Original Article

Economic analysis of refrigerant blend compared to conventional R-134a based on Power consumption for air conditioning application

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Abstract

Aim: This paper presents the power consumption analysis of refrigerants HFO-1234yf , HFC-134a and their blends at different mass fraction ratios for better performance and cooling capacity.
Materials and Methodology: HFO-1234yf is an eco-friendly refrigerant with higher power consumption, HFC-134a is a refrigerant with very good COP and also with high GWP 1430. To overcome this, Tests have been carried out with blending these two refrigerants(X3, X4, X5, X6, X7) and two pure refrigerants (X1, X2) with two different evaporating temperatures (15 C and 30 C). CYCLE_D-HX simulation tool is used to enthalpy and entropy calculations. Thermodynamic analysis has been done to find out Power consumed and Cooling capacity of an air conditioning system. Statistical Packages for the Social Sciences (SPSS) software was used for determining the statistical significance between the two groups. The parameters were maintained as confidential ratio of 95%, threshold 0.01, G power 80% and enrolment ratio as 1. Results and Discussion: Results show that Power consumption at Te=15 C (0.26008 KW) for HFO-1234yf is higher than Te=30c (0.23463KW). There exists a statistically insignificant difference between the two groups (p=0.797; p>0.05).
Conclusion:Te=30 C provides less power consumption and moderate cooling capacity than Te= 30C for the selected refrigerants and for the selected mass fraction ratio.
Keywords: HFC-134a, HFO-1234yf, CYCLE_D-HX, Power consumption, cooling capacity, Evaporating temperature(Te) , Air conditioning, VCR cycle.

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INTRODUCTION:

This paper presents the Power consumption analysis of refrigerants HFO-1234yf /HFC-134a and their blends, using CYCLE_D-HX simulation tool working with two different evaporating temperatures and maintaining speed, Condensing temperature constant. During several years, HFC-134a has been vastly used as a refrigerant in Air conditioning and refrigeration applications. Investigations concluded that HFC contributes to environmental threats (Pabon et al. 2020). According to F- gas regulation with respect to Kigali amendment, Refrigerants with GWP of 150 should be eliminated and not approved to use in any applications (Smith 2015). To replace HFC-134a, HFO (hydrofluoroolefin) 1234yf and 1234ze can be used as a primary replacement for small scale applications like automobiles air conditioning systems. (Koban 2009).

The total number of research articles related to this study in Google scholar is 4440. (Tasdemirci, Alptekin, and Hosoz 2020) explains about automotive heat pumps, HF0-1234yf showed 13.9% lesser heating capacity than HFC-134a. (Kadam et al. 2021) performed 4E (Exergy, Energy, Environmental, and economic) analysis using HFC-134a with comparison to R717. Also explains about district cooling systems to reduce power consumption and to protect the environment. (Nunes et al. 2015) explains optimization and dynamic state response of a single VCR system using HFO-1234yf, HFC-134a and R12 refrigerants, with cooling capacity of 1-3 KW and used Air as cooled fluid. (Fridley et al. 2001) explains about energy efficiency room air conditioning systems and cost-efficiency analysis, and made a technical analysis of single-package and split type air conditioners.

Our team has extensive knowledge and research experience that has translate into high quality publications(Bhansali et al. 2021; Jayanth et al. 2021; Sudhakar, Ravel, and Perumal 2021; Sathiyamoorthi et al. 2021; Deepanraj et al. 2021; Raju et al. 2021; Arun Prakash et al. 2020; Kamath et al. 2020; Shanmugam et al. 2021; Rajasekaran et al. 2020; Adhinarayanan et al. 2020; Rajesh et al. 2020; Aurtherson et al. 2021). The drawback of this study is, HFO-1234yf shows high power consumption at lower temperatures compared to HFC-134a and gained knowledge on power consumption analysis of air conditioning systems. The aim of this study is to analyze power consumption of both the refrigerants and their blends at different mass fraction ratios, at different evaporating temperatures.

MATERIALS AND METHODOLOGY:

This study was conducted in a Renewable energy laboratory, Department of Energy and Environment,Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, SIMATS. Sample size was calculated using previous literature (Güngör and Hoşöz 2021). Gpower software is used for determining sample size for each algorithm requires 7 samples and totally 14 sample tests have been carried out, by varying the evaporator temperature(Te), (15 ºC and 20 ºC) mentioned below Table 1. The parameters were maintained as a confidential ratio of 95 %, threshold 0.01, G power 80 % and enrolment ratio as 1. In this study, no Human and animal samples were used so no ethical approval is required.

In this study CYCLE_D-HX tool was used to carry out power consumption analysis for air conditioning application.This simulation tool includes 70 single compounds and 96 pre-defined blends. Simulation results include pressure-enthalpy and temperature-entropy outlines. REFPROP.10 software was developed by NIST (National Institute of Standards and Technology). It is a refrigerant thermophysical characteristics database. This simulation tool calculates the thermodynamic and transport properties of fluids and its mixtures. In this study, a virtual model of the air conditioning system was developed using CYCLE_D-HX simulation software, developed by NIST (National Institute of Standards and Technology). Thermodynamic properties were taken from REFPROP.10 software. This air conditioning system works on the principle of VCR (cycle vapor compression refrigeration cycle). A typical VCR consists of an evaporator, condenser, compressor and throttling valve. In this study, Results have been evaluated without an internal heat exchanger IHX.

Table-1 explains the Refrigerant samples (HFO-1234yf, HFC-134a) and blends mass fraction ratio. To perform this study, Evaporating temperatures are maintained Te=15 C and Te= 30 C by maintaining the constant speed of the compressor at 1800 RPM and constant condensing temperatures for both the test conditions. Simulation results from CYCLE_D-HX and Refrigerant properties from REFPROP.10 software are taken into consideration for mathematical analysis to find out the power consumed at the above mentioned evaporating conditions and cooling capacity. Refrigerant charge is considered as 0.8KG. Motor efficiency is taken as 80%.

STATISTICAL ANALYSIS:

SPSS tool is used for T- test statistical analysis of power consumption analysis of HFO-1234yf (X2) and HFC-134a (X1) refrigerants and their blends (X3, X4, X5, X6) at different mass fraction ratio. The independent variable is evaporating temperatures (15 C and 30 C) and dependent variable is power consumed .Independent T test analysis is used to carried out to find power consumption analysis of both the evaporating temperature

RESULTS:

Table 1 represents the mass fraction ratio of refrigerant samples and their recognition used in this study to perform power consumption analysis. Table 2 and Fig.1, represents the Average power consumption (KW) of Air conditioning unit with Evaporating temperatures Te=15 C and Te=30 C working with HFO-1234yf , HFC-134a and their blends. It has been observed that while X1 consumption showed lower power consumption (0.24088 KW, 0.21544 KW). While X2 composition shows higher power consumption, (0.260085 KW, 0.234635 KW). This is due to their thermodynamic properties of refrigerants. It has been also observed that, at higher temperatures (Te= 30 C) Power consumption is low compared to (Te=15 C). This is due to, at higher temperatures Compressor work will be low in Air conditioning units. The compressing mechanism consumes more power in the VCR cycle. It has been observed that, Cooling capacity and power consumption increases at lower temperatures, in both the refrigerants, This is due to, at Lower temperatures, compressor input work will be high. Compressor consumes power during the refrigeration process, to increase the pressure of the refrigerant.

Table 3 and Fig.2 represents the Average cooling capacity (KW) of Air conditioning unit with Evaporating temperatures Te=15 C and Te=30 C working with HFO-1234yf , HFC-134a and their blends. It has been observed that HFC-134a shows higher cooling capacity in Te=15 C compared to Te=30C. It is due to lower temperatures, Mass flow rate is high and that results in higher cooling capacity i.e evaporative cooling will be high. HFO-1234yf has lower cooling capacity in both temperature conditions (0.5049, 0.4471). As the mass fraction ratio of HFO-1234yf increases with HFC-134a, cooling capacity decreases i.e X3,X4,X5,X6,X7.

Table 4 represents the Statistical analysis of Evaporating temperatures T_E=15° C and T_E=30° C temperatures . It is observed T_E=30° C has lower power consumption than T_E=15° C. Table 5 represents the independent t-test showing significant difference between the two groups. There exists a statistical significant difference between the two groups ($p=0.797$; $p>0.05$).Fig.3. Bar chart representing the comparison of mean values of T_E 30° C and T_E 15° C . It was found that T_E 30° C showed lesser power consumption with mean (0.22681 KW) compared to T_E 15° C (0.252265 KW). X axis: temperature, Y-axis: mean evaporation rate, ± 1 SD.

DISCUSSION:

Power consumption of Te=15 C is high and cooling capacity is also high in HFC-134a compared to HFO-1234yf . T-test statistical analysis has been done to find significance and it is obtained as ($p=0.797$; $p>0.05$) .

From the literature study comparison of HFC-134a and HFO-1234yf refrigerants and their blends for power consumption analysis in air conditioning applications, Te = 30 Cshows better performance than Te = 15 C.(Tasdemirci, Alptekin, and Hosoz 2020; Direk and Kelesoglu 2019)Power consumed by HFO-1234yf with IHX was increased by 5-8% and cooling capacity was increased by 11-12%. (Siricharoenpanich et al. 2019) If mass flow rate is higher, it has an effect on the condenser, resulting in high pressure drop. Power input decreases, cooling capacity increases with increase in Mass flow rate. This results in a 31% increase in COP. (Cho, Lee, and Park 2013) HFC-1234yf showed lower power consumption and cooling capacity than HFC-134a by 4-7%. Cooling capacity without IHX of HFO-1234yf system shows decrement upto 7%, but with IHX decreased upto 1.8%. (Direk et al. 2017) compared HFO-1234yf with HFC-134a system with and without IHX, at 25% effectiveness relative cooling capacity is not influenced by changing condenser and evaporator temperatures.

The limitations of this study are complexity of the VCR cycle,and refrigerant leaks at the system due to high mass flow rates. At a very lower temperature power consumption will be very high. To overcome the drawback of the proposed method, use of efficient IHX internal heat exchangers and recirculation of coolants may reduce minimum power consumption.

CONCLUSION:

Based on the results obtained, Power consumed at Te= 30 C is low compared to Te= 15 C and the cooling capacity for Te = 15 C is high compared to Te = 30 C for the collected data.

DECLARATION:

Conflict of interests

There is no conflict of interest in this manuscript.

Authors contribution

Author SS was involved in experimental analysis, data collection and manuscript writing. Author AS was involved in conceptualization, data validation. and in critical review of manuscript.

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Tables and figures

Table 1: Samples mass fraction ratio and its recognition used in this study

S.NO	REFRIGERANT SAMPLE	MASS FRACTION RATIO	RECOGNITION
1	R-1234yf/R-134a	0/100	X1
2	R-1234yf/R-134a	100/0	X2
3	R-1234yf/R-134a	90/10	X3
4	R-1234yf/R-134a	80/20	X4
5	R-1234yf/R-134a	70/30	X5
6	R-1234yf/R-134a	60/40	X6
7	R-1234yf/R-134a	50/50	X7

Table 2: Average power consumption (KW) of Air conditioning unit with Evaporating temperatures Te=15 C and Te=30 C working with HFO-1234yf , HFC-134a and their blends.

Refrigerant sample	Te = 15 c	Te = 30 c
X1	0.24088	0.21544
X2	0.260085	0.234635
X3	0.254413	0.228973
X4	0.254016	0.228576
X5	0.253724	0.228284
X6	0.252259	0.22679
X7	0.250483	0.225043

Table 3: Average cooling capacity (KW) of Air conditioning unit with Evaporating temperatures Te=15 C and Te=30 C working with HFO-1234yf , HFC-134a and their blends.

Refrigerant sample	Te = 15 C	Te = 30 C

X1	0.5973	0.5151
X2	0.5049	0.4471
X3	0.5053	0.4675
X4	0.5119	0.4687
X5	0.5275	0.4863
X6	0.5492	0.4872
X7	0.5531	0.4913

Table 4: Statistical analysis of Evaporating T_E=15º C and T_E=30º C temperatures . It is observed T_E=30º C has better performance than T_E=15º C.

	Groups	N	Mean	Std.Deviation	Std.Error Mean
Power consumption	T_E=15º C	7	0.252265	0.005827	0.002202
	T_E=30º C	7	0.226812	0.005819	0.002199

Table 5: Independent t-test showing the statistical analysis. There exists a statistical insignificant difference between the two groups (p=0.797; p>0.05)

Independent Samples Test										
Power consumption KW	**Equal Variances Assumed**	**Levene's Test for Equality of Variances**		**T test for Equality of Means**						
		F	**Sig**	**t**	**df**	**Sig(2 tailed)**	**Mean differences**	**Std error differences**	**95% confidence Interval of the Difference**	
									Lower	**Upper**
	Equal Variances Not Assumed	.000	0.797	8.177	12	0.023	.025453	.003112	.018671	.032235
				8.177	12	0.019	.025453	.003112	.018671	.032235

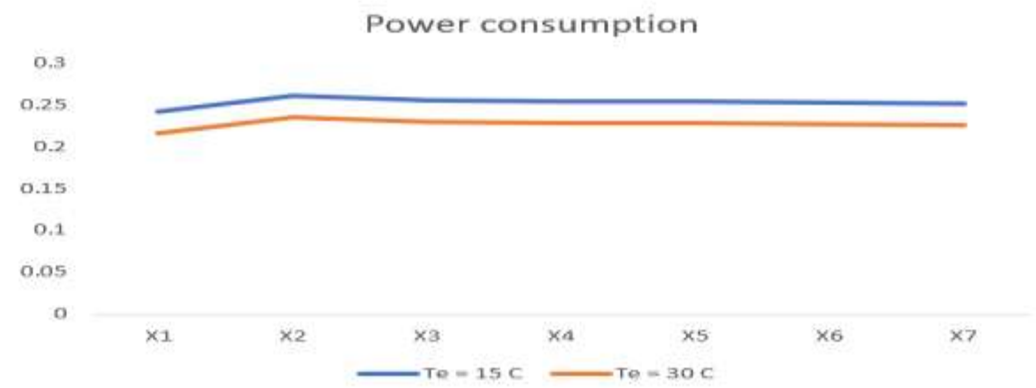

Fig. 1. Represents the Average power consumption (KW) of Air conditioning unit with Evaporating temperatures Te=15 C and Te=30 C working with HFO-1234yf , HFC-134a and their blends.

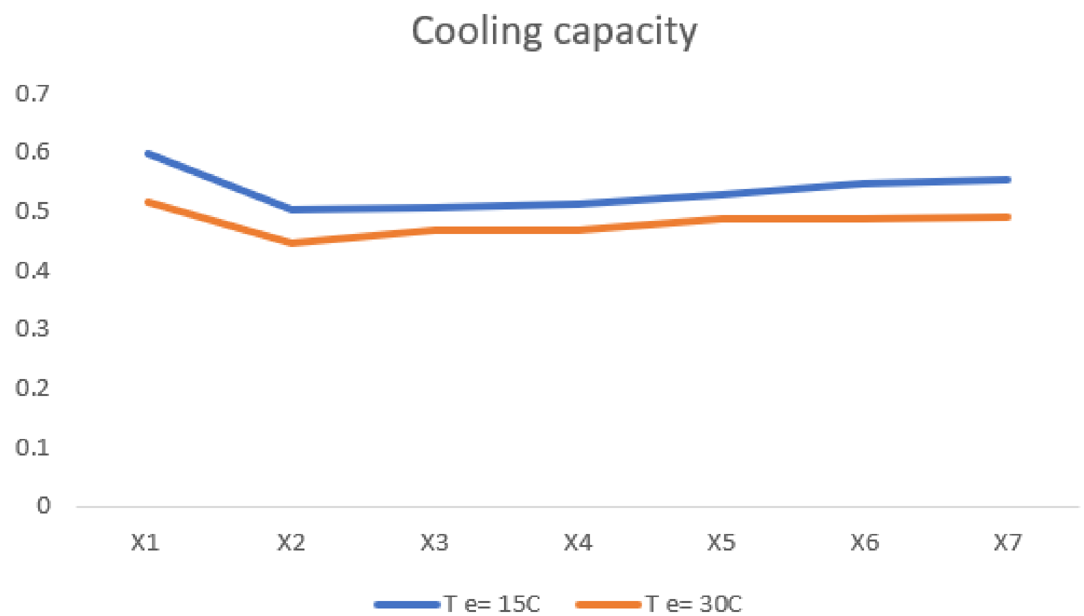

Fig. 2. Represents the Average cooling capacity (KW) of Air conditioning unit with Evaporating temperatures Te=15 C and Te=30 C working with HFO-1234yf , HFC-134a and their blends.

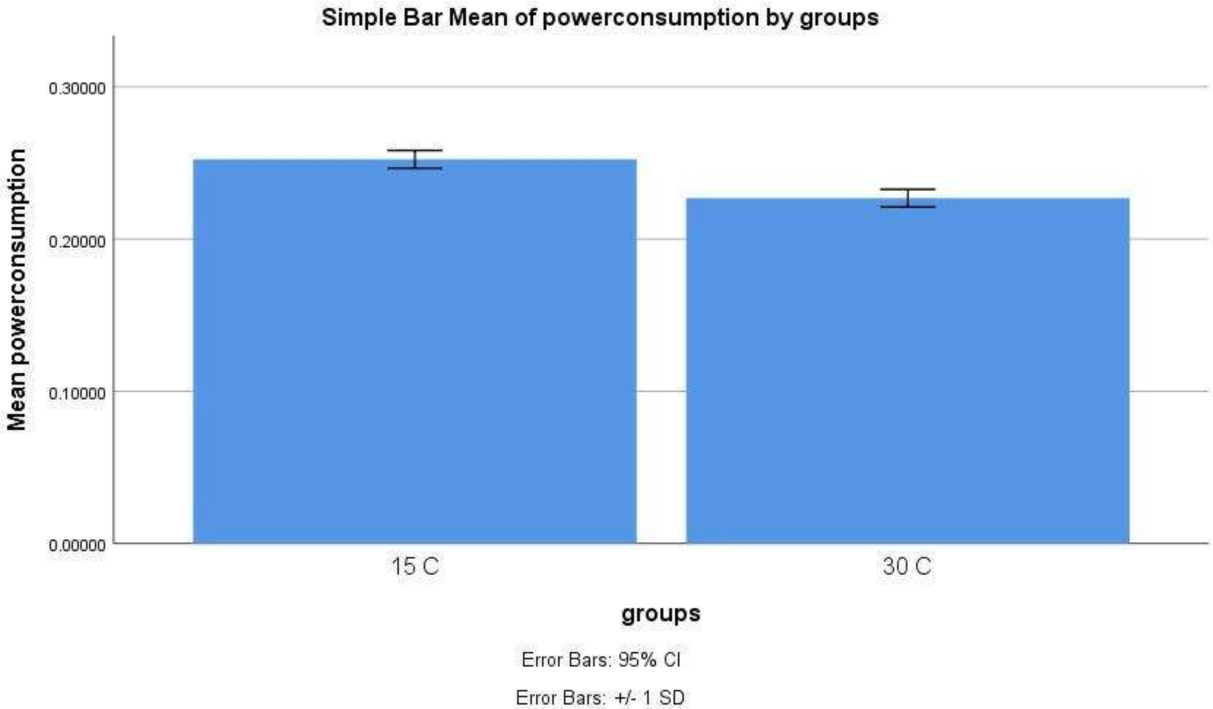

Fig. 3. Bar chart representing the comparison of mean values of T_E 30º C and T_E 15º C . It was found that T_E 30º C showed lesser power consumption with mean (0.22681 KW) compared to T_E 15º C (0.252265 KW). X axis: temperature, Y-axis: mean evaporation rate, ± 1 SD