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COMBINATION OF ELECTRIC AIR HEATER AND REFRIGERATION SYSTEM TO REDUCE ENERGY CONSUMPTION: A SIMULATION OF THERMODYNAMIC SYSTEM

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ABSTRACT

This study is about the analysis of thermodynamic system of a refrigeration system with two condensers coupled in series to the electric air heater system. The condenser produces waste heat reaches 90^{o}C and the heat is accumulated into a space heater up to 140^{o}C. That means: the heater works only up to 50^{o}C, so the temperature of the air is high and dry, but has a very low RCES (Ratio of Specific Energy Consumption) in dew point 20^{o}C, which is indicate that the system is very significant.

Keywords: Electric air heater; Energy consumption; Refrigeration system; Simulation of thermodynamic system

1. INTRODUCTION

The cooling technique began to develop scientifically since 17th century, starting from research conducted by Robert Boyle (1627-1691) in the UK, further studies in the field of refrigeration techniques has been done, when French scientist Sadi Carnot (1796-1832) published Second Law of Thermodynamics in 1824. Similarly, the spray dryer technique, since it was introduced in 1870 (Sollohub & Cal, 2010), is one tool that is used as a dryer for a wide range of processed food products (Salunkhe & Kadam, 1998), pharmaceuticals (Broadhead et al., 1992) and non-food materials in the form of small particles (Masters, 1991).

The testing parameters associated with thermodynamics and dryers, especially spray dryers has been done, including;

1. The inlet drying temperature, for example in the inlet drying temperature is high which is about 159.52°C (Cheow & Hadinoto, 2010; Erenturk et al., 2005; Langrish & Fletcher, 2001; Liu et al., 2010; Masters, 1991; Schuck, 2002; Tee et al., 2012), the low inlet air temperature (Medina-Torres et al., 2013) and sensitive material damage to heat due to high temperature (Rattes & Oliveira, 2007; Fang & Bhandari, 2012).
2. Feed flow rate; feed flow rate of 10.5 ml/min (Masters, 1991; Langrish & Fletcher, 2001; Tee et al., 2012).
3. The ambient air temperature was about 20−25°C and relative humidity of 35−45% (Chegini & Ghobadian, 2005).
4. Concentrated feed is obtained 20−35°C (Chegini & Ghobadian, 2005).
5. The speed of atomization (Kalil & Sial, 1974; Masters, 1991; Desobry et al., 1997;

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Cai & Corke, 2000; Al-Asheh et al., 2003; Abadio et al., 2004; Goula & Adamopoulos, 2005).

6. The operational velocity and the inlet air pressure and outlet temperature (King et al., 1984).

The drying process of a material occurs through two processes, namely the heating process and the drying process. The drying is done to reduce the amount of hot water by mechanical conditions of temperature, RH and air flow control, without damaging the structure of the product (Brennan, 2006). Hot air is an important factor for determining the efficiency of the spray dryer. In the spray dryer, drying air flow through the electric water heater into the drying chamber.

In this research, the process of heating using electric air heater, and the heat added by the refrigerating effect of the two condenser coupled in series in a thermodynamic simulation. In this refrigeration system, the evaporator acts as a dehumidifier and the condenser acts as a heat pump. The previous experimentation which was using two parallel condensers from the refrigeration system that combined the performance of a spray dryer (Kosasih, 2014), was able to reduce the use of energy / specific energy consumed of overall system (system combination spray dryer with refrigeration) by 39%, compared with a spray dryer system without refrigeration, the air temperature out of the evaporator at 10°C and the air flow rate of 450 liter.minute^{-1}, the system only requires the energy consumption of 1.37 Joule.liter^{-1}, which is much smaller than without the use of refrigeration systems, that is of 3.52 Joule.liter^{-1} (Kosasih, 2014). With a dehumidifier, specific humidity of the air is lower and makes better drying capacity, which air with low specific humidity moisture is able to take over much of the material in the drying process.

Simulations with condenser series made to cover up the weakness to control the rate of heat flow from the condenser parallel. Simulations carried out without the use of the substance/ material to be dried, only to supply heat at the heater only.

2. SIMULATION SETUP

2.1. Method

Air refrigeration system in this study consists of a hermetic compressor, two condensers, expansion valve, evaporator and blower. Basically the refrigeration system is a heat pump system, where heat/thermal energy is transferred, so get the effect of heating by the condenser unit. The refrigeration system also obtains a cooling effect (dehumidification) by the evaporator unit. The use of two condenser refrigeration system is coupled in series, can be seen as in Figure 1, heat energy from the first condensation process will help the performance of the electric heater to reach the heating temperature control air conditioning system, so that work can be minimized in the heater. However, if the excess heat in the air, then a second condenser cooling fan will throw heat into the environment. Thermal energy in the form of heat is absorbed by the refrigerant in the evaporator ambient air, the temperature and pressure conditions enthalpy evaporation will increase, so that the liquid phase of refrigerant is transformed into steam / gas with constant pressure (isobars). Furthermore, the refrigerant vapor is pressed by the compressor, so the temperature and pressure rise to pressure and condensing temperature in the condenser. At the end of the compression process, refrigerant vapor can achieve superheated steam (superheat). During the condensation process in the condenser, will be issued and the amount of energy supplied to the electric air heater room in the form of latent heat of the constant condensation pressure, so the enthalpy back down. And the latent heat will increase the drying air becomes drier, before entering the room heater. Then it used to dry the material in the drying chamber of a spray dryer system.

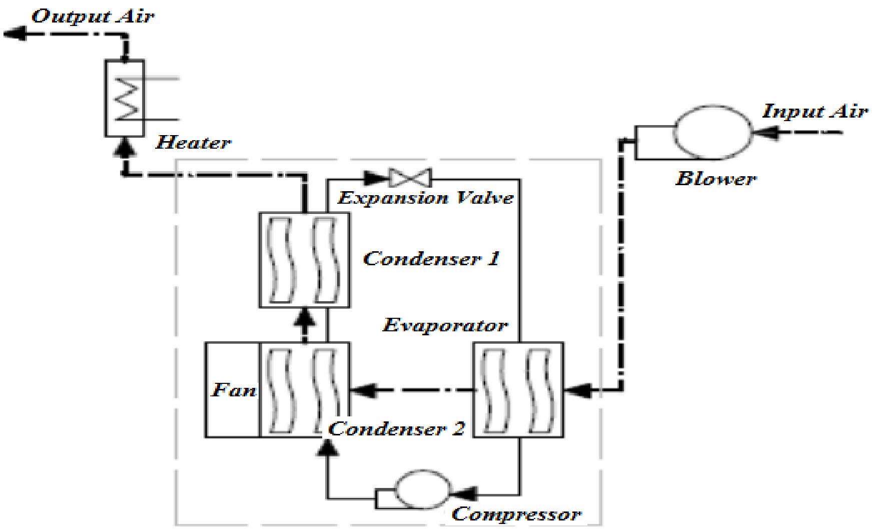


Figure 1 Schematic combine system of refrigeration with dual condenser series on electric water heater

2.2. Simulation

The thermodynamic simulation of measuring the minimum temperature drying required for drying materials with condensation temperature variation (T_{a3}) and the evaporation temperature of the refrigeration system with the temperature-controlled heater at 60-140^{o}C.

The simulation began with the determination of the design, as follows:

Table 1 Parameter simulation

Parameter Set up of Simulation	
Air mass flow rate ($\dot{m}_a$)	0.0029, 0.0058 and 0.0087 kg/s
Surrounding air temperature (T_{a1})	29^{o}C
Dew Point Temperature (T_{a2})	10, 15 and 20^{o}C
Air temperature out of the condenser that will go into room heater (T_{a3})	50, 60, 70, 80 and 90^{o}C
Refrigerant temperature R 134a	-4.31^{o}C at pressure 2.5 MPa
Saturation temperature condensation	40, 50, 60, 70 and 80^{o}C
Dry air temperature of the condenser and heater	60, 80, 100, 120 and 140^{o}C
Compressor Efficiency	90 %

Simulations carried out by using a thermodynamic formula as follows:

1. Dry air masses

$$\dot{m}_a = \dot{m}_{da} + \dot{m}_v \quad (1)$$

2. Humidity (Humidity/Specific humidity/Humidity ratio). Defined as the mass of water vapor in the dry air mass:

$$\omega = \frac{\dot{m}_v}{\dot{m}_{da}} \quad (2)$$

$$\frac{\dot{m}_a}{\dot{m}_{da}} = 1 + \omega \quad (3)$$

$$\dot{m}_{da} = \frac{\dot{m}_a}{1+\omega} \quad (4)$$

3. Enthalpy. Heat is owned by the air every kg of dry air. Stated:

$$h = h_{da} + h_w \quad (5)$$

4. The air enthalpy (kJ/kg):

$$h_a = 1007\times T_{a1}-26+ 1\times (2501000 + 1840\times T_{a1}) \quad (6)$$

$$h_{a4}\ wet = 1007\times T_{a4}-26+ \omega 1\times (2501000 + 1840\times T_{a4}) \quad (7)$$

5. The amount of water that occurs in the evaporator due to evaporation:

$$\dot{m}_w = \dot{m}_{da}\times (\omega_{a1}-\omega_{a2}) \quad (8)$$

$$\dot{m}_w = \dot{m}_{da}\times (\omega_{a1}-\omega_{a2}) \quad (8)$$

$$h_w = 4.196\ T_{a2} + 0.006 \quad (9)$$

or $$h_w = \dot{m}_w\times (-40+4203\times PE)$$

$$Q_w = \dot{m}_w\times h_w \quad (10)$$

6. The amount of heat energy evaporating:

$$Q_E = ((\dot{m}_{da}\times (h_{a1}-h_{a2})) - Q_w \quad (11)$$

$$h_{r2} = (((h_{r\ i2}-h_{r1})/\ \eta\ comp) + h_{r1}) \quad (12)$$

$$\dot{m}_r = (Q_E/\ (h_{r1}-h_{r4}) \quad (13)$$

7. The amount of heat energy compressors:

$$P_c = (\dot{m}_r\times (h_{r2}-h_{r1}) \quad (14)$$

8. The amount of heat energy in the condenser to double condenser:

$$Q_{c\ 1} = (\dot{m}_r\ (h_{r2}-h_{ra3})) \quad (15)$$

or $$Q_{c\ 1} = (\dot{m}_{da}\times (h_{a3}-h_{a2}))$$

$$h_{ra3} = (h_{r2} - (Q_{c\ 1}/\ \dot{m}_r)) \quad (16)$$

$$Q_{c\ 2} = (\dot{m}_r\times (h_{ra3} - h_{r3})) \quad (17)$$

or $$Q_{c\ 2} = Q_E + P_c-Q_{c1} \quad (19)$$

$$Q_{C\ total} = Q_{c1} + Q_{c2} \quad (18)$$

9. Heater power:

$$P_h = \dot{m}_{da}\ (h_{a4}-h_{a3}) \quad (19)$$

10. Consumptions energy specific:

$$CES = ((P_{comp} + P_h + Q_{c2})/\ 40)/\ \dot{m}_{da}) \quad (20)$$

$$CE = (P_{comp} + P_h + Q_{c2})/\ 40) \quad (21)$$

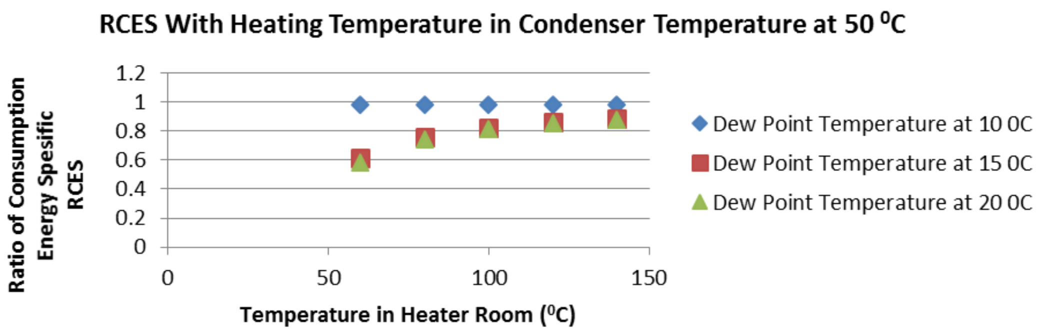
$$\text{CES without Refrigeration System} = h_{a4\ wet} - h_{a1} \quad (22)$$

11. Ratio of consumption energy specific:

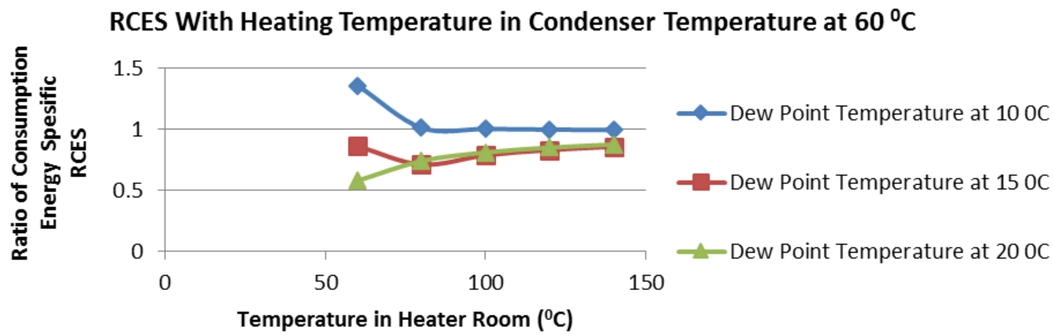
$$\text{RCES} = \text{CES / CES without Refrigeration System} \quad (23)$$

3. RESULTS

In this simulation, set the highest temperature of the condenser out by 90°C at which the temperature is at a pressure of 32.5 bar gauge with pessimistic assumptions for the critical temperature refrigerant R 134 A is the highest and safest on the temperature. This can be seen in Figure 2.



(a)



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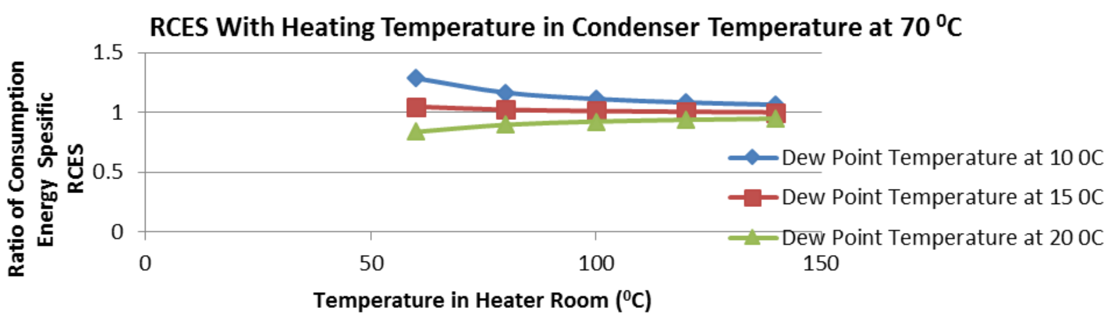

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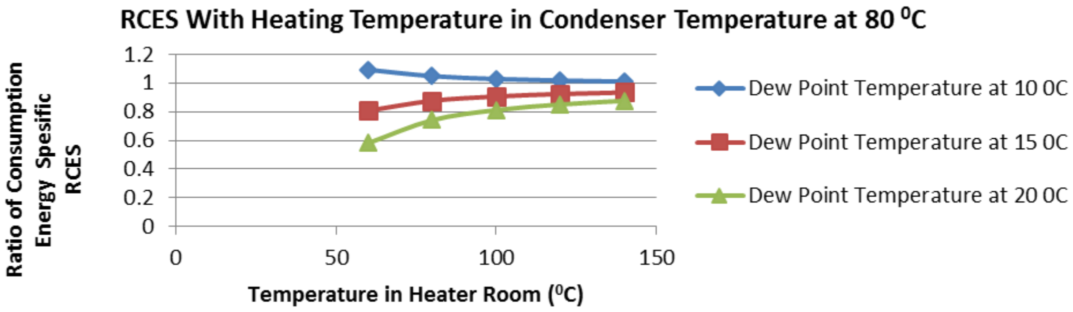

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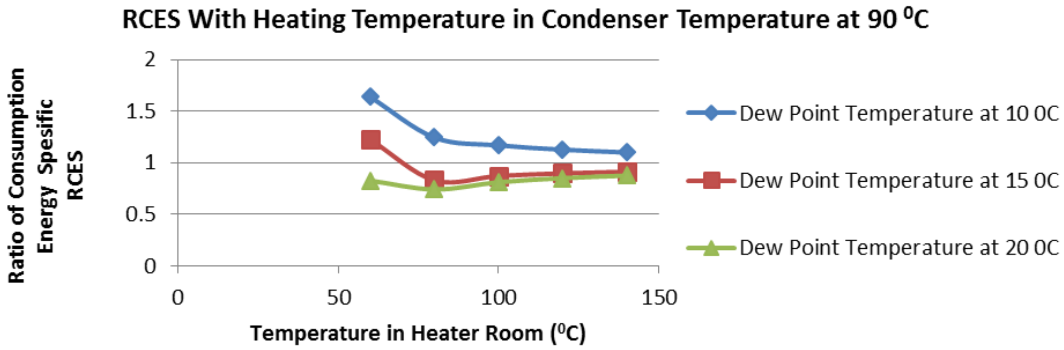

(e)

Figure 2 RCES with heating temperature in condenser temperature

In figure 3 illustrates another analysis of the same data, as follows:

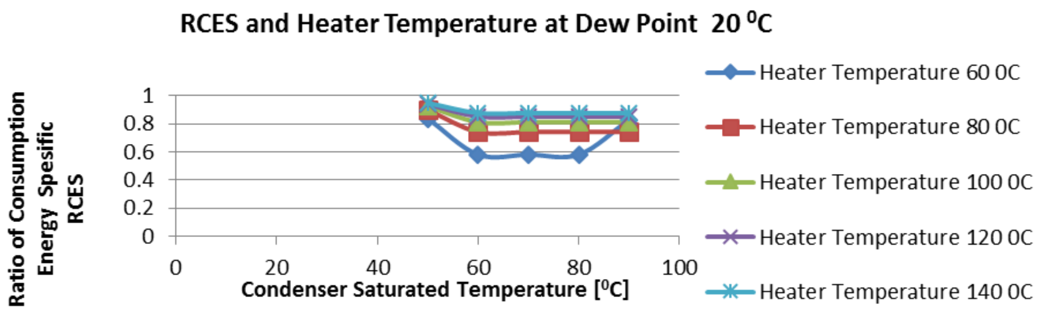

Figure 3 RCES and heater temperature with dew point temperature

4. DISCUSSION

Figure 2 shows that the larger the output temperature of the condenser, the greater the work of the compressor case. The greater the temperature produced on the room heater by the condenser, the smaller the actual performance of the heater. For example, at temperatures of condenser 90°C, the temperature in the room heater is 80°C, RCES is very small, when the temperature is 100°C in room heater and continue to grow, then gradually the heater is needed, but the RCES was still under 1. If RCES under 1, showed a reduction of energy in the system due to the use of a dehumidifier. In the picture above, the lowest RCES contained in dew point temperature at 20°C. Dehumidifier influence on the rate of drying, where the air will be able to pick up steam on more material in the drying chamber. This proves the dehumidifier function successfully reduced energy consumption that occurs, in addition, it can improve the drying work.

Figure 3 shows the optimum temperature in each dew point temperatures, but the dew point at 20^{o}C, the optimum conditions long enough visible. This indicates that the temperature in the condenser does not need to be high, because the drying has been already happened and RCES always lower with this refrigeration system. Dehumidifier is able to make the drying air humidity low, so that the rate of evaporation to be increased because of the air entering the drying chamber has been in dry conditions.

5. CONCLUSION

From what has been presented can be summarized as follows: (1) to get a high temperature, the heater work must also be high, but the output of heat from the condenser to the refrigeration system, the hot heater can be aided up to 90^{o}C; (2) the thermodynamic simulation of the dehumidifier function is very significant, if compared without dehumidifier, the dew point temperature of 20^{o}C, RCES very small 20^{o}C; (3) by adding large compressor work and increasing the amount of the specific enthalpy of the air produced by the condenser, it will increase the rate of drying to the room heater because the ratio of specific humidity decreases; (4) dehumidifier can replace the heater as a dryer material, if required drying air temperature ranging from 60-90^{o}C. If it is above that value, the heater is still needed, but with less power.

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