Application of Graph Theoretic Approach in Performance Analysis of Refrigerants

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Abstract

The objective of this study is to develop a methodology for selection of a refrigerant between different refrigerants on the basis of their characteristics with effects. The study analyses the complete performance of refrigerants for identification and discussion of key-attributes with their sub-factors. An index is used to analyse and compare the performance of different refrigerants. Refrigerants have several positive characteristics such as zero ozone depletion potential (ODP), very low global warming potential (GWP), non-toxicity, high miscibility with mineral oil, good compatibility with the materials usually employed in refrigeration systems. An attempt is made by the authors to represent the overall effect of the identified refrigerant attributes quantitatively by employing a simple, systematic and mathematical tool to guide user in taking an appropriate decision. This is accomplished by using a graph theory and matrix approach (GTMA).

***Keywords**:* Refrigerants, ODP, GWP, GTMA.

Introduction

For a given refrigeration application, the selection of refrigerant is very much important because the size, initial and operating cost, safety and serviceability of any refrigerator depends on the refrigerant. Because of the environmental issues known as ozone layer depletion and global warming, the selection of suitable refrigerant has become one of the most important issues in recent times. Therefore it becomes more important to understand the issues related to the selection and use of refrigerants. The refrigerants chlorofluorocarbon (CFCs) and hydro chlorofluorocarbon (HCFCs) both are responsible for ozone layer depletion and global warming since they have high ozone depleting potential (ODP) and global warming potential (GWP). Therefore there is a great need to replace such refrigerants with eco-friendly refrigerants to protect the environment. R134a, a hydro fluorocarbon (HFC) refrigerant that possesses zero ozone depletion potential has been recommended as an alternative. Although R134a has a relatively high GWP but it has various favourable characteristics such as zero ODP, non-flammability, stability and similar vapour pressure as that of R12. Therefore R134a has

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been considered as the long term replacement refrigerant for R12. Also the issues of ozone layer depletion and global warming have led to consideration of hydrocarbon (HCs) refrigerants such as propane, isobutene, n-butane or hydrocarbon blends as working fluids in refrigeration and air conditioning systems. Generally hydrocarbons are highly flammable but in spite this, these have several positive characteristics such as zero ODP, very low GWP, non-toxicity, high miscibility with mineral oil, good compatibility with the materials usually employed in refrigeration systems [1-5].

Refrigerants

A fluid used for heat transfer in a refrigeration system that absorbs heat during evaporation from the region of low temperature and pressure, and releases heat during condensation at a region of higher temperature and pressure [1, 4].

Primary and Secondary Refrigerants

Fluids suitable for refrigeration purposes can be classified into primary and secondary refrigerants. Primary refrigerants are those fluids, which are used directly as working fluids, e.g. in vapour compression and vapour absorption refrigeration systems.

As the name implies, secondary refrigerants are those liquids, which are used for transporting thermal energy from one location to other. Unlike primary refrigerants, the secondary refrigerants do not undergo phase change as they transport energy from one location to other [1].

Classification and Designation of Refrigerants

Figure 1 shows the classification of fluids used as refrigerants in vapour compression refrigeration systems. All the refrigerants are designated by R followed by a unique number [1, 4].

Fully Saturated, Halogenated Compounds

These refrigerants are derivatives of alkanes (C_nH_{2n+2}) such as methane (CH_4), ethane (C_2H_6). These refrigerants are designated by R XYZ, where:

X+1 indicates the number of Carbon (C) atoms

Y-1 indicates number of Hydrogen (H) atoms

Z indicates number of Fluorine (F) atoms

The balance indicates the number of Chlorine atoms. Only 2 digits indicate that the value of X is zero [1].

Ex: R 22

X = 0 ⇒ No. of Carbon atoms = 0+1 = 1 ⇒ derivative of methane (CH_4)

Y = 2 ⇒ No. of Hydrogen atoms = 2-1 = 1

Z = 2 ⇒ No. of Fluorine atoms = 2

The balance = 4 – no. of (H+F) atoms = 4-1-2 = 1 ⇒ No. of Chlorine atoms = 1

The chemical formula of R 22 = $CHClF_2$

Similarly it can be shown that the chemical formula of:

R12 = CCl_2F_2

R134a = $C_2H_2F_4$ (derivative of ethane)

Hydrocarbons

Propane (C_3H_8): R 290

n-butane (C_4H_{10}): R 600

Iso-butane (C_4H_{10}): R 600a

Unsaturated Hydrocarbons: R1150 (C_2H_4)

R1270 (C_3H_6) [1]

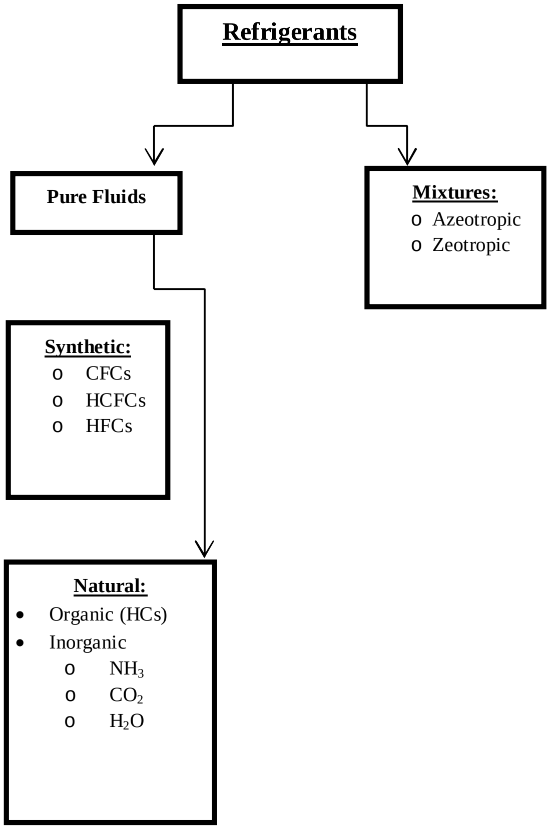

Figure 1.Classification of Refrigerants [1]

Inorganic Refrigerants

These are designated by number 7 followed by the molecular weight of the refrigerant [1].

Ex.: Ammonia: Molecular weight is 17

∴ the designation is R 717

Carbon dioxide: Molecular weight is 44

∴ the designation is R 744

Water: Molecular weight is 18

∴ the designation is R 718

Mixtures

Azeotropic mixtures are designated by 500 series, whereas zeotropic refrigerants (e.g. non-azeotropic mixtures) are designated by 400 series [1].

Azeotropic Mixtures

R 500: Mixture of R 12 (73.8 %) and R 152a (26.2%)

R 502: Mixture of R 22 (48.8 %) and R 115 (51.2%)

R503: Mixture of R 23 (40.1 %) and R 13 (59.9%)

R507A: Mixture of R 125 (50%) and R 143a (50%)

Zeotropic Mixtures

R404A: Mixture of R 125 (44%), R 143a (52%) and R 134a (4%)

R407A: Mixture of R 32 (20%), R 125 (40%) and R 134a (40%)

R407B: Mixture of R 32 (10%), R 125 (70%) and R 134a (20%)

R410A: Mixture of R 32 (50%) and R 125 (50%)

Common Refrigerants Used in Refrigerator

Here are some examples of such refrigerants which are preferred to be used in refrigerator.

Refrigerant R12

Its chemical formula is CCl_2F_2 and its boiling point is -30^{0}C at 1 bar. It is a non-flammable, non-explosive, non-irritating, non-toxic and odourless refrigerant. Also, it does not affect the material of the refrigeration system. It is available in abundance and is quite cheap. However, its use is being discontinued nowadays for its contribution to ozone depletion which will be discussed later [1, 2, 4].

Refrigerant R22

Its chemical formula is $CHClF_2$. it is also a non-toxic, non-flammable, non-corrosive and non-irritating refrigerant. It is the most common refrigerant for use in large refrigeration systems and is preferred to R12 [1, 2, 4].

Refrigerant R134a

R134a is the long-term replacement refrigerant for R12 because of having favourable characteristics such as zero ODP, non-flammability, stability and similar vapour pressure as that of R12. But it has a relatively high global warming potential [1, 2, 4].

Refrigerant R600a

Natural refrigerants that are being suggested are hydrocarbons (HCs). Due to absent of chlorine they do not participate in ozone layer depletion. Refrigerant R600a is one of them. Its chemical formula and name are C_4H_{10} and iso-butane respectively [1, 2, 4].

GTMA (Graph Theoretic and Matrix Approach)

The model can include all the subsystems along with the interactions there in and thus becomes a tool for Refrigerant Performance analysis. A graph is required for visual analysis of a Refrigerant, but quantification of these interactions is necessary for design and analysis.

Assumptions for Developing Graph Theoretic Model

The proposed graph theoretic model for refrigerant systems is based on some assumptions as listed below:-

- The structure of the system can be compared quantitatively with its performance.
- The interactions as well as the subsystems discussed are assumed for general refrigerants. The subsystems must be identified separately for applying the model to any specific refrigerant.
- Variable permanent matrix is capable of storing complete information related to a real life situation of a typical refrigerant as all its elements are variables and functions of characterizing attributes representing subsystem and interconnections. These attributes if identified comprehensively, the matrix represents refrigerant system completely.
- Permanent function of the variable permanent matrix characterizes uniquely the refrigerant form the point view of the structure.
- Performance of the refrigerant depends on individual performance of subsystems, sub-systems and their components along with interactions between them.

- Permanent function values of sub-subsystems are used in permanent matrices of subsystems. Permanent function values of subsystems are used to calculate permanent functions of refrigerant system.

Literature Review

Saha R and Grover S demonstrated the identification and analysis of website performance factors by developing a mathematical model using graph theoretic approach [3].

In this approach, interaction among identified key website performance attributes is represented through digraph, matrix model and a multinomial.

Calm JM has studied the emission and environmental impacts of the different refrigerants (R11, R123, and R134a) [6]. He also investigated the total impact in form of TEWI by analysing the direct and indirect CO2 emission equivalent due to leakage and energy consumption by the system.

Benhadid-Dib S and Benzaoui A have showed that the uses of halogenated refrigerants are harmful for environment and the use of "natural" refrigerants become a possible solution [8]. Here natural refrigerants are used as an alternative solution to replace halogenated refrigerants.

Granryd E has enlisted the different hydrocarbons as working medium in refrigeration system [9].

He studied the different safety standards related to these refrigerants. He showed the properties of hydrocarbons (i.e. no ODP and negligible GWP) that make them interesting refrigerating alternatives for energy efficient and environmentally friendly.

Cabello R, Torrella E and Navarro-Esbri J have analysed the performance of a vapour compression refrigeration system using three different working fluids (R134a, R407c and R22) [11]. They analysed that the power consumption decreases when compression ratio increases with R22 than using the other working fluids.

Mani K, Selladurai V are experimental analysis of a new refrigerant mixture as drop-in replacement for CFC12 and HFC134a are investigate that the refrigerants chlorofluorocarbon (CFCs) and hydro chlorofluorocarbon (HCFCs) both have high ozone depleting potential (ODP) and global warming potential (GWP) and con-tributes to ozone layer depletion and global warming [13].

According to manual of company Danfoss practical application of Refrigerant R600a isobutene in domestic refrigerator systems is observed by Refrigerant R600a or isobutene, is a possible replacement for other refrigerants, which have high impact on the environment, in domestic refrigerators [15]. It has zero ozone depletion potential ODP and a negligible global warming potential GWP.

Methodology

The graph theoretic approach evaluates the performance of refrigerants in terms of a single numerical index. The various steps in the proposed approach are presented here, which will help in evaluation process of performance of a refrigerant [3, 17, 18].

1. Identify various factors that affect a refrigerant’s performance. Different refrigerants may have a different set of

factors affecting their performance depending on the type of refrigerant.

2. Broadly group these factors as measuring factors and characteristics factors. For the application of this methodology the factors are written in composite form to avoid mathematical complexity in the further analysis.
3. Logically develop a digraph between the factors depending on their interdependencies (similar to Fig. 2). The nodes in the digraph represent factors while edges represent interaction among factors.
4. Identify the sub-factors affecting a refrigerant's performance factors identified in step (1).
5. Develop all sub-factor digraph considering inheritances and interactions among one of the groups of sub-factors. The nodes in the digraph represent sub-factors while edges represent interaction among sub-factors.

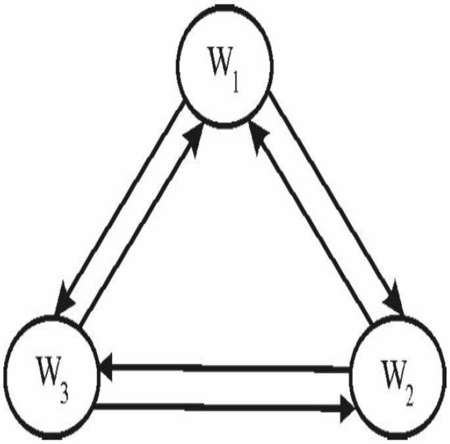

Figure 2.Diagraph

6. At the sub-system level use attribute values as depicted in Tables 1 and 2. This will provide numerical values for inheritance of attributes and their interactions with the help of experts.
7. Develop sub-factor variable permanent matrix (VPM) with diagonal elements representing inheritances and the off diagonal elements representing interactions among them.
8. Find the value of permanent function for sub-factor with the help of Eq. (1).

Table 1.Inheritance Values of Attributes

Qualitative measure of attributes	Assigned value of attributes (W)
Exceptionally low	0.1
Very low	0.2
Low	0.3
Below normal	0.4
Normal	0.5
Above normal	0.6
High	0.7
Very high	0.8
Exceptionally high	0.9

Table 2.Interaction Values of Attributes

Dependency effect of attribute ‘i’ on attribute ‘j’	Assigned value of attributes (Wij)
Very strong	0.5
Strong	0.4
Medium	0.3
Weak	0.2
Very Weak	0.1

1. Repeat steps (3) to (9) for each sub-factor.
2. Develop performance factor digraph at system level as explained in steps (3).
3. At system level, the permanent value of each sub-factor [obtained in step (9)] provides inheritance of the refrigerant performance factor. The quantitative value of interactions among factors is obtained from Tables 1 and 2. This will form performance variable permanent matrix (VPM) at system level.
4. Find the value of permanent function for the system by Eq. (1). This is the value of the refrigerant performance index [3].

$$VPF - W = perW = \prod_{i=1}^{3} W_i + \sum_i \sum_j \sum_k \left(w_{ij} w_{ji} \right) + \sum_i \sum_j \sum_k \left(w_{ij} w_{jk} w_{ki} \right) \tag{1}$$

Table 3.Degree of influence of performance attributes i on j

S.No.	Attributes	Factors	very strong	strong	medium	weak	very weak
			(Wij= 0.5)	(Wij= 0.4)	(Wij= 0.3)	(Wij= 0.2)	(Wij= 0.1)
1	Thermo-Physical properties (1W)	suction pressure (1Ws1), discharge pressure (2Ws1), latent heat of vapourisation (3Ws1), isentropic index of compression (4Ws1), pressure ratio (5Ws1), vapour specific heat (6Ws1)		4		2	3
2	Environmental properties (2W)	ozone depletion potential (1Ws2), global warming potential (2Ws2), total equivalent warming index (3Ws2)					4
3	Safety properties (3W)	toxicity (1Ws3), flammability (2Ws3), chemical stability (3Ws3), miscibility (4Ws3), leakage (5Ws3)			2	1,4	
4	Economical properties (4W)	cost (1Ws4), availability (2Ws4)			1		3

The performance of a refrigerant can thus be evaluated based on the above discussed methodology.

Identification of Refrigerant Performance Factor

The refrigerant performance depends on a number of factors with the contribution of each factor towards its acceptability [1, 4].

The factors identified in literature article are categorized into four categories. Grouping is done because number of factors identified is large and due to which calculation of matrices becomes a very difficult task. These factors are categorized as below.

1. Thermodynamic and thermo-physical properties (1W)
2. Environmental properties (2W)
3. Safety properties (3W), and
4. Economical properties (4W)

Thermodynamic and Thermo-Physical Properties

1. Suction pressure: At a given evaporator temperature, the saturation pressure should be above atmospheric.
2. Discharge pressure: At a given condenser temperature, the discharge pressure should be as small as possible.
3. Pressure ratio: Should be as small as possible for high volumetric efficiency and low power consumption
4. Latent heat of vaporization: Should be as large as possible so that the required mass flow rate per unit cooling capacity will be small.
5. Isentropic index of compression: Should be as small as possible so that the temperature rise during compression will be small.
6. Vapour specific heat: Should be large so that the degree of superheating will be small.

The thermodynamic properties are interrelated and mainly depend on normal boiling point, critical temperature, molecular weight and structure [1, 4].

Environmental Properties

Next to thermodynamic and thermo-physical properties, the environmental properties are very important. In fact, at present the environment friendliness of the refrigerant is a major factor in deciding the usefulness of a particular refrigerant. The important environmental and safety properties are:

1. Ozone Depletion Potential (ODP): According to the Montreal protocol, the ODP of refrigerants should be zero, i.e., they should be non-ozone depleting substances.
2. Global Warming Potential (GWP): Refrigerants should have as low a GWP value as possible to minimize the problem of global warming.
3. Total Equivalent Warming Index (TEWI): The factor TEWI considers both direct (due to release into atmosphere) and indirect (through energy consumption) contributions of refrigerants to global warming [1, 4].

Safety Properties

1. Toxicity: Ideally, refrigerants used in a refrigeration system should be non-toxic. However, all fluids other than air can be called as toxic as they will cause suffocation when their concentration is large enough. Thus toxicity is a relative term, which becomes meaningful only

when the degree of concentration and time of exposure required to produce harmful effects are specified.

2. Flammability: The refrigerants should preferably be non-flammable and non-explosive. For flammable refrigerants special precautions should be taken to avoid accidents.
3. Chemical stability: The refrigerants should be chemically stable as long as they are inside the refrigeration system.
4. Miscibility with lubricating oils: Oil separators have to be used if the refrigerant is not miscible with lubricating oil (e.g. ammonia).
5. Ease of leak detection: In the event of leakage of refrigerant from the system, it should be easy to detect the leaks [1, 4].

Economic Properties

The refrigerant used should preferably be inexpensive and easily available [1, 4].

Example

To demonstration the proposed methodology, refrigerant Rxyz is taken as an example. It is proposed to find the value of refrigerant performance index. For determining the index we require numerical values of all performance factors and their interdependencies, i.e. all values in refrigerant performance variable permanent matrix. The value of diagonal elements in the VPM-W, i.e., the value of performance factors W1, W2, W3 and W4 are evaluated by applying graph theoretic methodology.

Step by step methodology discussed in previous section is used to evaluate refrigerant performance index in this example.

Step 1: The various factors affecting refrigerant performance and their inter-dependencies with each other are identified in Table 3.

Step 2: The dependencies of factors and sub-factors are visualized through digraphs shown in Figs. 3 to 7. The subscript starting with‘s’ represents subsystem.

Note:

1. Arrow head pointed to that factor which affected by the other factor which is on tail side.
2. 1W means first factor at system level attributes.
3. 2Ws1 means it is the second factor in the first sub-system.

As explained the nodes in the digraph represent attributes identified in each sub-factor. The interaction among attributes is represented by edges. All diagraphs at system level and sub-system level are represented below:

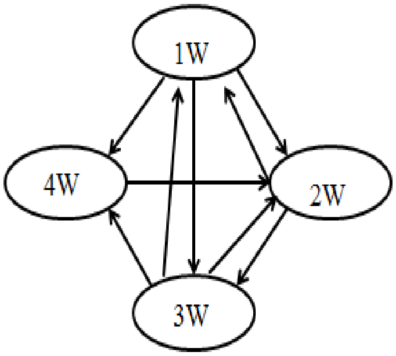

Figure 3.Diagraph of Major Factors at System Level

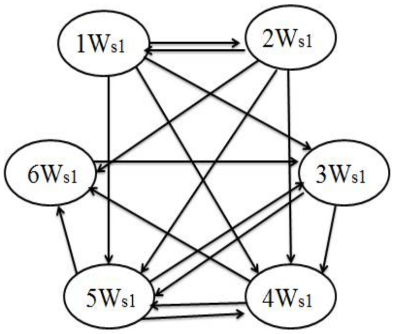

Figure 4.Diagraph of Thermo-Physical Properties

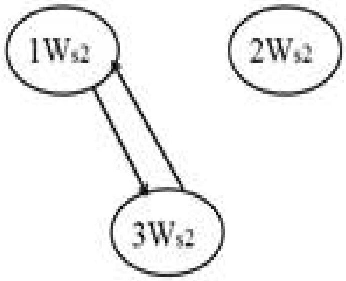

Figure 5.Diagraph of Environmental Properties

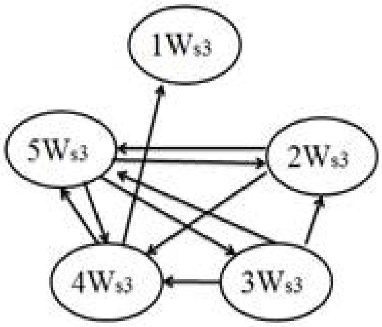

Figure 6.Diagraph of Safety Properties

Figure 7.Diagraph of Economical Properties

Step 3: Variable permanent matrix (VPM) for digraph for major factors and each subsystem is written.

Note

1. W1, W2, W3 and W4 represent the inheritance value of 1st, 2nd, 3rd and 4th attributes respectively.
2. Wi, j shows factor j is affected by factor i and represent the interaction value.

The general form of variable permanent matrix is considered as

VPM (Ws3) is given by:

		1	*2*	*3*	*4*	*5*	*factor*
		W1	W1,2	W1,3	W1,4	W1,5	*1*
		W2,1	**W2**	W2,3	W2,4	W2,5	*2*
VPM(Ws3)=		W3,1	W3,2	**W3**	W3,4	W3,5	*3*
		W4,1	W4,2	W4,3	**W4**	W4,5	*4*
		W,1	W5,2	W5,3	W5,4	**W5**	*5*

Step 4: At the subsystem level Tables 1 and 2 are used to determine numerical values for inheritance of attributes and their interactions. For sub subsystem 1, the values taken from Table 1 are W1 = 0.7, W2 = 0.8, W3 = 0.9, W4 = 0.8, 1 W5 = 0.9, the values taken from Table 2 in conjunction with Table 4 are w2,4 = 0.4, w2,5 = 0.3, w3,2 = 0.3, w3,4 = 0.4, w3,5 = 0.4, w4,1 = 0.4, w4,5 = 0.3, w5,2 = 0.2, w5,3 = 0.3, w5,4 = 0.4.

The VPM (Ws3) shall be

		1	*2*	*3*	*4*	*5*	*factor*
		0.7	0	0	0	0	*1*
		0	**0.8**	0	0.4	0.3	*2*
VPM(Ws3)=		0	0.3	**0.9**	0.4	0.4	*3*
		0.4	0	0	**0.8**	0.3	*4*
		0	0.2	0.3	0.4	**0.9**	*5*

(2)

Similarly, the variable permanent matrices for different subsystems (based on their digraphs) are written through Eqs. (2) to (5).

VPM (Ws1) =

		1	*2*	*3*	*4*	*5*	*6*	*factor*
		0.8	0.4	0.3	0.5	0.2	0	*1*
		0.5	**0.7**	0	0.4	0.5	0.3	*2*
VPM (Ws1)=		0	0	**0.8**	0.4	0.4	0	*3*
		0	0	0	**0.9**	0.3	0.4	*4*
		0	0	0.5	0.3	**0.9**	0.4	*5*
		0	0	0.5	0	0	**0.8**	*6*

(3)

VPM (Ws2) =

$$\text{VPM(Ws2)} = \begin{array}{ccc|c} 1 & 2 & 3 & factor \\ \hline \mathbf{0.8} & 0 & 0.5 & 1 \\ 0 & \mathbf{0.9} & 0 & 2 \\ 0.5 & 0 & \mathbf{0.8} & 3 \end{array} \tag{4}$$

VPM (Ws4) =

$$\text{VPM(Ws4)} = \begin{array}{cc|c} 1 & 2 & factor \\ \hline \mathbf{0.6} & 0 & 1 \\ 0.4 & \mathbf{0.7} & 2 \end{array} \tag{5}$$

Step 5: The permanent of matrix VPM (Ws1), Per Ws1, is calculated by evaluating the matrix on the lines of the Eq. (1).

The value of permanent function which leads to the inheritance of performance factor Ws1 may be written as Per Ws1 = 0.7296.

Step 6: Similarly the values of permanent functions of different subsystems are evaluated from the variable permanent matrices in Eqs. (2) to (5) and are written as under:

Per Ws1= 0.7296

Per Ws2= 0.801

Per Ws3= 0.56532

Per Ws4= 0.42

Step 7: To obtain variable permanent matrix-refrigerant performance for this example, values are substituted as per Step 4.

VPM (W) =

$$\text{VPM(W)} = \begin{array}{cccc|c} 1 & 2 & 3 & 4 & factor \\ \hline \mathbf{0.73} & 0.2 & 0.1 & 0.4 & 1 \\ 0 & \mathbf{0.801} & 0 & 0.1 & 2 \\ 0.2 & 0.3 & \mathbf{0.497} & 0.2 & 3 \\ 0.3 & 0 & 0.1 & \mathbf{0.42} & 4 \end{array} \tag{6}$$

Step 8: Value of permanent function for the system is evaluated as per Eq. (5). The value of permanent of above matrix [Eq. (6)] is 0.205863, which indicates refrigerant performance index for the case considered. By carrying out similar analysis refrigerant performance index for different refrigerant can be obtained. The performance of websites may thus be compared and rated for a particular period of time.

Per (W) = 0.205863

Refrigerant Analysis and Discussion

Refrigerant performance index is at its best when the inheritance of all its factors is maximum. Since, Table 3 is used at subsystem level, maximum value of Per W1 is obtained when inheritance of all the sub-factors is maximum, i.e., value taken from Table 2 is 0.9. Thus, Eq. (2) may be rewritten as:

$$\text{VPM(Ws3)}= \begin{array}{ccccc|c} 1 & 2 & 3 & 4 & 5 & \textit{factor} \\ \hline \mathbf{0.9} & 0 & 0 & 0 & 0 & 1 \\ 0 & \mathbf{0.9} & 0 & 0.4 & 0.3 & 2 \\ 0 & 0.3 & \mathbf{0.9} & 0.4 & 0.4 & 3 \\ 0.4 & 0 & 0 & \mathbf{0.9} & 0.3 & 4 \\ 0 & 0.2 & 0.3 & 0.4 & \mathbf{0.9} & 5 \end{array} \qquad (7)$$

The value of the permanent of the above function is 0.88938, i.e., Per Ws3 (max.) = 0.88938. Similarly, refrigerant performance index is at its worst when the inheritance of all its factors and sub-factors is minimum. This is the case when inheritance of the entire sub-factor is minimum, i.e. value taken from Table 2 is 0.1. Thus, Eq. (2) may be rewritten as:

$$\text{VPM(Ws3)}= \begin{array}{ccccc|c} 1 & 2 & 3 & 4 & 5 & \textit{factor} \\ \hline \mathbf{0.1} & 0 & 0 & 0 & 0 & 1 \\ 0 & \mathbf{0.1} & 0 & 0.4 & 0.3 & 2 \\ 0 & 0.3 & \mathbf{0.1} & 0.4 & 0.4 & 3 \\ 0.4 & 0 & 0 & \mathbf{0.1} & 0.3 & 4 \\ 0 & 0.2 & 0.3 & 0.4 & \mathbf{0.1} & 5 \end{array} \qquad (8)$$

The value of the permanent of the above function is 0.00226, i.e., Per Ws3 (min.) = 0.00226. Similarly, maximum and minimum values for each subsystem are evaluated and different values of permanent of subsystem matrices are summarized in Table 4. Thus, the maximum and minimum value of refrigerant performance index indicates the range with in which it can vary. Experts can use this range to decide a threshold value for a given set of similar refrigerants.

Table 4.Values for Maximum/Minimum Refrigerant Performance Index

System/sub system	Current value	minimum value	maximum value
Per Ws1	0.7296	0.01533	1.14837
Per Ws2	0.801	0.026	0.954
Per Ws3	0.56532	0.00226	0.88398
Per Ws4	0.42	0.01	0.81
Per W	0.205863	0.174378	0.946405

Conclusion

After getting a scale of index, it will be quite easier to determine and select the best refrigerant on the basis of its index so calculated. The more the index moves towards the higher value of the scale i.e., 0.946405, more will be its overall performance. Hence a refrigerant with a high value of index is to be selected.

Synthetic refrigerants that were commonly used for domestic refrigeration applications are: R 11 (CFC 11), R 12 (CFC 12), and R 22 (HCFC 22), R 502 (CFC 12 + HCFC 22) etc. has lower value of refrigerant index. However, these refrigerants have to be phased out due to their Ozone Depletion Potential (ODP). The synthetic replacements for the older refrigerants are: R-134a (HFC-134a) and blends of HFCs. These refrigerants have better refrigerant index. Generally, synthetic refrigerants are non-toxic and non-flammable. However, compared to the natural refrigerants the synthetic refrigerants offer lower performance and they also have higher Global Warming Potential (GWP). Other natural refrigerants that are being suggested are hydrocarbons (HCs) and carbon di-oxide (R-744). Though these refrigerants have some specific problems owing to their eco-friendliness, they are being studied widely and are likely to play a prominent role in future.

The scenario changed completely after the discovery of ozone layer depletion in 1974. The depletion of stratospheric ozone layer was attributed to chlorine and bromine containing chemicals such as CFCs, HCFCs etc. Since ozone layer depletion could lead to catastrophe on a global level, it has been agreed by the global community to phase out the ozone depleting substances (ODS). As a result except ammonia, all the other refrigerants used in cold storages had to be phased-out and a search for suitable replacements began in earnest. At the same time, it was also observed that in addition to ozone layer depletion, most of the conventional synthetic refrigerants also cause significant global warming. In view of the environmental problems caused by the synthetic refrigerants, opinions differed on replacements for conventional refrigerants.

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