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# Comparative Performance of R438A and R32/R125/R600A Mixture for Replacing HCFC22 used in Air-Conditioners

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***Abstract*— In this study, the energy performance of R438A and M1 (R32/R125/R600A) mixture has been assessed theoretically in a residential air conditioner. The performance has been assessed for five different condensing temperatures, i.e. 35, 40, 45, 50 and 55 °C with an evaporator temperature of -10 °C. The volumetric cooling capacity, coefficient of performance, compressor power consumption and compressor discharge temperature were used as the parameters for comparing the performance of the residential air conditioner. Total equivalent warming impact of the air conditioner was assessed for a 15-year life time. The results indicated that volumetric cooling capacities of M1 and R22 are similar, so that R22 compressor can be used for M1 without modifications, but R438A has slightly lower volumetric cooling capacity. The coefficient of performance of R438A was found to be higher than that of M1 by at least 17 % with 26 % lower compressor power consumption at all condenser temperatures. The compressor discharge temperature of R438A was observed to be at least 10°C lower than that of M1. Total equivalent warming impact of R438Awas found to be lower than that of M1 by about 13% due to its higher energy efficiency. The results showed that R438A is a more energy efficient and environment-friendly alternative to R22 than M1 in residential air conditioners.**

***Keywords— R32/R125/R600A Mixture; R438A; Residential air conditioner; Total equivalent warming impact***

## I. INTRODUCTION

Montreal Protocol was signed in 1987 and India ratified it in 1992. As per this protocol, developed countries like India have to phase out HCFCs completely by 2040 (Richard [1]).

As an alternative to R22 in air conditioning, R-407C is mainly used for retrofitting whereas R-410A is the next popular choice for new systems and use of HC-290 is growing in Europe as it requires minimal modifications (Devotta et al [2]). The major problem associated with R410A is its lower critical temperature, which restricts its usage in compression based systems working at higher condensing temperatures whereas for R407C, a change to POE lubricant is required and HC-290 is flammable.

Many researchers tested hydrocarbons (HCs) and their mixtures as alternatives to R22 in residential air conditioners due to their good thermodynamic and thermo-physical properties. In related work, Park et al [3] investigated experimentally the use of propylene, propane, seven mixtures composed of propylene, propane, HFC152a, and dimethylether in air-conditioners and heat pumps. In further work, R433A (30% propylene and 70% propane) was tested in air-conditioner (Park et al [4]). Zaghdoudi [5] simulated the performance of R134a, R290, R600, R404A, R407A, R407B, R407C, 407D, R410A, R410B, and R417A with the help of software Cycle_D and reported R290 to be the best candidate for R22. In another work, Cheng et al [6] assessed the performance of R32 and R290 in a small split household air conditioner with 5 mm finned tube heat exchanger and reported with COP of R32 and R290 were 26.8% and 20.4% higher than R22, 7.3% and 2.1% higher than R410A. Similarly, Al-Joudi & Al-Amir [7] tested R290, R407C and R410A in a split type air conditioner of 2 TR and reported that R290 is the better replacement for R22 when the air conditioning system works under high ambient temperature. Padalkar et al. [8] studied the performance of a split air conditioner with nominal cooling capacities up to 5.1 kW, using HC R290. It was found that with PFC (parallel flow condenser), HC-290 gave highest EER of 3.7 which was 37% higher than that of HCFC-22. However, HC refrigerants have their own drawbacks with respect to flammability.

Another option for replacing R22 in air conditioners is R407C. Devotta et al [9] in their experimental study on window air conditioner concluded that retrofitting with R-407C is an option to extend the life of old units, although the performance is slightly poorer. On the other hand, in a comprehensive review made with possible substitutes, it has been reported that use of R410A is not recommended because the plant will operate with a significant decrease of refrigeration power Sarbu [10].

Allgood & Lawson [11] reported that in existing refrigeration & air conditioning systems, the use of R438A (ASHRAE, 2009), which is a non-ozone depleting zeotropic blend of

HFC-32, HFC-125, HFC-134a,HC-600 and 601a(8.5:45.0:44.2:1.7:0.6 wt%, respectively), resulted in similar cooling performance & energy efficiency, lower discharge temperature, similar evaporator & condenser pressure and no change of lubricant during retrofit. In related work, Elgendy et al [12] studied the performance of direct expansion water chiller working with R438A. It has been reported that cooling capacity and COP of the system using R-438A are lower than R-22 by 11% and 12.5%, respectively. However, compressor discharge temperature using R-438A is slightly lower than R-22 which confirms that R-438A can be used as a retrofit refrigerant for R-22 to complete the remaining life time of the existing plants. Recently, Ramu et al [13] proposed the refrigerant mixture R32/R125/R600a (in the ratio of 0.4:0.4:0.2, by mass) to be used in air conditioners to replace R22 and reported that the new refrigerant mixture is an ozone-friendly alternative to phase out R22 in the existing refrigeration systems to extend its life without modifications. TEGWI of new refrigerant mixture was found to be higher than that of R22 by about 20%. Arora et al [14] performed the exergy analysis of vapour compression refrigeration system with R-22, R-407C and R-410A. Pardal et al [15] did a study of thermoeconomic analysis which can be incorporated into refrigeration or an air conditioning system. Kalla and Usmani [16] reported the comparative performance study of vapour compression refrigeration system with R134a/M09/R410a/R407c/R290/M50. Kalla and Usmani [17] also reviewed refrigeration cycles and systems.

To the authors' knowledge, there is no specific work reported on the energy performance comparison of R438A and R32/R125/R600a mixture (referred to as M1 in this paper) as an alternative to R22 in residential air conditioners. The main objective of this paper is to investigate which of these two refrigerant blends can be a potential alternative to R22.

## II. CHARACTERISTICS OF R22, R438A AND M1

Refrigerant blend R438A composed of R32, R125, R134a, R600 and R601a (8.5:45.0:44.2:1.7:0.6 wt%, respectively) is considered as a viable alternative to R22. R438A is a zeotropic mixture with temperature glide of 6.19 °C and GWP of 2265 (Elgendy et al, 2014). The new refrigerant mixture M1 composed of R32/R125/R600a (in the ratio of 0.4:0.4:0.2, by mass) is also considered as candidate for R22 substitution. M1 is a zeotropic mixture with GWP of 1670 (Ramu et al, 2014). The properties of the refrigerants (such as vapour pressure, latent heat, density and specific heat) for wide range of temperatures (between 0 and 60 °C) are compared in Figs. 1–4. Fig. 1 depicts the variation of vapour pressure of R22, M1 and R438A against temperature. It is observed that R22 has approximately the same vapor pressure as R438A. However, M1 has 25% and 41% higher vapour pressures at lower temperatures and higher temperatures, respectively. Hence for M1, the compressors will operate relatively at higher pressures. The variation of latent heat of the three investigated refrigerants is shown in Fig. 2. At low temperatures (0-20ºC), the latent heat of M1 is found to be higher than that of R22

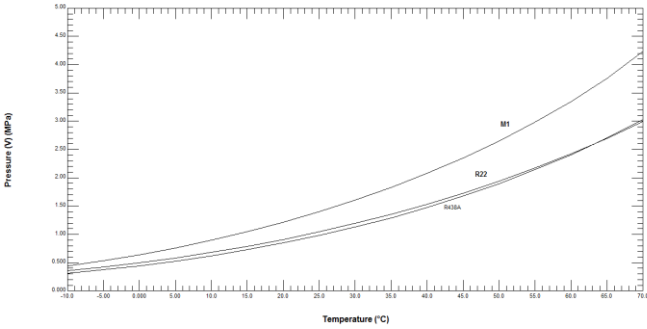


Fig.1. Variation of vapour pressure with temperature

which ensures more refrigeration effect in the evaporators. Similarly, at higher temperatures, the latent heat of M1 is found to be lower than that of R22 at higher temperatures between 40 and 60ºC. Hence, low heat rejection is expected with refrigerant mixture M1 in the condensers. However, R438A is having the latent heat lower than that of R22 throughout the temperature range considered. This will result in less refrigeration effect in the evaporator as well as low heat rejection in the condenser.

The liquid densities of R22, M1 and R438A are compared in Fig. 3.The liquid densities of M1 and R438A are found to be lower than that of R22 by about 45% and 2.6% respectively, across the considered range of temperatures between 0 and 60ºC. Due to the lower liquid density of M1 and R438A, the mass charge requirement would be reduced compared to that of R22. The lower liquid density values of the refrigerant mixtures have lower friction in the tubes of heat exchangers, which ensures better heat transfer coefficients compared to R22 in the condensers and evaporators.

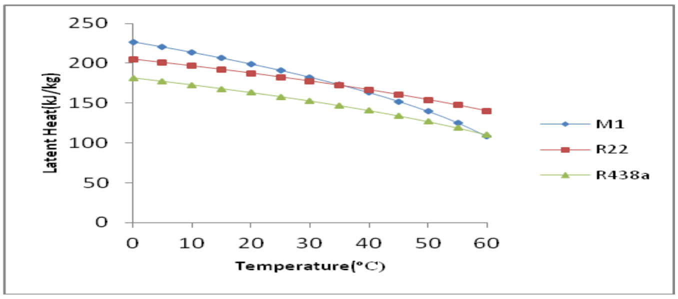


Fig.2. Variation of latent heat with temperature

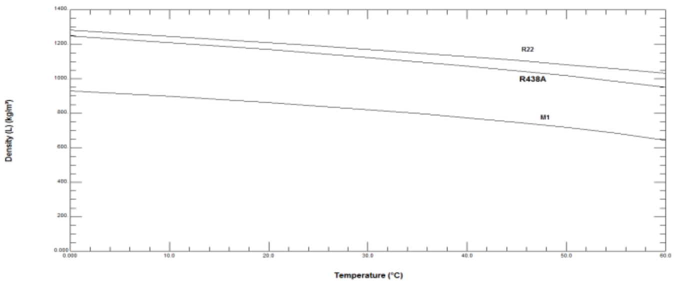


Fig. 3. Variation of liquid density with temperature.

The variation of viscosity of R22, M1 and R438A against temperature is shown in Fig. 4.A low viscosity is desirable to achieve higher heat transfer coefficients. It is observed that liquid viscosity of M1 is found to be lower than that of R22 which yields better heat transfer coefficients in the condensers. Same is applicable for R438A for temperatures above 15ºC whereas for temperatures below 15ºC R438A and R22 have approximately the same viscosity. Properties such as critical temperature, critical pressure, boiling point, molecular weight, ODP and GWP of R22, M1 and R438A are compared in Table 1. M1 and R438A both have zero ODP. As compared to R22, GWP of M1 is lesser whereas GWP of R438A is higher. The critical temperatures of both M1 and R438A are lower than R22 whereas critical pressure of M1 was found to be approximately same as that of R22. Critical pressure of R438A is lower than that of R22.

## I. THERMODYNAMIC ANALYSIS

Fig. 5(a) and (b) respectively show the schematic diagram and pressure enthalpy diagram of a vapour compression refrigeration cycle. In a residential air conditioner, throttle valve is replaced by a capillary tube. Process 3-4 represents compression, 4-1 condensation, 1-2 expansion and 2-3 evaporation. 3-4s is the isentropic compression. Refrigerant state at point 3 is saturated vapour, at point 4 it is superheated vapour, at point 1 it is saturated liquid and at point 2 it is two phase mixture. Theoretical assessment of the refrigerants is done from energy point of view using first law of thermodynamics. Environmental impact of refrigerants is also studied.

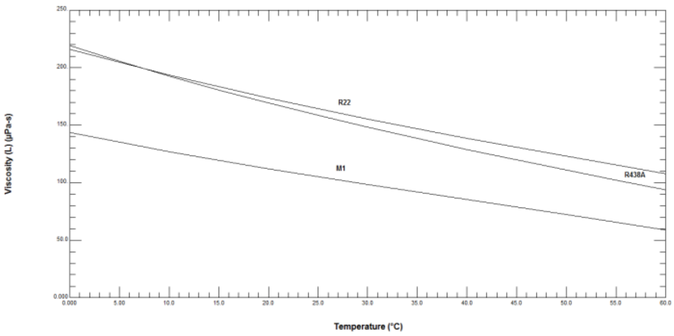


Fig. 4. Variation of liquid viscosity with temperature.

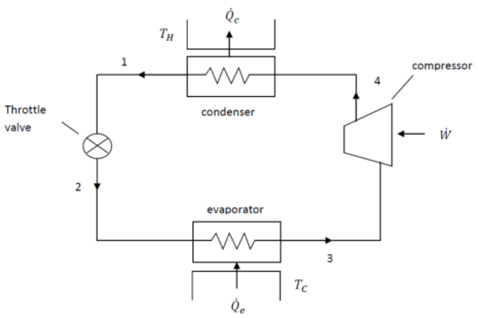


Fig.5(a). Vapour compression refrigeration cycle.

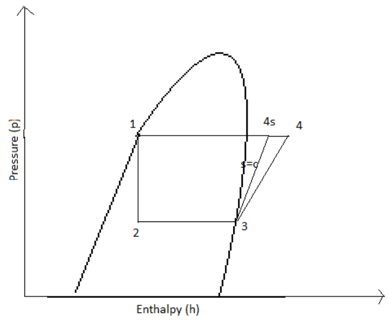


Fig.5(b). Pressure enthalpy diagram of Vapour compression refrigeration cycle.

The following assumptions have been made based on compressor displacement of $1m^3/s$:

i Compressor isentropic efficiency is 0.7 ( Genetron Properties v1.1[18])

ii Life of the air conditioner is 15 years, leakage is 25% per year,

iii Evaporator temperature -10ºC,

iv No pressure drop in condenser and evaporator,

v No superheating and subcooling,

vi Steady state processes in the system.

vii Charge required for R22 is 900g and for M1 and R438A it is 750g and 883g respectively, due to their lower liquid densities.

In this analysis, the thermodynamic properties of the refrigerants are taken from REFPROP version 8 [19] and simulation has been done with the help of Genetron Properties v1.1 and EES (Klein and Alvarado [20]) softwares.

## II. TOTAL EQUIVALENT WARMING IMPACT

The method of calculating total equivalent warming impact(TEWI) is provided below (AIRAH [21]):

TEWI = GWP (**direct**; refrigerant leaks incl. EOL) + GWP (**indirect**; operation)

$$= (GWP \times m \times L_{annual} \times n) + GWP \times m \times (1 - \alpha_{recovery})) + (E_{annual} \times \beta \times n)$$

where:

GWP = Global Warming Potential of refrigerant, relative to $CO_2$ (GWP $CO_2$ = 1)

$L_{annual}$ = Leakage rate p.a. (Units: kg)

$n$ = System operating life (Units: years)

$m$ = Refrigerant charge (Units: kg)

$\alpha_{recovery}$ = Recovery/recycling factor from 0 to 1

$E_{annual}$ = Energy consumption per year (Units: kWh p.a.)

$\beta$ = Indirect emission factor (Units: kg $CO_2$ per kWh)

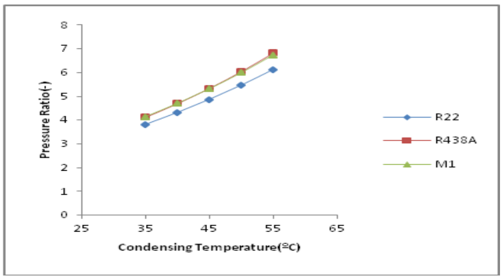


Fig. 6. Variation of pressure ratio with condensing temperature.

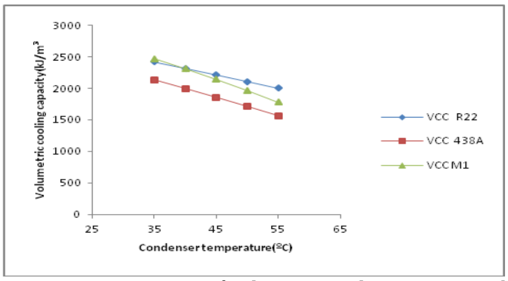


Fig. 7. Variation of volumetric cooling capacity with condensing temperature

In this work, the $CO_2$ emission factor is assumed to be 0.89 kg of CO2/kWh (IEA [22]).

## III. RESULTS

Theoretical assessment of residential air conditioners has been done using R22, M1 and R438A at five different condensing temperatures (35, 40, 45, 50 and 55 °C) at an evaporator temperature of -10ºC and the results obtained are discussed in this section.

Variation of pressure ratio

The variations of pressure ratio against condenser temperature are compared in Fig. 6. The pressure ratios of M1 as well as R438A were observed to be higher than that of R22 by approximately 8.6%, 9.2%, and 10.1% at 35, 45 and 55 °C, respectively. Hence, volumetric efficiency will be lesser with M1 as well as with R438A.

Variation of volumetric cooling capacity (VCC)

The variation of VCC at different condensing temperatures is shown in Fig. 7. VCC of M1 was found to be closer to R22 for condensing temperatures up to 40ºC and deviations in VCC for 45 and 55 °C are found to be 3.3% and 11%, respectively. Hence, M1can be used as drop-in substitute without major modification in the existing R22 systems. As regards R438A, VCC is within 13-21% of R22 as the condensing temperature varies from 35 to 55ºC.

Variation of Coefficient of performance (COP)

The COPs of the three refrigerants are compared in Fig. 8. The COP of R438A is lower than that of R22 by about 6%, 9.5% and 14.2% at 35, 45 and 55 °C, respectively due to its lower

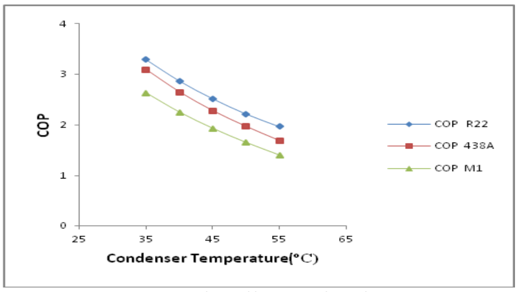


Fig. 8. Variation of coefficient of performance with condensing temperature

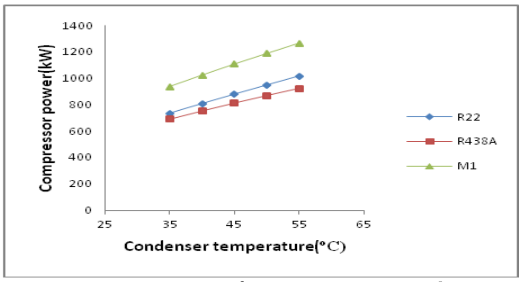


Fig. 9. Variation of compressor power with condensing temperature

evaporator capacity which offsets the advantage due to its lower compressor work consumption. The COP of M1 is much lower than that of R22 by about 20%, 23.4% and 28.9% at 35, 45 and 55 °C, respectively due to its lower evaporator capacity as well as higher compressor work.

Variation of compressor power consumption

Power consumptions of the three refrigerants are compared in Fig. 9. The power consumption of R438A was found to be lower than that of R22 by 5.7%, 7.4%, and 9.2% at 35, 45 and 55 °C condensing temperatures, respectively. On the other hand, the power consumption of M1 was found to be higher than that of R22 by 27.7%, 26.1%, and 24.5% at 35, 45 and 55 °C condensing temperatures, respectively.

Compressor discharge temperature

The comparison of compressor discharge temperature of the three refrigerants is shown in Fig. 10. The compressor discharge temperatures of R438A as well as M1 were found to be lower than that of R22 for a wide range of condenser temperatures due to their lower specific heat ratios. Due to the lower compressor discharge temperature, the life of the compressor will increase. The compressor discharge temperature of R438A was found to be lower than that of R22 by 18.2, 22.1 and 25.7 °C at 35, 45 and 55 °C condensing temperatures, respectively. However, the compressor discharge temperature of M1 was found to be lower than that of R22 by only 8.1, 10.1 and 11.9°C at 35, 45 and 55 °C condensing temperatures, respectively.

Total equivalent warming impact (TEWI)

The TEWI of the three refrigerants is calculated for 15 year life time of the air conditioner at 50 °C and −10 °C condensing and evaporator temperatures, respectively. The TEWIs of the

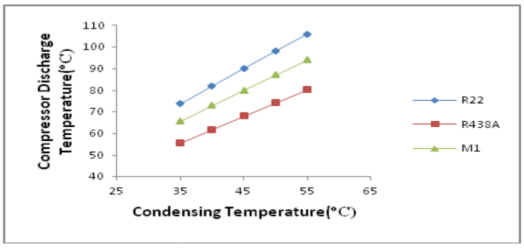


Fig. 10. Variation of compressor discharge temperature with condensing temperature

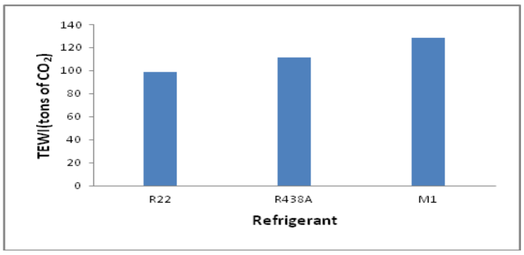


Fig. 11. Comparison of TEWI.

air conditioner working with R22, M1 and R438A are compared in Fig. 11. TEWI of R438A was found to be lower than that of M1 by about 13% due to its higher energy efficiency even though it is having higher GWP.

Oil management

R438A can be used to convert R22 systems without the need to change out the mineral oil (Allgood & Lawson, 2010). Similarly, in case of M1, R600a is taken as a viable additive to tackle the oil miscibility issue in the compressor.

## IV. CONCLUSIONS

The energy performance assessment has been made for a residential air conditioner working with R22, M1 and R438A and the following conclusions were made.

- For R438A, cooling capacities are within 13-21% of R22 across the range of condenser temperature whereas for M1, cooling capacities are within 2-11% of R22.
- The COP of the residential air conditioner working with R438A was found to be lower than that of R22 by 6%, 9.5% and 14.2% at 35, 45 and 55 °C condensing temperatures, respectively. The COP of M1 is much lower than that of R22 by about 20%, 23.4% and 28.9% at 35, 45 and 55 °C, respectively.
- The power consumption of R438A was found to be lower than that of R22 by 5.7%, 7.4%, and 9.2% at 35, 45 and 55 °C condensing temperatures respectively. For M1, the power consumption was found to be higher than that of R22 by 27.7%, 26.1%, and 24.5% at 35, 45 and 55 °C condensing temperatures, respectively.
- The TEWI of R438A was found to be lower than that of M1 by about 13% due to its higher energy efficiency.
- The compressor discharge temperature of the air conditioner working with R438A is the lowest as compared to M1 as well as R22, which may increase the compressor life.
- In most systems, the existing mineral oil lubricant in the compressor can be used with both R438A and M1.

The results discussed in this paper confirmed that R438A is energy efficient and environment-friendly alternative to replace R22 systems as compared to M1.

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