Effect of Hydrogen (g) Mixture With Refrigerant On The Pressure Of Cooling Machine Components

D. H. Praswanto[1], S. Djiwo[2], M. Asroni[3], A. Nugroho[4]*
[1,2,3]Department of Mechanical Engineering, National Institute of Technology, Malang, Indonesia
[4]Departement of Mechanical Engineering, University of Muhammadiyah, Kalimantan Timur, Indonesia
**Coresponding Author Email: djoko@lecturer.itn.ac.id*

ABSTRACT

Refrigerant is substance or chemical composition which alternately compressed and condensed into a liquid and then expanded into vapor or gas when pumped through the cooling system. Alternative refrigerants are needed to replace full the halogenated refrigerants which are believed to contribute to ozone depletion in the atmosphere. In the last decade, many research and development of studies on the synthesis and characterization alternative refrigerants have been carried out. With replace a limited Ozone Depleting Substance (ODS) with any alternative can involve major changes in the design of various components such as insulation, lubricants, heat exchangers and motors. The purpose of this research is to determine the effect of hydrogen mixture with refrigerant R134a on the pressure of each component. This research used an experimental method on a direct cooling device. The data which obtained from the experimental results on this cooling machine then will process to determine the pressure that occurs in each component of the cooling machine. Based on the results of this research, the effect of the hydrogen mixture on refrigerant R134a on the performance of the cooling machine is the differences density of each mixture ratio. If more of hydrogen additions there, the density of result mixture also getting smaller. This will affect the pressure that occurs in the compressor because the relationship between density and pressure is directly proportional. The conclusion is the refrigerant from a mixture of hydrogen gas and Freon R134a is suitable for use as a refrigerant for air condition. Because at 60 minutes, the mixture ratio of 85%:15% can reduce the water temperature slowly until 20.2ºC. The slow cooling is felt bad when applied on the food preservation.

Keywords Refrigerant, Hydrogen, R134a
Paper type Research paper

INTRODUCTION (*HEADING 1*)

Nowdays the develop of refrigeration techniques are more advanced and was used in various fields of human life, both for convenience and for food preservation. Air conditioning to get comfort are process for air and regulate temperature, humidity, cleanliness as well as distribution simultaneously to get the comfortable conditions needed by the humans in it [1]. On the operation, the refrigeration system requires a fluid which easily absorbs and releases heat. Refrigerant or cooling material is a fluid that used to absorb heat through a phase change from liquid to gas (evaporation) and dissipate heat through a phase change from gas to liquid (condensation) so in general the refrigerant is heat transfer on the cooling system [2], [3]. Each of refrigerant has different thermodynamic characteristics, which will affect the refrigeration effect and the coefficient of performance (COP) of the refrigerant itself [4].

The cooling process which are one of the thermal processes often found in the system from air condition into food preservation. In this system refrigerant is use to heat transfer [5]. Basically, the refrigerant absorbs that heat because of the temperature is lower than the source temperature which being absorbed. Therefore, the refrigerant function is to heat transfer [6].

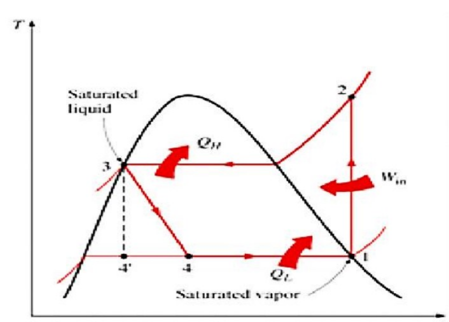

Fig. 1. T-S Vapor Compression Cycle Diagram

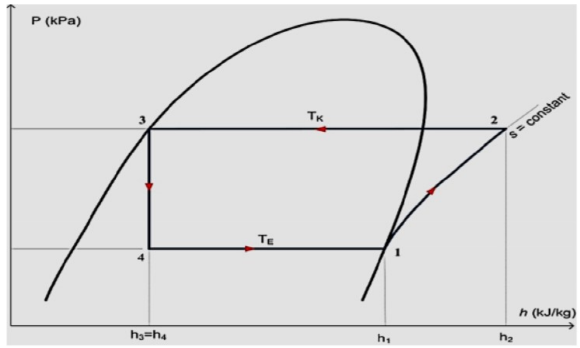

Fig. 2. P-H Vapor Compression Cycle Diagram

The processes that occur in the vapor compression cycle as shown in Figure 1 and Figure 2 above are as follows:

1. Compression process (1-2)

   The process is carried out in the compressor that occur with isentropic. The baseline of the refrigerant when enters the compressor is low pressure saturated steam. After compressing, the refrigerant will become a high pressure vapor. Because this process takes isentropic, the outside temperature of the compressor also increases.

2. Condensation Process (2-3)

   The process on the inside of condesor. The high-pressure and high-temperature of refrigerant stem from the compressor will dissipate heat so that the phase changes into liquid. That is cause of the condenser inside there is a heat exchange between the refrigerant and its environment (air), so that heat moves from the refrigerant into cooling air which causes the refrigerant vapor to condense into a liquid.

3. Expansion Process (3-4)

   This expansion process takes place icoenthalpy. It means that there is no change in enthalpy but a decrease in pressure and a decrease in temperature. The pressure drop process occurs at the expansion valve in the form of a capillary tube which functions to regulate the refrigerant flow rate and reduce the pressure.

4. Evaporation Process (4-1)

   The process takes place isobar isothermal (constant pressure, constant temperature) in the evaporator. The heat inside room is absorb by the low-pressure liquid of refrigerant so that the refrigerant changes phase into low-pressure vapor. The refrigerant condition when enters on evaporator actually is a mixture of the liquid and vapor phases.

Refrigerant is a substance or chemical composition which is alternately compressed and condensed into a liquid and then expanded into vapor or gas when pumped through the cooling system [7]. Alternative refrigerants are needed to replace the fully halogenated refrigerants which confirmed to contribute ozone depletion in the atmosphere. In the last decade, many research and development studies on the synthesis and characterization of alternative refrigerants have been carried out. To replace a limited Ozone Depleting Substance (ODS) with any alternative can involve major changes in the design of various components such as insulation, lubricants, heat exchangers and motors. The trial should be optimize the system performance and make sure the system reliability and security [8]. Several alternative refrigerants are available in the market. Several people have suggested natural refrigerants to replace ODS, namely, ammonia, propane, and CO2 [9].

The most commonly used alternative refrigerant is R134a. Refrigerant R134a has good properties, non-toxic, non-flammable and stable relative[10]. However, this type of refrigerant has several disadvantages. One of them it has the potential as a substance that cause global warming effects. Therefore, European regulation No. 2006/40/EC and No. 517/2014 limits the HFCs used that have a Global Warming Potential (GWP) of more than 150 in MAC systems and Vapor Compression Refrigeration (VCR) or other vapor compression refrigeration systems. To reduce the high GWP of the Refrigerant R134a, several adjustments were made [11]. One of them is mix the R134a refrigerant with a substance which have suitable for use as a refrigerant mixture by observing the rules that the substance is safe to use as a refrigerant [12]–[14]. The refrigerant characteristics have ODP and GWP values as shown in table 1.

Table 1. ODP and GWP value of refrigerant synthetics and Natural [9]

Refrigerant type	Refrigerant name	ODP[1]	GWP[2]	Comments
CFC	R11	1.00	4750	Very high ODP and GWP
	R12	0.82	10900	No longer sold
HCFC	R22	0.06	1810	Medium ODP and GWP
	R124	0.03	610	Phasing out via montreal protocol
HFC	R134a	0	1430	Zero ODP, Medium GWP

	R410A	0	2090	
HC	R717	0	0	Zero ODP, Low GWP
	R744	0	1	
	R290	0	<20	

[1] Ozone depletion potential, [2] Global warming potential

In this research was used the refrigerant R134a with a mixture of hydrogen (g). Hydrogen compounds have the opportunity to be used as environmentally friendly refrigerants that have physical properties as shown in table 2. Mixing hydrogen and R134a is a new invention from hydrocarbon refrigerants research which has never studied before. The purpose of this research is to determine the effect of addtions hydrogen to refrigerant R134a on the pressure of each component.

Table 2. Physical properties of hydrogen compounds [12]

Phase	**Gas**
Density	(0 ºC, 101.325 kPa) 0,08988 g/L
Melting point	14,01 K (-259,14 ºC, -434,45 ºF)
Boiling point	20,28 K (-252,87 ºC, -423,17 ºF)
Triple point	13,8033 K, 7,042 kPa
Critical Point	32,97 K, 1,293 MPa
Heat of melting	0,117 $kJ.mol^{-1}$
Heat of evaporation	0,904 $kJ.mol^{-1}$
Calor capacity	(25 ºC) 28,836 $J.mol^{-1}.K^{-1}$

METHOD

The research used an experimental method, to analyze the effect of a mixture of hydrogen compounds with refrigerant R134a on the pressure of each component on the cooling machine. The parameters measured are temperature and pressure on the compressor, condenser, expansion valve and evaporator with use a data logger. The schematic of the research tool on the cooling machine is as shown in figure 3.

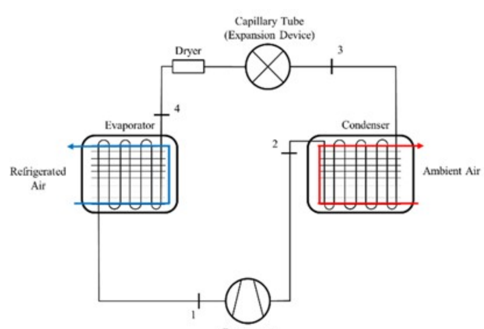

Fig. 3. Schematic diagram of the refrigeration system with the measurement location [14].

The first step before testing is to mix hydrogen and refrigerant R134a with mass ratio which is determined in a test tube, then the refrigerant mixture is fed into the cooling machine system through the compressor. The composition variation used in this research is the ratio between hydrogen and refrigerant R134a as follows: 15%:85%, 30%:70%, 45%:65%. The position of the instrument temperature sensors and pressure gauge in each process as shown in figure 4.

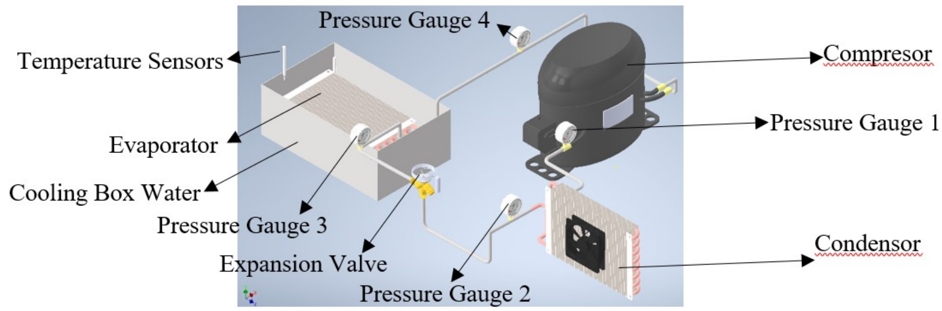

Fig. 4. Schematic instrument temperature sensors and pressure gauge

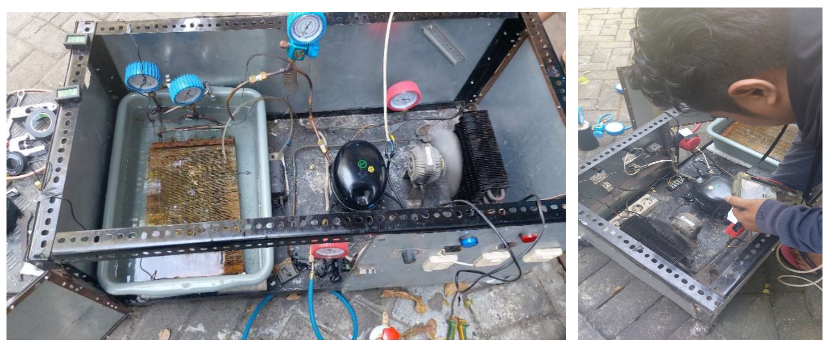

Fig. 5. The Data Collection Models

DISCUSSION

Table 3 The Experimental Data with Refrigerant Ratio R134a (100%):H2 (0%)

Rasio Refrigerant	t (Minutes)	Pressure (psi)		T₁ (°C)	T₂ (°C)
R134a : H_2 100% : 0%	10	P_1	135	26,3	27,5
		P_2	130		
		P_3	40		
		P_4	35		
	20	P_1	135	25,2	26,4
		P_2	130		
		P_3	39		
		P_4	35		
	30	P_1	134	23,7	24,9
		P_2	129		
		P_3	39		
		P_4	34		
	40	P_1	134	22,5	23,7
		P_2	129		

		P_3	38		
		P_4	34		
	50	P_1	133	20,6	21,8
		P_2	128		
		P_3	37		
		P_4	34		
	60	P_1	132	19,4	20,5
		P_2	127		
		P_3	37		
		P_4	34		

Table 4 The Experimental Data with Refrigerant Ratio R134a (85%):H2 (15%)

Rasio Refrigerant	t (Minutes)	Pressure (psi)		T_1 (°C)	T_2 (°C)
R134a : H_2 85% : 15%	10	P_1	135	26,4	27,5
		P_2	130		
		P_3	40		
		P_4	35		
	20	P_1	134	25,5	26,6
		P_2	130		
		P_3	38		
		P_4	35		
	30	P_1	133	24,3	25,3
		P_2	129		
		P_3	38		
		P_4	34		
	40	P_1	133	22,8	23,7
		P_2	128		
		P_3	37		
		P_4	34		
	50	P_1	132	21,4	22,2
		P_2	127		
		P_3	36		

		P_4	33		
	60	P_1	130	20,2	21,1
		P_2	126		
		P_3	35		
		P_4	33		

Table 5 The Experimental Data with Refrigerant Ratio R134a (70%):H2 (30%)

Rasio Refrigerant	t (Minutes)	Pressure (psi)		T_1 (°C)	T_2 (°C)
R134a : H_2 70% : 30%	10	P_1	135	26,6	27,6
		P_2	130		
		P_3	40		
		P_4	35		
	20	P_1	133	25,5	26,6
		P_2	130		
		P_3	39		
		P_4	34		
	30	P_1	132	24,3	25,3
		P_2	129		
		P_3	37		
		P_4	34		
	40	P_1	132	23,8	24,7
		P_2	128		
		P_3	36		
		P_4	33		
	50	P_1	131	22,4	23,2
		P_2	127		
		P_3	35		
		P_4	33		
	60	P_1	129	21,2	22,2
		P_2	123		
		P_3	35		
		P_4	32		

Table 6 The Experimental Data with Refrigerant Ratio R134a (55%):H2 (45%)

Rasio Refrigerant	t (Minutes)	Pressure (psi)		T_1 (°C)	T_2 (°C)
R134a : N_2 55% : 45%	10	P_1	135	26,6	27,6
		P_2	130		
		P_3	40		
		P_4	35		
	20	P_1	133	25,7	26,7
		P_2	130		
		P_3	39		
		P_4	34		
	30	P_1	131	24,7	25,8
		P_2	127		
		P_3	36		
		P_4	34		
	40	P_1	130	23,5	24,6
		P_2	126		
		P_3	35		
		P_4	33		
	50	P_1	129	22,9	23,8
		P_2	123		
		P_3	33		
		P_4	32		
	60	P_1	128	21,4	22,3
		P_2	121		
		P_3	32		
		P_4	31		

Table 7 The Density of mixture R134a with Hydrogen (g)

No.	**Ratio Mixture**	**Density (kg.m^{-3})**
1.	R134a : H_2 85% : 15%	12,19766
2.	R134a : H_2 70% : 30%	10,04532
3.	R134a : H_2 55% : 45%	7,89299

Based on the calculation table above, the gas density of each ratio was obtained. The calculation results show that each ratio of the gas mixture R134a with hydrogen has a different density.

It caused by the calculation formula which use a gas density of R134a of 14.35 kg.m-3 and a density of hydrogen of 1.251 kg.m-3. Then, the density is multiplied by the ratio of gas mixing to the volume of the mixing tube and divided by the total volume of the cylinder. Finally, the density of the gas mixture ratio of R134a (85%) : H2 (15%) is 12.19766 kg/m-3, the density of the gas mixture ratio of R134a (70%) : H2 (30%) is 10, 04532 kg/m-3, the density of the gas mixture ratio of R134a (55%) : H2 (45%) is 7,89299 kg/m-3.

The diffrences of density will affect on the pressure that occurs in the compressor. Because the relationship between pressure and density is directly proportional, so the change of density will be affect in a change in pressure, and conversely [15].

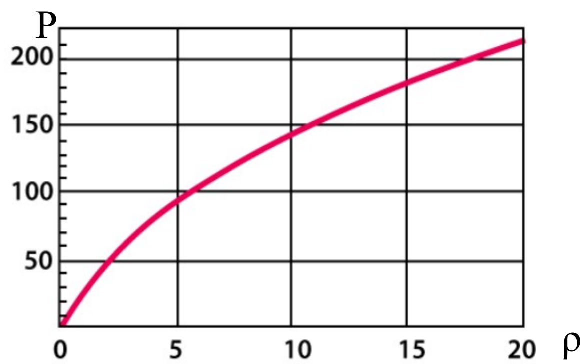

Fig. 6. Effect Density on the pressure

Here are some graphs of the compressor data pressure which taken every 10 minutes for 60 minutes

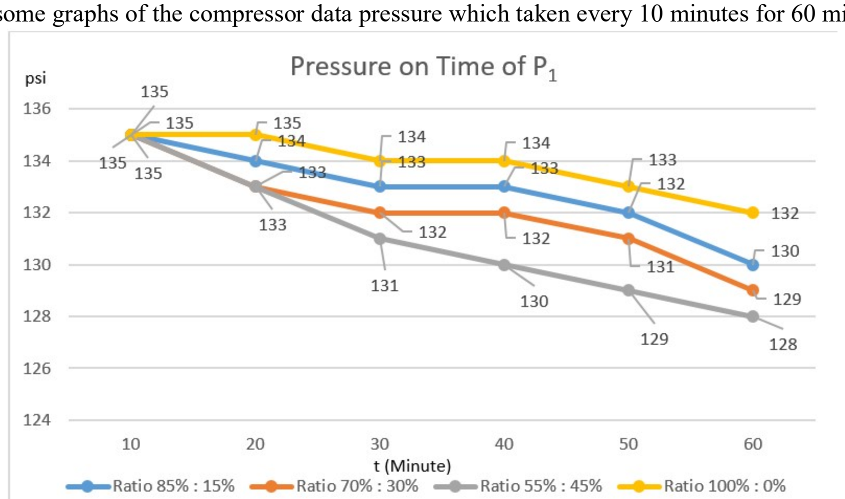

Fig. 7. Pressure on time of P1

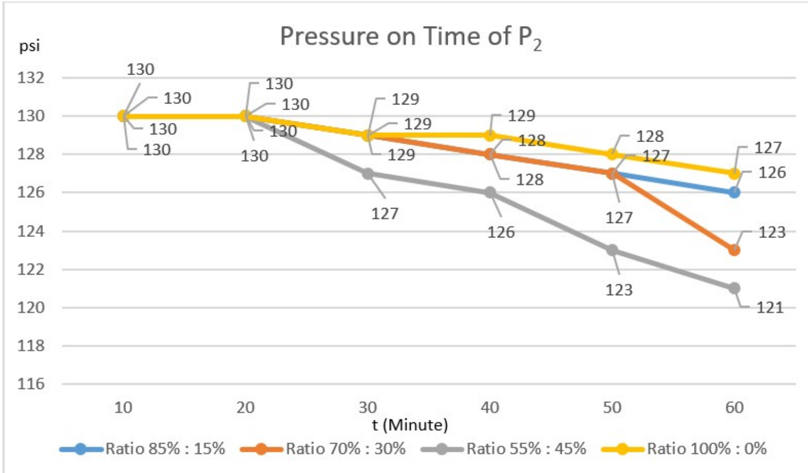

Fig. 8. Pressure on time P_2

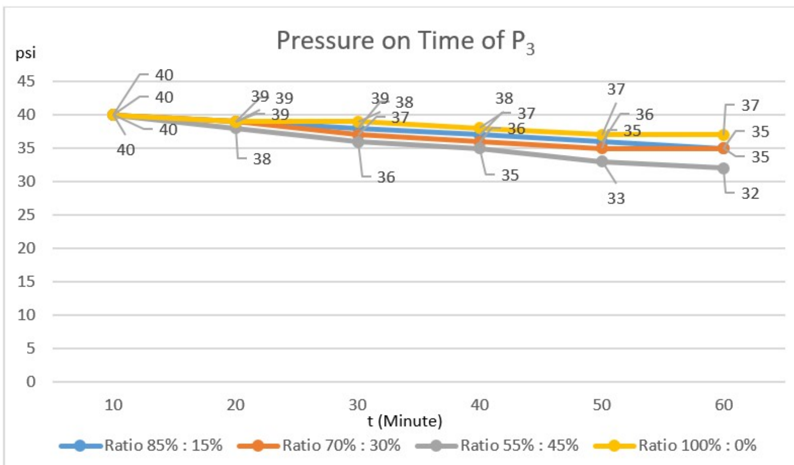

Fig. 9. Pressure on time P_3

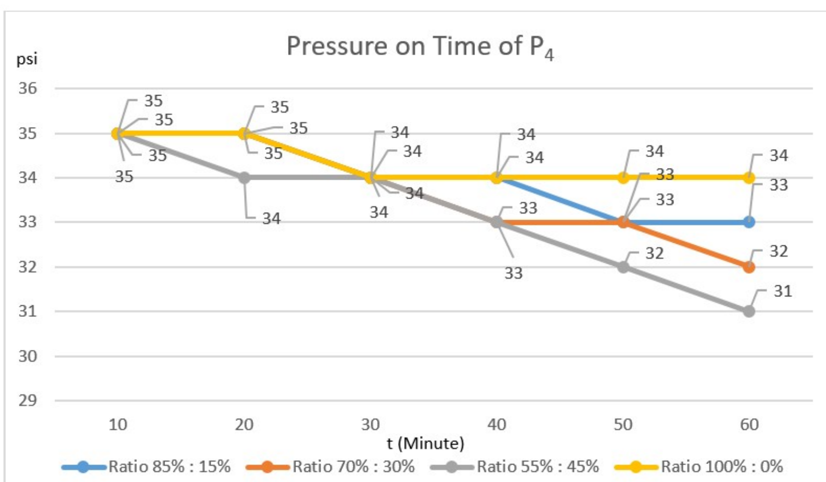

Fig. 10. Pressure on time P_4

The graph above shown that the data pressure for each mixing ratio at the pressure point from P1 to P4 has a different pressure. The mixing ratio of 85%:15% has large density so the pressure is large also it causes on compressor performance heavier also. While the ratio of 55%:45% has a smaller density which produces small pressure and makes compressor performance lighter. It is mean that the theory of the relationship between pressure and density is correct.

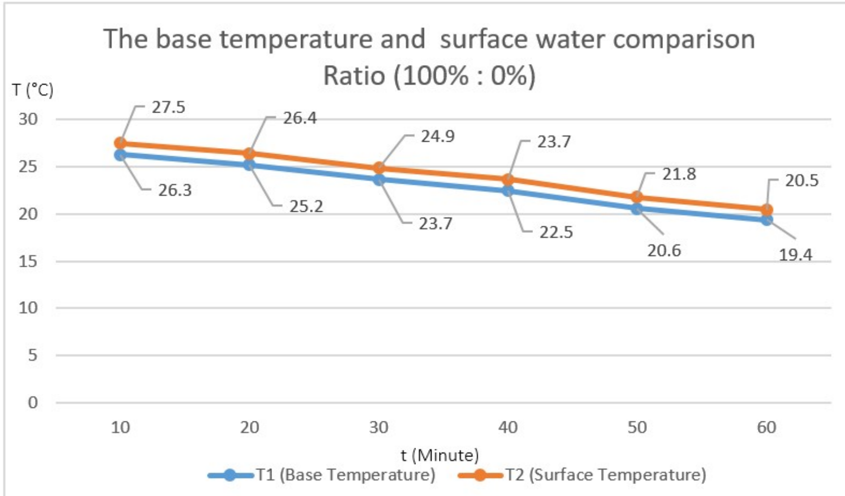

Fig. 11. The base temperature and surface water comparison with ratio (100%:0%)

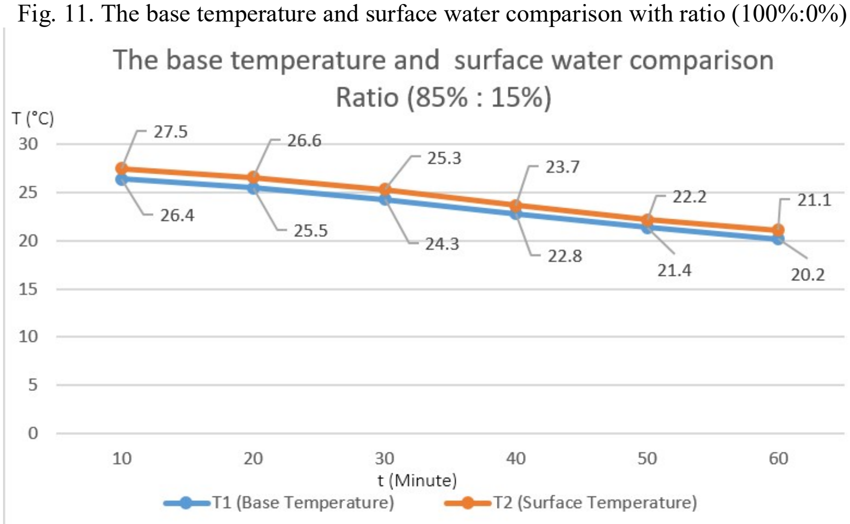

Fig. 12. The base temperature and surface water comparison with ratio (100%:0%)

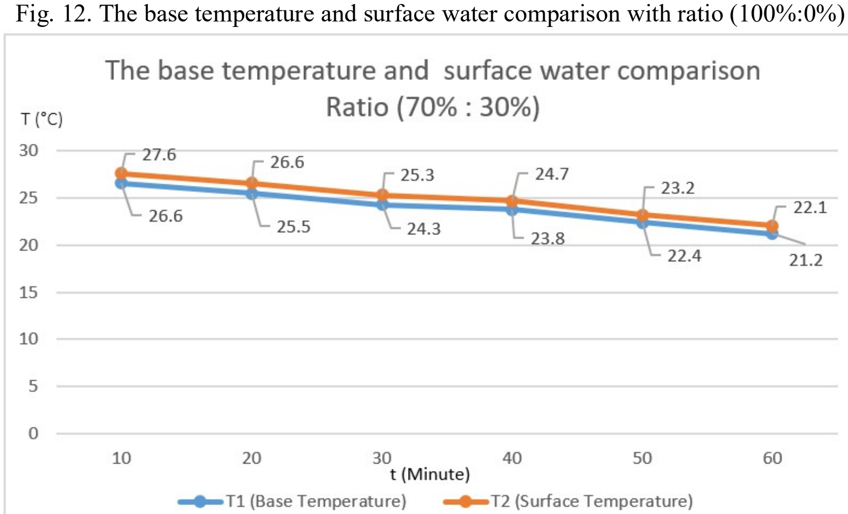

Fig. 13. The base temperature and surface water comparison with ratio (70%:30%)

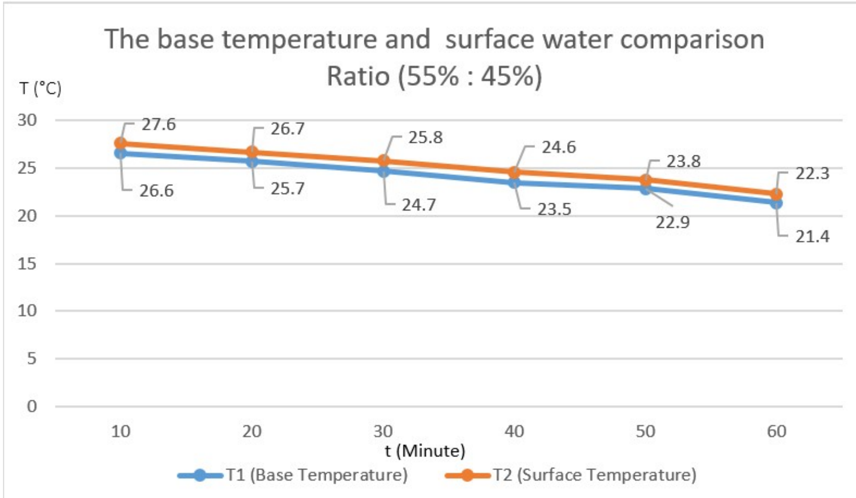

Fig. 14 The base temperature and surface water comparison with ratio (70%:30%)

The picture above shown the data the base and surface water temperatures of the cooling machine process with different mixture ratios. It can be seen that the graph with ratio of 85%:15% has higher cooling rate than other variations. This is caused by mixture of refrigerant R134a is more than other variations. So the temperature of the water in the container can be decrease more quickly. Refrigerant has several characteristics, which one is the latent heat of vaporization. Refrigerants which have high latent heat of vaporization will be more profitable because of on the same refrigerant capacity can produce the bigger refrigeration effect [16]–[18].

CONCLUSION

The effect of the hydrogen mixture on refrigerant R134a on the cooling machine performance is the differences density of each mixture ratio. If there are more of hydrogen mixture then the density result mixture smaller also. That will be effect on the compressor pressure because the relationship between density and pressure is directly proportional. It can be concluded that the refrigerant result from a mixture of hydrogen gas and Freon R134a are suitable for use as a refrigerant for air condition. Because at 60 minutes, the mixture with ratio of 85%:15% can lower the water temperature slowly until it reaches 20.2ºC. The slow cooling is felt bad when applied on the food preservation.

ACKNOWLEDGMENT

Thanks a lot to The Research and Community Service Institution (LPPM) National Institute of Technology (ITN) Malang, Indonesia which was funded the research so our team could finished and publish the research results also.

REFERENCES

[1] H. Krishnaswamy, S. Muthukrishnan, S. Thanikodi, G. A. Arockiaraj, and V. Venkatraman, "Investigation of air conditioning temperature variation by modifying the structure of passenger car using computational fluid dynamics," *Therm. Sci.*, vol. 24, no. 1PartB, pp. 495–498, 2020, doi: 10.2298/TSCI190409397K.

[2] M. S. Ahmed and A. M. Elsaid, "Effect of hybrid and single nanofluids on the performance characteristics of chilled water air conditioning system," *Appl. Therm. Eng.*, vol. 163, no. June, 2019, doi: 10.1016/j.applthermaleng.2019.114398.

[3] G. Fekadu and S. Subudhi, "Renewable energy for liquid desiccants air conditioning system: A review," *Renew. Sustain. Energy Rev.*, vol. 93, no. May, pp. 364–379, 2018, doi: 10.1016/j.rser.2018.05.016.

[4] S. Wu, T. X. Li, and R. Z. Wang, "Experimental identification and thermodynamic analysis of ammonia sorption equilibrium characteristics on halide salts," *Energy*, vol. 161, pp. 955–962, 2018, doi: 10.1016/j.energy.2018.07.129.

[5] A. Roccato, M. Uyttendaele, and J. M. Membré, "Analysis of domestic refrigerator temperatures and home storage time distributions for shelf-life studies and food safety risk assessment," *Food Res. Int.*, vol. 96, pp. 171–181, 2017, doi: 10.1016/j.foodres.2017.02.017.

[6] M. L. Davenport, D. Qi, and B. E. Roe, "Food-related routines, product characteristics, and household food waste in the United States: A refrigerator-based pilot study," *Resour. Conserv. Recycl.*, vol. 150, no. July, p. 104440, 2019, doi: 10.1016/j.resconrec.2019.104440.

[7] W. Tao, Y. Guo, Z. He, and X. Peng, "Investigation on the delayed closure of the suction valve in the refrigerator compressor by FSI modeling," *Int. J. Refrig.*, vol. 91, pp. 111–121, 2018, doi: 10.1016/j.ijrefrig.2018.05.004.

[8] X. F. Lu *et al.*, "Thermodynamic cycle design of a 700W@3K sub-cooled helium refrigerator test facility," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 502, no. 1, 2019, doi: 10.1088/1757-899X/502/1/012120.

[9] Y. Wang, M. Li, W. Du, Q. Yu, X. Ji, and X. Ma, “Performance comparative study of a solar-powered adsorption refrigerator with a CPC collector/adsorbent bed,” *Energy Convers. Manag.*, vol. 173, no. May, pp. 499–507, 2018, doi: 10.1016/j.enconman.2018.07.080.
[10] J. Gill and J. Singh, “Analyse énergétique d’un système frigorifique à compression de vapeur utilisant un mélange de R134a et de GPL comme frigorigène,” *Int. J. Refrig.*, vol. 84, pp. 287–299, 2017, doi: 10.1016/j.ijrefrig.2017.08.001.
[11] Y. Heredia-Aricapa, J. M. Belman-Flores, A. Mota-Babiloni, J. Serrano-Arellano, and J. J. García-Pabón, “Overview of low GWP mixtures for the replacement of HFC refrigerants: R134a, R404A and R410A,” *Int. J. Refrig.*, vol. 111, pp. 113–123, 2020, doi: 10.1016/j.ijrefrig.2019.11.012.
[12] M. Setiyo, S. Soeparman, N. Hamidi, and S. Wahyudi, “Caractéristiques de l’effet refroidissant d’un système frigorifique à demi-cycle sur un système au GPL,” *Int. J. Refrig.*, vol. 82, pp. 227–237, 2017, doi: 10.1016/j.ijrefrig.2017.06.009.
[13] M. Asadnia and M. Mehrpooya, “A novel hydrogen liquefaction process configuration with combined mixed refrigerant systems,” *Int. J. Hydrogen Energy*, vol. 42, no. 23, pp. 15564–15585, 2017, doi: 10.1016/j.ijhydene.2017.04.260.
[14] J. Yu, Y. Jiang, W. Cai, and F. Li, “Heat transfer characteristics of hydrocarbon mixtures refrigerant during condensation in a helical tube,” *Int. J. Therm. Sci.*, vol. 133, no. July, pp. 196–205, 2018, doi: 10.1016/j.ijthermalsci.2018.07.022.
[15] M. Rasti, J. H. Ban, and J. H. Jeong, “Development of a continuous empirical correlation for refrigerant mass flow rate through non-adiabatic capillary tubes,” *Appl. Therm. Eng.*, vol. 127, pp. 547–558, 2017, doi: 10.1016/j.applthermaleng.2017.08.070.
[16] R. Brignoli, J. S. Brown, H. M. Skye, and P. A. Domanski, “Refrigerant performance evaluation including effects of transport properties and optimized heat exchangers,” *Int. J. Refrig.*, vol. 80, pp. 52–65, 2017, doi: 10.1016/j.ijrefrig.2017.05.014.
[17] K. Li *et al.*, “Investigation on the Influence of Refrigerant Charge Amount on the Cooling Performance of Air Conditioning Heat Pump System for Electric Vehicles,” *J. Therm. Sci.*, vol. 28, no. 2, pp. 294–305, 2018, doi: 10.1007/s11630-018-1056-6.
[18] X. Liu, T. Wang, and M. He, “Investigation on the condensation process of HFO refrigerants by molecular dynamics simulation,” *J. Mol. Liq.*, vol. 288, p. 111034, 2019, doi: 10.1016/j.molliq.2019.111034.