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Energy consumption analysis using HFC-134a and HFO-1234yf refrigerants in air conditioning applications: Technical and economical comparative study

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ABSTRACT
This study considered a theoretical investigation of appropriate drop-in replacement of Hydrofluorocarbons HFC-134a with Hydro-Fluoro-Olefin HFO-1234yf, which is environmentally friendly with low global warming potential (GWP). This numerically comparative performance analysisis limited to vapor compression refrigeration (VCR).HFO-1234yf was particularly chosendue to its similar thermo-physical properties with HFC-134a.

Both refrigerants were investigated, and condenser temperatures of about 38 °C.Results of evaporatorpressure drop, superheat, power input and cooling capacity are also reported. It was found that the operation condition, such as the coefficient of performance (COP) of HFO-1234yf,is lowerby 34% compared toHFC-134a. On the other hand, thesystem's power consumption using HFO-1234yf refrigerant is higher by 34% compared toHFC-134a refrigerant.Compared to HFC-134a, it was determinedthat refrigerant mass flowrate amounts ofHFO-1234yf werehigher by about 24%.Moreover, the compressor discharge temperature and pressure are 3% higher for HFO-1234yf compared toHFC-134asystems, and enthalpy is 6% lower for HFO-1234yf systems. Expansion valve outletrefrigerant temperature, pressure, and enthalpy are very similar.

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Nomenclature

A Cross-suction (m^2)
v Flow velocity (m/s)
V Specific volume(m^3/kg)
h Refrigerant enthalpy (kJ/kg)
Cp Specific heat ($kJ/kg.$℃)
$\dot{m}_r$ Refrigerant mass flow rate (kg/s)
P Power input (kW)
T Temperature (℃)
K Temperature in Kelvin (̊K)
$\dot{W}_C$ Compressorpower consumption (kW)
$\dot{Q}_{evap}$ Cooling capacity(kW)
η_{is} Isentropic Efficiency
η_v Volumetric Efficiency
η_{cs} Overall Compressor Efficiency

Abbreviation
COP*Coefficient of Performance*
GWP*Global Warming Potential*
ODP*Ozone Depletion Potential*
VCR *Vapour compression refrigeration*
HFC *Hydrofluorocarbon*
HFO *Hydrofluoroolefin*
CFC *Chlorofluorocarbon*
LCCP *Life cycle climate performance*
LCA*Life cycle analysis*
POE *Polyolester oil*
PVE *Polyvinyl ether lubricants*

I. INTRODUCTION

This study aims to investigate the theoretically proper drop-in alternative of HFC-134a with HFO-1234yf, an environmentally friendly refrigerant, by simulating the components of avaporcompression refrigeration system using a numerical method and Danfoss simulation software. The hydrofluoroolefins (HFOs), 2,3,3,3 tetrafluropropene, known as HFO-1234yf, is a refrigerant with a similar thermophysical property to the widely usedhydrofluorocarbons HFC- 134a refrigerant. The hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) are gradually phased down after the Montreal Protocol amendment in 2016 in Kigali (Rwanda) and replacing them with low-GWP (Global Warming Potential) and low-ODP (Ozone Deplete Potential).The HFC-134a was taken as the baseline refrigerant in the comparative performance analysis helping to find the essential change in the system equipment to handle the drop in refrigerant stated earlier. Also, to detect the compatibility with system components material and the environmental characteristics [4] [6] [16].Moreover, the system design needs to be optimized to improve the performance with HFO 1234yf handling. Inaddition,various compressors application such as reciprocating, scroll, screw, and centrifugal compressors in flooded systems. The compressor suction-line internal heat exchanger (IHX) is a crucial modification to the cycle to improve the thermodynamic properties of the system handling HFO-1234yf hence improving the superheating effect of the compressor power reduction and compressor life extension [21]. Moreover, the internal heat exchanger (IHX) positively influencesthe system operating HFO-1234yf. The COP increases by increasing the sub-cooling degree of the system.Additionally, according to the low vapor density at a higher refrigerant vapor temperature of the HFO-1234yf, the total system refrigerant charge is 10% lower than HFC-134a,influencing the operation and maintenance cost of the system. Consequently, the internal heat exchanger (IHX) is recommended to improve volumetric efficiency and energy performance. Also, the working pressure of the parallel flow condenser of HFO-1234yf refrigerant is lower compared to HFC- 134a refrigerant [20].Table (1) illustrates and compares the thermophysical and environmental properties, material compatibility, health and safety classification, and common application of HFC-134a and HFO-1234yf.

Thermophysical, environmental and safety properties of HFC-R134a and HFO-R1234yf

Parameter	R134a	R1234yf
Refrigerant type	HFC	HFO
Chemical nomenclature	1,1,1,2-Tetrafluoroethane	2,3,3,3-Tetrafluoropropene-1-ene
Chemical formula	CF3CH2F	CF3CF=CH2
Molecular mass Mw [kg/kmol]	102.3	114.04
Critical temperature Tcrit [°C]	101	94.7
Critical pressure Pcrit [bar]	41	34
Evaporation enthalpy (Latent heat) at 20 °C Δh_{evap} [kJ/kg]	182.5	149.3
Vapor Pressure at 20 °C [bar]	5.717	5.92
Normal boiling point Tboil [°C]	-26.3	-29.45
Melting Point [°C]	-142.3	-150
ODP	0	0
GWP_{100}	1430	4
Atmospheric life time [yr]	13.4	0.029
ASHREA safety classification	A1	A2L
Flammability	Non flammable	Low flammablility
Toxicity	Low toxicity	Low toxicity
OEL (Occupational exposure limit) [ppm]	1000ppm	200,000 ppm
Decomposition temperature [°C]	368	170–190
Acute Toxicity Exposure Limit (ATEL)	50,000	101,000 ppm
Common Application	Med temp,High temp, Residental & light A/C, DX Chillers, Cetrifugal Chillers, Mobile	Med temp,High temp, Residental & light A/C, DX Chillers, Mobile

Table 1*-HFC-134a and HFO-1234yfRefrigerant Properties*

HFO-1234yf is an alternative to HFC- 134a in mobile air conditioners, where the cooling capacity was slightly lower compared with HFC- 134a at different compressor RPMs. Moreover, the refrigerants' isentropic efficiency η_{is} is slightly lower for HFO-1234yf compared to HFC-134a. Furthermore, the compression ratio of HFC- 134a is higher than HFO-1234yf. Similarly, the subcooling range increased between 9 to 12 K. According to the lower latent heat of HFO-1234yf compared to HFC- 134a, which causes a high mass flow rate and a large pressure drop and leads COP to decline in HFO-1234yf [2]. The volumetric efficiency η_V, is a crucial factor defining the performance of the refrigerant flows through the vapor-compression refrigeration system, primarily through the compressor. As the ambient temperature, Ta is conversely affecting the volumetric efficiency η_V for all refrigerants. The result confirms the similarity of the volumetric efficiency η_V for HFO-1234yf and HFC- 134a refrigerants, which proves that HFO-1234yf is an appropriate alternative refrigerant for air-conditioning systems, including rotary compressors, expected of its higher volumetric efficiency [22].

1.1 Thermo-Physical Properties

Refrigerant properties arecrucial to designingthe vapor compression refrigeration cycle (VCRC) applications. The thermophysical properties andchemical stability are essential in (VCRC) design process,for instance,high latent heat, high critical temperature, positive evaporating pressure, high evaporating pressure, and low condensing pressure, appropriate heat transfer characteristics.Moreover, the normal boiling point and freezing point of the refrigerant is a crucial temperature to distinction between liquid and gas to provide a sufficient refrigerant phase change in refrigeration cycles, and it should be below the critical point. Safety propertiesinclude non-flammabilityand non-toxicity refrigerants, environmental impacts such as ODP and GWP, high efficiency, compatibility with compressor lubricants and equipment materials—cost, and availability [1] [5] [14].

1.2 Global Environmental Properties

Chlorofluorocarbons refrigerant CFCs and hydrochlorofluorocarbons refrigerantHCFCs release chlorine, which reacts with stratospheric ozone. Ozone depletion potential (ODP), including CFCs and HCFCs, will bephased out of production under the Montreal Protocol (UNEP 2009). In the United States, CFC production and importation were entirely banned in 1996.The global warming potential (GWP) index definesthe relative ability of C02 and its equivalents,such as Halocarbons (CFCs, HCFCs, and HFCs),which trap the radiant energy increasing the greenhouse gasGHG. A shorter atmospheric lifetime generally results in lower ODP and GWP100 values. The life-cycle climate performance (LCCP), which includes the total equivalent warming impact (TEWI),consists of the direct and indirect emissions effects associated with manufacturing the refrigerant and end-of-life disposal [1] [13].

1.3 Materials Compatibility

The Halogenated refrigerant HFO-1234yf is Chemically stable and satisfactorily compatible under normal conditions with most common metals, such as steel, cast iron, brass, copper, tin, lead, and aluminum. But Magnesium alloys and aluminum-containing more than 2% magnesium areincompatible. POEs and PVE lubricants are thermally and chemically stable of HFO-1234yf refrigerant, as stated by Rohatgi et al. (2012). Furthermore, Elastomeric hoses in mobile air-conditioning and gasketing materials with HFO-1234yf refrigerants were very similar to R-134a, as Minor and Spatz (2008) measured. In addition, the Silicone elastomer is not well-matched in HFO-1234yf according to the shrinkage rate in hardness. According to DuPont Fluoroproducts (2003), acrylonitrile-butadiene-styrene, polyphenylene oxide, and polycarbonate plastic materials were incompatible with R-l34a and HFO-1234yf refrigerants [1] [7] [14].

1.4 Health & Safety

The toxicity risk of TFA (Trifluoroacetate) to organisms and human health is essential to consider. The TFA degradation of the HFOs' refrigerants into the atmosphere, a rapid partitioning of TFA into droplets of clouds, rain, snow, and fog occurs. These TFA droplets contaminate the water bodies such as rivers, streams, and lakes, hence the groundwater, ecological environment, and water-treatment facilities [24].Low global warming potential gasesreduce the direct and indirect emissions of the refrigeration or air conditioning system by applying the Total Equivalent Warming Impact (TEWI) to meet environmental obligations. Hence, by increasing energy efficiency, reducing the refrigerant charge volumes,improving maintenance,minimizing and avoiding leakageto the atmosphere using waste refrigerant management and recovery and reclaim, and eliminating the need to produce new refrigerant gases [10].

II. LITERATURE REVIEW & BACKGROUND

Zilio et al. theoretically investigated HFO-12345yf asan eco-friendly refrigerant alternative to HFC-134a; they found the heating COPofHFC-134a is 4.04, which is higher by 5.9% than HFO-12345yf. The expansion valve adjustment of the HFO-1234yf system was modified, and the evaporation and condensation temperatureswere set to 0 ℃degrees and 45℃ degrees, respectively [23].DaviranS. et al.studied and investigated the performance of both refrigerants with different operation temperatures, HFO-1234yf and HFC-134a, adopted in an on-road automotive investigation.They found that the HFO-1234 performs better than HFC-134a according to the lower value of average pressure drop of HFO-1234 during condensation and evaporation, where pressure drop during condensation is 4% and 10% during evaporation[1] [5].

1.5 Design Considerations:

Thermal efficiency is evaluatedbythe vapor-compression system usingthe systemCOP and the volumetric cooling capacity. Also, the evaporator, condenser pressure, and temperature are the key factors describing the system's operation. Moreover, the COP is highly affected by the refrigerant critical point, where the condenser operating temperature is contrariwise proportional to the COP (Ramesh Chandra Arora, 2010).Due to safety reasons,flammability classification 2L indicatesa low risk of burning. Hence, the refrigerants'safety demands though similar to other flammable refrigerants (Energiteknik, 2014).A crucial point constraint of a vapor-compression system operationis the evaporation temperature set to approximately 0 ̊C and condensing temperature to around40 ̊C. The superheating and subcooling are set to 5 ̊C. The compressor’s isentropic efficiency is assumed to be 70%.(Adria´nMota-Babiloni et al, 2014).In order to increase compressor lifetime, the refrigerant discharge temperature mustbe reduced as much as possible (B.O. Bolaji et al., 2011).In addition,the system's pressure ratio and condenser pressure should be as low as possible. Hence, reducing system components and piping weightminimizes the system's initial cost (B.O. Bolaji et al., 2011) [8] [16] [18].

Direk.etal. find that the compressor speed directly influences the COP and cooling capacities of the (VCR)system with HFO-1234yf andHFC-134a refrigerants. Moreover, the internal heat exchanger (IHX)is simplya concentric double pipe modified to the system toenhance the COP and cooling capacities by increasing thesub-cooling temperature of the condensed liquid refrigerant, as Pottker and Hrnjak demonstrated. Furthermore, the internal heat exchanger (IHX) improves the superheating effect and accordingly increases the heat duty of the compressor;consequently, the compressor power increases, particularly at high compressor speeds.Also, the air stream temperature influences the cooling capacity [9].

III. METHODOLOGY

In this study, both refrigerants were under the following assumptions to find out and compare the critical performance data of the studied system of vapor-compression refrigeration(VCR):

- Steady-statesystem.
- Disregarded heat loss and pressure drops.
- Constant superheating and subcooling.
- Isenthalpic throttling in the expansion valve.

The Copland YB36K1E-TFMW-GCG compressor used in this experiment is compatible with refrigerants HFC-R134a and HFO-1234yf; this compressor is used for (MT)medium temperature applications, which is consistent with HFC and HFO refrigerants. The refrigerant velocity is approximated to 3.5 $m^3/_s$ to assure return and avoid noise where it is adequate for (MT) medium temperature application. To perform a system performance study; both refrigerantproperties were individually considered. At each point of the refrigeration cycle from a tablegenerated by Denso, the density of both refrigerants at the compressor inlet is 9.665 $kg/m^3$for HFC-134a and 11.96 kg/m^3 for HFO-1234yf and at 2.006 bar and 2.22 bar of pressure respectively;also, both refrigerants were at 0°C of temperature. Table (2) illustrate the main specifications of the scroll compressor used in the experiment according to manufacturer data.

Compressor model	Emerson's Copeland	
Code	YBD31K1E-TFMN-GBS	
Technology	Scroll	
Application	MT Medium Temperature	
Refrigerant	R-134a	R-1234yf
Cooling Capacity[kW]	5.82	5.47
Power supply	380 - 420 V	
Total power [kW]	3.92	
Nominal horsepower	5 hp	
Total current [A]	11.3	
Frequency [Hz]	50	
Phase	3 ph	
PED category	II	
Displacement [m³/h]	14.4	
Suction [inch]	7/8"	
Discharge [inch]	1/2"	
LP side volume [litres]	6.4 L	
HP side volume [litres]	0.6 L	
Tc cond. temp [°C]	45	

Table 2- Compressor Specifications

Figure (1) illustrates system Diagram which shows each point of the vapor compression refrigeration cycle for both refrigerants, where point (1) when presents the compressor refrigerant inlet, and point (2) presents the refrigerant leaving the compressor and entering the condenser. Point (3) illustrates the refrigerant condition at the sab cooling region after leaving the condenser, then point (4) shows the refrigerant condition after leaving the expansion valve and entering the evaporator.

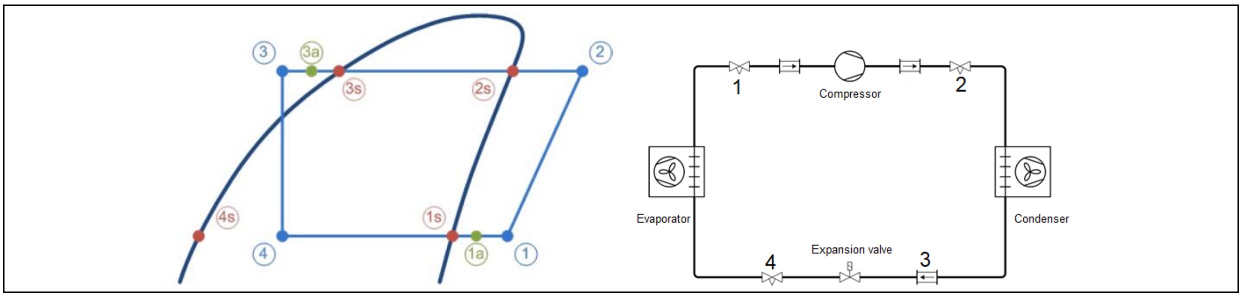

Figure 1-System Diagram

Figures (2& 3) show the p-(h) diagram for both refrigerants, illustrating the enthalpy(h)of each point in the cycle for both experimental refrigerants. Moreover, tables (3 & 4) show all thermodynamic properties details for each point in the cycle for both refrigerants.

HFC-134a

Point	Description	Temperature [°C]	Pressure (a) [bar]	Density [kg/m^3]	Enthalpy [kJ/kg]	Entropy [kJ/(kg·K)]
1	Compressor suction	-2.0	2.006	9.665	399.4	1.759
2	Compressor discharge	64.0	9.414	39.54	447.8	1.804
2s	Condensation dew point	37.2	9.414	46.19	418.8	1.714
3s	Condensation bubble point	37.2	9.414	1159	252.9	1.18
3a	Condenser outlet	37.2	9.414	1159	252.9	1.18
3	Subcooling	37.2	9.414	1159	252.9	1.18
4	Expansion valve outlet	-10.0	2.006	30.68	252.9	1.202
4s	Evaporation bubble point	-10.0	2.006	1327	186.5	0.9501
1s	Evaporation dew point	-10.0	2.006	10.04	392.6	1.733
1a	Evaporator outlet	-2.0	2.006	9.665	399.4	1.759

Table 3-HFC-134a Experimental Data

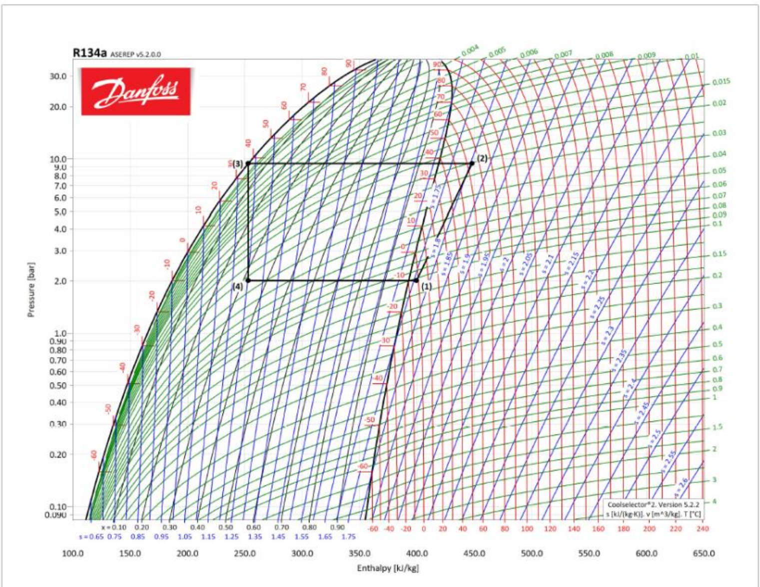

Figure 2- HFC-134a detailed log p-h diagram

HFO-1234yf

Point	Description	Temperature [°C]	Pressure (a) [bar]	Density [kg/m^3]	Enthalpy [kJ/kg]	Entropy [kJ/(kg·K)]
1	Compressor suction	0	2.218	11.96	365.6	1.63
2	Compressor discharge	71.1	9.754	45.29	422.7	1.718
2s	Condensation dew point	38.3	9.754	55.13	386.3	1.605
3s	Condensation bubble point	38.3	9.754	1041	252.4	1.177
3a	Condenser outlet	38.3	9.754	1041	252.4	1.177
3	Subcooling	38.3	9.754	1041	252.4	1.177
4	Expansion valve outlet	-10.0	2.218	32.13	252.4	1.2
4s	Evaporation bubble point	-10.0	2.218	1207	187.3	0.9528
1s	Evaporation dew point	-10.0	2.218	12.56	356.7	1.597
1a	Evaporator outlet	0	2.218	11.96	365.6	1.63

Table 4-HFO-1234yf Experimental Data

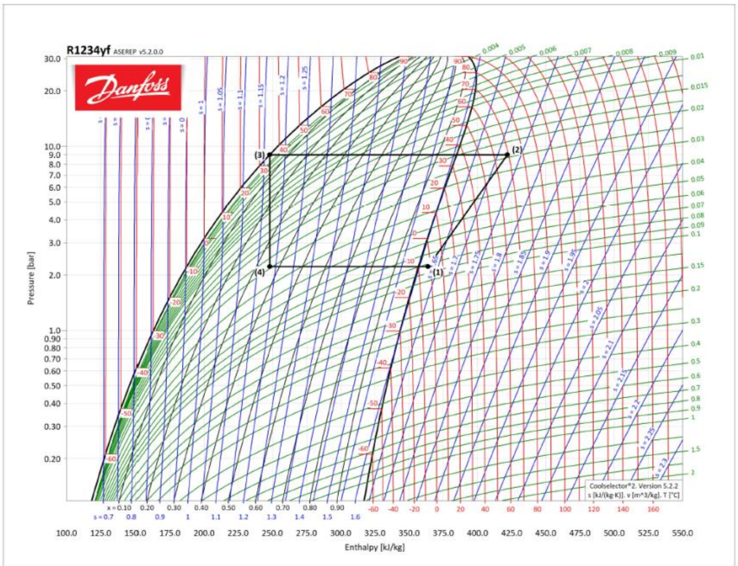

Figure 3- HFO-1234yf detailed log p-h diagram

The mass flow rate of both refrigerants obtained using the following equations:

$$\dot{m}_r = \frac{A.v}{V}$$

Equation 1-Mass flow rate

Where A present the cross-suction area of the inlet pipe, v is the flow velocity, and V is the specific volume of the refrigerant which can be obtained by the Ideal gas law $P.V = n.R.T$.

$$\eta_{is} = \frac{\dot{m}.(h_2' - h_1)}{\dot{m}.(h_2 - h_1)} = \frac{W_{is}}{W}$$

Equation 2- Isentropic efficiency

The isentropic efficiency data were extracted from the p-h chart (enthalpy and pressure), where the entropy of the compressor inlets and outlet presented by S_1=S_2, which means the entropy at point 1 and point 2 are identical for both refrigerants.

Then the compressorpower consumptionin kWcalculated using the following equation:

$$\dot{W}_C = \frac{\dot{m}_r.(h_2 - h_1)}{\eta_{is}}$$

Equation 3- Compressor Power Consumption

The experimental data were evaluated and determined with respect to measured temperature and pressure at each point of the system. Where the enthalpy of the refrigerant at the inlet and the outlet of the evaporator, $h_4$and h_1, respectively. Then, the cooling capacity, $\dot{Q}_{evap}$ of the evaporator can be computed in kW as follows:

$$\dot{Q}_{evap} = \dot{m}_r.(h_1 - h_4)$$

Equation 4- Cooling Capacity

On the other hand, the volumetric efficiency equation is presented in the following equation:

$$\eta_v = 1 + C - C.(\frac{P_h}{P_l})$$

Equation 5- Volumetric Efficiency

Where applied for both refrigerants with the same system configuration, where $C = \frac{v_C}{v_S}$, and P_h represent the high-pressure side of the system and P_l is the low-pressure side of the system for both refrigerants.

IV. RESULTS AND DISCUSSION

4.1 Isentropic Efficiency η_{is}

The isentropic efficiency is the ratio of work required for isentropic compression to the real work of the compressor applied to the refrigerant. The key factors influencing the isentropic efficiency is the compression friction, the losses in the fluid flow through the valves and its throttling effects, and the increase of the entropy as a result of heat exchange between the refrigerant and the cylinder wall during compression (Guo, 2007). The isentropic efficiency of the system using HFC-134a is higher than that of HFO-1234yf, which is 73.5% and 62.4%, respectively. The following equation illustrates the isentropic efficiency formula.

$$\eta_{is} = \frac{\dot{m}_r \, . (h'_2 - h_1)}{\dot{m}_r \, . (h_2 - h_1)}$$

Equation 6 - Isentropic efficiency

4.2 Compressor Power Consumption

The compressor is anessential device in the vapor compression refrigeration system, which is used to draw the refrigerant from the evaporator providing low pressure and temperature to remove heat from the space intended to be cooled and to compress the refrigerant into the condenser in aproper pressure to reject heat in the space which designed to be heated.

The power consumption of compressor in the experimented refrigerants of the HFC-134a and HFO-1234yfwere obtained as the following 7.839kW and 10.935kW respectively using the following equation.

$$\dot{W}_C = \frac{\dot{m}_r . (h_2 - h_1)}{\eta_{is}}$$

Equation 7 - Compressor Power Consumption

4.3 Cooling Capacity

The cooling capacity is defined as the capability of a cooling system to remove heat in the unit of kilo wattskW. The cooling capacity ofsystem using HFC-134arefrigerant is 17.441 kW, where it is for HFO-1234yf is 13.527 kWthis shows a reduction of 25.3% incooling capacity of the HFO-1234yf compared to HFC-134a. Thecooling capacity equation is illustrated as follows:

$$\dot{Q}_{evap} = \dot{m}_r \, . (h_1 - h_4)$$

Equation 8 - Cooling Capacity

4.4 Cooling Coefficient of Performance COP

Refrigerant selectioncritically impacts the efficiency of the vapor compression cycle.The COP (Coefficient of Performance) values for HFC-134a and HFO-1234yf refrigerants are 2.225 and 1.237 respectively. This indicates a significant decrease of 57.1% in the COP for HFO-1234yf compared to HFC-134a, the cooling COP equation is illustrated as follows:

$$\text{COP} = \frac{\dot{Q}_{evap}}{\dot{W}_C}$$

Equation 9 -Cooling Coefficient of Performance COP

4.5 Volumetric Efficiency η_v

The volumetric efficiency is a quantity of compressor ability to delivers the refrigerant without a direct impact to the compressor efficiency, the main factor to improve the volumetric efficiency is the perfect design to reduce physical compressor size to handle the proper refrigerant capacity. Moreover, the volumetric efficiency influenced by the same factors affecting the isentropic efficiency, the volumetric efficiencyequation is illustrated as follows:

$$\eta_v = 1 + C - C.(\frac{P_h}{P_l})$$

Equation 10 -Volumetric Efficiency

Then, the volumetric efficiency of the system using HFC-134a is 81%, and for HFO-1234yf is 82.3% which shows no significant difference between both refrigerants; also, it confirms a slight improvement with the HFO-1234yf refrigerant.

4.5 Overall Compressor Efficiency η_{cs}

The overall compressor efficiency for the hermetic compressor which applied in this experiment is defined as the ratio of isentropic work to the motor compressor power consumption.Moreover, to increase the specific volume of the refrigerant entering the compressor which led to reduce the pumping rate of the compressor and power consumption. The overall compressor efficiency of the system using HFC-134a refrigerant is 74% and the HFO-1234yf refrigerant is 62%, this shows the distinction of HFC-134a refrigerant over the HFO-1234yf refrigerant.The overall compressor efficiency and other performance parameters are illustrated in tables (5 & 6), also the overall compressor efficiency equation is illustrated as follows:

$$\eta_{cs} = \frac{\dot{m}_r.(h'_2 - h_1)}{\dot{W}_C}$$

Equation 11- Overall Compressor Efficiency

4.7 Pressure Ratio

The pressure ratio has an extreme influence on the efficiency of the vapor compression cycle. This reduction is related to changes in the thermodynamic and physical properties of the refrigerant at the inlet and outlet of the compressor. In this experiment, the refrigerant pressure ratio in the cycle for both refrigerants were approximately identical, where the pressure drop for HFC-134a is 78.7% and for HFO-1234yf refrigerant is 77.3% as illustrated in the table (5 &6).

It was found that the operation condition, such as the coefficient of performance (COP) of HFO-1234yf, is lower by 57.1% compared to HFC-134a. On the other hand, the compressor power consumption using HFO-1234yf refrigerant is higher by 33% compared to HFC-134a refrigerant.It was determined, compared to HFC-134a, that refrigerant mass flowrate amounts of HFO-1234yf werevery similar.Moreover, the compressor discharge temperature and pressure are 3% higher for HFO-1234yf compared toHFC-134a systems, and enthalpy is 6% lower for HFO-1234yf systems. Expansion valve outlet temperature, pressure, and enthalpy are very similar. Tables (5 & 6) clearly demonstrate and evaluate the key parameter of the performance of both experimental refrigerants.

HFC-134a

Compressor Power [kW]	Cooling Capacity [kW]	Cooling COP	Refrigerant Mass Flow [kg/s]	Overall Compressor Efficiency	Pressure Drop
7.839	17.441	2.225	0.119	74%	78.7%

Table 5- HFC-134a Experimental Results

HFO-1234yf

Compressor Power [kW]	Cooling Capacity [kW]	Cooling COP	Refrigerant Mass Flow [kg/s]	Overall Compressor Efficiency	Pressure Drop
10.935	13.527	1.237	0.119	62%	77.3%

Table 6- HFO-1234yf Experimental Results

Table (7) illustratestheannual system performance, cooling capacity, compressor power input, and the COPforHFC-134acompared to HFO-1234yf refrigerants which were conducted in the experiment with same conditions.

Annual system performance for HFC-134a compared to HFO-1234yf refrigerants

Refrigerant:	HFC-134a	HFO-1234yf	Difference	
Evaporating temperature	-10.0	-10.0		°C
Return gas temperature	-2.00	0.00		°C
Annual electricity consumption	34335	47895	-33.0 %	kWh
Parameters at full load and ambient temperature 40.0 °C				
Cooling capacity	17.44	13.53	25.3 %	kW
Power input	7.84	10.94	-33.0 %	kW
Overall Compressor Efficiency	74%	62%	17.6 %	
COP	2.23	1.24	57.1 %	

Table 7-Annual system performance for HFC-134a and HFO-1234yf refrigerants

V. ANALYSIS

The experimental resultshave proven that isentropic and volumetric efficiency values for HFO-1234yf were close to results obtained using HFC-134a. It was figured out that HFO-1234yf refrigerant could be safely used in the systems designed for HFC-134a. Moreover, some improvements in the energetic parameters may be achieved by making possible adjustments to the expansion valve.

VI. CONCLUSIONS

This study concluded, as a result, shows the compressor power consumption of HFO-1234yf refrigerant is higher by 33% compared to HFC-134a refrigerant, counterrally the cooling capacity of HFO-1234yf refrigerant is lower by 25.3% when compared to HFC-134a refrigerant. Similarly, the cooling COP of HFO-1234yf refrigerant is lower than HFC-134a refrigerant by 57.1%. Moreover, their refrigerant mass flowrate is approximately identical, where HFO-1234yf refrigerant is higher by 0.4% than HFC-134a.Furthermore, the pressure drop during the condensation and evaporation process of HFO-1234yfrefrigerant is slightly lower than HFC-134a for an identical mass flow rate of 77.3 % and 78.7%, respectively.The isentropic efficiency ofthe system using HFC-134a is higher than that of HFO-1234yf, which is 73.5% and 62.4%, respectively.Then, the Volumetric efficiency of the system using HFC-134a is 81%, and for HFO-1234yf is 82.3% which shows no significant difference between both refrigerants; also, it confirms a slight improvement with the HFO-1234yf refrigerant. The annual power consumption of the compressor using HFO-1234yf is higher by 33% when compared to HFC-134a refrigerant.

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