International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 06 | June 2021 www.irjet.net p-ISSN: 2395-0072

Comparative Analysis of Charge Reduction Techniques with R290

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Abstract - *Refrigeration and air conditioning systems have become a huge part of our daily needs. Due to increasing demands and applications of this systems, it is important to analyze the thermal performance of all the system to see which of them performs better. In the present paper charge reduction techniques numerically analyzed keeping the system properties same. Air conditioning system having capacity 1TR has been used for this comparative analysis. For numerical analysis MATLAB is used to develop programs. This study specifically deals with comparative analysis of various refrigerant-oil mixtures which gives brief idea about optimal mixture and its proportion.*

Key Words: **refrigerant charge reduction, COP, EER, refrigeration oils and lubricants, compressor.**

1.INTRODUCTION

In refrigeration and air conditioning applications, HCFCs are being replaced by HFCs and natural fluids as alternative refrigerants. At present non-ozone depleting R-410A is being considered as the major alternative refrigerants in air conditioning. Still, R-410A has a GWP of 2100, which is significantly harmful.

HC-290 is flammable. As per ASHRAE Standard 34 [18], HC-290 is classified as Class 3 (high flammability fluid) whereas ISO 817 and EN 378 classify HC-290 as A3 class fluid (low toxicity and high flammability). LFL of HC-290 is 0.038 kg/m3 by mass and 2.1% by volume. As per the existing regulations, the flammability risk can be avoided if the HC-290 charge in the system is less than 20% of the lower flammability limit (LFL). Poggi et al [3] reported that the charge reduction is possible with reduction in the internal volume of the systems, including heat exchangers, liquid line, and receiver. Use of mini-channel in compact heat exchangers enables refrigerant charge reduction compared to other options without affecting the system performance

Parts of the scientific community as well as environmentalists have suggested that natural refrigerants, i.e. compounds which are naturally occurring in the environment, should be used as substitutes for the man-made HFC compounds now being used. In some countries, e.g. Denmark and Austria, legislative measures have already been taken towards a phase out of HFCs. Within the EC, the use of fluids with a global warming potential above 150 (including all commonly used HFCs) is being banned in mobile air conditioning according to a gradual phase out program. On the global scale, regulations on HFCs and other greenhouse gases are discussed within the Kyoto protocol and later amendments, however, without any agreements yet. However, this reduction may come at the cost of slightly reduced system performance, which in itself is detrimental from an environmental point of view.

From literature, it is found that use of propane (HC-290) as a safe and energy efficient alternative to HCFC-22 in a typical split air conditioner with nominal cooling capacities up to 5.1 kW. The optimized performance is obtained with 290g of R290 charge, for which the cooling capacity is 2690 W and the coefficient of performance (COP) is 3.55, meeting the safety and energy efficiency requirements.

The choice of lubricating oil for R290 RACs is not yet clear. Mineral oil (MOs) are currently in use, but system performance when using MO is compulsory under existing standards due to the high solubility of R290 in the compressor sump. Some polyalkylene glycol synthetic oils (PAGs) do not melt as much as MO, but the use of PAG in R290 RACs is less studied. The results showed that using the PAG could reduce the weight of R290 on the compressor by about 10-13 g and improve the thermal energy by 1.8-2.3%, but the Coefficient of Performance (COP) was lower under temperature mode due to the combination of R290 and oil viscosity in oil sump. high temperatures were appropriate in view of the EER / COP of R290 RACs. The solubility of R290 in the compressor oil sample was 10.8-14.4% for the program by PAG and 13.5-18.9% for the program by MO. Using the PAG VG60 can reduce the amount of charging required in the system because R290 solubility in oil. However, the viscosity was much lower under the temperature mode when using the MO, which could increase the RAC power consumption. PAG oils with a viscosity level below VG60 were expected to continue to improve temperature.

Three types of refrigerant oil mixtures have been numerically analyzed. For comparative analysis Propane refrigerant is used. Three types of mixtures include MO + propane, PAG + Propane and POE + Propane. Various proportions of these mixtures ranging from 0.1%-1% oil in Refrigerant oil mixture have been studied. The operating temp range is considered as evaporator temp=-15^{0}c and condenser temp= 40^{0}c.

Nomenclature

ASHRAE	American society of heating, refrigerating and air conditioning engineers
EER	energy efficiency ratio
EES	engineering equation solver
EN	European Nation
GHG	greenhouse gas
GWP	global warming potential
HC	hydrocarbon
HCFC	hydrochlorofluorocarbon
MO	Mineral oil
HFC	hydrofluorocarbons
POE	international electrotechnical commission
ISO	international standards of organisation
LFL	lower flammability limit, kg/m3
MP	Montreal protocol
ODP	ozone depletion potential
PAG	polyalkylene glycol
T	temperature, C
UFL	upper flammability limit, kg/m3

1.1 HC-290 safety

HC-290 is flammable. According to ASHRAE Standard 34 [18], HC-290 is classified as Class 3 (high flammability fluid) with ISO 817 and EN 378 classifies HC-290 as A3 class fluid (low toxicity and high flammability). HF-290 LFL is 0.038 kg/m3 in size and 2.1% in volume. According to existing regulations, the risk of burns can increase should be avoided if the HC-290 charge in the system is less than 20% of low temperature range (LFL) [19]. Poggi et al. [12] reported that the reduction in tariff is possible by internal reduction programming volume, including temperature range, liquid line, and the recipient. The use of a small channel in changing heat exchanges makes it easy refrigeration charge reduction compared to other external options affects system performance. Coulbourne and Suen [13] presented a risk assessment model for HC-290 burn risk. Refrigerator weight data, leaks, hardware failure, heat sources, room size, installation height, and low ventilation rate was used to model the model.

2. METHODOLOGY OF NUMERICAL SIMULATION

For numerical solution MATLAB is used to develop codes. The user can select the numbers of input parameters related to calculations and simulation. The MATLAB code gives the output in the graphical representations which are very easy to analyze. The accurate result depends on the accuracy of inputs given. We used two different steps for simulation in MATLAB. Different inputs need to be provided at different steps. The steps and different inputs required for simulation are given below:

a) Steps of MATLAB simulations

I. Calculation of oil properties at required temp ranges.
II. Calculation of mixture properties.
III. Plotting graphs

2.1 Calculation of oil properties at required temp ranges.

For oils under consideration, from manufacturers catalogue the density of the oil is known at To = 20°c only. The density at other temperatures is evaluated with the simple relation recommended by Mermond et al. [16]:

$$\rho_0(T) = \rho_0(T_0) - A(T - T_0) \qquad (1)$$

Where,

ρ_0= Density of oil in
T = Temp at which density needs to be calculated
T_0= Temp at which density value is known i.e. 20^0c

The value of the coefficient A is fixed to 0.6, as indicated by Conde [17].
The heat capacity of the oil is calculated with the equation of Liley and Gambill [19] which is;

$$c_{POil} = \frac{4.186[0.388 + 0.00045(1.8T + 32)]}{\sqrt{s}} \qquad (2)$$

The enthalpy of oil is easily deduced from integration of above Eq. which gives:

$$h_{oil} = h_{ref} + \int_{Tref}^{T} c_{POil} dT \qquad (3)$$

2.2 Calculation of mixture properties.

To analyse the oil effect on the enthalpy calculation, a simple thermodynamic model allowing to express the total enthalpy h_t of a refrigerant-oil mixture is given by the following relation:

$$h_t = (1 - X' - C_g)\, h_{L,r} + C_g h_{oil} + X' h_V \quad (4)$$

Where,

h_t = Total enthalpy of refrigerant-oil mixture.
C_g = Oil mass fraction in mixture.
X'= vapour quality of refrigerant/oil mixture.

The operating conditions have been chosen for condenser temperature of 40˚C and evaporator temperature -15˚C for selected three different type of oils. (PAG, POE, MO) For 98% composition of R290 and MO, Properties obtained are;

Enthalpy of the refrigerant at entry to compressor is h_1 = 567.460 kJ/kg
Enthalpy of the refrigerant at the at outlet of the compressor is h_2= 638.143 kJ/kg
Enthalpy of refrigerant at outlet of the expansion valve $h_3 = h_4$= 307.090 kJ/kg

Pressure ratio = 4.723

From the equation

COP = $\frac{h1-h4}{h2-h1} = \frac{567.460-307.090}{638.143-567.460}$ = 3.65

Pressure ratio = $\frac{Pc}{pe}$ = 4.723

Capacity of the system = 1 TR = 3.5 kW

The net refrigeration effect = $m_r \times (h_1 - h_4)$ = 3.5 kW

Mass flow rate of refrigerant = 3.5/ $(h_1 - h_4)$ = 0.01344 kg/s

Compression work= $m_r \times (h_2 - h_1)$
= 0.01344 × $(h_2 - h_1)$ =0.95 kW

Heat rejected in the condenser = $m_r \times (h_2 - h_3)$ = 4.44 kW

Heat absorbed in the evaporator = $m_r \times (h_1 - h_4)$ = 3.49 kW

3. RESULTS AND DISCUSSION

3.1 Compressor work

Figure 1 shows the variation of compressor work for HC-290 with different oil tests. The highest compressor work was 71.8 kj/kg with 1% PAG and 99% propane mixture composition. The lowest compressor work was 64.1kj/kg with 10% mineral oil and 90% propane mixture composition. The use of MO decreases the compressor work as compared with PAG and POE synthetic lubricants and eventually reduces the HC-290 charge. Table 1 shows results obtained using which fig 1 is plotted.

Table 1 Variation of compressor work with mixture composition

Mixture composition	Compressor work in kj/kg		
	MO	PAG	POE
0.9	64.1	65.2	64.9
0.91	64.8	65.9	65.6
0.92	65.6	66.7	66.4
0.93	66.3	67.4	67.1
0.94	67	68.1	67.8
0.95	67.8	68.9	68.6
0.96	68.5	69.6	69.3
0.97	69.2	70.3	70
0.98	70	71	70.7
0.99	70.7	71.8	71.5
1	71.4	72.5	72.2

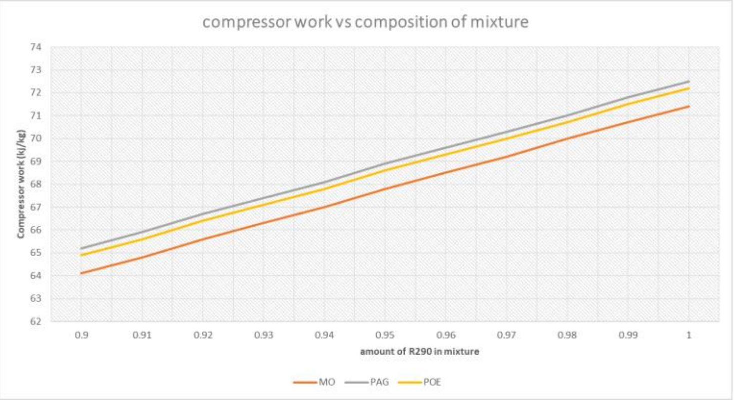

Figure 1 Variation of compressor work with mixture composition

3.2 Refrigerating effect

Fig 2 shows the variation of Refrigerating effect for HC-290 with different oil tests. The baseline Refrigerating effect was 209 kj/kg with 10% PAG and 90% propane mixture composition. The highest Refrigerating effect was 260 kj/kg with 1% mineral oil and 99% propane mixture composition. The use of MO increases the Refrigerating effect as compared with PAG and POE synthetic lubricants and eventually reduces the HC-290 charge. Table 2 shows results obtained using which fig 2 is plotted

Table 2 Variation of refrigerating effect with mixture composition

Mixture composition	Refrigerating effect in kj/kg		
	MO	POE	PAG
0.9	214	194	180
0.91	215	199	183

0.92	217	202	186
0.93	222	210	190
0.94	228	225	194
0.95	234	227	199
0.96	237	235	215
0.97	249	241	225
0.98	256	247	232
0.99	264	249	239
1	272	255	251

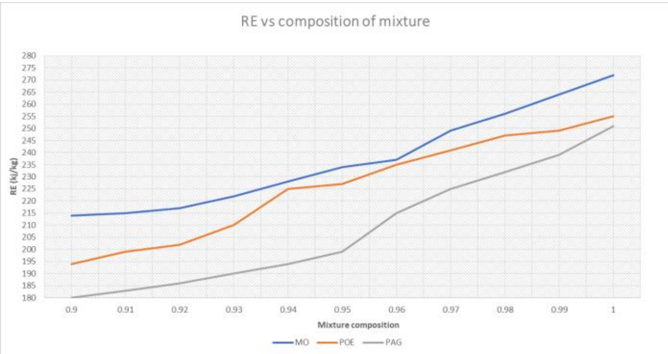

Figure 2 Variation of refrigerating effect with mixture composition

3.3 COP

Fig 3 shows the variation of COP for HC-290 with different oil tests. The baseline COP was 3.494 with 10% PAG and 90% propane mixture composition. The highest COP was 3.5714 with 1% mineral oil and 99% propane mixture composition. The use of MO increases the COP as compared with PAG and POE synthetic lubricants and eventually reduces the HC-290 charge. Table 3 shows results obtained using which fig 3 is plotted.

Table 3 Variation of COP with mixture composition

Mixture composition	COP		
	PAG	MO	POE
0.9	2.760736	3.338534	2.989214
0.91	2.776935	3.317901	3.033537
0.92	2.788606	3.307927	3.042169
0.93	2.818991	3.348416	3.129657
0.94	2.848752	3.402985	3.318584
0.95	2.888244	3.451327	3.309038
0.96	3.08908	3.459854	3.391053
0.97	3.200569	3.598266	3.442857
0.98	3.267606	3.657143	3.493635
0.99	3.328691	3.734088	3.482517
1	3.462069	3.809524	3.531856

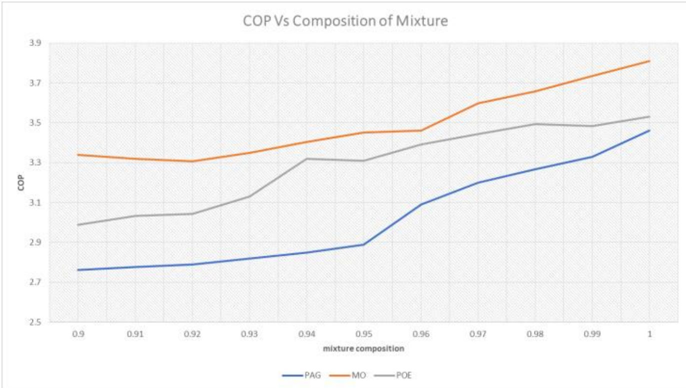

Figure 3 Variation of COP with mixture composition

3.4 Refrigeration cycle in coolpack software

Coolpack is a collection of simulation programs that can be used for designing, dimensioning, analyzing and optimizing refrigeration systems. The Coolpack program is freeware one. On plotting above refrigeration cycle in software results obtained were in the range of which obtained using MATLAB software. Fig 4 shows the screenshot of Coolpack software and fig 4 shows results obtained using Coolpack software.

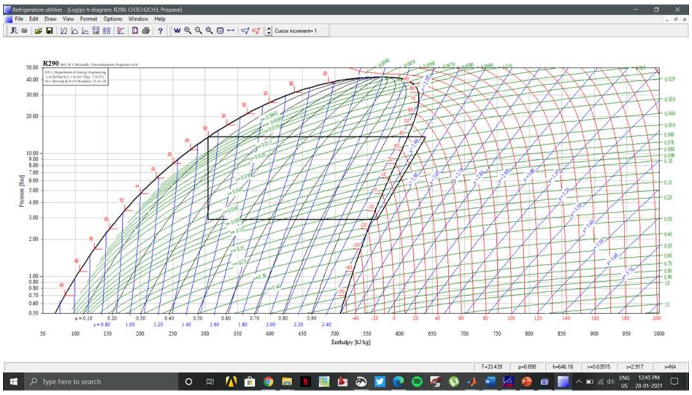

Figure 4 coolpack software screenshot

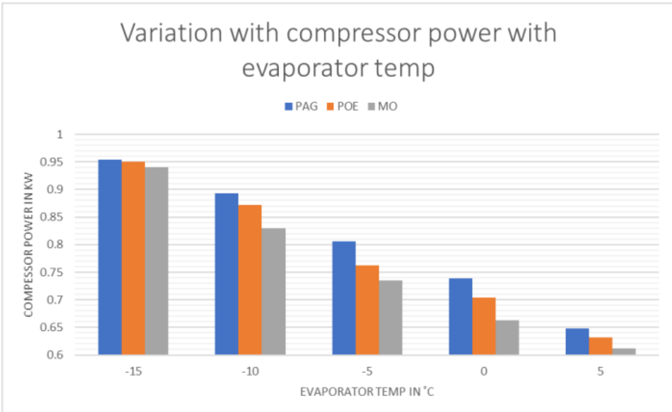

Figure 5 Variation of compressor power with evaporator temp.

From fig. 5, with the decrease in evaporator temperature, The work of compressor increases and mass of refrigerant circulated per minute decreases which results in increase of compressor power.

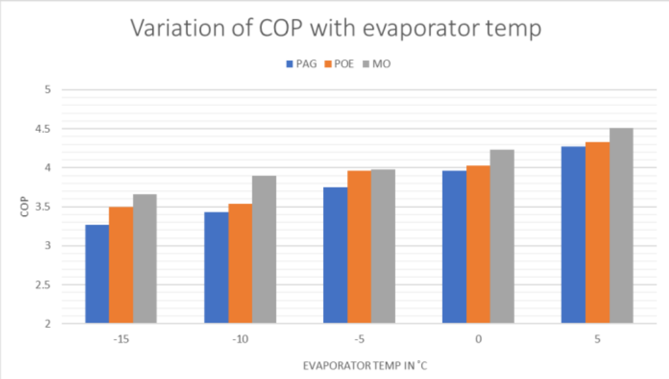

Figure 6 Variation of COP with evaporator temp.

From Fig 6, It is observed that for the same evaporator temperatures, MO COP is 10.65% higher than PAG. It is also observed that the trend of COP is decreases with decrease in evaporator temperature.

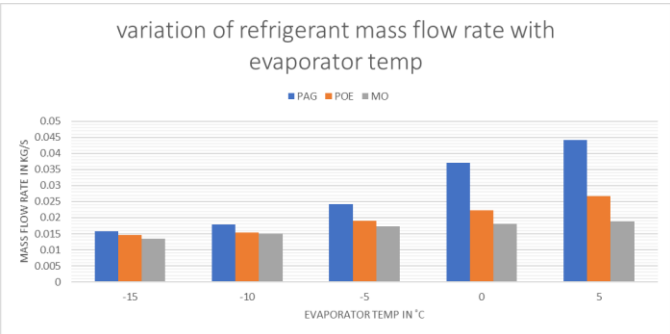

Figure 7 Variation of refrigerant mass flow rate with evaporator temp.

From fig 7, Mass flow rate required for MO is 12% less with compare to PAG, hence there will be less loads on to the compressor with minimum energy (power) required for compression processes.

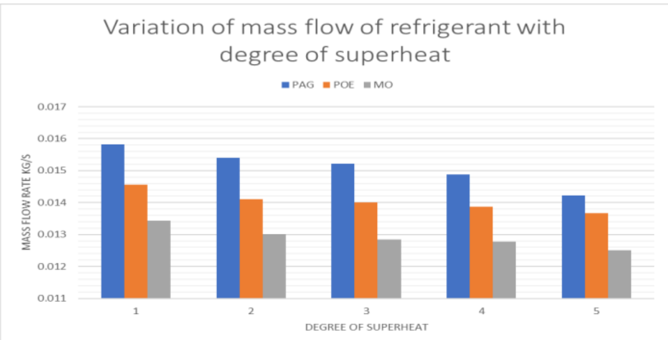

Figure 8 Variation of mass flow rate with degree of superheat

From fig 8, Mass flow rate for MO is less i.e. 0.01344 kg/s and for PAG is 0.0151kg/s, hence, the refrigeration effect increases per kg of refrigerant circulated in the refrigeration cycle. Since the refrigeration effect is more the amount of refrigerant circulated can be reduced.

4. CONCLUSIONS

Three oil and propane mixtures for compressors used in refrigeration systems are modeled and analyzed using MATLAB software. The lubricating oils considered were Mineral Oil (MO), PAG and POE. The comparative analysis is based on the three plots plotted using MATLAB. The model estimates thermodynamic and transport property data using REFPROP v10. The following conclusions made based on obtained results.

When mineral oil is used as lubricating oil for compressor, compressor work required was minimum, refrigerating effect obtained in system was maximum and eventually COP obtained was on higher side. Use of synthetic oils showed comparatively low performance of system. Decrease in lubricating oil fraction in mixture decreases the compressor work. Decrease in lubricating oil fraction in mixture eventually increases the COP of system. Power consumption for synthetic oils is very high whereas MO and consumes low power for fixed condenser temperature and for different evaporating temperatures per TR. This analysis will help to select a suitable refrigeration compressor oil according to the application. This analysis is only based on lubricant-refrigeration mixture properties and behavior of different compositions in compressor. Other parameters such as cost of lubricant, life of lubricants, operating cost are not considered for the analysis. As MATLAB is easily available software, it would be very useful tool to model this kind of applications mathematically. Coolpack also plays an important role to verify results in some aspects.

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