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# POTENTIAL REPLACEMENT TO CHLOROFLUOROCARBON REFRIGERANTS – A REVIEW

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## ABSTRACT

Present day mankind depends very heavily on refrigeration and air conditioning systems for daily needs. These cover a wide range of applications such as food processing, comfort cooling, health and recreation etc. Refrigerants are the working fluids for refrigeration and air conditioning systems. Generally refrigerants are classified into various types on the basis of their physical and chemical changes during the course of operation. The most preferred type of the refrigerant mixture is zeotropic mixtures. Refrigerants emit green house gases and these gases have a significant impact on the environment. Global warming and ozone depletion are the most important environmental issues caused by the refrigerants. Refrigerants are the derivatives of alkanes namely methane and ethane. Chloroflurocarbon, hydrochloroflurocarbon, hydroflurocarbon and hydrocarbon are the major chemical compounds which are used as refrigerants since 1970s. The presence of chlorine and fluorine in the derivatives of methane and ethane modifies the emission of green house gases and their impacts. The present study deals with the drawbacks of existing refrigerants and also finding a suitable replacement to the presently used working fluids with respect to their chemical compositions, thermodynamic properties and environmental properties. The results obtained from this study supported that the blend of R410A (CH2F2/C2HF5:50/50 by mass)/R600a (C4H10) as a potential replacement for R22 (CHClF2).

**Keywords**:Refrigerants, chemical composition, thermodynamic properties, ozone depletion, global warming

## I. INTRODUCTION

Generally in refrigeration and air-conditioning, vapour compression-based systems are employed. Halogenated refrigerants preferred as refrigerants to vapour compression based systems because of their good thermodynamic and thermo-physical properties. However, halogenated refrigerants possess comparatively poor environmental properties with respect to ozone depletion potential (ODP) and global warming potential (GWP). Montreal and Kyoto protocols limit the utilization of halogenated refrigerants in the vapour compression based refrigeration systems. The usage of chlorofluorocarbon (CFCs) was completely stopped in most of the nations based on Montreal protocol 1987. However, hydrochloroflurocarbons (HCFC) refrigerants can be used until 2040 in developing nations and developed nations should phase out by 2030 [1]. Consumption of HCFC refrigerants has been reduced in most of the developed nations. United Nations Framework Convention on Climate Change (UNFCCC) calls for reduction in emission of green house gases, which includes hydroflurocarbons (HFCs) as refrigerants [2]. The demand for refrigerants in refrigeration and air-conditioning sector is large globally, it is necessary to find long-term alternatives to existing with respect to the guidelines of international protocols. Refrigerant mixtures with low environment impacts such as HC and HFC are considered as potential alternatives to phase out the existing halogenated refrigerants.

Very few pure fluids are possessing properties which are closer to the existing halogenated refrigerants. The refrigerant mixtures offer more flexibility in searching new alternatives with better environmental properties to match the desirable with the existing halogenated refrigerants. The two alternative options are HC and HFC mixtures with lower GWP. HC-based mixtures are environment-friendly, which can be used as alternatives without modifications in the existing systems. The most possible two alternative options are HC and HFC mixtures with lower GWP. HC-based mixtures are environment-friendly, which can be used as alternatives without modifications in the existing systems. However, the usage of HC refrigerant mixtures in large capacity systems limited because of its high flammable nature [3]. In small capacity refrigeration units such as, domestic refrigerators, bottle coolers, visi coolers, deep freezers, etc., the HC refrigerant mixtures are preferred because which require less refrigerant quantity compared with the halogenated refrigerants. HFC mixtures are ozone-friendly, but it has significant GWP. HFC mixtures are immiscible with mineral oil, which require synthetic lubricants (such as polyester). HFC refrigerants used with the synthetic lubricants which are highly hygroscopic in nature, expensive, cause irritation when it comes in contact with skin, which leads to several service issues while retrofitting [4]. The problems associated with HC and HFC refrigerant mixtures, can be overlooked by mixing hydrocarbons with HFC refrigerants, which promotes the miscible nature (with mineral oil) and also reduces the flammability of HC mixtures [5].

Many reported earlier investigations revealed that HFC/HC mixtures are miscible with mineral oil. When HFC/HC mixture used alone, the GWP of HFC/HC mixture was also reported to be less than one-third of HFC. It is possible to mix HC refrigerants with HFC to replace the existing halogenated refrigerants [6]. Wang and Li [7] summarized the perspectives of natural working fluids in China for refrigeration and air conditioning applications, which include both compression and absorption-based refrigeration systems in their earlier reports. An overview of various pure HC refrigerants used for refrigeration and air-conditioning applications was presented by Gryand [8]. Corberan et al. [9] reviewed the standards followed for vapour compression refrigeration system working with HC refrigerants and reported the specific requirements for air-conditioning and refrigerating equipment selected for operating with hydrocarbons. The historical development of pure refrigerants from early use to the present and in the future were compiled and reported by Calm [10]. The performance of the vapour compression-based refrigeration systems working with environment-friendly alternatives were collected by Mohanraj et al. [11] and suggested that the refrigerant mixtures are good substitutes for phasing out existing halogenated refrigerants. Based on the previous reviews cited above, it is understood that there is no specific reviews reported on refrigerant mixtures. This review sets out more broadly about up-to-date study covering the performance of new refrigerant mixtures with special emphasis on studies reported during the last decade.

## II. TYPES OF REFRIGENT MIXTURES

The selection of refrigerant mixtures is becoming of great interest due to the phase-out of pure halogenated refrigerants. Very few pure fluids are having suitable properties and they can be used as alternatives to the existing halogenated refrigerants. A refrigerant mixture obtained by mixing two or more refrigerants and that provides an opportunity to adjust the properties to desirable levels. Azeotropes, near azeotropes and zeotropes [12] are the three categories of mixtures used in refrigeration and air-conditioning applications.

## III. PROPERTIES OF MIXTURES

A mixture used as a refrigerant should have certain properties like thermodynamic, thermo physical, chemical and environmental which are closer to the existing halogenated refrigerants to meet the requirements of system performance, material compatibility and environment considerations. [13]

**Thermodynamic and thermo-physical properties**

The thermodynamic requirements of the alternatives pertain to vapour pressure of mixtures, critical pressure, critical temperature, freezing point, normal boiling point, volume of suction vapour per ton, coefficient of performance (COP), power consumption per ton, specific heat ratio, etc. A positive pressure inside the system is required to eliminate the possibility of ambient moisture infiltration into the system. The critical temperature should be very high, so that the condenser temperature line on the pressure enthalpy diagram is far from the critical point, which ensures reasonable refrigeration effect. The critical pressure of the new mixtures should be low. Boiling point of the refrigerants should be low, which will produce low temperature. Freezing point of the alternatives should be lower than system temperatures. The specific heat ratio of the alternative mixtures should be low. Hence, lower discharge temperature can be expected, which will improve the compressor life. Molecular weight of the refrigerant affects the compressor size because the specific volume of the vapour is directly related to it.

A low molecular weight refrigerant is preferred for the reciprocating refrigerant compressor. The volume of suction vapour required per ton of refrigeration is an indication of the size of the compressor. Reciprocating compressors are preferred with refrigerants having high pressure and small volume of vapour. Rotary compressors are used with refrigerants having low pressure and large volume of suction vapour. [14]

Thermo physical properties such as thermal conductivity and viscosity are required for choosing an alternative. A high thermal conductivity in both liquid and vapour phases is desirable to achieve high heat transfer coefficient in both condenser and evaporator. Similarly, low viscosity in both liquid and vapour phases is desirable to achieve high heat transfer coefficient with reduced power consumption. All the pure and mixed HC refrigerants have lower viscosity and higher thermal conductivity, which results in better condenser and evaporator performance. The liquid density is another factor considered for choosing an alternative. Lower liquid density is preferable to reduce the refrigerant charge requirement. Most of the pure and mixed HC refrigerants are having lower liquid density, which results in less refrigerant charge requirement.

**Chemical properties**

Under retrofit conditions, compatibility of the refrigerant with materials and chemical interaction between refrigerant and lubricant inside the system is the most important. The refrigerant– lubricant combinations will affect electric insulation properties of the motor winding varnishes and ground insulation sheets. The chlorine-based refrigerant mixtures are miscible with mineral oil, which is user-friendly. However, HFC refrigerant mixtures are not miscible with mineral oil, which requires a synthetic lubricant. This synthetic lubricant is highly hygroscopic in nature and has many service issues. Hence, user-friendly lubricants are preferred for the use of HFC-based refrigerant mixtures. HC refrigerant mixtures are miscible with both mineral oil and synthetic lubricants. Hence, HC refrigerants are preferred as additives with HFC mixtures to overcome the miscibility issue with mineral oil. The safety classification of the refrigerants consists of two alphanumeric characters: alphabet indicates the toxicity and numeric digit indicates flammability of refrigerant. [14].

**Environmental properties**

The halogenated refrigerants are the family of chemical compounds derived from the hydrocarbons (methane and ethane) by substitution of chlorine and fluorine atoms for hydrogen. The presence of halogenated atoms is responsible for ODP and GWP. The first major environmental impact that struck the refrigeration industries is ODP due to man-made chemicals into the atmosphere. The chlorine-based refrigerants are stable enough to reach the stratosphere, where the chlorine atoms act as a catalyst to destroy the stratospheric ozone layer which protects the earth's surface from direct UV rays. The second major environmental impact is GWP, which is due to the absorption of infrared emissions from the earth, causing an increase in global earth's surface temperature. The infrared radiation cannot pass through the atmosphere because of absorption by greenhouse gases including the halogenated refrigerants. HFC refrigerants have significant values of atmospheric lifetime and GWP compared with chlorine-based refrigerants. [14].

## IV. EXPERIMENTAL & THEORETICAL STUDIES WITH REFRIGERANT MIXTURES

During the last decade, many experimental and theoretical investigations have been reported with new refrigerant mixtures. In this section, the performance of the new refrigerant mixtures used in air-conditioning is discussed. The refrigerant mixtures are grouped as HC mixtures [15–20], HFC mixtures [21–26], HFC/HC mixtures [27–33], HCFC mixtures [34–37].

**Hydrocarbon mixtures (HC)**

Many HC refrigerant mixtures were developed to replace the halogenated refrigerants. HC mixtures are miscible with both mineral oil and synthetic lubricants. Hence, HC mixtures can be used as substitutes without changing the lubricant in the existing systems using HCFC and HFC refrigerants.

Purkayastha and Bansal [15] experimented with LPG mixture composed of R290, R170, R600a (in the ratio of 98.95: 1.007: 0.0397, by mass) as substitute for R22 in a 15-kW heat pump. It has been reported that COP of LPG mixture was higher than that of R22 by 12%. The volumetric refrigeration capacity of LPG was reported to be 14% higher than that of R22 with 10% lower condenser capacity. Chang et al. [16] studied the performance and heat transfer characteristics of HC mixtures composed of R290, R600a and R600 as alternatives to R22 in a heat pump. Their results concluded that cooling and heating capacities of HC refrigerant mixtures increase with increase in R290 mass fraction, which are lower than that of R22. The COP of binary HC mixtures composed of R290/R600a (in the ratio of 50:50, by mass) and R290/R600 (in the ratio of 75:25, by mass) was reported to be higher than R22 by 7 and 11%, respectively.

Park and Jung [17] have investigated the thermodynamic performance of a heat pump working with R22 and its alternative refrigerant mixtures composed of R170 and R290, with five different mass percentage of R170 (2, 4, 6, 8 and 10%). It has been reported that COP of the new refrigerant mixture gets decreased with increase in R170 mass percentage. The COP of the mixture was reported to be higher than that of R22 in the composition range up to 6% of R170. The refrigeration and heating capacities of R170/R290 mixture increased with increase in R170 mass percentage. The capacities were similar in the composition range between 4 and 6% of R170. The compressor discharge temperature of the R170/R290 was reported to be lower in the range of 16.6–28.21°C. Hence, higher compressor life can be expected with this mixture. The refrigerant charge requirement was observed to be lower by about 58% due to its lower liquid density. The refrigerant mixture R170/R290 with 4–6% of R170 was identified as long-term energy efficient and environment-friendly drop in substitute for phasing out R22 in heat pump applications. Park et al. [18] experimentally studied the thermodynamic performance of seven mixtures composed of R1270, R290, RE170 and R152a as alternatives for R22 in a residential air conditioner. The results reported in their study are compared in Table I. The compressor discharge temperature of the refrigerant mixtures is found to be lower than that of R22. Hence, increased compressor life can be expected with refrigerant mixtures. The refrigerant charge requirement is also found to be lower than that of R22 due to its lower liquid density.

Park et al. [19] have conducted an experimental investigation in an R22-based residential air conditioner working with R432A (near azeotrope mixture composed of R1270 and RE170, in the ratio of 80:20, by mass) as an alternative. It has been reported that R432A has 8.5–8.7% higher COP than that of R22 with 1.9–6.4% higher refrigeration capacity. The compressor discharge temperature of R432A was reported to be lower in the range between 14 and 17°C.

Hence, the life of the system can be improved. The charge requirement of new R432A was found to be 50% lower than that of R22. R432A has zero ODP and very low GWP of less than 5. Hence, R432A was reported as a good environment-friendly and energy efficient alternative to replace R22 in air-conditioner and heat pump applications. Park et al. [20] investigated the performance of a R22-based residential air-conditioner and heat pumps working with R433A (near azeotrope mixture composed of R1270 and R290, in the ratio of 70:30, by mass) as an alternative. It has zero ODP and very low GWP with a low temperature glide of 0.41°C. The results reported that COP of R433A is 4.9–7.6% higher than that of R22 with 1–5.5% higher capacity. The compressor discharge temperature was reported to be lower in the range between 22.6 and 27.9°C. The charge requirement of R433A is about 57% lower than that of R22 due to its lower liquid density. R433A was reported as a good energy efficient and environment-friendly alternative option to replace R22 in air-conditioning and heat pump applications.

**Table I.** Performance comparison of refrigerant mixtures with R22, Park et al. [18].

| Refrigerant mixture composition | By mass (%) | COP | Evaporator capacity (W) | Compressor discharge temperature (°C) | Refrigerant quantity (g) |
|---|---|---|---|---|---|
| R22 | | 3.78 | 3600 | 80.2 | 1170 |
| R1270/R290 | 20:80 | 3.9 | 3362 | 63.8 | 525 |
| R1270/R290 | 50:50 | 3.91 | 3589 | 65.5 | 550 |
| R1270/R290 | 80:20 | 3.92 | 3729 | 67.4 | 530 |
| R290/R152a | 60:40 | 3.84 | 3572 | 64.9 | 630 |
| R290/R152a | 71:29 | 3.91 | 3533 | 64.4 | 600 |
| R290/R152a | 75:25 | 3.91 | 3527 | 64.6 | 600 |
| R1270/R290/RE170 | 45:40:15 | 3.99 | 3551 | 67.5 | 540 |

**HFC Mixtures**

The HFC-based mixtures such as R404A, R407C and R410A are reported as potential alternatives to R22 in refrigeration, air-conditioning and heat pump applications [21]. However, HFC mixtures are not miscible with mineral oil, which is used as a lubricant in CFC and HCFC systems. HFC mixtures require synthetic lubricant like polyester. Hence, a major modification is required for HFC mixtures to retrofit in HCFC systems. The properties of commonly used HFC mixtures are compared in Table II [14]. The properties of new refrigerant mixtures are calculated based on their mass fraction and properties of individual pure refrigerants.

**Table II.** Properties of HFC mixtures as alternatives.

| Refrigerant | Composition | By mass | Replaces | Boiling Point | Molecular weight | Critical temperature | Critical pressure | ASHRAE safety code | ODP | GWP |
|---|---|---|---|---|---|---|---|---|---|---|
| R404A | R125/R143a/R134a | 44:52:4 | R22 | -46.6 | 97.60 | 72.1 | 3.74 | A1 | 0 | 3800 |
| R407C | R32/R125/R134a | 23:25:52 | R22 | -43.8 | 86.2 | 87.3 | 4.63 | A1 | 0 | 1700 |
| R410A | R32/R125 | 50:50 | R22 | -51.6 | 72.8 | 72.5 | 4.95 | A1 | 0 | 2000 |
| R507 | R125/R143a | 50:50 | R502 | -50.98 | 98.86 | 70.9 | 3.79 | A1 | 0 | 3900 |
| NRM | R152a/R125 | 85:15 | R12 | -28.59 | 74.14 | 106.2 | 4.38 | A1 | 0 | 612 |
| NRM | R161/R125/R143a | 10:45:45 | R502 | -49.29 | 96.63 | 72.81 | 3.80 | A1 | 0 | 3466 |
| NRM | R32/R134a | 25:75 | R22 | -32.5 | 89.52 | 95.37 | 4.49 | A1 | 0 | 1112.5 |
| NRM | R32/R125/R134a | 20:40:40 | R502 | -42.62 | 99.22 | 82.56 | 4.23 | A1 | 0 | 1990 |

Sami et al. [22] investigated the performance of five HFC mixtures such as R32/R125 (in the ratio of

60:40, by mass), R410A, R32/R125/R23 (in the ratio of 25:70:5, by mass), R407C and R32/R125/R143a/

R134a (in the ratio of 50.5:5:5:39.5, by mass) as alternatives to R22 in a heat pump. Their results showed that ternary mixture composed of R32/R125/R23 (in the ratio of 25:70:5, by mass) is a good substitute to replace R22 in low-temperature heat pumps, which has higher heating COP compared with other investigated refrigerants. The quaternary blend composed of R32/R125/R143a/R134a has higher cooling COP compared with other investigated refrigerants. Payne and Domanski [23] tested with R410A in a R22-based vapour compression-based systems working at outdoor temperature ranging from 27 to 55°C. R410A is a near azeotropic refrigerant mixture composed of R32 and R125 (in the ratio of 50:50, by mass). Their results reported that capacity and efficiency of both systems decreased linearly with increasing outdoor temperature. The capacities of both systems were approximately equal at 35°C, whereas at 55°C outdoor temperature, the capacity with R410A was reduced by about 9% compared with that of R22. Owing to its lower critical temperature, the performance of R410A was degraded more than R22 when ambient temperature gets increased. Henderson et al. [24] compared the performance of a domestic and commercial heat pumps working with R22 and its alternatives (R410A and R290). They suggested that R410A is a good substitute compared with R290 to replace R22 in domestic and commercial heat pumps. Chen [25] made a comparative study on the performance and environmental characteristics of R410A and R22 in residential air conditioners. He reported that the use of R410A systems will reduce the size of the heat exchangers and also improved the power saving. He also reported that the overall environmental impact of R410A is 4–11% lower than that of R22 in residential air conditioners.

Hepbasli [26] studied the exergy performance of a solar-assisted ground source heat pump system for residences using R410A as refrigerant. It has been reported that the maximum exergy destruction occurs at the high-pressure side (in the compressor and condenser) due to its lower critical pressure. The exergy destruction in the low-pressure side (expansion valve and evaporator) is found to be lower. Hence, R410A is not suitable for the high-temperature heat pump applications. R410A has about 50% higher saturation pressure compared with R22, which affects the characteristics of the system components. Hence, R410A requires change in system modifications. Most of the studies reported in the literature are using HFC mixtures such as R404A, R407C and R410A as alternatives to R22. R404A can be used as an alternative to R22 in low-temperature refrigeration applications. R407C and R410A can be used as an alternative to R22 in air-conditioning applications and heat pump applications. However, R410A cannot be used for high-temperature heat pump applications due to its lower critical temperature. The HFC refrigerant mixtures have zero ODP with significant GWP. Owing to the GWP, HFC refrigerant mixtures are considered as interim alternatives to phase out the CFC and HCFC-based refrigerants. However, the HFC refrigerant mixtures will continue to dominate the refrigeration and air-conditioning industries for next decade because of their safety and the current strong position in the market.

**HFC/HC Mixtures**

To overcome the problems faced with HFC and HC refrigerants (oil miscibility and flammability), many investigators tried with HFC/HC mixtures as alternatives to HCFC and CFC refrigerants by retaining the mineral oil as lubricant. The flammable nature of HC refrigerants can be reduced by mixing it with HFC refrigerants. On the other hand, the miscibility of HFC refrigerant with mineral oil can be tackled. The properties of the new HFC/HC mixtures discussed in this section are listed in Table III. The properties of new refrigerant mixtures are calculated based on their mass fraction and properties of individual pure refrigerants.

**Table III.** Properties of HFC/HC mixtures as alternatives.

| Refrigerant | Composition | By mass | Replaces | Boiling point | Molecular weight | Critical temperature | Critical pressure | ODP | GWP |
|---|---|---|---|---|---|---|---|---|---|
| R417A | R125:R134a:R600 | 46.6:50:3.4 | R22 | -38 | 106.75 | 89.9 | 4.10 | 0 | 2200 |
| R422A | R125/R134a/R600a | 85.1:11.5:3.4 | R22 | - 49.86 | 115.84 | 72.54 | 3.67 | 0 | 3043 |
| R430A | R152a/R600a | 76:24 | R134a | - 21.04 | 64.14 | 118.43 | 4.30 | 0 | 104 |
| R431A | R290/R152a | 71:29 | R22 | - 43.1 | 50.46 | 101.51 | 4.32 | 0 | 43 |
| NRM | R407C/HC blend | 80:20 | R22 | - 40.13 | 79.31 | 93.34 | 4.486 | 0 | 1364 |
| NRM | R407C/LPG | 70:30 | R22 | - 35 | 69.7 | 95.7 | 4.27 | 0 | 1133 |
| NRM | R124/R142b/R600a | 90:08:02 | R22 | -13 | 129.3 | 124.5 | 3.75 | 0.026 | 750.4 |
| NRM | R134a/HC blend | 91:09 | R12 | - 26.18 | 97.50 | 102.57 | 4.04 | 0 | 1184 |
| NRM | R134a/R290 | 45:55 | R22 | - 34.95 | 70.16 | 98.68 | 4.16 | 0 | 596 |
| NRM | R134a/R600a | 80:20 | R12 | - 23.22 | 93.24 | 107.82 | 3.97 | 0 | 1044 |

Kim et al. [27] experimented with two mixtures of R134a/R290 (45/55, by mass percentage) and R134a/R600a (80/20, by mass) as alternatives to R22 and R12, respectively, by retaining the same lubricant.

The performance characteristics of the refrigerant mixtures are compared with R12, R290, R134a and R22. The cooling and heating capacity of R290/R134a was reported to be higher than that of R22 and COP was reported to be lower than that of R22 and R290. They also reported that COP of the R134a/600a mixture was higher than that of R12 and R134a. The discharge temperature of the refrigerant mixtures studied was found to be lower than R22 and R12. Hence, higher compressor life can be expected with new refrigerant mixture. Jung et al. [28] studied the performance of 14 refrigerant mixtures composed of R32, R125, R134a, R152a, R290 and R1270 as alternatives to R22 for heat pump applications. It has been reported that COP of ternary mixtures composed of R32, R125 and R134a are 4–5% higher than that of R22. The COP values of binary mixture composed of R32 and R134a are 7% higher, capacities are similar to that with R22 and COP of binary azeotrope of R290, and R134a are 3–5% higher than that of R22. Compressor dome temperature and discharge temperature were found to be lower than that of R22 and hence the system reliability and fluid stability with these mixtures would be better than that of R22. Jabaraj et al. [29,30] experimented with new refrigerant mixture composed of R407C with 10, 15, 20 and 25% of HC blend (composed of R290 and R600a, in the ratio of 45.2:54.8, by mass) as alternatives to R22 in a window air conditioner. It has been reported that R407C with 20% of HC blend demands an increase in condenser tube length of 19% compared with R22. The energy consumption of 10 and 20% of HC blend were 1.31–2.5 and 4.83–9.46% less than R22. The COP of the above mixtures was 8.19–11.15 and 1.68–3.23% higher than, and the discharge temperatures were 7.95–9.81 and 10.79–12.37% lower than R22. Pull-down time was reduced by 32.51 and 13.88%. The refrigeration capacity was 9.54–12.76 and 4.02–5.85% higher than R22. The compressor discharge temperature of the system working with new refrigerant mixture was found to be lower compared with R22. Hence, higher compressor life can be expected with new refrigerant. They also reported that oil miscibility of R407C/HC mixture working with mineral oil was good. The charge requirement of this refrigerant mixture was lower than that of R22 by 300 g due to its lower liquid density. Mohanraj et al. [31] investigated the performance of a direct expansion solar assisted heat pump (DXSAHP) working with R22 and mixture of R407C/LPG as an alternative.

It was reported that R407C/LPG (in the ratio of 70:30, by mass) has 1.2% higher instantaneous compressor power consumption with 1–4.5% lower heating capacity than that of R22. The energy performance ratio of the mixture was reported to be lower in the range of 2–5% compared with that of R22. The solar energy input ratio of the new mixture was reported to be higher than that of R22 in the range of 7–14%. TEWI of R407C/LPG was reported to be lower compared with R22. The charge requirement of R407C/LPG is about 25% lower than that of R22 due to its lower liquid density. Mohanraj et al. [32] also reported the exergy performance of a DXSAHP working with R22 and R407C/LPG mixture. Their results indicated that R407C/LPG mixture has higher exergy destruction in the compressor and expansion valve due to its higher operating pressure, whereas R407C/LPG mixture has lower exergy destruction in the heat exchangers (condensers and evaporators) due to its non-linear behaviour during phase change. Suguna ramu and Senthil kumar reported that R32, R125 and R600a (0.4:0.4:0.2 by mass) can be used as a valid replacement for R22 on the basis of better ODP, GWP, low molecular weight and low compressor discharge temperature.[33]

**HCFC based refrigerants**

HCFC mixtures are considered as interim alternatives due to its ODP. R123 is an HCFC refrigerant having

very low value of ODP with lower GWP of 120. Owing to its lower GWP, R123-based mixtures can be used as temporary replacements in the existing systems. The properties of HCFC-based refrigerant mixtures are

listed in Table IV. Sami and Desjardins [34] studied the behaviour of R415A (composed of R23/R22/R152a, in the ratio of 5:5:90, by mass) and R415B (composed of R23/R22/R152a, in the ratio of 5:15:80, by mass) as alternative to R502 in an air source heat pump. Their results concluded that R415A and R415B have better COP compared with R502 with the use of suction accumulators at lower ambient temperatures below -51°C. They also reported that heated suction accumulator contributes in evaporating the more volatile component of refrigerant mixture, which results in increasing the mixture thermal capacity. Kumar and Rajagopal [35] investigated the performance of R12 and the mixture composed of R123 and R290 with different mass percentages. It has been reported that the COP of mixture (R123/R290, in the ratio of 70:30, by mass) had better COP than that of R12. The discharge temperature of the mixture was also found to be lower than that of R12 by about 5–22°C. The environmental impact of this NRM was reported to be lower. Zhao et al. [36] investigated the performance of a geothermal heat pump working with two non-azeotropic refrigerant mixtures composed of R123/R290 (in the ratio of 50:50, by mass) and R290/R600a/R123 (in the ratio of 50:10:40, by mass). It has been reported that COP of the R123/R290 mixture is above 3. The volumetric heating capacity of this refrigerant mixture was calculated to be about 3200 kJ/m$^3$. The COP of the ternary refrigerant mixture (R290/R600a/R123) was reported to be 3.5. However, HCFC-based mixtures could be used as an interim alternative to extend the life of HCFC-based systems. Nuntaphan et al. [37] studied the performance of a zeotropic HCFC-based refrigerant mixture composed of R22/R124/R152a (in the ratio of 20:57:23, by mass) in a solar-assisted heat pump water heater. Their results showed that R22/124/R152a mixture has highest COP in the range between 2.5 and 5.0. They also reported that mixture has lower environmental impact compared with R22.

**Table IV.** Properties of HCFC-based refrigerants.

| Refrigerant | Composition | By mass | Replaces | Boiling point | Molecular weight | Critical temperature | Critical pressure | ODP | GWP |
|---|---|---|---|---|---|---|---|---|---|
| NRM | R123/R290 | 70:30 | R12 | 6.8 | 120.28 | 86.41 | 3.83 | 0.0084 | 90 |
| NRM | R290/R600a/R123 | 50:10:40 | R22 | - 11.15 | 89.03 | 94.62 | 3.95 | 0.0048 | 60 |

## V. CONCLUSION

This review article consolidates and reports the experimental and theoretical investigations for an alternate to the existing R22 carried out. Based on the several research and review reports it is suggested that new refrigerant mixture with thermo physical, thermodynamic and environmental properties which are closer to the desirable can be a potential replacement to the existing R22.

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