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Low Energy-Specific Consumption of Refrigerants For Combination Of Electric Air Heater And Refrigeration System Using Double Condensers: A Simulation Of Thermodynamic System

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Abstract. This research is an attempt to get the lowest Energy Specific consumption from a combination of spray drying systems and refrigeration systems with double condensers. Drying is simulated in a low temperature range for heat sensitive materials. The thermodynamic simulation in this study was carried out to replace refrigerant R-134a with another refrigerant that meets the operational temperature of drying heat-sensitive materials. Refrigerant R-152a has the lowest specific energy consumption value compared to R-12, R-134a and R-600a refrigerants. Refrigerant R-152a is recommended to replace R-134a in using a spray drying system combination tool and refrigeration system with double condensers for heat sensitive materials with energy savings of more than 39%.

Nomenclatures:

$\dot{m}_a$ **= mass flow rate of air [kg/s]**

$\dot{m}_{da}$ **= mass flow rate of dry air [kg/s]**

$\dot{m}_v$ **= mass flow rate of water vapor [kg/s]**

$\dot{m}_r$ = mass flow rate of refrigerant [kg/s]

$\dot{m}_w$ = Mass of water [kg/s]

h = Enthalpi of wet air [kJ/kg]

h_{da}= Enthalpi of dry air [kJ/kg]

h_w= Enthalpi of water vapor [kJ/kg]

h_r = Specific enthalpi of refrigerant [kJ/kg]

$h_{r\,i}$ = Specific enthalpi of refrigerant (isothermic) [kJ/kg]

h_a = Specific enthalpy of air [kJ/kg]

h_{a4wet} = Specific enthalpy of water in wet conditions [kJ/kg]

h_{ra3} = Specific enthalpi of refrigerant out 1 [kJ/kg]

h_{r3} = Specific enthalpi of refrigerant out 2 [kJ/kg]

P_{comp} = The power of compressor [J]

P_c = The power of condensor [J]

$P_{c\,fan}$ = The power of condenser fan [J]

P_h = The power of Heater [J]

Q_{c1} = The number of heat in condenser 1 [liter/s])

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Q_{c2} = The number of heat in condenser 2 [liter ⁄ s])

$Q_{C\ total}$ = The total amount of heat [liter/s]

Q_w = The number of heat in water [liter/s]

Q_E = The number of evaporation heat [liter/s]

rces= Ratio of Specific energy consumed [none]

CES = Spesific Energy consumed in Dehumidifier [J]

CE = Energy consumed in Dhumidifier [J]

T_{a1} = Inlet air temperature in evaporator[°C]

T_{a2} = Outlet air temperature in evaporator [°C]

T_{a3} = Outlet air temperature in the first condensor [°C]

ω = humidity ratio [kg water vapor/kg air]

ηcomp = Efficiency of compressor [%]

INTRODUCTION

At present, the use of Waste Heat Recovery (WHR) in applied technology for processing food ingredients is increasingly being investigated, especially for the drying process. Generally, there are several types of drying technology used in food processing. Extra energy is needed to encourage an efficient drying process to reduce the system's energy consumption. The combination of spray dryers with electric air heaters and refrigeration systems has proven to be efficient in terms of energy consumption. Combination of spray dryer and refrigeration system with double condensers using R134a refrigerant. The cooling system is supported by the amount of heat energy that is wasted from condensation steps of refrigerant that can improve engine efficiency and increase productivity [1,2]. The experiment has been able to reduce the use of specific energy consumed by the system as a whole by 39%, compared to the spray dryer system if without using a refrigeration system. The temperature of the air coming out of the evaporator is set at 10 °C and the air flow rate is 450 liters. minute 1, and energy consumption of 1.37 Joules liter-1is needed. where the value is much smaller than if without using a refrigeration system, which is 3.52 Joules. liter-1 [3].

However, research has been carried out on the environment and economic values that have been developed to explore alternatives to increase taxes at low costs [4]. The selection of the types of refrigerants that are environmentally green and have implications for the value of low energy consumption is one of the solutions to the solutions offered by the researchers. The choice of coolant in the cooling system is determined by the physical and thermodynamic properties of refrigerants to produce low and high work at the COP. The high latent heat value of the evaporation process can be used for lower cooling mass flow. This makes the efficiency and capacity of the compressor increase. Not only does the compression work decrease, the use of compressors needed is reduced, allowing the work of smaller compressors to be used [5].

Some studies on the types of refrigerants that have been used by previous researchers as seen in table 1.

TABLE 1. Research on Refrigerants in Refrigeration Systems

Name of Researcher	Year	Type of refrigerant
Gupta K, Parasad M	1983	R23/R12,R23/R22 and R23/R717
Eggen G, K. Aflekt K.,	1998	CO2
Pearson A, P. Cable P.	2003	CO2
Van Riessen GJ	2004	NH3/CO2
Minetto S, Cecchinato L, Corradi M, Fornasieri E, Zilio C	2005	CO2
S. Arivazhagan, S.N. Murugesan, R. Saravanan, S. Renganarayanan,	2005	R134a
M. Izquierdo, M. Venegas, N. García, E. Palacios	2005	LiBr–H2O
Lee TS, Liu CH, Chen TW	2006	NH3/CO2
S. Arivazhagan, R. Saravanan, S. Renganarayanan	2006	R134a
Kruse H, Rüssmann H.	2006	N2O such as R717, propane, propene, CO2 and N2O
Bhattacharyya S, Bose S, Sarkar J.	2007	CO2-C3H8
Di Nicola G, Giuliani G, Polonara F, et al.	2007	CO2+N2O
Park KJ, Seo T, Jung D.	2007	R22

(continued)

Name of Researcher	Year	Type of refrigerant
Getu HM, Bansal PK	2008	R744–R717
Ge YT, Cropper R	2008	R22 and R404A
Pearson A	2008	NH3
Dopazo JA, Fernàndez-Seara J, Sieres J, Uhìa FJ	2009	CO2/NH3
Bingming W, Huagen W, Jianfeng L, et al	2009	NH3/CO2
Bhattacharyya S, Garai A, Sarkar J.	2009	N2O-CO2
Kilicarslan A, Hosoz M	2010	R23/R152a, R23/R290, R23/R507, R23/R234a, R23/R717, R23/R404A
Antonio Messineo	2012	R744-R717
Da Silva A, Bandarra Filho EP, Antunes AHP.	2012	R744 , R404A and R22
Wang Q, Li DH, Wang JP, et al.	2013	R23/R507
Dubey A, Kumar S, Agrawal G.	2014	CO2/ propylene (R744-R1270)
Llopis R, Sánchez D, Sanz-Kock C, et al.	2015	R152a
Chen Y, Han W, Jin H.	2015	CO2
Polzot A, D'Agaro P, Gullo P, Cortella G	2015	CO2
Gullo P, Elmegaard B, Cortella G	2015	CO2
Gullo P, Elmegaard B, Cortella G	2016	R744
Zhili Sun, Youcai Liang, Shengchun Liu, Weichuan Ji, Runqing Zang, Rongzhen Liang, Zhikai Guo	2016	R41/R404A and R23/R404A
G. Besagni, R. Mereu, F. Inzoli,	2016	R134a
EA Kosasih, Warjito, Imansyah HI and Nanang Ruhyat	2016	R134a

A refrigeration system consisting of an evaporator and a double condenser combined with a spray drying system has been tested in previous studies. The study used R 134a type refrigerant [1,2]. The hot exhaust condenser and waste evaporator engine models are based on experimental / simulation data. Energy production by WHR is evaluated in tropical conditions and is used for drying in spray dryers. Comparative analysis of thermodynamic performance of refrigeration systems with double condensers for R-12, R-152a and R-600a refrigerants is a type of replacement refrigerant suitable for R-134a. The operating parameters considered in this paper include the difference in evaporator discharge temperature at the dew point temperature with ambient temperature, the exhaust temperature of the second condenser, the magnitude of the air mass flow rate, and the amount of specific energy consumption required as objective functions.

In choosing the refrigerant to be used, it must consider the safety standards of ANSI / ASHARE 34-1994, whether the refrigerant is easy to react (inert), not explosive, non-toxic (pure or mixed with air), and flammable. Refrigerants should not react easily with lubricants and other refrigeration machine parts. In addition, refrigerants must not be affected by moisture and do not damage or poison the stored product in the event of a leak (Dossat Roy J., 1984). Safe from stratospheric ozone damage or ODP (Ozone Reduction Potential) and greenhouse gas effects that are expected to affect global warming [6], as shown in table 2.

TABLE 2. Value ODP and GWP Refrigerant

Materials	Refrigerant	*Ozon Depletion Potenstial (ODP)*	*Global Warming Potential (GWP)*
CFC	R11	1	3800
	R12	1	8100
	R114	1	9000
HCFC	R22	0.055	1500
	R123	0.02	90
	R124	0.022	470
HFC	R23	0	11700
	R134a	0	1300
	R152a	0	120
Natural Refrigerants	R290	0	3
	R600a	0	3
	R717	0	<1

The selection of refrigerants is already obtained can be further saved. It will support research into the use of refrigeration systems with double condensers on spray drying systems that can save energy consumpstion and can be used for heat sensitive materials.

Determination of substitution of refrigerant R-134a is chosen based on the drying requirements for heat sensitive materials. The ideal drying temperature for heat sensitive materials is the temperature range 40 - 110ºC, RH <5% (Geankoplis, 1993), 50-60ºc [7], 60 - 80ºC [8] or 60 - 90ºC [1]. In table 3. the specification properties of several types of refrigerants are showed.

In this study determined refrigerants that are capable of operating at a temperature of -10ºC and the critical temperature is not greater than 100ºC. So that in this study selected refrigerants from R-12, R-152a and R-600a refrigerants as in table 3.

METHODOLOGY

Choosing of Refrigerant

The temperature and drying conditions that occur in the product have a very important influence [9, 10]. The more heat is given to the material, the material will be dry faster [11]. In a previous study, the temperature of hot air discharged into the environment by a double condenser in the refrigeration system could reach temperatures of 90^0C [1] compared to ordinary refrigeration systems which ranged from 40-60ºC [10,12]. The spray dryer combination device scheme with heat pump is shown in Fig. 1.

TABLE3. Physical and Thermodynamic Properties of Various Refrigerants [10]

Refrigeran	Normal Boiling Point, ⁰C	Temperatur Kritis, ⁰C	Tekanan Kritis, Bar	Titik Beku, ⁰C
R-11	23,7	197,78	43,7	-111,0
R-12	-29,75	111,97	41,15	-136,0
R-22	-40,80	96	96,2	-160,0
R-113	45,9	214,1	34,15	-36,6
R-114	3,6	145,8	32,7	-94,0
R134a	-26,07	101,06	40,56	-96,6
R-152a	-24,15	113,3	45,2	-117,0
R-290	-42,1	96,8	42,56	-187,1
R-600a	-11,73	135	36,45	-159,6
R-717	-33,35	31,1	73,72	-77,7
R-718	100	374,5	221,3	0,0
R-744	-78,4	31,1	73,72	-56,6

In figure 1 the scheme of the refrigeration system is combined with a spray drying system. The main advantage of this system is the refigeration system which consists of two condensers installed in parallel.

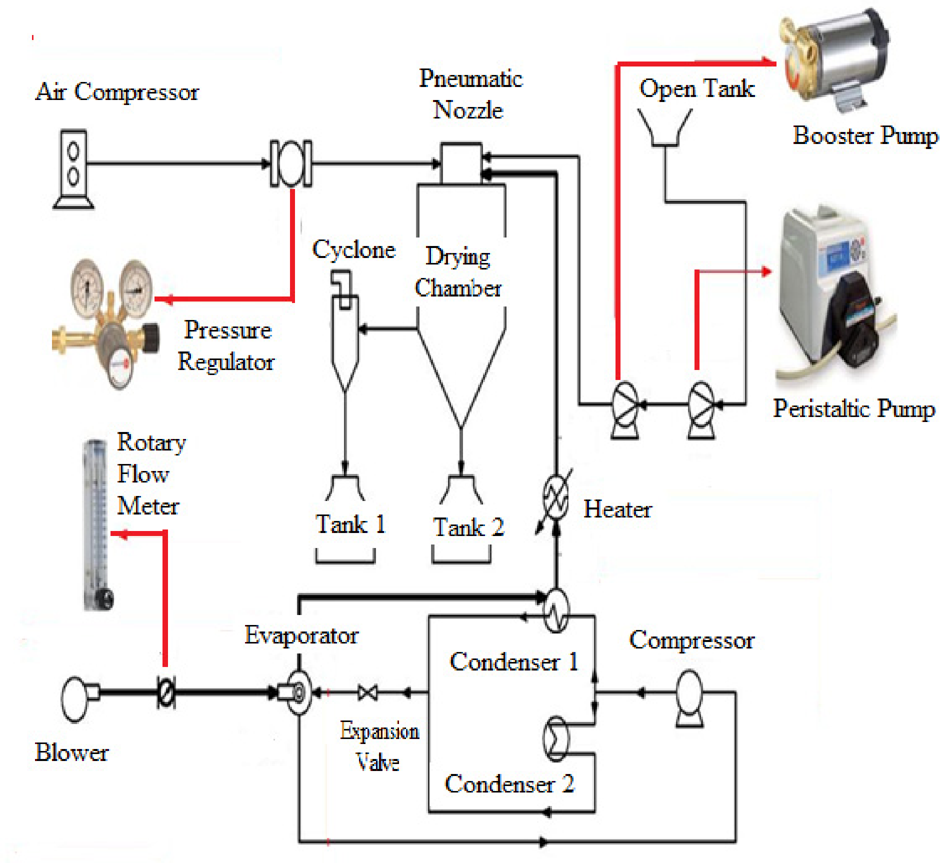


FIGURE 1. Scheme of Combination Spray Dryer and Refrigeration System With Double Condenser [1]

Simulation

In this study, a combination of spray dryer and refrigeration system with double condensers was used in thermodynamic simulations. Air as a drying medium is used in the drying process. However, the discussion is limited only to the drying water medium is to be able to supply heat to the heater from the spray drying system. So that it can be known as the amount of energy consumption to help with the heater. The workings of a double condenser refrigeration system are as follows:

The air from the environment is sucked by a blower and then flowed to the evaporator. The air flow rate is measured and read using rotameter. The air flow rate when entering the evaporator varies with the speed at 150, 300 and 450 lpm. Inside the evaporator, the air is dehumidified (reducing the humidity of the specific air). Specific air humidity is kept constant during the cooling process, although the relative humidity will increase. When the relative humidity increases, the water content of the air must be released. This will require cooling of the air by refrigerants below the temperature of the air dew point (10, 15 and 20° C). Furthermore, air through the one condenser and the second condenser in parallel. The air coming out of the second condenser will be heated higher by the heater to then flow towards the drying chamber. Waste Heat Recovery (WHR) from the second condenser makes the air already in high temperature and saturated dry conditions. Dry air conditions like this will contribute to a large amount of energy for the heater so that the energy consumption needed by the heater is not too high. The simulation began with the determination of the design, as follows in table 3.

TABLE 4. 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 ^{0}C
Dew Point Temperatur (T_{a2})	10, 15 and 20 ^{0}C
Air temperature out of the condenser that will go into room heater (T_{a3})	50, 60, 70, 80 and 90 ^{0}C
Refrigerant temperature R 134a	-4.31 ^{o}C at pressure 2.5 MPa
Saturation temperature condensation	40, 50, 60, 70 and 80 ^{0}C
Dry air temperature out of the condenser and heater	60, 80, 100, 120 and 140 ^{0}C
Compressor Efficiency	90 %

Simulations carried out by using a thermodynamic formula for refrigeration only to produce a mass of air flow rate with a dry air temperature of the condenser and heater and 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

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

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

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

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)

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

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

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

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

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

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

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

6. The amount of heat energy evaporating

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

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

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

7. The amount of heat energy Compressors

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

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 $Q_{c\,1} = (\dot{m}_{da} \;.\; (h_{a3} - h_{a2}))$

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

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

or $Q_{c\,2} = Q_E + P_c - Q_{c1}$ (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 Spesific

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

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

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

11. Ratio of Consumptions Energy Spesific

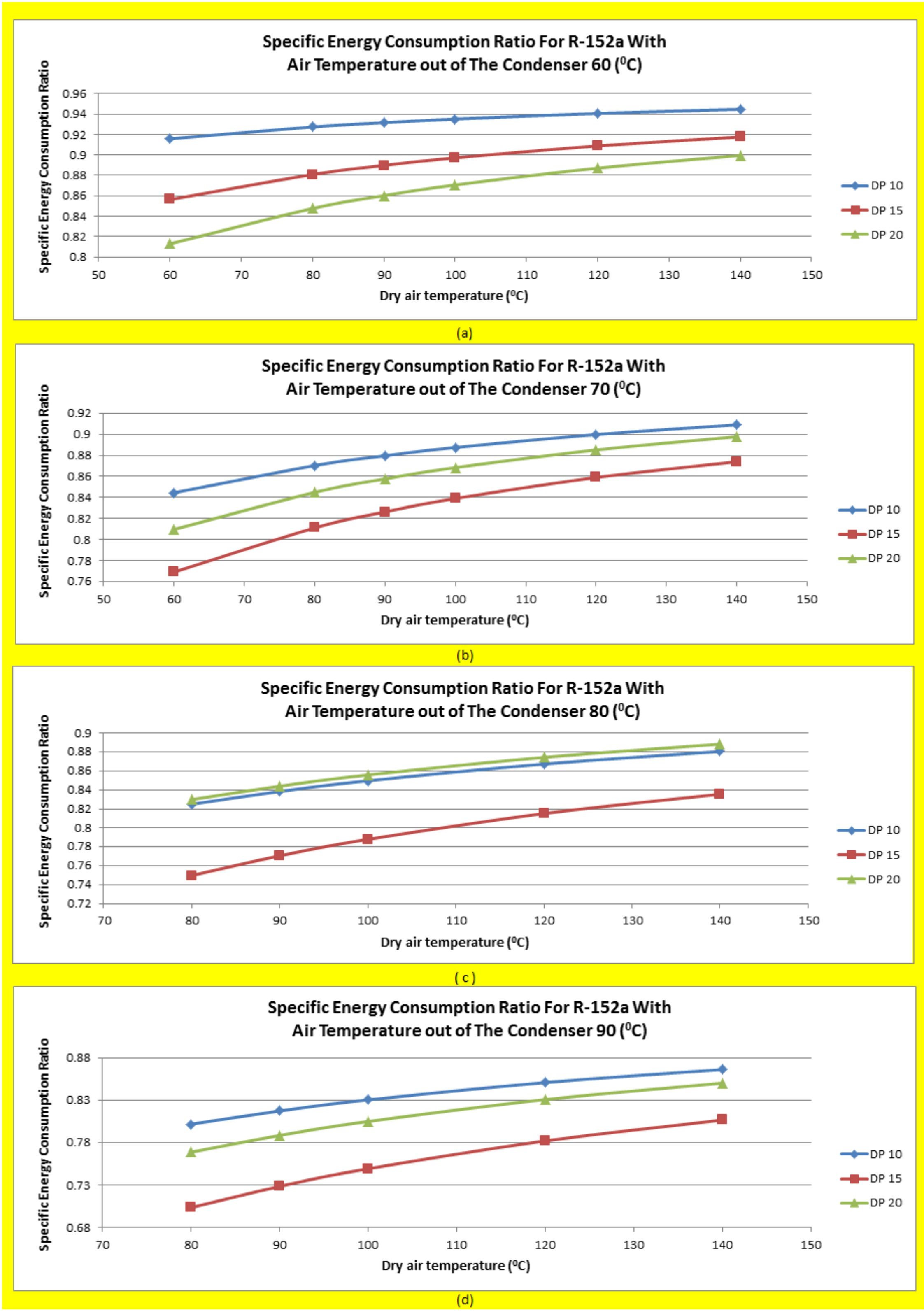
$$\text{RCES} = \text{CES} / \text{CES without Refrigeration System} \qquad (23)$$

Thermodynamic simulations have been carried out in this study using R-134a, R-12, R-152a and R-600a refrigerants. The results are shown in Fig.2, about the specific energy consumption ratio with the temperature of the air coming out of the condenser at temperatures of 50, 60, 70, 80, and 90^{0}C and the temperature of the air dew point selected at temperatures of 10, 15 and 20ºC at each air flow rate at 0.0029, 0.0058 and 0.0087 kg/s.

FIGURE 2. Graph of Energy Specific Consumptions and Ratio of Energy Specific Consumptions from R-134a, R-12, R-152a and R-600a Refrigerants

In Fig. 2 shows the comparison of the specific energy consumption of each refrigerant. The lowest specific energy consumption value indicates the lowest cost energy use. R-134a refrigerant has almost the same value as the R-600a refrigerant. While the advantage is seen in the R-152a referigerant. The R-152a has the advantage of good energy consumption which is close to 90 J/kg. And it is more economical at high temperatures, namely at air temperatures when the condenser temperature is at 90ºC.

Likewise, the specific energy consumption ratio of refrigerant R 152a has a value below 1. Refrigerant R-12 also shows a better value compared to refrigerant R-134a. There are two choices in this section (R-12 or R 152a), but from the image display, R-152 refrigerant can be selected and used to replace R-134a refrigerant.



FiIGURE 3. Graphs of Energy Consumptions Specific and Air Temperature Out of The Condenser 90^{o}C from R-152a Refrigerant at The Resulting Dry Air Temperature.

In figure 3. the temperature of the air out of the condenser starts from temperatures 60 to 90^{o}C, simulated on three conditions of air humidity from the evaporator room, at temperature of 10, 15, and 20^{o}C. The drying air temperature can reach temperatures of 60 to 140°C. indicates that the temperature of the drying air produced from this refrigeration system is to be dry and is able to dry heat sensitive materials from 60°C to a temperature range of 140°C. if necessary.

It is noteworthy from Fig. 3, that there is the best temperature of air humidity in the condition of the air coming out of the evaporator at 15°C for refrigerant R152a. And when the temperature of the air exits the condenser at a temperature of 90°C. Shows the best performance value of refrigerant R152a with the lowest specific energy consumption. This shows the effectiveness of the refrigeration system with double condenser and electric air heater can operate up to high temperatures.

Based on the physical properties of refrigerant in table 3. R-12 and R-152a refrigerants can be substituted to R 134a refrigerant. Boiling temperatures from each of these refrigerants are hardly different. But from GWP as shown in table 2, the GWP value of R-12 refrigerant is still higher than R-152a refrigerant. So that the refrigerant that can be recommended to substitute R-134a refrigerant is R-152a refrigerant.

CONCLUSION

This research was developed to replace the refrigerant that has been used in previous studies, namely a combination of spray drying systems and double condenser for cooling systems that use R-134a refrigerant. The purpose of this study was to obtain the lowest specific energy consumption value from previous studies, where the use of R134a refrigerants had reached savings of energy consumption from the system up to 39%. Air as a drying medium prepared by a cooling system for subsequent use for drying in a spray drying system is assessed at the temperature of the air coming out of the evaporator at 10, 15 and 20°C with an air flow rate of 450 liters. minutes, just like in an experiment using R134a. Analysis of energy consumption and specific energy consumption ratio of this study indicate that R-152a refrigerant has the lowest specific energy consumption value compared to R-12, R-134a and R-600a refrigerants. So refrigerant R-134a can be replaced with refrigerant R-152a. Although in terms of security ratings R-152a has a low light speed, A2 and has a low ODP and GWP value.

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