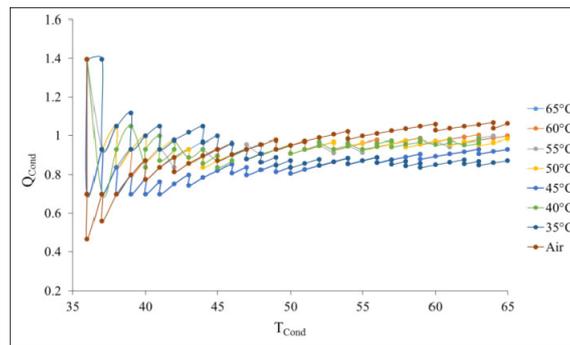

(c) At mass flow rate of 3 kg/min

Figure 3 The variation of compressor power at various mass flow rate
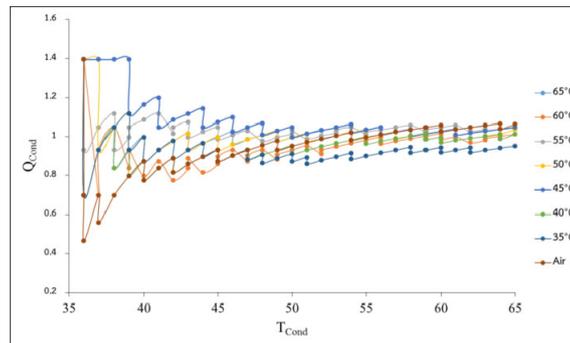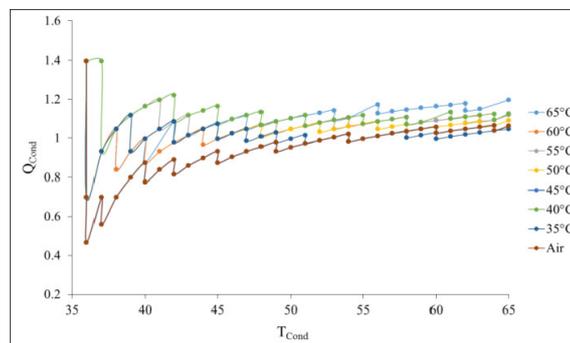
3.2 The useful heat form condenser

From the Figure 4 shows the variation of useful heat from the condenser (Q_{Cond}) of the heat pump that used the hot water boosted inside evaporator section of heat pump at various mass flow rate of 1 kg/min, 2 kg/min and 3 kg/min, respectively. It was found that the heat pump compressor would use more electric power, and made the useful heat from condenser decreased. The useful heat from the condenser in each mass flow rate was in the range of 0.558 – 1.396 kW, 0.698 - 1.396 kW and 0.698 - 1.196 kW, respectively. While the compressor of conventional heat pump that used air source in evaporator section consumed the electric power in the range of 0.465 – 1.396 kW.

(a) At mass flow rate of 1 kg/min
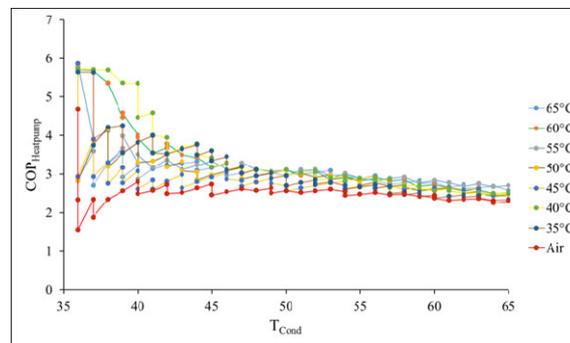
(b) At mass flow rate of 2 kg/min

(c) At mass flow rate of 3 kg/min

Figure 4 The variation of useful heat from condenser at various mass flow rate

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3.3 Cofficient of performance (COP)

Figure 5 shows the coefficient of performance a heat pumps. COP of the boosted heat pump obtained in the range of 2.85-3.36. The optimum hot water temperature at the flow rate of 1 kg/min was at 40 °C, which could raise the highest coefficient of performance (COP) of 3.36. For the coefficient of performance (COP) of the conventional heat pump (air source type) was equal to 2.51. For the mass flow rate of 2 kg/min, COP was higher than the results of mass flow rate 1 kg/min with a value between 2.95-3.69. The optimum hot water temperature at the flow rate of 2 kg/min was 45 °C, while the coefficient of performance (COP) of the conventional heat pump was equal to 2.51. Finally, at the mass flow rate of 3 kg/min. The coefficient of performance (COP) was in the range of 2.97-3.63 while the coefficient of performance (COP) of the conventional heat pump was equal to 2.51. From the experiments, could increase higher than with the conventional heat pump (an air source heat pump type) the coefficient of performance (COP) of the boosted heat pump a value between 2.97 to 3.63.

(a) At mass flow rate of 1 kg/min
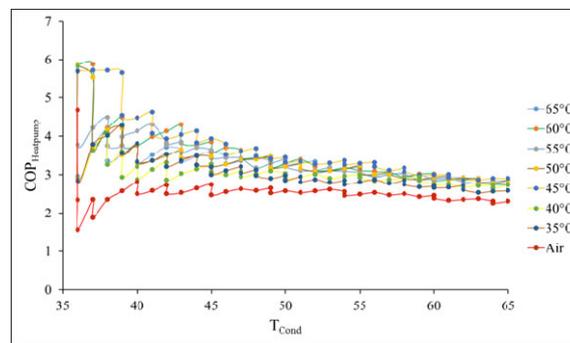
(b) At mass flow rate of 2 kg/min
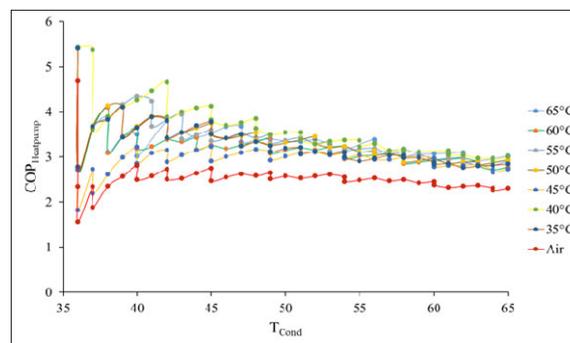
(c) At mass flow rate of 3 kg/min
Figure 5 Coefficient of performance (COP) of heat pump at various mass flow rate

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3.4 Experimental summary

From Table 1. shows the summarize of the coefficient of performance (COP) of boosted heat pump and it was found the coefficient of performance (COP) of the boosted heat pump could increase higher than the conventional heat pump at every mass flow rate. Moreover, the coefficient of performance (COP) would be decreased when the water temperature in the storage tank increased because the power using of the heat pump was increased. The optimum mass flow rate was clear that at 2 kg/min provided the highest COP of 3.69 and the suitable hot water temperature that supplied to the evaporation section was equal to 45 °C.

Table 1 Coefficient of performance of boosted heat pump

Boundary	Coefficient of Performance (COP)						
	35 °C	40 °C	45 °C	50 °C	55 °C	60 °C	65 °C
1 kg/min	3.11	3.36	2.85	3.04	3.24	3.16	3.05
2 kg/min	3.10	3.07	3.69	3.36	2.95	3.51	3.31
3 kg/min	3.29	3.63	2.97	3.36	3.40	3.21	3.35

5. Conclusion

This research studied the effect study of hot water mass flow rate and inlet water temperature on boosted heat pump performance comparing with the conventional heat pump. The results showed that COP of the boosted heat pump was higher than the conventional heat pump at every mass flow rate, moreover, COP would be decreased when the water temperature in storage tank increased because the power consumption of heat pump increased. The suitable of mass flow rate was clearly at 2 kg/min and the hot water temperature that fed to the evaporation section of boosted heat pump was equal to 45 °C. The boosted heat pump could be reached the highest COP of 3.69 while COP of conventional heat pump was equal to 2.51.

6. References

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