A review on comparative evaluation of R1234yf as alternate refrigerant to R134a in mobile air conditioning system

Key words:
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Abstract

The HFC emission from automobile air conditioning system is major contributor to global HFC emission. As concerns with environmental aspect low global worming potential refrigerants is extreme need for air conditioning and refrigeration sector. The global warming potential of refrigerant R1234yf is 4 whereas refrigerant R134a with high GWP 1430, and has similar thermodynamic properties to R134a. In the present study thermodynamic properties of a new generation, low GWP R1234yf is compared with different refrigerants. The thermodynamic cycle analysis and experimental analysis of varies research studied here for mobile air conditioning system with refrigerant R1234yf as an alternate refrigerant to R134a over different operating conditions. From the study, it can be summarised, that the energy performance of R1234yf is obtained close results to the system using refrigerant R134a with application of internal heat exchanger at lower condensing temperatures. Hence, even though the performance parameters values for R 1234yf are lower than that of R134a, but the difference is comparatively small, so R1234yf with introducing internal heat exchanger can be a possible good alternative to R134a due to its environment friendly properties.

Nomenclature

A2L	Mildly flammable refrigerants category
GWP	Global Warming Potential
HCFC	Hydrochlorofluorocarbon
HFC	HFC Hydrofluorocarbon
ODP	Ozone depleting potential
HFO	HFO Hydrofluoroolefin

MAC	MAC Mobile Air Conditioning
ODS	ODS Ozone-depleting substance
GHG	greenhouse gas
F gases	Fluorinated greenhouse gases
COP	Coefficient of performance
W	Work (kW)
IHX	Internal heat exchanger
UA	Overall heat transfer coefficient (W / K)
Taie	Temperature of air inlet to the evaporator
Taic	Temperature of air inlet to the condenser

Introduction: -

Montreal Protocol (1989) [1] aimed to remove use of refrigerant containing chloride and fluoride gases due to Ozan Depletion Potential. Since many of the refrigerants are found to be greenhouse gases also TEWI (total equivalent warming impact) in addition to ODP has become an important criterion for developing environmentally safe alternate refrigerants. This aspect formed part of the KYOTO summit held in December 1997. The KYOTO summit agreed that by 2010 greenhouse gas emission from industrialized countries be reduced to level below that of 1990. The gases covered are CO2, nitrous oxide, methane, CFC, sulphur hexa fluoride and HCFCs. Most of the HCFCs are in recent practise are 2000 times high potent than CO2 in terms of GWP for air conditioning and refrigeration climate consideration involves optimizing refrigerants, recovery, recycling, servicing practice and disposal. For earth climate, Montreal Amendment scheduled to phase out HCFCs completely by 2020 in developed countries and the process of phase out started in 2013 and then stepwise reduction until complete HCFCs phase out by 2030. Production/use of HFCs (R32, R125, R134a, R143a and their blends R404A, R407 and R410) is not regulated by Montreal protocol but may be regulated by individual countries. The Kigali Amendment is an amendment[2] to the Montreal Protocol adopted by the 28th meeting of parties to the Montreal Protocol on substances that deplete the Ozone Layer on 15 October 2016 in Kigali, Rwanda, aims to phase-out of hydrofluorocarbons by reducing their consumption and production. Under Kigali Amendment, HFCs global use will be cut by around 85% before 2050.

The mobile air conditioning system is one of the major considerable sources of greenhouse gas emission. The table represents the emission associated with R134a system during life cycle. Yang et al. [3] evaluate up to 20 % of energy from fuel use in the MAC. The direct emission values estimation by Sherman et al. [4] considering the value summarizes as in following table 2.

The table 1 summarised the value of average direct emission of non-enhanced system with R134a and that of enhanced R134a system and alternate refrigerant R1234yf. Due to lower GWP of R1234yf direct emission is significantly lower relative to system with R134a.

Table 1 Direct GHG emission(average) [4]

	Emission total (kg of CO_2e)		**% Compared to Non-Enhanced R134a**	
Emission source	**Non-Enhanced R134a**	**Enhanced R134a**	**Enhanced R134a**	**R1234yf**
Initial charge manufacture	2.5-4.5	2.5-4.5	0%	+174 %
Leakage	597-1190	298-597	-42%	-99.90%
Recharge manufacture	2.3-3.8 (3 service events)	1.5-2.5 (2 service events)	-17%	+76 %

Service	83	83	0%	-99.90%
EOL	104	104	0%	-99.90%
Direct emission total	788-1390	489-788	-10%	-98%
indirect	3460-10300	2080-5700	-	-
Total	4250-11700	2570-6480	-	-

Different methods of production of R1234yf are analysed by Sherry et al [5] and concluded that though the short-term cost of R1234yf is higher by factor 10, but the long-term cost are 2-3 times higher than that of R134a. Globally, HFCs emitted of by air conditioning, refrigeration and MVAC sectors is approximately 80%, with the remainder accounted by the fire suppression, solvents sectors, foam-blowing and aerosols. While majority of global HFC emissions cause by developed nations, the total HFC emissions is projected quadruple by 2030 in developing nations. The HFC emission increasing rapidly driven by the increase in refrigeration and AC demand.

As from the table 2 most of the properties are same for both the refrigerant. ODP is zero for both refrigerant and boiling point for R134a and R1234yf are –26.07 [°C] and –29.45 [°C] respectively. Critical pressure and critical temperature are also higher for both the refrigerant and value is also same so we can easily design compressor because of higher value of critical pressure and temperature. Self-ignition temperature is 405 [°C] for R1234yf which is quite higher so flammability is issue is also less.

Thermophysical property

Pamela reasor et. al[6] study about the thermophysical property of R1234yf and compared values to the R134a and R410A to evaluate the drop in replacement potential in R1234yf in system designed for these other refrigerants. The thermophysical properties of refrigerant R1234yf is very similar to R134a and not as similar to R410A. The simulation study has shown that the for-outlet temperature and heat load R134a and R1234yf have similar results however pressure drop does vary and pipping design modification.

Significant potential for environment regulation observes by Barbara minor [7] for R1234yf as compared to R134a, R152a a and CO2 world's major region by Life Cycle Climate Performance (LCCP) calculation. As per ASTM-681-04(ASTM-2004) HFO R1234yf is mildly flammable and less than HFC-152a and HFC-32.

Akasaka tanaka et. Al [8] and Higashi studied about the thermo physical properties of R1234yf and R1234ze(f). R1234yf is expected as the new source of low GWP and zero ODP. The critical temperature, critical density and critical pressure are some the refrigerant thermo physical properties, which can be used to develop the air conditioners. R1234yf has lower GWP, but mildly flammable and with the double bond it become not stable. The acentric factor acts as the important factor to predict the thermo physical properties by the state of cubical equation. Based on the analysis of author, critical temperature of R1234yf is low when compared to the R1234ze (f).

Table 2 Refrigerant property comparison R134a and R1234yf [6][9] [10]

Refrigerants	Chemical composition	Molecular weight [kg/kmol]	Normal boiling point [°C]	Critical Temp[°C]	Critical pressure [MPa]	ODP	GWP	Safety class (Security classification ASHRAE 34)	Atmospheric life time (year)
R134a	CH2FCF3	102	-26.07	101.1	4.059	0	1400	A1	14
HFO-1234yf	CF3CF=CH2	114	-29.45	95	3.382	0	4	A2L	<0.05 (11 days)
R152a	CF3-CH-F2	66.5	-25	113.5	45.8	0	140	A2	16.4 days
R290	CH3-CH2-CH3	44.096	-42.09	134.6	4.23	0	11	A3	1.6
R600a	CH3-CH-CH3-CH3	58.12	-11.67	134.6	3.65	0	3	A3	0.034

R407C	R32+R125+R134 (23/25/52)	86.2	-43.6	86.1	4.62	0	1530	A1/A1	0.016 (6 days)
R410A	R32+R125 (50/50)	72.56	-50.5	72.5	4.96	0	1730	A1/A1	18.18
R404A	R125+R134+R143 (44/4/52)	97.6	-46.5	72.04	3.72	0	3300	A1/A1	16.95

Kumar et. al [11] investigated the impact of compression ratio on the strength of various materials to reduce flammability. By reducing the compressor ratio, system operating temperature and pressure can be decrease which results in reduction in flammability of R1234yf. So that the chance of leakage of oil and refrigerant to the environment from the system reduce, therefore lower the risk of flammability. For both the refrigerant the thermal properties and material compatibility is nearly similar. Retrofitting can be performed easily in the currently existing automobile air conditioning system operating with R134a. At present the price of R1234yf is higher as compared to R134a. The COP and cooling capacity of R1234yf can be increase by reducing the mass of R1234yf refrigerant with comparatively smaller compression ratio, with more efficient minichannel evaporator and condenser.

Sundaresan et al [12] study the thermo physical properties and process of R134a and R1234yf. The result also predicted many terms and factors to know the importance of these refrigerants R134a and R1234yf. According to the evaluation of ANSI standard 97 no evidence of break down has been seen of R1234yf with POE oils of refrigeration and other materials. R-1234yf requires higher compressor work as compared to R134a. R1234yf has a shorter run time to complete the cycle of compressor when compared to other refrigerants.

Yohan Lee et al[13] have studied about the alternative refrigerant as a replacement of R134a they have taken refrigerant R1234yf and mixture of R134a/R1234yf with different compositions 15%, 10%, and 5% and measured in both weather conditions. For mixture of R134a//R1234yf, flammability reduces with more R134a and for 10% and above content of R134a, the mixture turns non-flammable.

Biao Feng et al[14] studied flammability behaviour of R1234yf refrigerant with flame retardants. The experimental results suggested reduced combustibility hazards of refrigerant R1234yf.

The spherical vessel and schlieren photography method applied to measure burning velocity of R1234yf by Takizawa et all[15] and found 12 $\pm$0.3 cms^{-1} which is lower than that of HFC 32 (6.7 cms^{-1}). The low burning velocity reduce the fire hazard during utilization.

Esbri et al [16] performed experimental study of refrigerant R1234yf as a replacement of R134a in current automobile air conditioning system. The thermo physical properties of R34a and R1234yf are identical and R1234yf is referred as the good option to replace the R134a in the application of air conditioning and refrigeration. Chlorine is not containing in R1234yf and hence the ODP value is zero. The GWP is low and the emissions of 1234yf could not increase in trifluoroacetic acid (TFA) concentrations of rain water. lower cooling capacity of R1234yf to the R134a is observed.

The transport characterises of different refrigerant compared by Atilla et al[17] conclude that due to lower liquid viscosity of R1234yf than R134a the friction is lower and hence less energy consumption. Fig.1. The lower value of liquid density of R1234yf results in less need of refrigerant charge and can meet cooling capacity compared to R134a Fig.2.

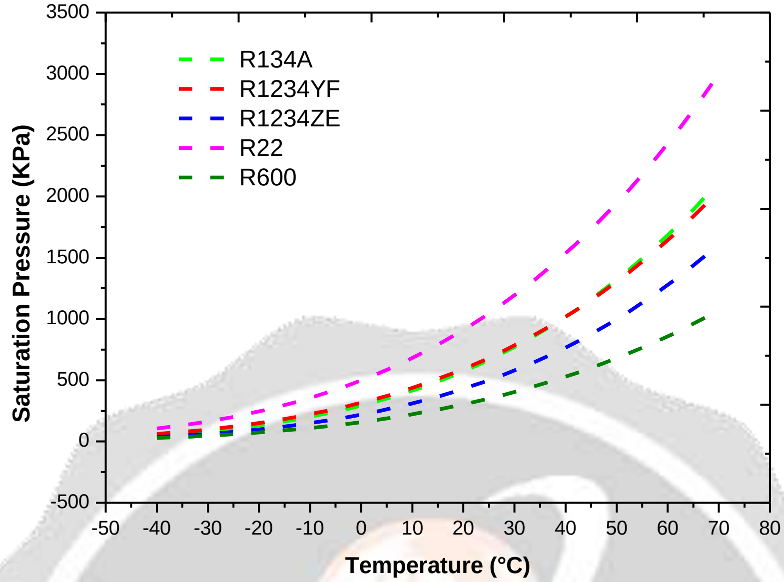

Fig. 1 Saturation pressure Vs Temperature (EES)

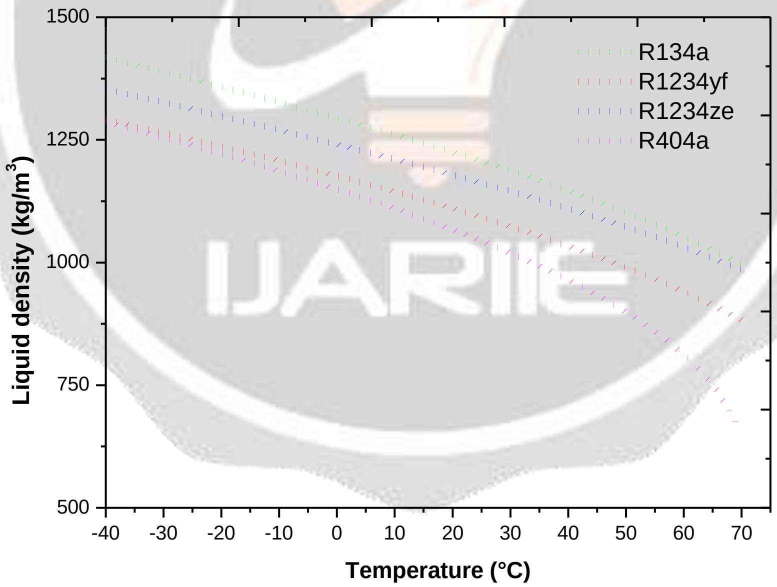

Fig. 2 liquid density variation with temperature (EES)

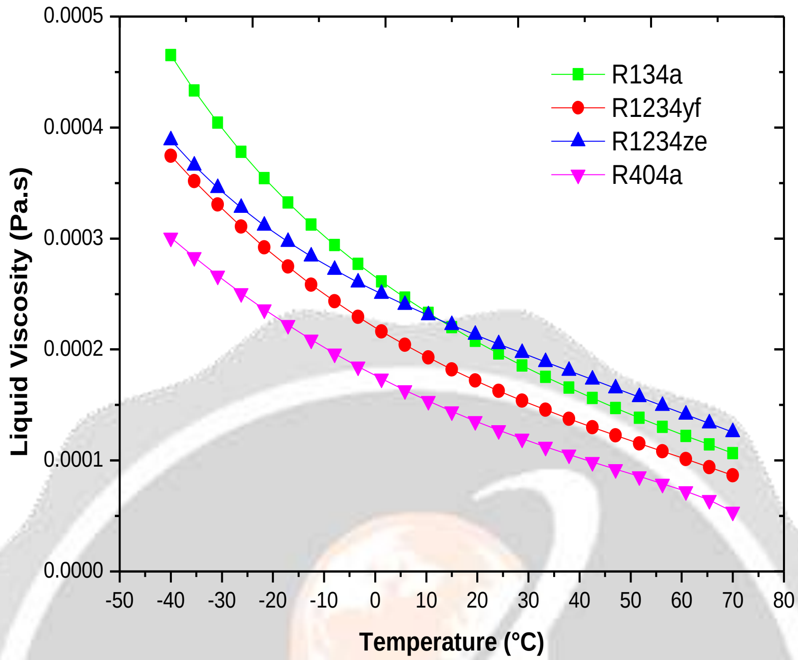

Fig. 1 liquid viscosity Variation with temperature (EES)

Vaghela [18] carried out a numerical analysis of different alternative refrigerant like R410A, R152a, R1234yf, R600a and R290. Their thermodynamic properties were compared with the current refrigerant in automobile air conditioning system. With high flammability R290 and R600a and due to very higher saturation pressure R410A, R404Aand R407C cannot be considered as substitution of R134a for automobile air conditioning system. After performance analysis they concluded that though COP of R1234yf is 6.3 % low. however, R1234yf is the best reasonable elective alternate to refrigerant R134a. Fig.3 and Fig. 4.

D. Sanchez et al[19] made experimental analysis and concluded that R152a and R1234yf are the suitable refrigerant as direct drop-in replacement to R134a with consideration of 4.5 % and 8.6 % decrease in cooling capacity with 1.6 % - 6.7 % increment in power consumed with appreciable 10% lower average COP with safety class A2L. As R1234ze (E), R600a and R290 required different pressure ratio compare to R134a are not appropriate replacements. Fig. 5 and Fig.6. The experimental analysis suggests R152a and R1234yf are alternatives to refrigerant R134a considering cooling capacity and the power consumption. As R1234ze(E), R600a and R290 required different compressor than R134a are not appropriate for alternate systemFig.7.

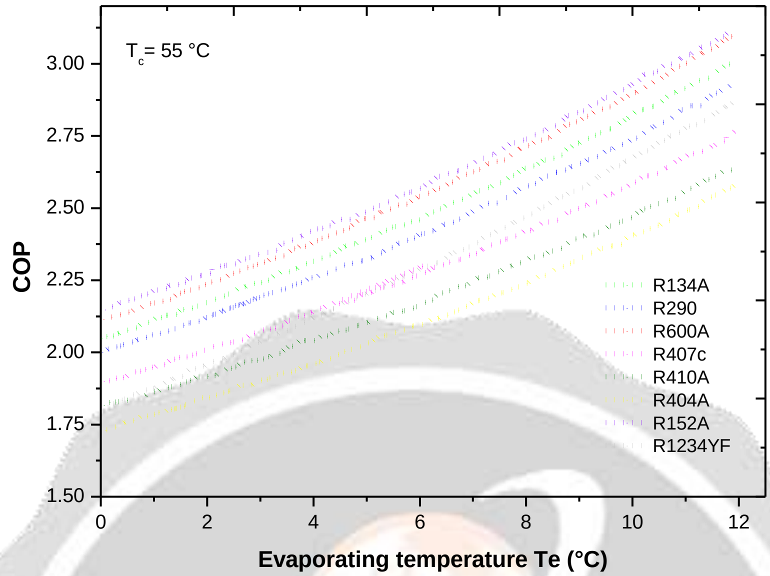

Fig. 2 Variation of COP with evaporating temperature [18]

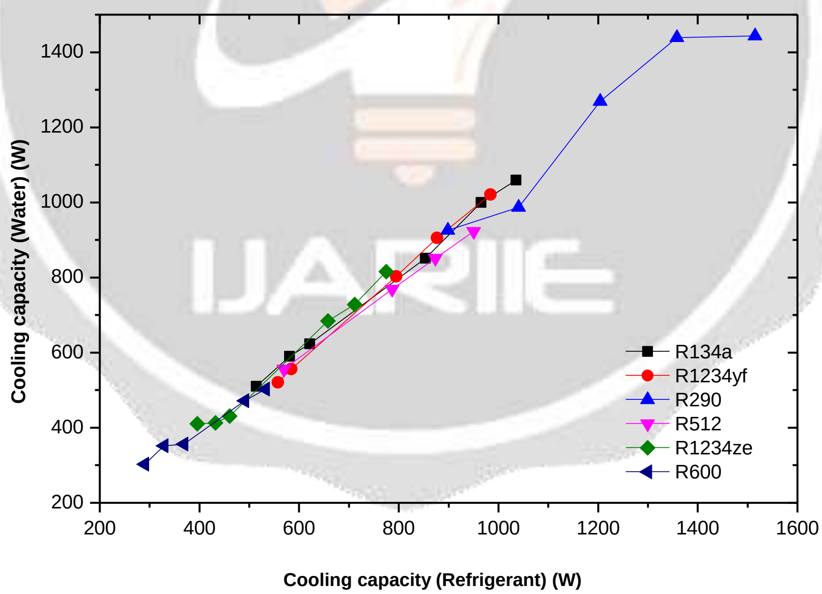

Fig. 3 Cooling capacity validation at evaporator [19]

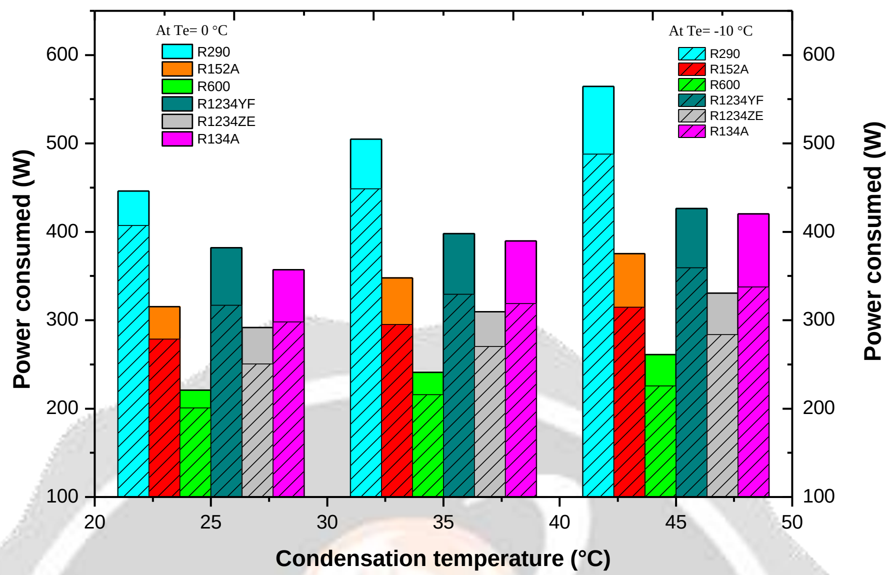

Fig. 6 Power consumption Vs Condensation temperature for Teva= -10 °C and Teva= 0 °C [19]

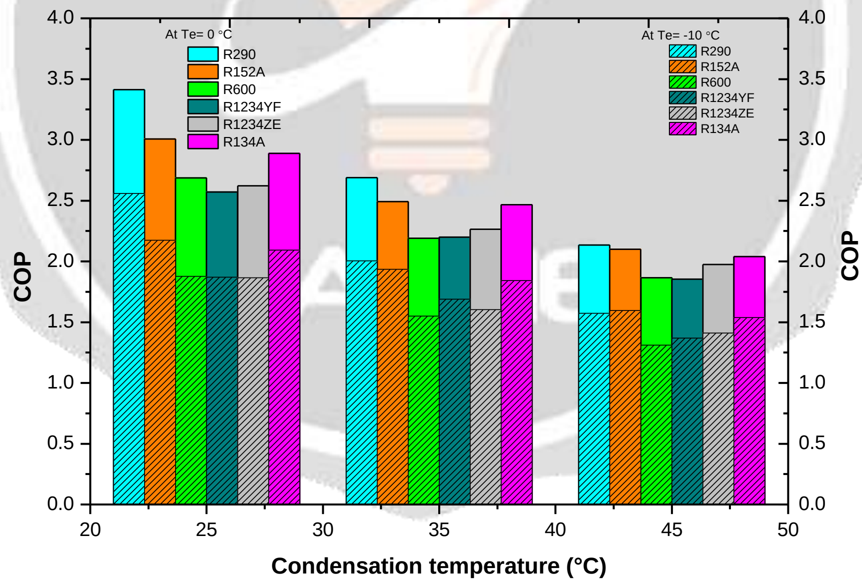

Fig. 7 COP Vs Condensation temperature for Teva= -10 °C and Teva= 0 °C [19]

Daviran et al[20] made performance comparison of R1234yf and R134a in simulated air conditioning system by. A simulation of an automotive air conditioning system using R1234yf as the drop-in replacement of R134a was carried out. In this simulation air conditioning system, a wobble-plate type compressor, flat-plate multi-louvered fin type evaporator, a thermostatic expansion valve and parallel-flow mini channel condenser is used. From the REFPROP

8.0 software the thermodynamic properties of the refrigerants are determined, and thermodynamic analysis is simulated in computer program. In the thermodynamic cycle analysis two different operating conditions have been studied. (i) constant cooling capacity and (ii) constant mass flow rate of the refrigerant. In the study following conclusions are made: R1234yf performs better than R134a as the pressure drop of R1234yf is lower during evaporation and condensation process. The compressor pressure ratio and discharge temperature of R1234yf is less as compared to R134a, so it increases the durability of compressor.

As working pressure of R1234yf is less than to R134a, it will effectively increase the COP. Due to lower operating pressure less thickness piping system is possible which reduce cost and improve proficiency. For minichannel exchanger in the same operating conditions refrigerant side overall heat transfer coefficient of R1234yf is 18–21% lower to R134a. R1234yf mass flow rate is 27% larger than that of R134a at a constant cooling capacity. The 1.3- 5 % lower COP of R1234yf than HFC-134a, in identical cooling capacity. For constant refrigerant mass flow rate, R1234yf COP is 18% higher than R134a.Fig.8.

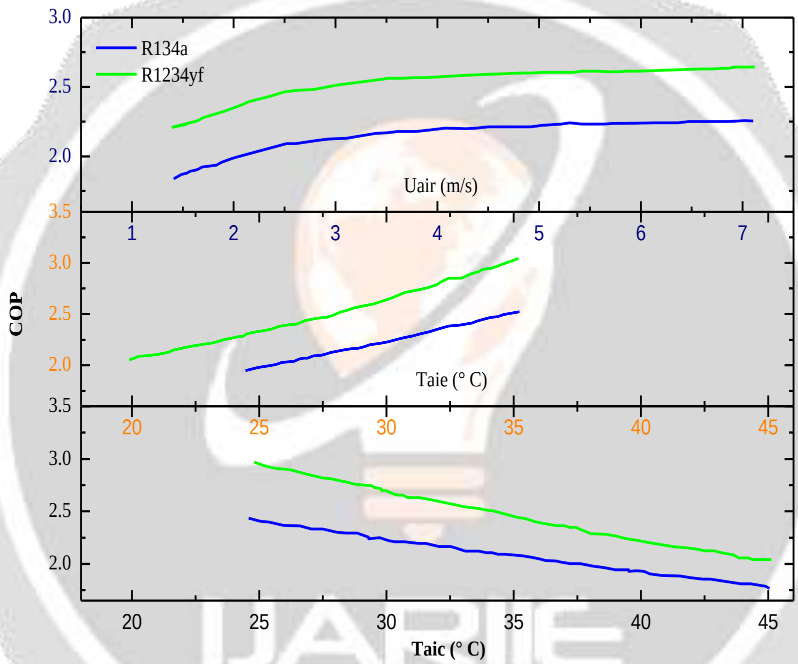

Fig. 8 Variation of COP with evaporator inlet air temperature, inlet air temperature of condenser and inlet air velocity to the condenser [21]

The exergy destruction and exergy efficiency are reduced with increasing in temperature of air at evaporator inlet is observe in second law analysis by performed by Golzari et al[22] for R134a and R1234yf. In compressor maximum destruction of exergy about 53% and 21% in condenser, 15% in thermosetting expansion valve and 11% in evaporator. Fig.9. Higher exergy efficiency for HFO- 1234yf found compared to HFC- 134a. Fig.10.

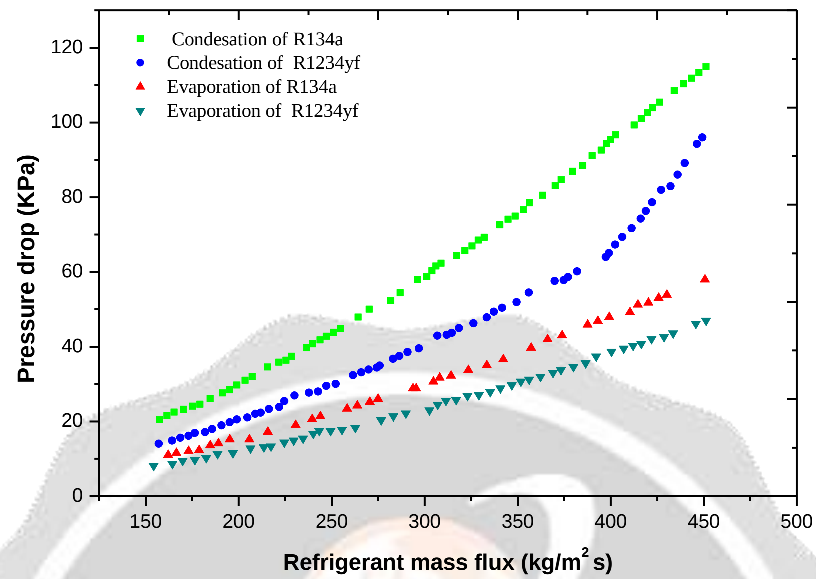

Fig. 9 condensation and evaporation pressure drop verses f refrigerant mass flow [23]

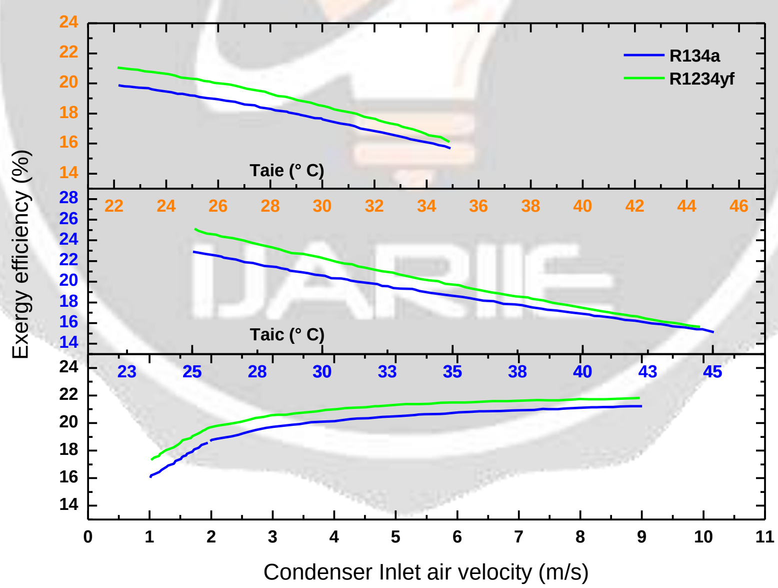

Fig. 10 Effect of evaporator inlet air temperature, inlet air temperature of condenser and inlet air velocity to the condenser on exergy efficiency [23]

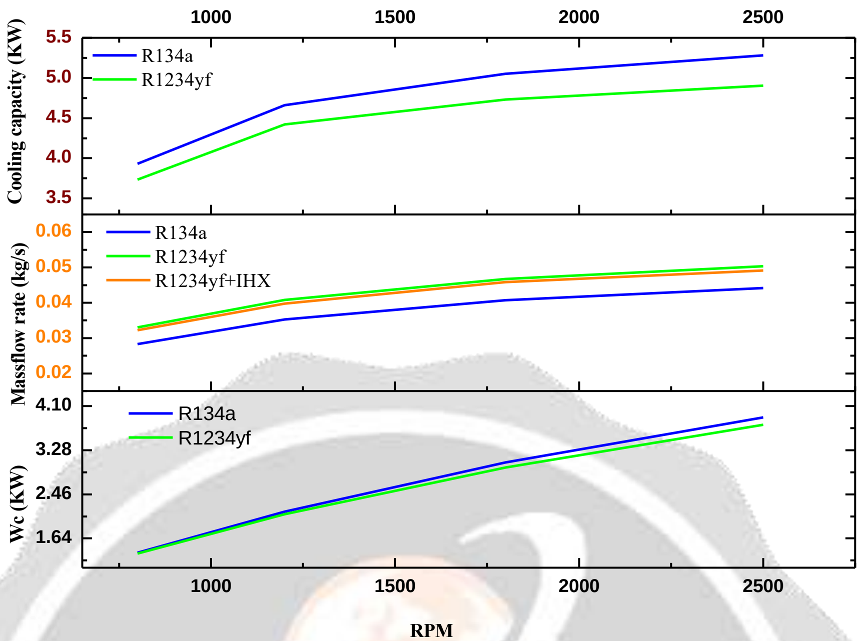

Fig. 11 comparison of mass flow rate, cooling capacity, compressor work with compressor speed [24]

In the experimental analysis by Cho et al [25] the cooling capacity and COP of refrigerant R1234yf is lower by 4.5 % and 7 % respectively. Fig.11.The decrease is lower significantly by 2.9 % to 1.8 % with internal heat exchanger Fig.12. The COP is improved up to 4.6 % and under various operating condition sufficient cooling capacity can be ensured.

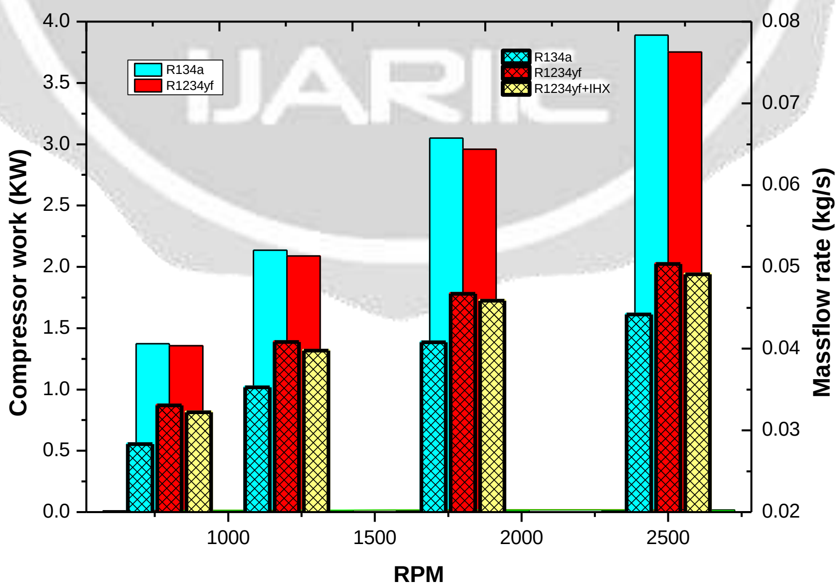

Fig. 12 Comparison of compressor work and mass flow rate with compressor speed [24]

Wantha et al[26] studied the relationship between overall heat transfer effect and COP affected by annular space, effectiveness, pressure drop and length of heat exchanger, at −6.4 °C and 6.4 °C evaporator and 46 °C condenser temperature. They concluded that at the same operating conditions, the 3.78 % COP increase of R1234yf and 2.11% increases of R134a with application of an internal heat exchanger. Fig.13. The overall heat transfer coefficient of R1234yf with tube-in-tube type internal heat exchanger is 11–17% less to the R134a for equal annular diameter ratio (Di/Do). Fig.14 and Fig.15.

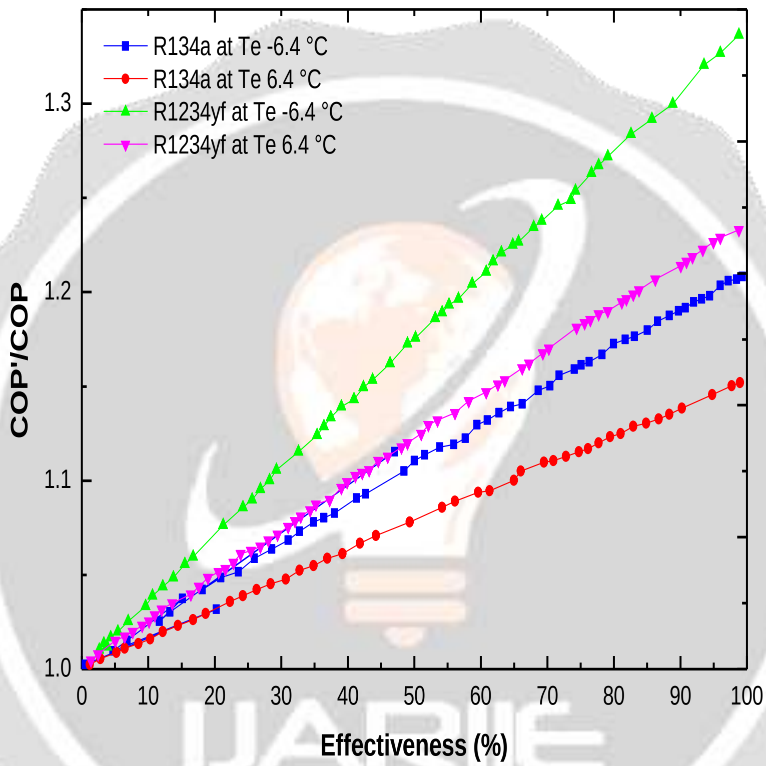

Fig. 13 Theoretical COP variation versus effectiveness of heat exchanger [26]

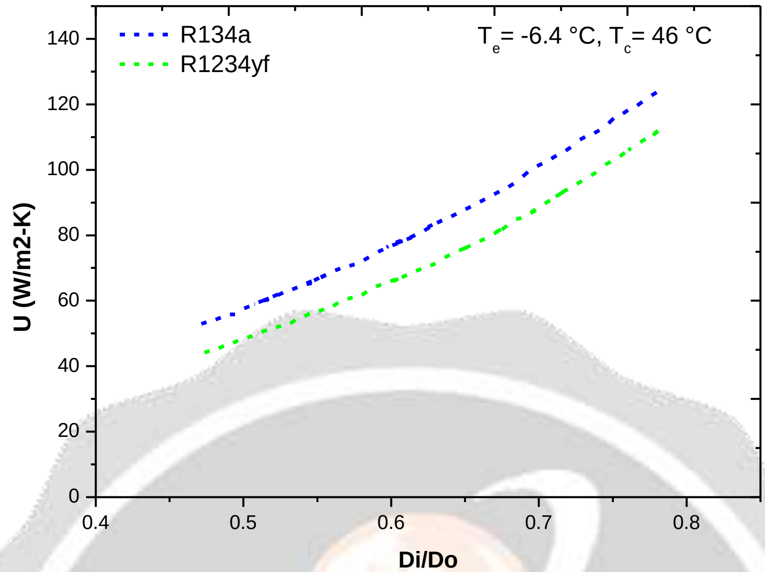

Fig. 14 Effect of annular diameter ratios on overall heat transfer coefficients [26]

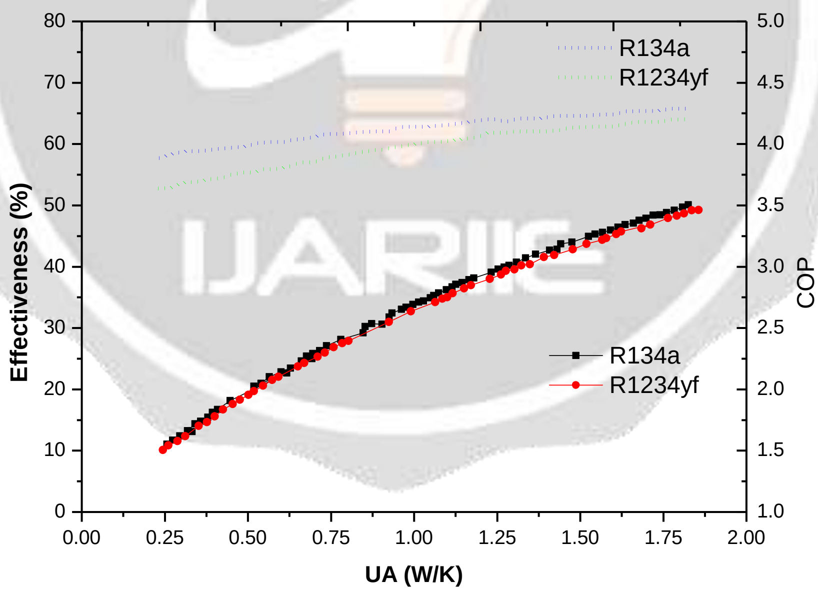

Fig. 15 Effect of overall heat transfer on COP and internal heat exchanger effectiveness [26]

Shi et al [27] carried out drop in test and optimization for charging fluid in expansion valve thermal bulb for refrigerant R134a and R1234yf and conclude that by adjusting the setting of thermosetting expansion valve R1234yf system performance improve significantly. The increase of 11.3% in cooling capacity averagely and increase of 8 %

COP averagely by adopting adjustable expansion valve for system with R1234yf as compared to original valve that compensate the performance insufficiency. Fig.16.

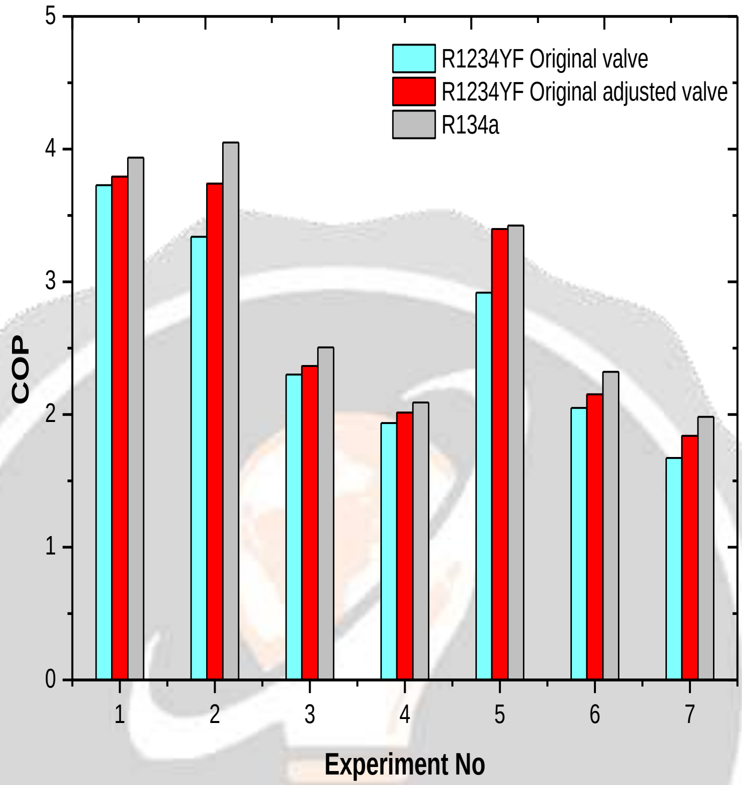

Fig. 16 The effect on COP before and after adjusting the TEV [27]

Experimental performance by Zhao gang Qi [28] for laminated plate evaporator and parallel flow microchannel evaporator with R1234yf and R134a conclude that flow performance and heat transfer of R1234yf for laminated plate type evaporator are better than R134a because of transportation and thermophysical properties with both high and low pressure of refrigerant at the entry of expansion valve. The cooling capacity of R1234yf with microchannel PF evaporator is closely identical and or high than of R134a under high and low pressure of refrigerant at the inlet of expansion valve. Fig.17. The pressure drop on air side is comparatively identical for both refrigerants and evaporators where R1234yf shows much higher pressure drop on refrigerant side of evaporator than R134a. That suggests microchannel perforated plate evaporator is a better alternate in R134a system for automobile air conditioning system.Fig.18. Fig.19. and Fig.20.

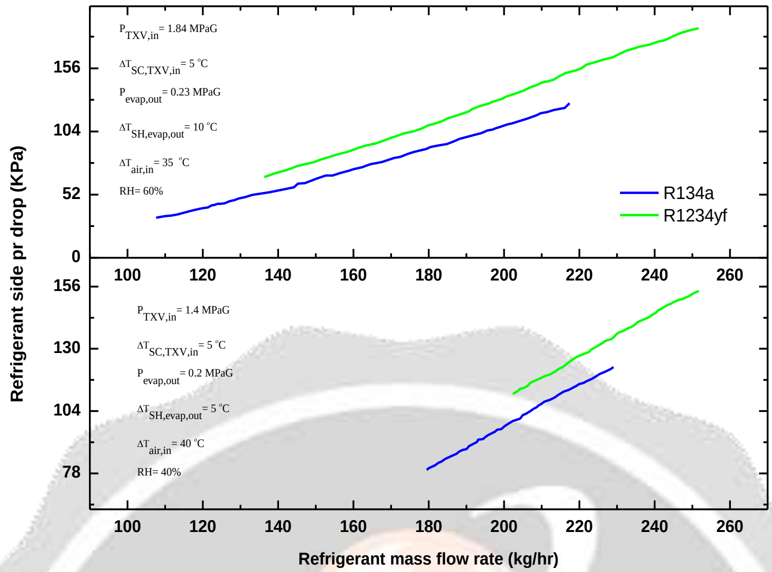

Fig. 17 Refrigerant side pressure drop (laminated plate evaporator and Perforated evaporator) [28]

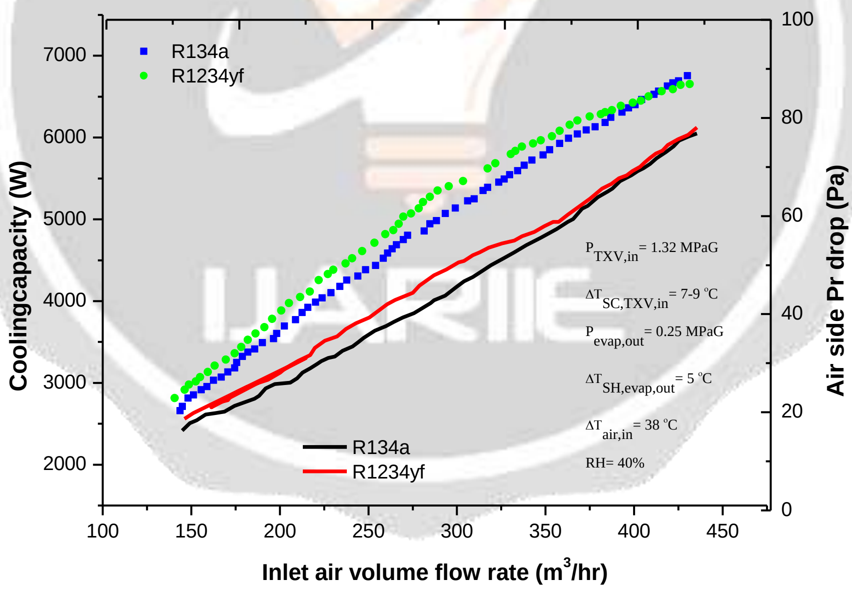

Fig. 18 Cooling capacity and air side pressure drop (PF evaporator) [28]

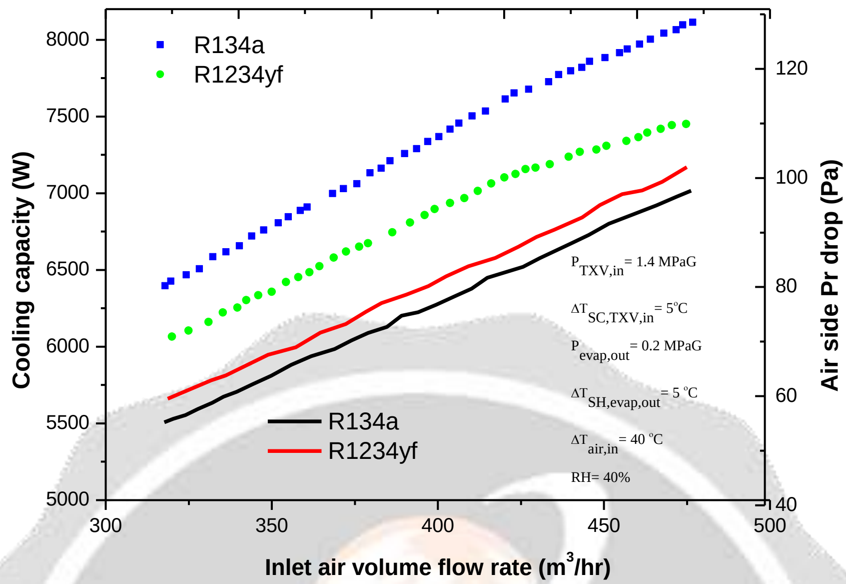

Fig. 19 Cooling capacity and air side pressure drop (laminated plate evaporator) [28]

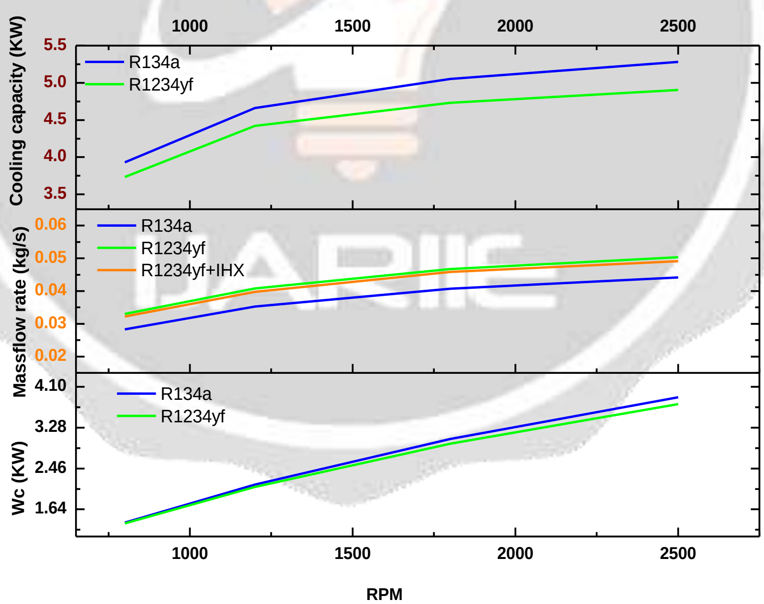

Fig. 20 comparison of compressor power, cooling capacity and mass flow rate with compressor speed [28]

Jarall [29] calculated and compared heat transfer and theoretical cycle data of refrigerant R1234yf with R1324a. Without imparting any modification in the existing components of the system and oil, conducted test with R134a first and then with alternate refrigerant R1234yf. From the results it is clear that R1234yf has lower values of discharge temperature, pressure ratio, Carnot efficiency and COP, and higher value of convection and evaporation heat transfer coefficients as compared to R134a. They also concluded that subcooling and superheating influenced

R1234yf more than R134a. At similar conditions, results data for these refrigerants presents 3.4-13.7% lower refrigerating capacity, COP lower by 0.35-11.88% of R1234yf and compressor efficiency by 0-6.3%. The overall heat transfer coefficient of evaporator lower by 3-27% and compressor discharge temperature lower 6-15 °C.

Zhao et al[30] conducted performance evaluation of automobile air conditioning system with laminated plate evaporator and micro channel condenser, using R134a and R1234yf as refrigerants for various operating conditions. After the analysis in different working conditions, the cooling capacity concluded that refrigerating effect 12.4 % and COP of R134a is 9% higher than R1234yf. both are more or less same for both the refrigerant.

Pottker et al [31] study the experimental effect on the performance results of air conditioning system with subcooling in condenser, under the identical operating variables. The 18% increase in COP for R1234yf and 9% for R134a at a defined operating condition. From the result analysis it can be concluded that performance a system with refrigerant R1234yf improved by the subcooling in condenser as compared to R134a. It is also concluded that with application of an internal heat exchanger decrease the COP significantly, which is increased by subcooling in condenser. The simultaneous application of both still results a better air conditioning system, for R1234y especially, besides the interference between IHX and condenser subcooling,

E. Navarro, et al [32] have done numerical analysis between R134a, R290 and HFO1234yf for open piston compressor in automobile air conditioning system at various condition. In the analysis compressor volumetric efficiency of R290 improve notable whereas R1234yf efficiency improvement observed for higher pressure ratio compared to R134a. R1234yf presents cooling capacity 9% and volumetric efficiency 5% lower than R134a and the difference is decrease at high condensing temperature and the performance even more improve with IHX.

Yohan Lee et al [33] experimentally analysed HFO1234yf in bench tester automobile air conditioning system. The results concluded that COP and refrigerating effect of HFO1234yf were 4.0% and 0.8% - 2.7% lower as compared to R134a. The refrigerant charge of R1234yf is 10%-11% less as compared to R134a so it is the long-term environment friendly solution to R134a.

Conclusion: -

The thermophysical properties of refrigerant R1234yf are extremely similar to R134a property. The R1234yf having closely similar range of cooling capacity to R134a. As high flammability of R290 and R600a, due to high saturation pressure of R407C, R410Aand R404 and due to safety mitigation R152a cannot be substitution of R134a.The overall heat transfer coefficient value of R1234yf is 18-20 % lower than R134a.The working pressure of R1234yf is lower than R134a which improves the COP of system. The lower operating pressure allow to use piping with less thickness which lower the cost. With Internal Heat Exchanger (IHX) under same operating condition R1234yf COP 3.78 % increases and COP of R134a increase by 2.11%. R1234yf leads to higher exergy efficiency, entropy generation and exergy destruction are less in case with system with R134a. For both refrigerant air side pressure drop is nearly close but higher refrigerant side pressure drop of R1234yf in evaporator than R134a is observed.

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