ISBN: 978-979-99723-9-2

ENERGY EFFICIENT COLD STORAGE AS HYBRID REFRIGERATION MACHINE USING HEATING EFFECT FROM CONDENSER WITH HYDROCARBON REFRIGERANT SUBSTITUTED FOR R-22

Azridjal Aziz[1)], Herisiswanto[1)], Afdhal Kurniawan Mainil[2)]

[1)]Jurusan Teknik Mesin, University of Riau, Kampus Bina Widya
Jl. Subrantas, Simpang Baru Panam, Pekanbaru, 28293, Indonesia
[2)] Jurusan Teknik Mesin, University of Bengkulu, Jl. Raya Kandang Limun, Bengkulu, 38371

e-mail: azridjal@yahoo.com

Abstract

The most commonly used refrigeration cycle is the vapor-compression refrigeration cycle. Amount of energy required to produce a cooling effect. On the other hand, the heat removed by the system to the environment to keep the principles of thermodynamics. In this study was developed a system that uses the principles of refrigeration and heat pumps in one machine (hybrid refrigeration systems). The aim of this study is to investigate the characteristics of vapor compression hybrid system using hydrocarbon refrigerants substituted for R-22. The use of hydrocarbon refrigerants mass (HCR-22) optimum for this hybrid system is 0.4 kg at 2.546 of COP. Energy saving for heating effect is 58.12% which can be used for heating or drying. The use of dummy coil for hot water in condenser is important for maintaining the thermodynamic stability of hybrid system. The average temperature difference between the heating or cooling coil to the temperature of hot or cold room is in the range 3 - 5°C. The 45 L of water in the box could be use as thermal energy storage with initial temperature 0°C at ice on the coil conditions to maintain a cold room at a temperature of 24°C along 120 minutes.

Keywords: Hybrid, refrigeration, energy, hydrocarbon, storage

INTRODUCTION

Vapor compression cycle is the cycle commonly used in the refrigeration cycle. In developing country like Indonesia, most of the vapor compression based refrigeration, air conditioning and heat pump systems continue to run on halogenated refrigerants due to its excellent thermodynamic and thermo-physical properties apart from the low cost. However, the halogenated refrigerants have environmental impacts such as ozone depletion potential (ODP) and global warming potential (GWP). Hence, it is necessary to look for alternative refrigerants to obtain the objectives of the international protocols (Montreal and Kyoto) and to satisfy the growing worldwide demand [1].

In spite of their high GWP, alternatives to refrigerant CFCs and HCFCs such as hydro fluorocarbon (HFC) refrigerants with their zero ODP have been preferred for use in many industrial and domestic applications intensively for a decade. HFC refrigerants also have suitable specifications such as non-flammability, stability, and similar vapour pressure to the refrigerant CFCs and HCFCs. The problems of the depletion of ozone layer and increase in global warming caused scientists to investigate more environmentally friendly refrigerants than HFC refrigerants for the protection of the environment such as hydrocarbon (HC) refrigerants of propane, isobutene, n-butane, or hydrocarbon mixtures as working fluids in refrigeration and air conditioning systems. Although HC refrigerants have highly flammable characteristics (A3) according to the standards of ASHRAE as a negative specification, they have not only several preferable specifications such as zero ODP, very low GWP, non-toxicity, and higher performance than other refrigerant types but also high miscibility with mineral oil and good accordance with the existing refrigerating

ISBN: 978-979-99723-9-2

systems. They are used in many applications with attention being paid to safety of the leakage from the system as for other refrigerants in recent years [2].

The commonly refrigerant used in this cycle is halocarbons, which is technically quite good, especially this type of refrigerant level and the level of toxin capable of low flame. But in the mid-1970's known that chlorine contained in the refrigerant halocarbons are released into the environment can damage the ozone layer in the stratosphere. It will have an impact on the environment, where high intensity UV radiation that reaches the earth as a result of destruction of the ozone layer can cause skin cancer [3]. One attempt to improve energy efficiency is to utilize the back (recovery) which has allowed energy wasted on an energy conversion device. The reason most commonly used in an attempt to modify the refrigeration system is producing energy-efficient refrigeration machine.

Many investigations have been conducted in the research into substitutes for R-22. Park et al. [4] tested two pure hydrocarbons and seven mixtures composed of propylene, propane, HFC152a, and dimethylether as an alternative to HCFC22 in residential air-conditioners and heat pumps. Their experimental results show that the coefficient of performance (COP) of these mixtures is up to 5.7% higher than that of HCFC22. D.J. Cleland et al. [5] investigated hydrocarbons as drop-in replacements for HCFC-22 in on-farm milk cooling equipment. A mixture of propane and ethane (Care-50) reduced energy use by 6–8%, and had similar system cooling capacity relative to HCFC-22. With propane (Care-40), energy use decreased by 5% but cooling capacity was 9% lower. The retrofits were simple and low cost because no alterations to the systems other than change in refrigerant and appropriate safety labelling and documentation were made.

The refrigeration machine that serves as cold storage is used to cool the room for storage materials by utilizing the cooling effects of the evaporator so that the material can stored last longer before use and it quality is well maintained. Refrigeration machine is one kind of energy conversion device, where the amount of energy required to produce a cooling effect. On the other hand, the heat removed by the system to the environment for fulfill the principles of thermodynamics. Heat from the condenser is released into the environment are usually as unused energy. Similarly, the heat pumps, the amount of energy required to produce a warming effect by absorbing heat from the environment. Heat is absorbed from the environment can actually be used to cool something, but usually tend as wasted energy.

Starting from the case of refrigeration machines and heat pumps as mentioned in previous paragraph, various works have been made to develop a system that uses the principles of refrigeration and heat pump in one machine. In this integrated machine, cooling and warming effects can be generated and used simultaneously, thus saving of wasted energy becomes higher. The machine with this two functions is known as a hybrid refrigeration system, because most refrigeration machine operating with vapor compression cycle, the machine is called as hybrid vapor refrigeration system.

In this study, performance of hybrid refrigeration machine using heating effect from condeser was investigated in an attempt to examine and assess the use of hydrocarbon refrigerants as drop-in replacements for R-22 in hybrid refrigeration systems. The refrigerant charge for this machine also investigated.

MATERIALS AND METHOD

An experimental setup of vapour compression refrigeration system was built up from air conditioning machine that modified as the hybrid refrigeration system. Figure 1 shows the schematic diagram of the experimental setup that also use for another study [6]. It consisted of two loops; a main loop and a secondary loop. The main loop were consisted

ISBN: 978-979-99723-9-2

of a compressor, condenser, pressure gauge, a sight glass, a filter-drier, capillary pipe as expansion device, compound gauge and evaporator. The compressor is a hermetic type. The main loop is the vapor refrigeration cycle.

The condenser and evaporator are of both copper serpentine tubes that placed in isolated tank/box, for minimizing the heat loss. In the condenser and evaporator tank, the refrigerant flows through the serpentine tube while the cooling water flows to the tank will produced hot water as heating effect from condenser and cooling water as cooling effect from evaporator. The secondary loop were consisted of a pump, cooling or heating coil and coil dummy. Both of the tank was filled with cooling water and circulated through the condenser tubes while the other tank was circulated through the evaporator tubes. The hot water coming out of the condenser tube was supplied to a heating coil for heat the heating room. The cooled water coming out of the evaporator tube was supplied to a cooling coil for cooling the cooling room. A portion of the hot water will flow into the dummy coil to remove some of the heat that is not absorbed in the heating room.

The water flow rates to box of condenser and evaporator was measured by water measuring cylinder (accuracy: ± 0,01 L). The refrigerant pressure in high pressure side and low pressure side were measured by pressure gauge with accuracy ±5 psi and ±1 psi, respectively. The temperature points of refrigeration system was measured by tc-08 thermocouple data acquisition module with accuracy ±0,5 ^{o}C. The electric current and voltage of compressor were measured by ampere meter (accuracy ±0,1 A) and voltmeter (accuracy ±1 V), respectively. The refrigerant charge was measured by weighing digital scale (accuracy ±10 gram).

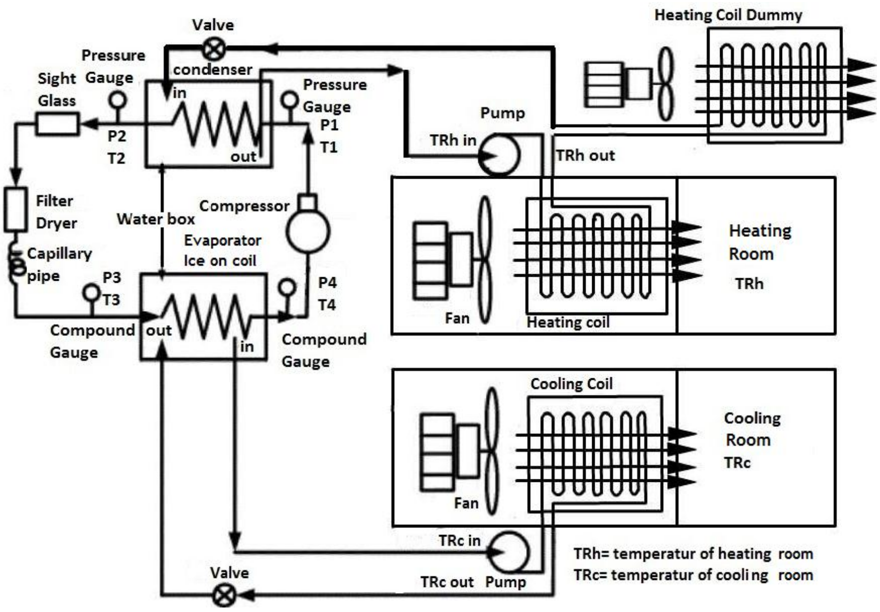

Figure 1 Schematic diagram of the experimental setup [6]

Data Reduction

The performance of the refrigeration system use in this study calculated from water side, with assumption heat rejected from condenser or cooling energy from evaporator and energy received to water in the box is both equal.

The amount of heat rejected in the condenser to the water is calculated by

$$Q_{cond} = \dot{m}_{wcond} \times C_P \times \Delta T_{cond} \quad (1)$$

ISBN: 978-979-99723-9-2

Where, Q_{cond} is heat rejected from condenser to the water (kW), $\dot{m}_{wcond}$ is mass flow rate of water in condenser box (kg/s), C_p is spesific heat of water (kJ/(kgK), and ΔT_{cond} is temperature difference of inlet and oulet in condenser box (K).

The cooling capacity of the evaporator is given by

$$Q_{evap} = \dot{m}_{wevap} \times C_P \times \Delta T_{evap} \tag{2}$$

Where, Q_{evap} is cooling capacity from condenser to the water (kW), $\dot{m}_{wevap}$ is mass flow rate of water in evaporator box (kg/s), C_p is spesific heat of water (kJ/(kgK), and ΔT_{evap} is temperature difference of inlet and oulet in evaporator box (K).

Power required to run the compressor is calculated by

$$W_k = \eta_m \times \sqrt{3} \times V \times I \times Cos\phi \tag{3}$$

Where, W_k is compressor power (kW), η_m is electric motor efficiency, $\cos\phi$ is power factor, V is electric motor voltage (V), and I is electric motor current (A).

The COP is the ratio between the amount of cooling capacity in the evaporator to the power required to run the compressor. The COP can be expressed as

$$COP = \frac{\dot{Q}_{evap}}{\dot{W}_k} \tag{4}$$

The PF is the ratio between the amount of heating rejected in the condenser to the power required to run the compressor. The PF can be expressed as

$$PF = \frac{Q_{cond}}{W_k} \tag{5}$$

The TP is the ratio between the amount of heating rejected and cooling capacity to the power required to run the compressor, ca be expressed as

$$Tp = \frac{Q_{cond} + Q_{evap}}{W_k} \tag{6}$$

RESULTS AND DISCUSSION

Refrigerant charge

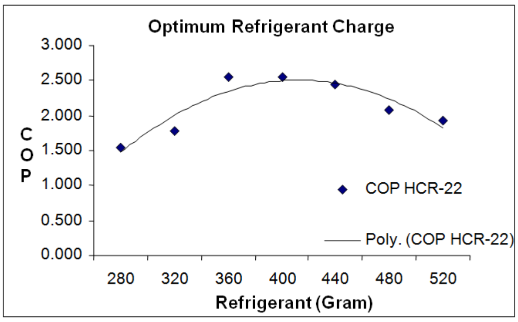

Figure 2 Coefficient of Performance (COP) vs refrigerant charge (gram)

ISBN: 978-979-99723-9-2

The optimum refrigerant charge was conducted by testing the Coefficient of Performance (COP) of the hybrid refrigeration machine with a gradual increase of refrigerant mass every 40 gram. Figure 2 shows the optimum refrigerant charge was achieved at refrigerant charge 400 gram with COP 2.55. It appears that the use of refrigerant charge more or less than the optimum value will cause the performance of hybrid refrigeration system decrease.

Cooling Capacity, Heating Capacity and Power of Compressor

The change in cooling capacity, heating capacity and power of the compressor with the running time of the hybrid refrigeration system are shown in Figure 3. It can be seen from Figure 3 that the heating capacity, cooling capacity, and heating capacity of dummy need 30 minute from transient condition to reach steady condition. The heating capacity should be bigger than cooling capacity because heating capacity is the sum of the cooling capacity and power of compressor. But in this case, It can be seen that the cooling and heating capacity tend to be similar, this is because some part of the heating capacity that not used in heating room would be release at the heating coil of dummy.

Useful average heating capacity in heating room is 1.172 kW, the average wasted heating in the dummy is 0.845 kW. It means that the energy savings for heating around 58.12%. Energy saving is useful energy for heating in heating room.

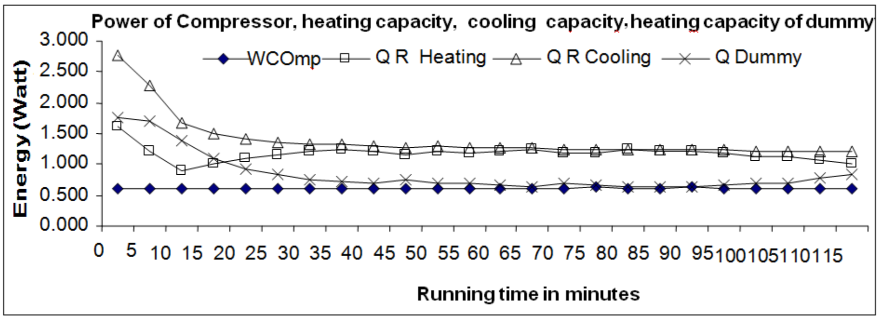

Figure 3 Energy of compressor, heating and cooling vs running time (minutes)

Performance of Hybrid Refrigeration Machine (COP, PF, TP)

Performance of hybrid refrigeration machine: Coefficient of Performance (COP), Performance Factor (PF) and Total Performance (TP) with running time in minutes are shown in Figure 4.

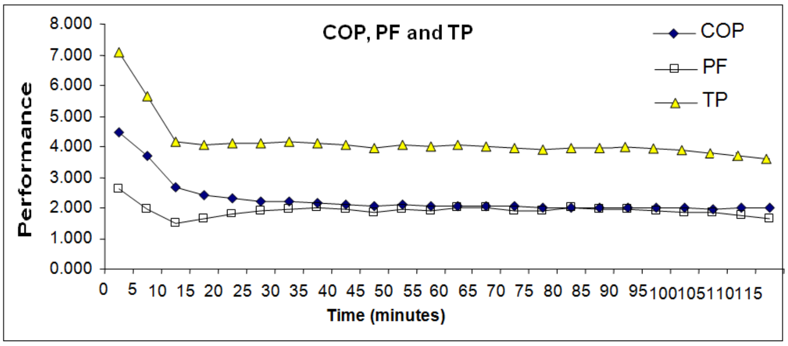

Figure 4 Performance (COP, PF, TP) of hybrid refrigeration machine

It can be seen from Figure 4 that the COP and PF are relatively similar after steady condition of hybrid refrigeration machine achieved. This is because, calculation of PF is

ISBN: 978-979-99723-9-2

based on useful heating capacity in heating room, not based on total heating capacity from this machine. The wasted heating capacity in heating coil dummy not involved for calculation of PF. TP was calculated from COP and PF, where COP and PF is cooling performance and heating performance, it used simultaneous in hybrid refrigeration machine.

Temperature variation of Heating Side and Cooling Side from Secondary Loop

Figure 5 shows temperature variation of heating side in secondary loop with running time (minutes). It can be seen from Figure 5 that the temperature of the heating side is relatively steady after the operation of the machine for 30 minutes. Steady condition of temperature from this machine can be maintained for up to 2 hours. The average temperature difference between the heating room with heating coil is around 3 °C.

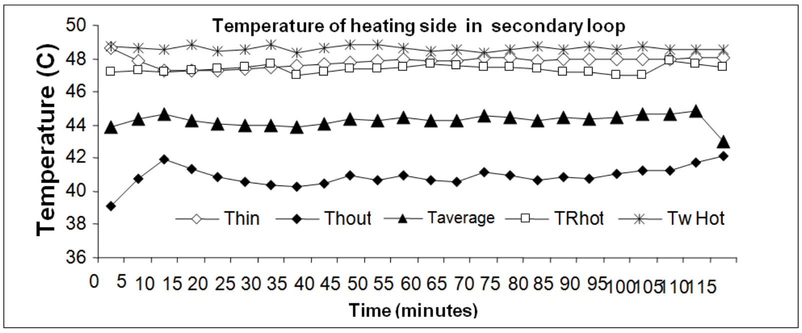

Figure 5 Temperature variation of heating side in secondary loop

Figure 6 shows temperature variation of cooling side in secondary loop with running time (minutes). It can be seen from Figure 6 that the temperature of the cooling side is relatively steady after the operation of the machine for 30 minutes. Steady condition of the temperature from this machine can be maintained for up to 2 hours. The average temperature difference between the cooling room with temperature of cooling coil is around 5 °C. This condition tend to be similar with heating side. Temperature variation and temperature difference at heating room and cooling room affected by heating load, cooling load and water flow rated in secondary loop.

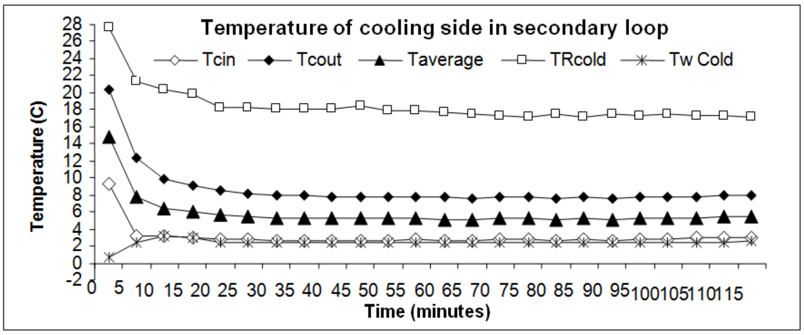

Figure 6 Temperature variation of cooling side in secondary loop

Temperature variation of cold water tank as Thermal Energy Storage (Ice on Coil Chilled Water Systems)

In this test condition hybrid refrigeration machines was worked to cool the evaporator coil so coil surface is covered by ice until the temperature of water in the cold water tank (45 L capacity) decrease to 0 °C. The temperature distribution at the cooling

ISBN: 978-979-99723-9-2

room, exit cooling coil and cold water tank are shown in Figure 7. It can be seen in Figure 7 that the temperature distribution at cooling room tends to fluctuate in the range between 23°C - 25°C. The similar condition also occurred at temperature of the exit cooling coil, fluctuation occurred because the cooling room is set at temperature of 24°C, so that the pump would be stopped pumping cold water at room temperature about 23°C and the pump will work again at room temperature about 25°C.

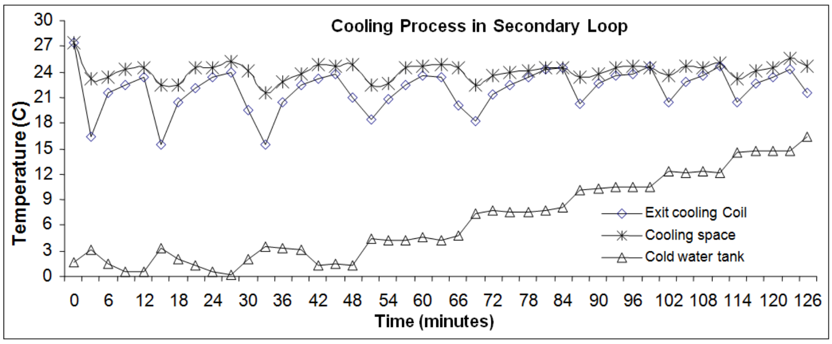

Figure 7 Temperature variation of exit cooling coil, cooling room and cold water tank (cold water tank as TES ice on coil)

Figure 8 shows the temperature distribution at inlet and outlet of cooling coil. In these conditions, it can be seen that the temperature of water at inlet and outlet of cooling coil tend to fluctuate at average temperature difference around 5°C. This condition coincided with the on or off of cold water pump that circulate cold water to the cooling coils. The temperature of water inlet and outlet of the cooling coil will increase linearly as increasing of cold water temperature due to heat exchange in the cooling room.

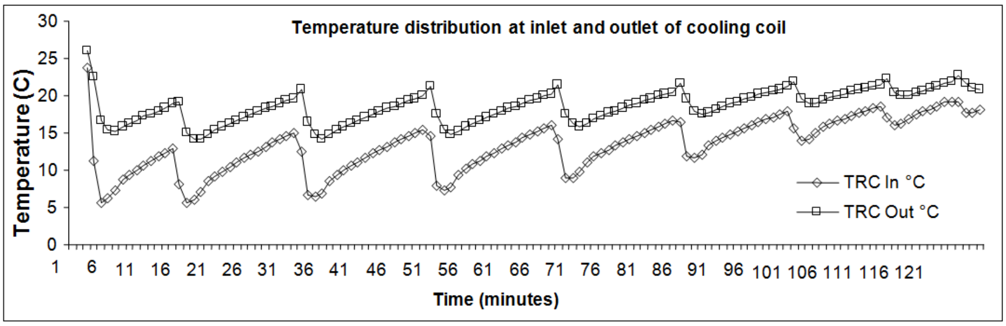

Figure 8 Temperature variation of inlet and outlet of cooling coil (cold water tank as TES ice on coil)

In this study, the hybrid refrigeration machine could be operated about only 2 hours at cooling room temperature 24°C. To serve the cooling room longer than 2 hours, the bigger capacity of cold water tank needed. Further study was needed to determine the relationship between the cooling time of cold water tank at certain fluid flow and volume with the cooling time of cooling room.

CONCLUSIONS

In this study, an ideal vapour-compression refrigeration system is used for the performance analysis of hybrid refrigeration machine using heating effect from condenser with hydrocarbon refrigerant substituted for R-22. The hydrocarbon refrigerant (HCR-22) charge as substituted for R-22 for optimum performance is 400 gram with COP 2.55. The

ISBN: 978-979-99723-9-2

use of heating coil dummy at heating side (condenser) is essential to maintain the thermodynamic balance of hybrid refrigeration machine. The average temperature difference between the heating or cooling coil with temperature of heating or cooling room is 3°C - 5°C. The use of cold water tank with capacity 45 L as a thermal energy storage ice on coil with initial temperature 0°C could be use to maintain the temperature of cooling room at 24°C for 2 hours (120 minutes). Energy utilization or saving was occurred from heating capacity around 58.12% at heating room that can be used for another drying purpose.

ACKNOWLEDGEMENTS

Authors gratefully acknowledge financial support for the reported work under the Andalan research, Riau University Research Center grant scheme.

REFERENCES

[1] M. Mohanraj., S. Jayaraj., C. Muraleedharan., Environment friendly alternatives to halogenated refrigerants-A review, *International Journal of Greenhouse Gas Control*, 2009, Jan, Vol. 3 No. 1, p. 108-119.

[2] A.S. Dalkilic., S. Wongwises., A performance comparison of vapour-compression refrigeration system using various alternative refrigerants, *International Communications in Heat and Mass Transfer*, 2010, Nov, Vol. 37 No. 9, p. 1340–1349.

[3] W .F. Stoecker., J.W. Jones., *Refrigeration and air conditioning*, McGraw-Hill, 1982, ch. 15.

[4] K.J. Park., T. Seo, D. Jung., Performance of alternative refrigerants for residential airconditioning applications, *Applied Energy*, 2007, Oct, Vol. 84 No. 10, p. 985–991.

[5] D.J. Cleland., R.W. Keedwell., S.R. Adams., Use of hydrocarbons as drop-in replacements for HCFC-22 in on-farm milk cooling equipment, *International Journal of Refrigeration*, 2009, Sept. Vol. 32 No. 6, p. 1403-1411.

[6] Aziz, Azridjal., Rosa, Yazmendra., Performansi Sistem Refrigerasi Hibrida Perangkat Pengkondisian Udara Menggunakan Refrigeran Hidrokarbon Subsitusi R-22, *Jurnal Teknik Mesin*, 2010, Juni, Vol. 7 No. 1, p. 11-16.