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Analysis of Selection of the Best Refrigerant Using the WASPAS Method

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Abstract

Every nation is working to stop ozone depletion and global warming as climate changes have just become apparent on a global scale. According to the prevailing theory behind ozone depletion, free chlorine radicals first eliminate ozone from the atmosphere before chlorine atoms continue to turn more ozone into oxygen. The migration of substances containing chlorine is what causes chlorine to be present in the stratosphere. This behaviour is common across a wide class of compounds called hydro chloro fluoro carbons (HCFCs) and chlorofluorocarbons (CFCs). The world's consumers and industries employ these substances in a variety of applications, particularly as refrigerants in air conditioning and refrigeration systems. The optimal refrigerant was chosen in this study using the WASPAS approach. In this paper R152a, R1234yf, R1234ze (E), R1233zd (E), R290, R600a, R744 and R1270 are used as an alternative for refrigerants. Vapour density, Latent heat of vaporization, Thermal conductivity of liquid, Critical Pressure and Saturated pressure are used to evaluate the performance of refrigerants. Rank of refrigerants R152a is third-ranked, R1234yf is ranked fifth, R1234ze (E) is ranked first, R1233zd (E) is fourth-ranked, R290 is fourth-ranked, R600a is ranked eighth, R744 is second and R1270 is seventh-ranked. The result of the analysis shows that the best refrigerant is R1234ze (E) with a coefficient value of 0.634741 followed by R744 with a coefficient value of 0.517734.

Keywords: CFC, Ozone Depletion, Vapor density, Latent heat of vaporization, Thermal conductivity of the liquid, MCDM

Introduction

Air conditioning and cooling units have made extensive use of the ozone layer-depleting CFCs and HCFCs Since 1930. Due to their propensity to cause damage to the ozone layer, these refrigerants must be transitioned down in conformity with the Montreal Protocol, which was adopted in 1987[1].The production and consumption of all currently used conventional refrigerants are prohibited, which is a critical stage. There is an essential need to hunt for clean, environmentally acceptable refrigerants for a brighter future. The search for refrigerants that don't contribute to ozone layer loss and global warming is increasingly widespread. [2].According to the prevailing theory behind ozone depletion, free chlorine radicals first eliminate ozone from the atmosphere before chlorine atoms continue to turn more ozone into oxygen. The migration of substances containing chlorine is what causes chlorine to be present in the stratosphere. This behaviour is exhibited by a wide family of compounds known as hydrochlorofluorocarbons (HCFCs) and chlorofluorocarbons (CFCs) [3]. Due to their numerous unique qualities, such as non-flammability, low toxicity, and good material compatibility, these compounds are used extensively by both consumers and businesses worldwide, particularly as refrigerants in air conditioning and refrigeration systems. [4]. In this paper R152a, R1234yf, R1234ze (E), R1233zd (E), R290, R600a, R744 and R1270 are used as an alternative for refrigerants. Vapour density, Latent heat of vaporization, Thermal conductivity of liquid, Critical Pressure and Saturated pressure are used to evaluate the performance of refrigerants. Their properties serve as the primary criterion for evaluating refrigerants and refrigerant mixtures. For pure and commercially available refrigerant combinations, observational results and their mathematical interpretations are readily available, but for new combinations, the application of combining rules is necessary[5].R-134a refrigerant is often used in automotive air conditioning systems since it has minimal ODP. Unfortunately, it's a high GWP. R-134a must consequently be replaced with substitute refrigerants[6]. Due to its low GWP and negligible ODP, R-152a is regarded as one of the better alternative refrigerants. This study compares the performance of two car air conditioning systems, one employing R134a and the other R-152a, through bench-level experiments [7]. R1234yf is currently replacing the GWP-equivalent refrigerant R134a in the automotive sector. The Society of Automotive Engineers (SAE) collaborated with the biggest automakers as well as material suppliers throughout the world to conduct the joint research work CRP1234 to evaluate the effectiveness of the R1234yf system. [8].R1234yf was utilised in MAC as a drop-in substitute for R134a. Another substitute for R134a that has been put forth in novel systems for medium-temperature applications is R1234ze(E). [9].R1233zd-E is a member of the hydrofluoroolefins (HFO), a potential class of these novel working fluids. R245fa may be replaced with HFO coolants[10]. In 1920, the hydrocarbon R290 was discovered to be a safe, colourless refrigerant with outstanding thermo-physical characteristics. The industry currently appears more open to this, given the current scenario and technological advancements. [11]. Propane (R290) and isobutane (R600a) are ideal replacement refrigerants due to their physical and thermodynamic qualities. Low critical pressures and substantial enthalpy differences in two-phase zones are the benefits of these refrigerants. The only concern is that hydrocarbons can catch fire if there is an accidental or unforeseen leak. [12].CO2 is known as R744 when used as a natural coolant in the cooling and refrigeration industry. R744 CO2 has favourable thermodynamic properties and provides several advantages over traditional and other substitute refrigerants[13].R290 and R1270 do not harm the environment because they are natural compounds with minimal GWP and no ozone depletion potential (ODP). Furthermore, they are advantageous as refrigerants in terms of both thermodynamic and transport qualities. Additionally, numerous studies show that R290 and R1270 provide performance that is comparable to or even superior to R22. [14,15].

Materials and Methods

Major components of decision theory and analysis are MCDM techniques. The MCDM techniques were grouped by Hwang and Yoon based on the data that was provided. Real-world decision-making situations are frequently complicated, and no single criterion, viewpoint, or evaluation of structures has to be examined to arrive at the best conclusion. [16,17].WASPAS was first proposed in 2012 and has since gained considerable traction. WPM and WSM are combined in this method (WSM). [18,19]

Step 1 The decision matrix X which shows the performances of different alternatives concerning various criteria is formed.

$$D = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & x\cdots & x_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \quad (1)$$

The weight vector may be expressed as

$$w_j = [w_1 \quad \cdots \quad w_n], \text{ here,} \sum_{j=1}^{n}(w_1 \ \cdots \ w_n) = 1 \quad (2)$$

Step 2: The decision matrix is normalized. Beneficial and non-beneficial criteria are normalized

$$n_{ij} = \begin{cases} \frac{x_{ij}}{max.x_{ij}} \mid j \in B \\ \frac{min.x_{ij}}{x_{ij}} \mid j \in C \end{cases} \quad (3)$$

In this case, n_{ij} represents the normalised score of the ith alternative for the j_{th} segment.$max.x_{ij}$ and $min.x_{ij}$ are the maximum and minimum values of x_{ij} in the jth column for benefit (B) and cost criteria (C) respectively

Step 3 Weighted normalized decision matrix is calculated as follows:

$$w_{ij} = w_i n_{ij} \quad (4)$$

Step 4: The preference score for the given alternative, based on WSM, is calculated as follows:

$$S_i^{WSM} = \sum_{j=1}^{n} w_j n_{ij} \quad (5)$$

Step 5: The preference score for the given alternative, based on WSM, is calculated as follows:

$$S_i^{WPM} = \prod_{j=1}^{n} (n_{ij})^{w_j} \quad (6)$$

Step 6: The preference score for the WASPAS method is calculated using equations (5) and (6),

$$S_i^{WASPAS} = \lambda\, S_i^{WSM} + (1-\lambda)S_i^{WPM} \quad (7)$$

$$S_i^{WASPAS} = \lambda \sum_{j=1}^{n} w_j n_{ij} + (1-\lambda) \prod_{j=1}^{n} (n_{ij})^{w_j}$$

where λ is between 0 and 1.

Finally, the alternatives are ranked based on the S_i^{WASPAS} values. The best alternative has the highest S_i^{WASPAS} value. If the value of λ is 0, the WASPAS method is transformed to WPM and if λ is 1, it becomes WSM.

In this paper R152a, R1234yf, R1234ze (E), R1233zd (E), R290, R600a, R744 and R1270 are used as an alternative for refrigerants. Vapor density, Latent heat of vaporization, Thermal conductivity of liquid, Critical Pressure and Saturated pressure are used to evaluate the performance of refrigerants. Vapour density: "The density of a vapour in respect to that of hydrogen is known as its vapour density". It can be expressed as the mass of a substance in a certain volume divided by the mass of hydrogen in the same volume. "Vapour density = mass of n molecules of gas/mass of n molecules of hydrogen" [20].Latent heat of vaporization: "A substance's physical characteristic is its latent heat of vaporisation. Its definition is the amount of heat needed to transform a single mole of liquid at its boiling point at mean atmospheric pressure". It is expressed as kg/mol or kJ/kg [21].Thermal conductivity of liquid: The nature of the liquid affects its thermal conductivity. Compared to water or slag, liquid metals have a significantly higher heat conductivity. [22].Critical Pressure: It is "the pressure above which liquid and gas cannot coexist at any temperature for a pure substance". The temperature above which a pure substance's gas cannot turn into a liquid regardless of the pressure being used [23]. Saturated pressure: the pressure of vapour or equilibrium the pressure that a vapour exerts on its condensed phases in a closed system when they are in thermodynamic equilibrium with one another at a specific temperature is known as vapour pressure. [24].

Analysis and Discussion

TABLE 1. Performance of Refrigerants

Refrigerants	VD	LHV	TCL	CP	SP
R152a	9.89	301.9	0.106	34	3.73
R1234yf	20.7	160.02	0.074	36.3	2.59
R1234ze (E)	40.6	154.8	0.078	36.2	0.59
R1233zd (E)	35.6	188.52	0.081	42.5	5.51
R290	11.9	367.73	0.103	36.3	1.87
R600a	5.01	349.56	0.097	73.8	39.7
R744	114	214.98	0.104	45.5	6.76
R1270	14.2	369.8	0.093	67.9	29.9

Table 1 displays the performance of various refrigerants. R152a, R1234yf, R1234ze (E), R1233zd (E), R290, R600a, R744 and R1270 are used as an alternative for refrigerants. Vapour density, Latent heat of vaporization, Thermal conductivity of liquid, Critical Pressure and Saturated pressure are used to evaluate the performance of refrigerants.

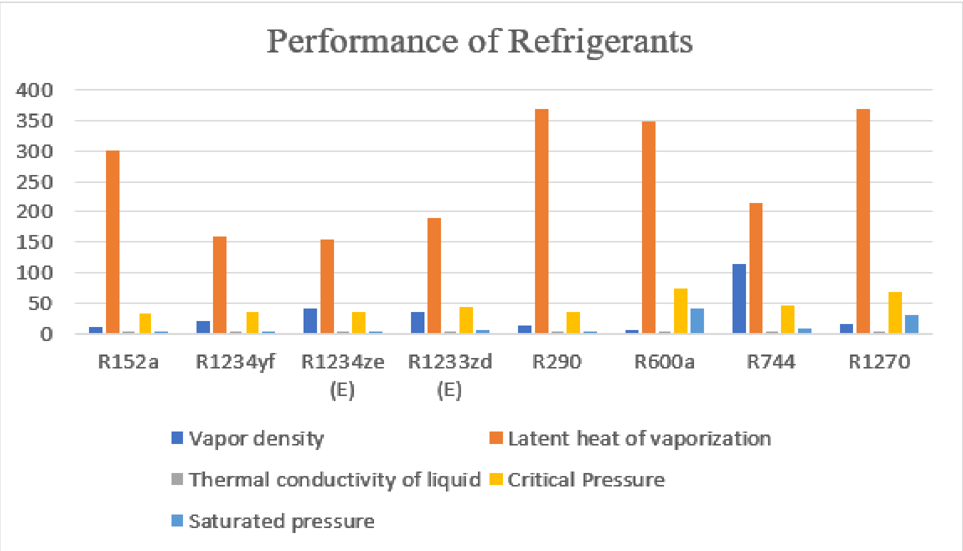

FIGURE1. Performance of Refrigerants

Figure 1 displays the graphical representation of the performance of various refrigerants. R152a, R1234yf, R1234ze (E), R1233zd (E), R290, R600a, R744 and R1270 are used as an alternative for refrigerants. Vapour density, Latent heat of vaporization, Thermal conductivity of liquid, Critical Pressure and Saturated pressure are used to evaluate the performance of refrigerants.

TABLE 2. Normalized decision matrix

0.086754	0.816387	1	1	0.158177
0.181579	0.43272	0.698113	0.936639	0.227799
0.35614	0.418605	0.735849	0.939227	1
0.312281	0.509789	0.764151	0.8	0.107078
0.104386	0.994402	0.971698	0.936639	0.315508
0.043947	0.945268	0.915094	0.460705	0.014861
1	0.581341	0.981132	0.747253	0.087278
0.124561	1	0.877358	0.500736	0.019732

Table 2 shows the normalized array value calculated using equation three.

TABLE 3. Weight

0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2
0.2	0.2	0.2	0.2	0.2

Table 3 shows the weight value taken for the analysis as equally distributed among the evaluation parameters.

TABLE 4. Weighted normalized decision matrix (WSM)

0.017350877	0.163277447	0.2	0.2	0.0316354
0.036315789	0.086544078	0.13962264	0.1873278	0.0455598
0.07122807	0.08372093	0.14716981	0.1878453	0.2
0.06245614	0.101957815	0.15283019	0.16	0.0214156
0.020877193	0.198880476	0.19433962	0.1873278	0.0631016
0.008789474	0.189053542	0.18301887	0.0921409	0.0029723
0.2	0.116268253	0.19622642	0.1494505	0.0174556
0.024912281	0.2	0.1754717	0.1001473	0.0039465

Table 4 displays a weighted normalized decision matrix array calculated using the WSM method using equation four.

TABLE 5. Weighted normalized decision matrix (WPM)

0.613279	0.960239	1	1	0.691558
0.710908	0.845749	0.930647	0.986994	0.743893
0.813438	0.840158	0.940498	0.987539	1
0.792335	0.873933	0.947624	0.956352	0.639647
0.636397	0.998878	0.994274	0.986994	0.793966
0.535287	0.988806	0.982411	0.856415	0.430936
1	0.897194	0.996198	0.943395	0.614018
0.65929	1	0.974171	0.870807	0.456075

Table 5 displays a weighted normalized decision matrix array calculated using the WPM method using equation four.

TABLE 6. Preference Score (WSM) (WPM)

Refrigerants	Preference Score WSM	Preference Score WPM
R152a	0.612264	0.407255
R1234yf	0.49537	0.410832
R1234ze (E)	0.689964	0.634741
R1233zd (E)	0.49866	0.401403
R290	0.664527	0.495295
R600a	0.475975	0.191906
R744	0.679401	0.517734
R1270	0.504478	0.255076

Table 6 lists the preference scores for the WSM Weighted Sum Model and the WPM Weighted Product. The preference score is calculated by adding the weighted normalized choice matrix (WSM) row values of the weighted normalized choice matrix (WSM). The preference score in the WPM Weighted Product Model from equation (5) is multiplied by the row value of table 5 which is equation 6.

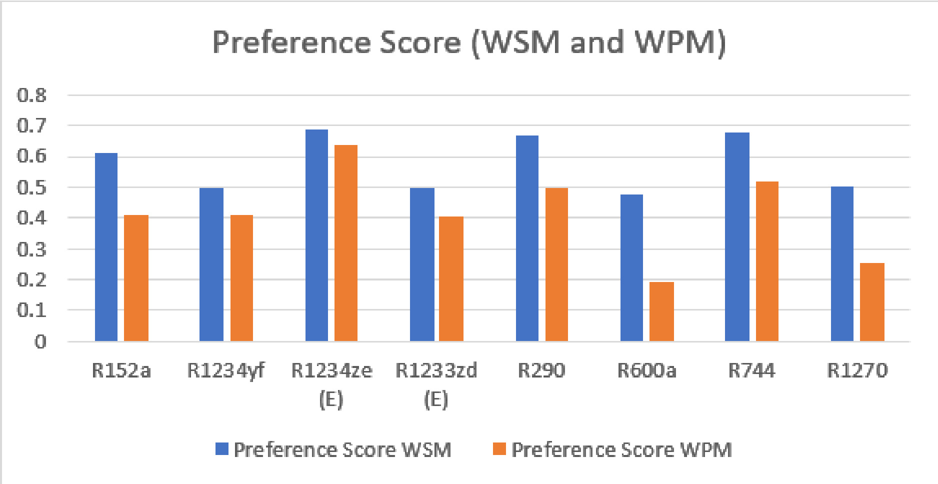

FIGURE 2. Preference Score (WSM) (WPM)

Figure 2 portrays the preference scores for the WSM and the WPM. The preference score is calculated by adding the weighted normalized choice matrix (WSM) row values of the weighted normalized choice matrix (WSM). The preference score in the WPM Weighted Product Model from equation (5) is multiplied by the row value of the weighted normalized decision matrix (6).

TABLE 7. WASPAS coefficient

Refrigerants	WASPAS Coefficient
R152a	0.509759
R1234yf	0.410832
R1234ze (E)	0.634741
R1233zd (E)	0.401403
R290	0.495295
R600a	0.191906
R744	0.517734
R1270	0.255076

Table 7 displays the WASPAS Coefficient value with a lambda value of 0.5. This value is calculated using equation 7. Hera WASPAS coefficient values of alternate refrigerants R152a is 0.509759, R1234yf is 0.410832, R1234ze (E) is 0.634741, R1233zd (E) is 0.401403, R290 is 0.495295, R600a is 0.191906,R744 is 0.517734 and R1270 is 0.255076.

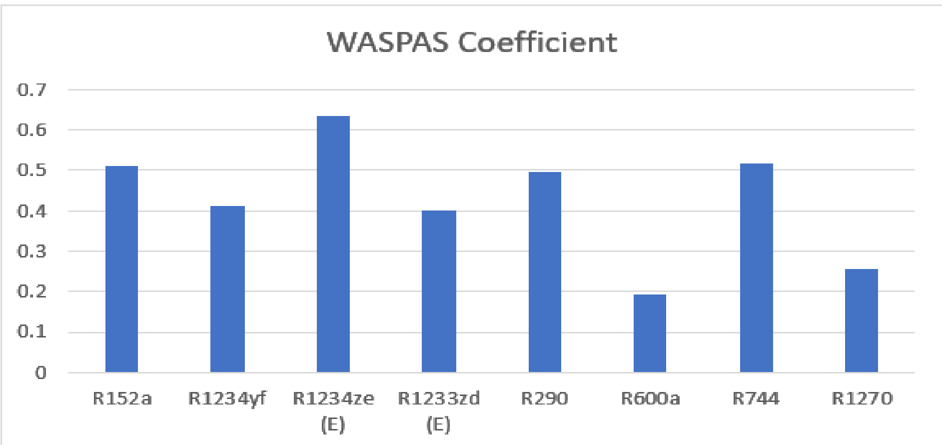

FIGURE 3. WASPAS coefficient

Figure 3 illustrates the WASPAS Coefficient value with a lambda value of 0.5. This value is calculated using equation 7. Hera WASPAS coefficient values of alternate refrigerants R152a is 0.509759, R1234yf is 0.410832, R1234ze (E) is 0.634741, R1233zd (E) is 0.401403, R290 is 0.495295, R600a is 0.191906,R744 is 0.517734 and R1270 is 0.255076.

TABLE 8. Rank

Refrigerants	Rank
R152a	3
R1234yf	5
R1234ze (E)	1
R1233zd (E)	6
R290	4
R600a	8
R744	2
R1270	7

The ranking of alternative WASPAS coefficient settings is displayed in Table 8. Rank of refrigerants R152a is third-ranked, R1234yf is rank fifth, R1234ze (E) is ranked first, R1233zd (E) is fourth-ranked, R290 is fourth-ranked, R600a is rank eighth,R744 is second and R1270 is seventh-ranked

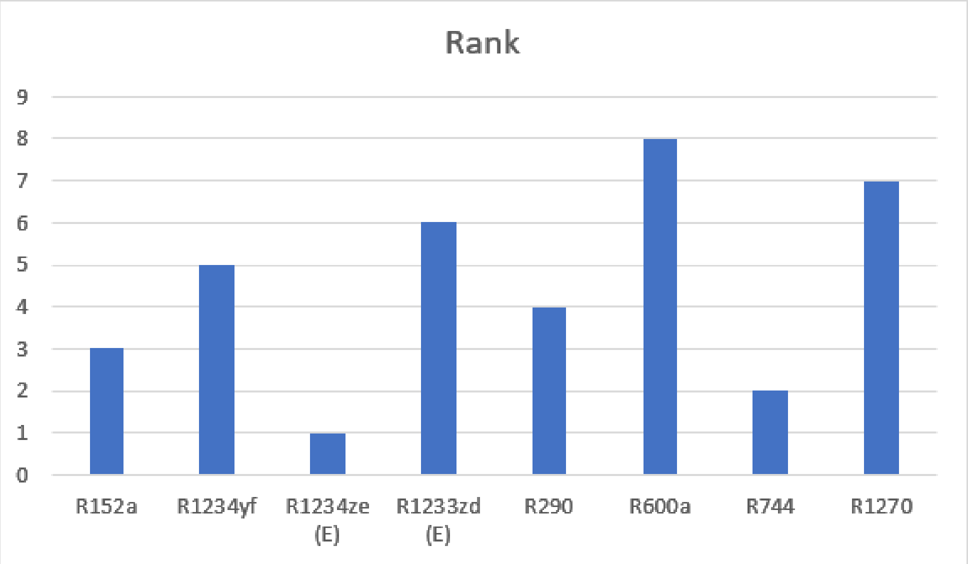

FIGURE 4. Rank

The ranking of alternative WASPAS coefficient settings is illustrated in figure 4. The rank of refrigerants R152a is third-ranked, R1234yf is ranked fifth, R1234ze (E) is ranked first, R1233zd (E) is fourth-ranked, R290 is fourth-ranked, R600a is ranked eighth,R744 is second and R1270 is seventh-ranked. The result of the analysis shows that the best refrigerant is R1234ze (E) with a coefficient value of 0.634741 followed by R744 with a coefficient value of 0.517734.

Conclusion

The production and consumption of all currently used conventional refrigerants are prohibited, which is a critical stage for the refrigeration and air conditioning industry. There is an essential need to hunt for clean, environmentally acceptable refrigerants for a brighter future. The search is on for refrigerants that don't contribute to global warming and the destruction of the ozone layer.In this paper, the WASPAS method was employed to select the best refrigerant. Vapour density, Latent heat of vaporization, Thermal conductivity of liquid, Critical Pressure and Saturated pressure are used to evaluate the performance of refrigerants.The result of the analysis shows that the best refrigerant is R1234ze (E) with a coefficient value of 0.634741 followed by R744 with a coefficient value of 0.517734.

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