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PERFORMANCE ANALYSIS OF OZONE LAYER FRIENDLY REFRIGERENT AS A POSSIBLE REPLACEMENT OF R-22 IN VAPOUR COMPRESSION REFRIGERATION SYSTEM

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ABSTRACT

The Montreal protocol set out mandatory time table to phase out R-22 by 2016. This paper hence discusses the alternative of R-22 in vapor compression refrigeration system. R-22 is replaced by a mixture of refrigerant R134a,R32,and R152a in a ratio of 0.4:0.2:0.4 IN MIXTURE 1 and 0.3:0.4:0.3 in MIXTURE 2 by mass respectively .The performance comparison in R-22 and the mixture refrigerants are made in terms of C.O.P , Variation of density with temp at constant pressure , Variation of enthalpy with temp at constant pressure , Variation of entropy with temp at constant pressure , Global warming potential , Molecular weight and and Ozone depleting potential.

KEYWORDS: ice plant , theoretical c.o.p , global warming potential ,ozone depleting potential , molecular weight, ice candy solution .

INTRODUCTION

The Montreal Protocol on Substances that Deplete the Ozone Layer (the Montreal Protocol) was agreed on 16 September 1987 and came into effect on 1 January 1989. It was developed in order to reduce the production of ozone-depleting substances. Its framework was defined by the Vienna Convention for the Protection of the Ozone Layer, in 1985. The emissions of ozone-depleting substances increased in the middle to late 20th century, peaking in the late 1980s and contributing to the formation of the 'ozone hole' over the Antarctic. This was linked to the increased use of chemicals such as chlorofluorocarbons (CFCs) in refrigeration, industrial cleaning, foam blowing and air conditioning. Ozone is destroyed by chlorine and bromine atoms within ozone-depleting substances, also referred to as 'halogen source gases', including:

- Chlorofluorocarbons (CFCs).
- Hydrochlorofluorcarbons (HCFCs).
- Halons.
- Methyl chloroform.
- Carbon tetrachloride (the main precursor of CFCs).

Methyl bromide.

Summary of Montreal Protocol control measures

Ozone depleting substances	Developed countries	Developing countries
Chlorofluorocarbons (CFCs)	Phased out end of 1995	Total phase out by 2010
Halons	Phased out end of 1993	Total phase out by 2010
CCl_4	Phased out end of 1995	Total phase out by 2010
Hydrochlorofluorocarbons (HCFCs)	Freeze from beginning of 1996 35% reduction by 2004 75% reduction by 2010 90% reduction by 2015 Total phase out by 2020	Freeze in 2013 at a base level calculated as the average of 2009 and 2010 consumption levels 10% reduction by 2015 35% reduction by 2020 67.5% reduction by 2025 Total phase out by 2030

Hydrobromofluorocarbons (HBFCs)	Phased out end of 1995	Phased out end of 1995
Methyl bromide (CH_3Br) (horticultural uses)	Freeze in 1995 at 1991 base level 25% reduction by 1999 50% reduction by 2001 70% reduction by 2003 Total phase out by 2005	Freeze in 2002 at average 1995-1998 base level 20% reduction by 2005 Total phase out by 2015
Bromochloromethane (CH_2BrCl)	Phase out by 2002	Phase out by 2002

R22 has been widely used in compression based refrigeration, air conditioning and heat pump systems due to its good thermodynamic and thermo-physical properties. Due to its poor environmental properties, it was phased out in many developed countries, whereas the developing countries are in transient to phase out R22 [1]. During last decade, many R22 alternatives refrigerant mixtures have been developed, which are summarized and reported in review articles [2-4]. Among the alternatives, the hydrocarbons (HCs) such as R290, R1270 and its mixtures R432A, R433A, hydroflurocarbon mixtures (HFCs) such as R404A, R407C and R410A and HFC/HC mixtures such as R417A and R422A are identified as the leading replacements for R22 in refrigeration, air conditioning and heat pumps units.

The hydrocarbons such as R290 and R1270 are reported as the possible alternatives to R22 for residential air conditioners and heat pumps [5-8]. Similarly, the hydrocarbon mixtures such as LPG mixture composed of R290, R170, R600a (in the ratio of 98.95: 1.007: 0.0397, by mass) [9], R290/R170 mixture (in the ratio of 94:6, by mass) [10], R432A (near azeotrope mixture composed of R1270 and RE170, in the ratio of 80:20, by mass) [11], R433A (near azeotrope mixture composed of R1270 and R290, in the ratio of 70:30, by mass) [12], mixtures composed of R1270, R290, RE170 and R152a [13] are reported as alternatives to R22 in compression based refrigeration and air conditioning units.

The reported studies confirmed that hydrocarbon based refrigerant mixtures are the good energy efficient and environment friendly alternative option to replace the R22. HFC mixtures such as R404A, R407C and R410A as leading substitutes for replacing R22 in compression based refrigeration, air conditioning and heat pump systems [4]. Out of these three substitutes, 404A is a good R22 replacement for low temperature applications [14-16]. The major problem associated with R410A is its lower critical temperature, which restricts its usage in compression based systems working at higher condensing temperatures. Wu *et al.* [17] investigated the performance of HFC mixture composed of R152a, R125 and R32, in the ratio of 48:18:34, by mass in a R22 based domestic air conditioner. Similarly, the performance of binary R32/R134a mixture was investigated for air conditioning [18] and heat pump applications [19]. The two major problems faced by HFC refrigerant are its GWP [20] and its immiscible nature with conventional mineral oil [28]. Hence, polyol ester oil (POE) is recommended for the compression systems working with HFC refrigerants.

To overcome the drawbacks with HC and HFC refrigerants, the mixtures composed of HC and HFC was developed . Park et al. [21] investigated the performance of residential air conditioner working with R22 and R431A mixture composed of R290/R152a (in the ratio of 71:29, by mass). In similar work, Jabaraj *et al.* [22, 23] used HC composed of R290 and R600a (in the ratio of 45.2:54.8, by mass) to tackle the miscibility issue of R407C with mineral oil in a residential air conditioner. In another work, Mohanraj *et al.* [24, 25] used LPG mixture as an additive with R407C to overcome the miscibility issue with mineral oil lubricant. Similarly, the low volatile hydrocarbon component (R600) in the R417A mixture tackles the miscibility issue with mineral oil [26]. The performance of R417A was evaluated for cold storage, heat pump, chiller and residential air conditioners [27-30]. In India, the mixture composed of R32 and R125 (in the ratio of 50:50, by mass) is a readily available under the commercial name of R410A. In this work, an attempt has been made to blend the R410A with R600a to tackle the miscibility issue and the drawbacks associated with R410A.

ICE PLANT -Experimental data are taken from Sharma ice candy plant (kolar road ,Bhopal). Plant is working on vapour compression refrigeration cycle using R22 refrigerant. It has centrifugal compressor of 2 tones capacity, capillary tube as expansion valve, air cooled condenser and evaporator tank filled with brine as secondary refrigerant. Evaporator tank has dimension of 1.2m×1.0m×1.0m. there are 16 seating for 16 cans and each can has a maximum capacity of 1.25 kg . plant can produce 20 kg of ice In 3-4 hours . Cans will be loaded when the brine temp falls below -3°C .

PERFORMANCE ANALYSIS OF ICE CANDY PLANT –Pressure and temperature reading for the calculation is taken from an ice candy plant working on vapour compression refrigeration cycle using R-22 as refrigerant. Theoretical C.O.P is calculated by using pressure – enthalpy chart at given pressure and temperature condition. Actual C.O.P is calculated as the ratio of desired effect and work supplied.

Table 2-pressure and temperature reading of ice candy plant

P1	P2	T1	T2	T3	T4	T5	T6
2 bar	12 bar	5 (°C)	85 (°C)	27 (°C)	-10 (°C)		

P1= INLET PRESSURE OF COMPRESSOR (BAR)
P2= EXIT PRESSURE OF COMPRESSOR (BAR)
T1= INLET TEMP OF COMPRESSOR (°C)
T2 = EXIT TEMP OF COMPRESSOR (°C)
T3= CONDENSOR EXIT TEMP (°C)
T4 = TEMP (°C) AFTER EXPANSION
Using pressure enthalpy chart of R22
At P1 =2 bar and T1=5(°C) , Enthalpy (h1) =414.5 kj/kg
At P2 =12 bar and T2=85(°C) , Enthalpy (h2)= 460 kj/kg
At P3 =12 bar and T2=27(°C) , Enthalpy (h3)= 429 kj/kg
At P4 =2 bar and T4=-10(°C) , Enthalpy (h)= 215 kj/kg
$(c.o.p)_{theo}$ = desired effect/work done =(h1-h4)/(h2-h1)
$(c.o.p)_{theo}$ =(491-184.3)/(553.2-491) =4.38

Calculation of actual C.O.P-

Heat extracted = mass of ice candy solution × sp heat capacity of ice candy solution × change in temp + mass of ice candy solution ×latent heat capacity of ice candy solution + mass of ice candy solution × sp heat capacity of ice candy solution × change in temp.sp heat capacity of ice candy solution = 3.93 kj/kg
latent heat capacity of ice candy solution =289 kj/kg
mass of ice candy solution = 20 kg
Initial temp of ice candy solution =30 °C
Final temp of ice candy solution ==-7 °C
Heat extracted = 8688.2 kj
Power supplied = 1.2 kwh= 1.2 × 3600 =4320 kj

$(c.o.p)_{actual}$ = heat extracted /compressor work
$(c.o.p)_{actual}$ =8688.2/4320= 2.01

Refrigerant selection criteria- Refrigerant selection are based on thermodynamic and thermophysical property , environmental property like global warming potential and ozone depleting potential, its miscibility with oil ,chemical stability etc. Based on these property and prior research paper R134a, R32 and R152a is taken as possible replacement of R22. Performance comparison is carried out using REFPROP .Readings of ice candy plant is used as input in performance comparison. MIX 1and MIX2 are two new refrigerant prepared by using these refrigerant. Constituent of mix1 and mix 2 and their concentration is shown in Table 3.

Table 3- Composition of refrigerant in mix 1 and mix 2 in ratio of mass

Mix ref	R134a (by mass)	R32 (by mass)	R152a (by mass)
MIX 1	0.4	0.2	0.4
MIX 2	0.3	0.4	0.3

For mix 1 ,whose composition is shown above ,theoretical c.o.p is calculated at same pressure and temp condition as R22
h1= 475.5 kj/kg
h2= 538.9 kj/kg
h3= 496.4 kj/kg
h4= 184.8 kj/kg
(c.o.p) theo of MIX 1 =(h1-h4)/(h2-h1)

(c.o.p) theo of MIX 1= (475.5-184.8)/(538.9-475.5) = 4.58

Again c.o.p theoretical for MIX 2 using the same condition of pressure and temperature

h_1=491 kj/kg
h_2=553.2 kj/kg
h_3= 511.3 kj/kg
h_4=184.3 kj/kg

(c. o.p) theo of MIX 2 =(h_1-h_4)/(h_2-h_1)

(c.o.p) theo of MIX 2 =(491-184.3)/(553.2-491) =4.93

A comparision of R-22 refrigitent with MIX 1 and MIX2 is shown below

h_4)/(h_2-h_1)

(c.o.p) theo of MIX 2 =(491-184.3)/(553.2-491) =4.93

A comparision of R-22 refrigitent with MIX 1 and MIX2 is shown below

a) **Variation of density with temp keeping pressure constant-**
When desity is high sp.volume will be low ,which means that for a given mass storage the required size of compressor will be small .A graph is plotted between density and temperature ,showing variation of density with temperature for R22 ,mix 1 and mix 2.Data for graph is taken from REFPROP at given pressure and temperature reading. It is clear from the graph(fig -5) that size of the compressor for mix 1 and mix 2 will be larger as compared to r22.Density of R22 is 14 % higher than mix 1 and 33% higher than mix 2 within the working temperature range.

b) **Variation of enthalpy with temp keeping pressure constant –**
Enthalpy of refrigerant is a good representation of heat extracting capacity. Higher the enthalpy greater the amount of heat a particular refrigerant can extract. Data for graph is taken from REFPROP at given pressure and temperature reading. Enthalpy versus temperature graph(fig -6) is plotted for R22 mix 1and mix 2, which shows that heat extracting capacity of mix 1and mix 2 is better than R22 .Enthalpy of mix 2 is 20 % higher than R22 and mix 1 is 17 % higher than R22 within the working temperature range.

c) **Variation of entropy with temperature keeping pressure constant –**
Entropy is measure of unstability of system . Data for graph is taken from REFPROP at given pressure and temperature reading. Entropy vs temperature graph (fig -7) is plotted for R22 mix 1and mix 2, which shows that entropy of mix 1and mix 2 is less as compared to R22 . Hence there will be slight rise in entropy when replacing R22 with mix1 and mix 2.Entropy of mix 2 is 21 % greater than R22 while for mix 1 it is 16 % higher than R 22 within the working temperature range.

d) **Global warming potential comparision-**
GWP is a relative measure of how much heat a greenhouse traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide . A graph(fig -8) is plotted showing the comparison of global warming potential of R 22 and constituent of mix 1 and mix 2 i.e R134a , R32 ,R152a . GWP of constituent of mix 1 and mix 2 replacing R22 is lower than R22 . Global warming potential of R 22 is 58 %higher than mix 1 and 60 % higher than mix 2 . Graph (fig -9) represent the ovearall global warming potential of mix 1 and mix 2 and its comparision with R22.

e) **Molecular weight-**
Latent heat of vaporization and specific heat depends on molecular weight. Latent heat of vaporization will be high for refrigerant having lower molecular weight. This is an advantage. A graph (fig -10) is plotted to give a comparison between molecular weight of R22 and mix 1and mix 2.Molecular weight of R22 is 86 which is much higher than mix1(mol wt 77) and mix 2 (mol wt 78). Higher molecular weight is representation of good thermodynamic and thermo physical properties. Also low molecular weight signifies less specific volume hence low volume of refrigerant is required for a given refrigeration effect.

f) **Ozone depleting potential-**
(ODP) of a chemical compound is the relative amount of degradation to the ozone layer it can cause, with trichlorofluoromethane (R-11 or CFC-11) being fixed at an ODP of 1.0. R22 has ODP of 0.05 and it has to phase out from vapour compression refrigeration system . R22 is replaced with mixture of refrigerants whose ODP is zero.

Theoratical C.O.P comparision -

RESULT AND DISCUSSION-

Table-4 result comparision of R22 with mix 1 and mix 2

REFRIGERENT	**R22**	**MIX 1**	**MIX 2**
C.O.P	**4.38**	**4.58**	**4.93**
Molecular weight	**86**	**77**	**78**
Global warming potential	**1700**	**700**	**690**
Ozone depleting potential	**0.05**	**0**	**0**

-

1) C.O.P of MIX 1 and MIX 2 is greater than C.O.P of R22, which ensure better performance. C.O.P is ratio of heat extracted from cold body and work supplied, hence higher C.O.P represent higher heat extraction rate at a given work supplied. C.O.P of mix 1 is 5% higher than R22 and that of mix 2 is 12 % higher than R22 .
2) Enthalpy of the MIX 1 and MIX 2 is greater than that of R22, which ensure better heat transfer. It is clear from graph that enthalpy of enthalpy of mix 1 is 17 % higher than R22 and mix 2 is 20 % higher than R 22.Higher enthalpy represents that heat extracting capacity of refrigerant is good which increases the refrigeration effect of the vopour compression cycle.
3) Density of MIX 1 and MIX2 is lower than R22 ,which means sp.volume is high ,which further signifies that large size of compressor is required. Density of mix 1 is 14 % higher R22 and mix 2 is 33 % higher than R 22 .
4) Entropy of the MIX 1 and MIX 2 is greater than that of R22. Entropy of mix 2 is 20 % higher than R 22 and mix 1 is 17 % higher than R22 .Higher the entropy greater will be the disorderness of the system .
5) GLOBAL WARMING POTENTIAL of MIX 1 and MIX 2 is lower than that of R22. GWP of R 22 is 58 % higher than mix 1 and 60 % higher than mix 2 .Since mix 1 and mix 2 have comparatively low GWP as compared to R22 it can be widely used in vapour compression cycle and will cause less harm to the environment as compared to R 22.
6) OZONE DEPLETING POTENTIAL of mixture is zero ,since it does not contain any ozone depleting element like chlorine . Non zero value of ODP of R22 is the major reason of its replacement from vapour compression cycle. Depletion of ozone has several bad effect on environment like melting of glacier ,rise in sea water level , harm full skin disease , destruction of eco system etc.
7) Molecular weight of mix 1 and mix 2 is less than that of R22 . Molecular weight of R 22 is 86 and for mix 1 and mix 2 it is 77 and 78 respectively.

CONCLUSION

mix 1 and mix2 can be possible replacement of R22 since c.o.p of mix 1 and mix 2 is higher than R22 , also it has zero ozone depleting potential and low global warming potential as compared R22 which makes it an environment friendly refrigerant.

It is miscible with organic refrigerant and also chemically stable. These all properties makes mix 1 and mix 2 as a possible replacement of R 22 in vapour compression refrigeration system.

LIST OF FIGURE

Fig-1 Compressor

Fig-2 Air cooled condenser

Fig-3 Capillary tube

Fig-4 Evaporator

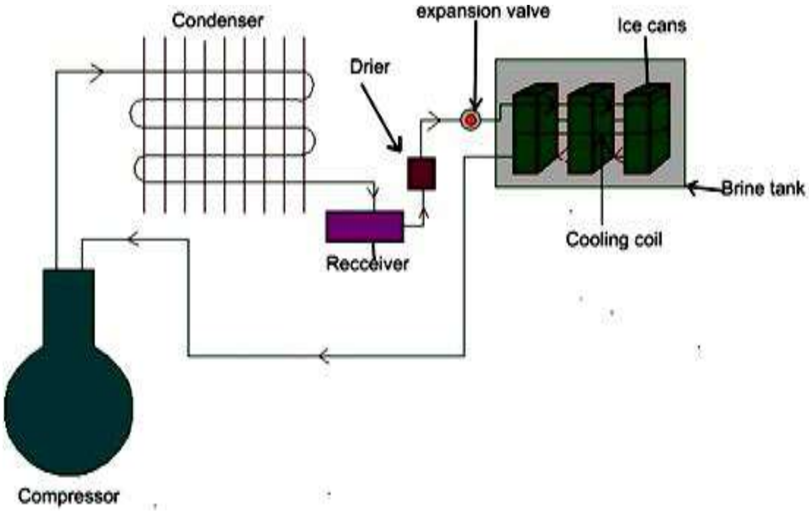

Fig-5 Block diagram of ice plant

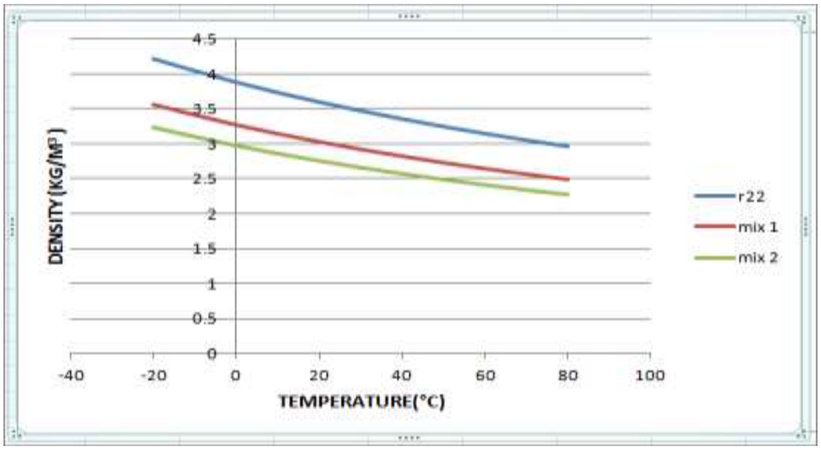

Fig-6 Density versus temperature

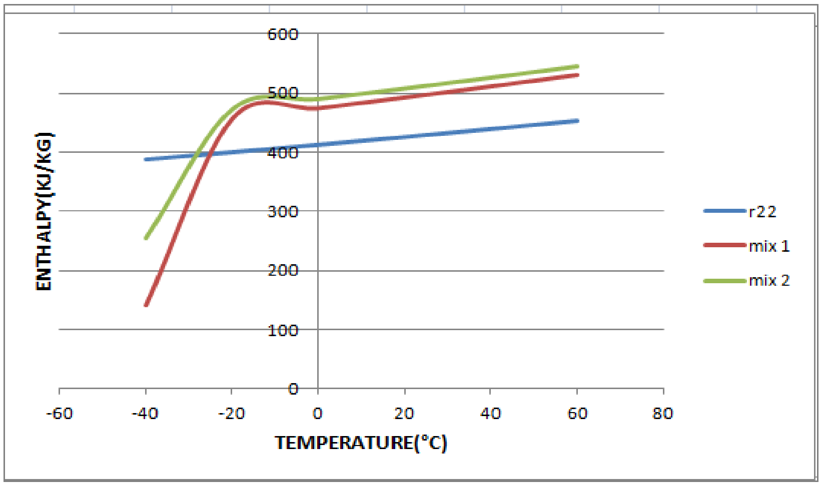

Fig-7 Enthalpy versus temperature

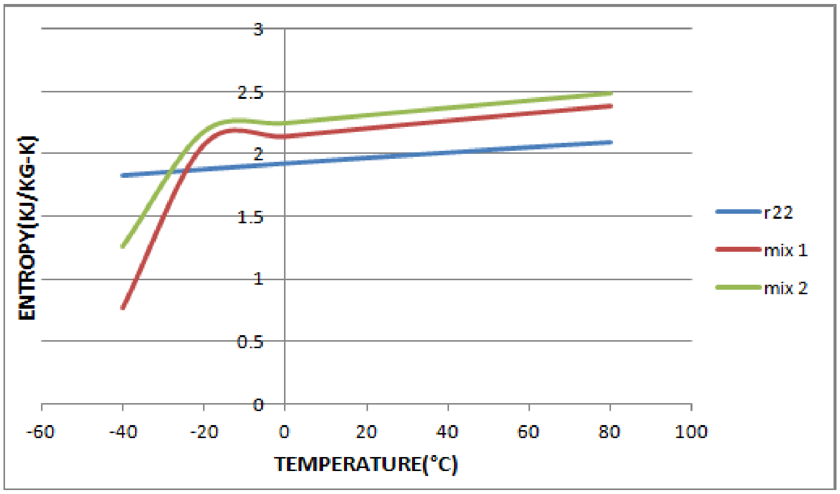

Fig-8 Entropy versus temperature

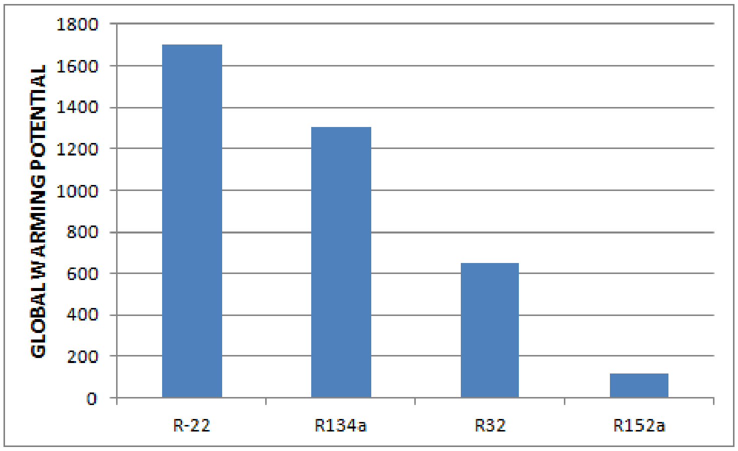

Fig-9 Global warming comparison of constituent refrigerant with R22

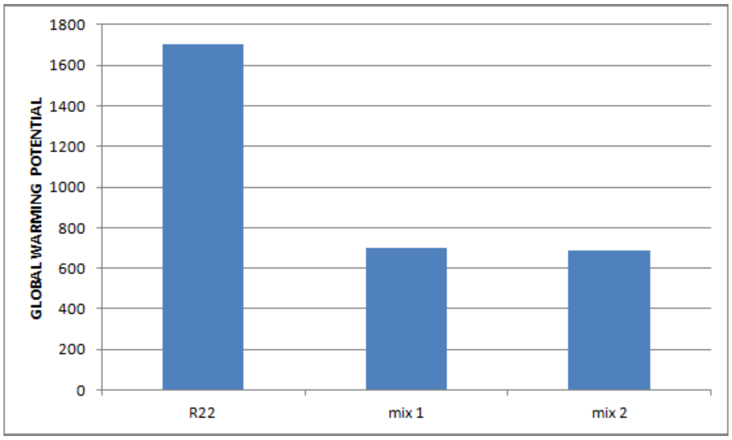

Fig-10 Global warming comparison of refrigerant mixtures with R22

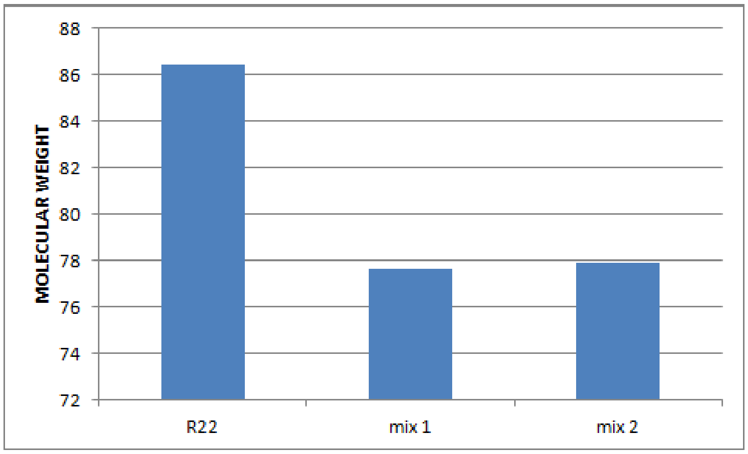

Fig-11 molecular weight of R22, mix 1 and mix 2

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