Energy Analysis Of Vapor-Compression Refrigeration (VCR) System

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Abstract: this paper presents an overview of the energy analysis of the VCR system using the HFC-236fa fluid and the result of manual calculation validation using software. The purpose of the energy analysis of the VCR system using the HFC-236fa fluid has been identified and discussed, including the results of manual calculation validation using the software. VCR system analysis is done by setting the rpm fan speed in five different speed levels. The results of the experimental data energy analyzer show that the HFC-236fa fluid performance approaches the COP compressor used in this system. The highest COP achieved was 3.07 while the lowest was 2.51.

Index Terms: Vapor-compression refrigeration, coefficient of performance, HFC-236fa, evaporator effect, refrigerant

1 INTRODUCTION

Based on the Scientific Assessment of ozone Depletion: 2010 published by NOAA, NASA, UNEP, WMO and EC agencies, the HFC-236fa refrigerant still has an ozone depletion potential (Ozone Depletion Potential) index and the index of global warming potential GWP (Global Warming Potential) low so that the bias becomes a solution to the impact of global warming. In this study the proposed FE-36 or HFC-236fa fluid is now widely used as fire extinguisher agents. ODP and GWP Index for HFC-236fa and some refrigerants are shown in Table 1.

Table 1. Index for ODP and GWP [1]

Refrigerant	ODP	GWP-20 Years
HCFC-22 (R22)	0.055	5130
HCFC-123	0.02	273
HFC-134 (R134)	0	3420
HFC-236fa (FE-36)	0	8100

To reduce the impact of global warming due to the depletion of ozone layer, alternative fluid is required. HFC-236fa has excellent thermal properties for use as refrigerant. HFC-236fa physical properties are shown in Table 2.

Table 2. Thermal properties of HFC-236fa and R22 [2-3]

Physical Properties	HFC-236fa
Chemical formula	$CF_3CH_2CF_3$
Molecular weight	152.04
Boiling Point at 1atm.	-1.44°C
Critical temperature	124.92°C
Critical Pressure	3200 kPa.
Critical Density	551.3 kg/m3
Chemical volume	0.0018 m3/kg
Chemical name	1,1,1,3,3,3-hexafluoropropane

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Thermal properties of fluid as refrigerant are very important. Thermal properties relate to the response of a material when heat is supplied to a solid, fluid, or fluid object. This response can be in the form of temperature rise, phase transition, change in length or volume, initiation of chemical reactions or changes in some other physical or chemical quantities [4-453]. HFC-236fa thermal properties at temperature, 10-90oC are shown in Table 3.

Table 3. HFC-236fa thermal properties [4]

Temperature [ºC]	Pressure [kPa]	Enthalpy (kJ/kg)			Entropy (kJ/K-kg)	
		Liq.	Lat.	Va.	Liq.	Va.
10	159.7	212.2	154.3	366.5	1.044	1.5890
20	229.6	224.6	148.8	373.4	1.087	1.5940
30	321.0	237.3	142.9	380.2	1.129	1.6000
40	437.8	250.2	136.7	386.9	1.171	1.6070
50	584.2	263.4	130.0	393.4	1.212	1.6140
60	764.7	227.0	122.6	399.6	1.253	1.6210
70	984.5	290.9	114.5	405.4	1.293	1.6270
80	1249.0	305.4	105.3	410.7	1.334	1.6320
90	1565.0	320.5	94.6	415.1	1.3760	1.6300

In the previous study, Abdullah et al, conducted a COP study using several alternative fluids such as R600a (isobutane), R290 (propane), R134a, R410A, and R32. Research was done by optimizing the use of finned-tube evaporator. In this research, the evaporator effect analysis and the cooling system performance coefficient (COP). This research uses temperature as a free variable. Condensing temperature setting was performed at 38oC and 45oC. COP values greater than R22 are R-600a (isobutane), R-290 (propane), and R134a. While the COP for R410A, and R32, is still below R22 with a percentage of about 9.5%. It can be said that the second COP of this fluid has only reached 90.5% [5]. Evaporator effect and COP studies have also been conducted using R410A fluid. Testing is done by using Rooftop Unit (RTU) with a capacity of 26.4 kW. Optimization is done by replacing the old ovaporator with evaporator prototype. Test results showed an increase of evaporator effect of 2 ± 1.5% and COP of 2.9 ± 1.5% [6]. Unlike the previous two studies, this study uses HFC-236fa cooling fluid. This study aims to know the value of evaporator effect and COP from HFC-236fa so it can be used as alternative fluid. HFC-236fa COP value is expected to be close to 3.0.

2 RESEARCH METHOD

2.1 Experimental Procedure

Before the experiment begins, all conditions of the equipment used and the condition of the test setting should be checked and confirmed to meet the safety requirements. Experimental research uses a VCR system with a capacity of 875 W and uses HFC-136fa fluid. Figure 1 shows a vapor compression cooling scheme used for COP testing.

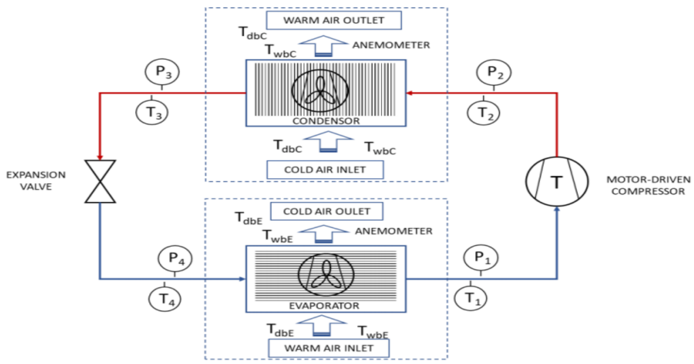

Figure 1. Schematic diagram of VCR experimental set up

Evaporator effect testing is done by controlling the speed of fan rotation in 5 levels. The lowest fan Rpm is shown at set level 1, while the highest rpm is shown at level 5 setting. Table 4 shows the velocity of air measured in the evaporator and the condenser at each fan level rpm. From this data we see that the higher the rpm fan then the faster the air flow rate of the evaporator and the condenser.

Table 4. Experimental set up

Fan rpm Level	V_{air} (m/s)	
	Evaporator	Condensor
1	1.10	0.90
2	1.30	1.00
3	1.40	1.20
4	1.50	1.40
5	1.60	1.50

The air velocity that enters the evaporator and the condenser is measured using the anemometer. The area of the evaporator and condenser cross section is measured for analyzing fluid flow.

Table 5. The summary for the uncertainties of the experimental parameters.

Parameters	Full scale	Accuracy
Pressure gauge, psi	160	+/- 1%
K-type thermocouples, K	227.6 to 1366.5	+/- 0.5%
Glass thermometer, °C	-5 to 110	+/- 0.5 °C
Anemometer, m/s	0.0 to 30.0	+/- 3%

2.2 Performance Analysis of the VCR system

Analytical model refers to the first law of thermodynamics and is set for VCR system settings. To evaluate energy performance, the process is assumed to be steady-state. The pressure drop on pipes and parts, heat transfer losses, kinetic energy, chemical and potential losses from the system were also ignored [7, 8]. Some of the features of thermodynamics are prioritized, such as pressure, temperature, time density and specific volume, enthalpy, entropy, and liquid-vapor properties in a state [9, 10]. In the refrigeration system, the compressor works by making the difference in pressure until the cooling fluid can flow from one part to another in the system. The pressure difference between the high pressure side and the low pressure side causes the refrigerant to flow through the regulator / valve (capillary pipe) to the evaporator. The fluid pressure in the evaporator should be higher than the fluid pressure inside the suction channel, so the cold fluid from the evaporator can flow through the suction channel to the compressor. The degree of refrigerant condition in both the condenser and the evaporator is always at the fluid level of fluid state, this is due to the latent nature of the substance so that the refrigerant can absorb and discharge heat as much as the specific heat of the fluid. In its operation, the refrigerant always mixes with lubricating oil, this is to reduce the friction factor in the installation pipes to be refrigerant. The pressure-enthalpy diagram on the vapor compression coolant engine cycle can be seen in Figure 1 [10-13].

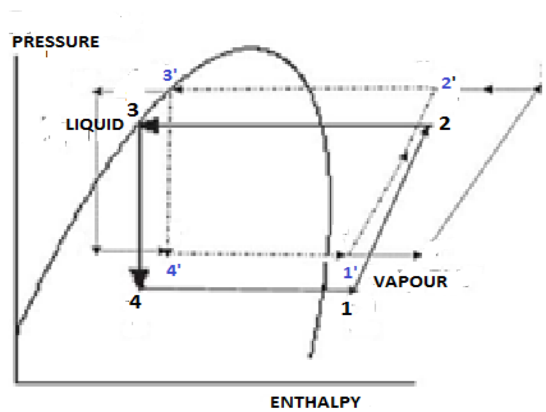

Figure 2. Pressure-enthalpy diagram

From the testing process, temperature and pressure data are obtained. This data is used to analyze the enthalpy value presented in the thermal properties table [2, 3]. If the temperature and pressure are not present in the enthalpy table, the calculations are carried out by interpolation or extrapolation analysis methods. The air flow rate through the evaporator is formulated as follows [8, 14]:

$$\dot{m}_{\text{air evaporator}} = \rho_{air}.\ A.\ v \tag{1}$$

The flow of air energy passing through the evaporator is formulated as follows [10-13]:

$$Q_{evap.} = \dot{m}_{air\ evaporator}\,(h_{in}–h_{out}) \tag{2}$$

While the mass flow rate of Refrigerant through the evaporator is formulated as follows [10, 11, 13]:

$$\dot{m}_{refrigerant} = \frac{Q_{evap}}{(h_1 - h_4)} \tag{3}$$

Compression work on the ideal cycle of vapor compression cooling machine is the result of mass flow rate with enthalpy increase during the isentropic compression process. The compression process is assumed to occur adiabatically, meaning the heat transfer from inside and outside the system is considered zero. Compression work is calculated by the following equation [10,11,13]:

$$W_c = \dot{m}.\ (h_2\text{-}h_1) \quad (4)$$

With Wc is compression work (kJ/s or kW), adalah is the flow rate of time (kg / s), and h1, h2 is the enthalpy at points 1 and 2 (kJ / kg). By the time the refrigerant passes the evaporator, there is a heat absorption from the desired space resulting in evaporation of the refrigerant. In the process of evaporation and condensation there is a kinetic energy change and the potential energy is negligible so that the price v_2^2 and gz at points 1 and 2 are considered zero. Because in the evaporator and condenser there is no work done then W = 0, so the mass and energy transfer rate in this condition is expressed in the following equation [10, 11, 13, 17, 18]:

$$Q_{in} = \dot{m}.\ (h_1\text{-}h_4) \quad (5)$$

Q_{in} is the evaporation process / refrigeration capacity (kJ / s or kW), is the flow rate of time (kg / s), and h1, h4 is the enthalpy at points 1 and 4 (kJ / kg). Refrigeration capacity is calculated based on heat energy that can be absorbed by the evaporator and heat loss in air. At this test the cooling load is the air flowed into the evaporator coil so that the heat absorbed by air can be calculated by the following equation [3, 12]:

$$Q_u = \dot{m}_u.\ C_p.\Delta\ T_u \quad (6)$$

With Q_u is a refigeration effect (kJ / s or kW), Cp is the heat type of air at constant pressure = 0.2403 (kJ / kg.K), uny is the mass flow rate of air (kg / s), and ΔTu is the change the air temperature flowing into the evaporator. The amount of air mass flow rate calculated based on the following equation [8, 14].

$$\dot{m}_u = \rho.A.V \quad (7)$$

$\dot{m}_u$ is the flow rate of the air mass of the evaporator channel (kg/s), ρ is the mass of the type (kg/m^3). Is the cross-sectional area of the evaporator (m^2) and v is the air flow rate (m/s). The mass of air type in this condition can also be searched with the following equation [9, 16]:

$$\rho = \frac{P}{R.T} \quad (8)$$

With P is the absolute pressure of air (N / m2), and R is the ideal airflow constant of 2,4061 (kJ / kg K). At the time the refrigerant passes through the condenser, there is a heat transfer from refrigerant to a cooler environment resulting in refrigerant refining. The heat flow rate in this condensing process is expressed in the following equation [10, 11, 13, 17, 18]:

$$Q_{out} = \dot{m}.\ (h_2\text{-}h_3) \quad (9)$$

With Q_{out} is condensation color flow rate (kJ / s or kW), is the flow rate of time (kg / s), and h2, h3 is the enthalpy at points 2 and 3 (kJ / kg). The next process is the throttling process analysis on capillary pipes or expansion valves. In this process there is no work done or incurred so that W = 0. The kinetic energy and potential energy changes are considered zero. Since the process is considered adiabatic (q = 0), the energy equation is shown in the following equation. [16]:

$$h_3 = h_4 \quad (10)$$

Mechanical energy is required by the compressor to calculate the refrigerant. Thermal discharge is performed on the condenser and the heat recovery (where the object will be cooled) occurs in the evaporator. To get a good evaporator performance the refrigerant at the condenser is lowered by an expansion valve. Here comes a bargain between the low pressures of the refrigerant followed by the low temperature with the flow rate of the mass of the refrigerant. COP vapor compression refrigeration engine is calculated by the following equations [10, 11, 13, 17, 18]:

$$COP = \frac{work\ compression}{refrigeration\ effect} = \frac{\dot{m}.(h1-h4)}{\dot{m}.(h2-h1)} \quad (11)$$

$$COP = \frac{(h1-h4)}{(h2-h1)} \quad (12)$$

2.3 Software refrigeration model

The use of software is used to offset the accuracy of analytical data analysis. Validation of performance analysis of VCR system on experimental data is done by using Genetron Properties 1.1 software. Genetron Properties 1.1 is a software that can be used to calculate and analyze fluid performance in a cooling system cycle. Input parameters for refrigerant and project description respectively are R236fa and Simplified Basic Cycle.

Table 3 shows input data parameters in the cycle of compressor, condenser, evaporator and suction line.

Input Cycle	Parameter
Compressor	Compressor displacement
Compressor	Compressor efficiency
Condenser	Condensing temperature
Condenser	Outlet subcooling
Evaporator	Operating temperature
Evaporator	Outlet superheat
Suction line	Temperature rise

3 Results and Discussion

3.1 Energy Analysis of the VCR system

The performance of the VCR system is usually measured by the cooling COP obtained in the experiment. High COP indicates that the VCR system works well and runs efficiently with the minimum required energy. Figure 3 shows the performance graph of the VCR energy system for various initial cooling charges at different fan rpm. Figures in this data indicate that COP values tend to be higher with an increase in the initial refrigerant load. However, COP decreases with increasing rpm fan. It should be noted that this VCR system is designed for cooling system by using refrigerant R22 compressor with maximum COP 2.98. Thus, it is normal for the system to have a slightly lower COP value than the compressor specs in use. The highest COP is achieved at the lowest rpm (1st rpm level) of about 3%. While the lowest COP occurs in the 2nd rpm level testing, which is lower by about 16%. If the COP data is averaged, then COP data generated using this fluid is about 2.7 or about 10.6% lower than the compressor specification used.

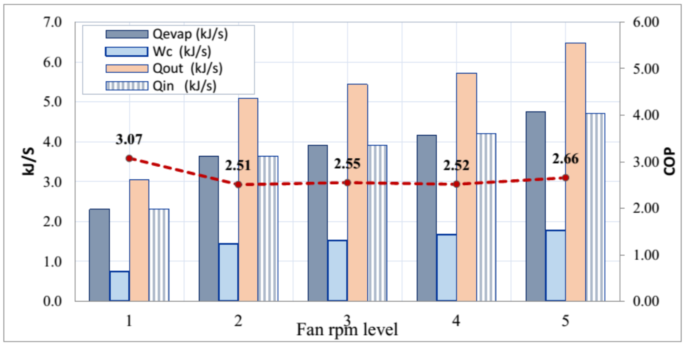

Figure 3. The performance of the VCR cycle system for various initial refrigerant charges at different fan speeds

3.2 Software refrigeration model

The modeling result of VCR system experimental data on variation of cooling loading at fan rpm was done with Genetron Properties 1.1 software. From results show up to levels that are still acceptable. The highest deviation between manual calculation results with software occurs at the 4-level kiapas rpm. While the lowest deviation occurs at rpm level fan -1. Figure 4 shows the value of COP analysis of mathematical calculations with sofware validation data Genetron Properties 1.1. From this data it is seen consistently that, the highest COP is obtained at the experimen level -1 or at the lowest fan rpm condition.

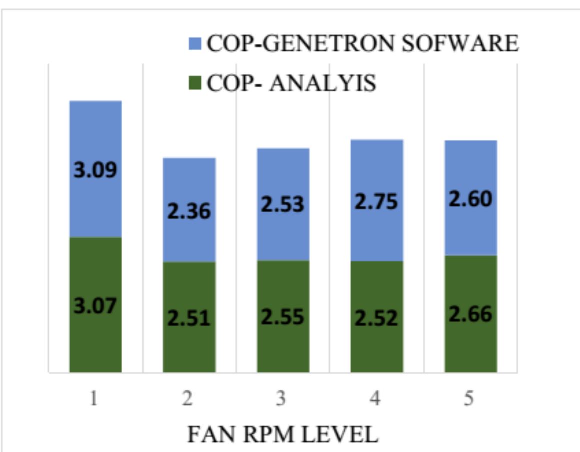

Figure 4. Software validation result of the VCR cycle performance.

4 Conclusion

Experimental data has been analyzed and validated using Genetron Properties 1.1 software. Analytical results show the performance of the HFC-236fa fluid that confirms the use of compressor censorship. Validation data using software has also verified that the results of experimental data analysis are mathematically not significantly different from the validation results using the software. For HFC-236fa fluid energy benchmarking data, further research will be conducted using the same VCR system using R22 refrigerant.

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