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Evaluation of Refrigerant Options Using TOPSIS-MADM Technique

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***Abstract*—**The working agent in a refrigerator or air-conditioning system that absorbs, carries and releases heat from the load to ambience is termed as a refrigerant. The selection of the refrigerant for a particular application like large commercial setup, mobile application like in passenger car or cold chain truck, small scale domestic system, etc., depends upon many factors. In this paper an attempt is made to evaluate the best possible option among many refrigerants for a particular applicationby using TOPSIS multi-attribute decision making (MADMv)technique. Twentyrefrigerants are evaluated based on different selection criteria that are relevant for the application in cold chain warehouse application.R717 gets highest rank from our analysis, other refrigerants also get ranked during the process. TOPSIS is one of the most reliable MADM techniques. Use of other techniques or change in the selection criteria based on application area may lead to change in ranking. This approach technique is likely to help in decision making towards selection of refrigerants for a particular application.

***Keywords*—** multi-attribute decision making(MADM); TOPSIS; global warming potential

I. INTRODUCTION

The main purpose of appropriate refrigerant selection is quick removal of heat from a material or space. The major components in vapor compression refrigeration cycle are, shown in Figure 1.

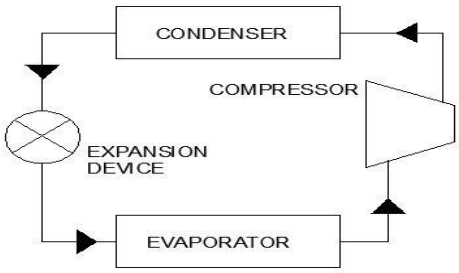

Fig. 1. Refrigeration system components.

With regard to the vapor compression cycle, the refrigerant is the working fluid in the cycle that alternately vaporizes and condenses as it absorbs and gives off heat, repeatedly [1]. The medium used for transferring heat, in the system should quickly absorbs heat and releases it to the atmosphere. Nomenclature of the synthetic refrigerants is doneaccording to the number of carbon atoms (m), hydrogen atoms (n) and fluorine atoms (p) present in the molecule. Accordingly equation 1 is recommended by ASHRAE for naming refrigerant [2].

$$R(m-1)(n+1)(p) \quad (1)$$

However, few series are already pre-defined for organic compounds (R600), mixtures (R400), and inorganic compounds (R700). Refrigerants are also tagged on the basis of their safety group’s i.e. On the basis of toxicity class A & B is defined i.e.

Class A ≥ 400 PPM
Class B < 400 PPM

Similarly, on the basis of Flammability class 1, 2 & 3 is defined as

Class 1: Do not show flame when tested at 21°C.
Class 2: Lower flammabilitywhen tested at 21°C.
Class 3: Higher flammability when tested at 21°C.

A few refrigerant nomenclaturealong with their name and chemical formulae is tabulated in Table 1.

Table 1. Refrigerants nomenclature.

Name	Chemical Formula	Nomenclature	Tagging
Ammonia	NH_3	R717	B2
Water	H_2O	R718	A1
Carbon dioxide	CO_2	R744	A1
Propane	$CH_3CH_2CH_3$	R290	A3
Difluoromethane	CH_2F_2	R032 or R32	A2

To be suitable for use as a refrigerant for a particular application, a fluid should possess certain chemical, physical and thermodynamic properties. Refrigerant for the cold chain warehouse application are selected on the basis of eight critical properties like dielectric strength and it should be high enough to act like an insulator, thermal conductivity should be high to facilitate higher heat transfer rate, critical temperature and critical pressure should be high in order to have a heat transfer without phase change, critical volume should be low, action of refrigerant with water & oil should be low to create chemical stability of the refrigerants, enthalpy of vaporization should be high tominimize the area under superheat and the area reduction due to throttling, etc.

In this paper a novel attempt is made to grade the refrigerants for a particular application using TOPSIS multi-attribute decision making (MADM) technique. Eight critical propertiesare selected for analysis. TOPSIS-MADM technique have been demonstratedto be able to analyze this type of quantitative data effectively in engineering applications like on market survey, production and manufacturing area [3], airline service quality [4] etc. A few examples are also available from applications in heat transfer [5], and even in selection of cricket players [6], etc.

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II. EVALUATION OF REFRIGERANTS USING TOPSIS MADM TECHNIQUE

TOPSIS is a multi-criteria decision analysis method, which was originally developed by Hwang and Yoon in 1981 [7]. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution. It is a method of compensatory aggregation that compares a set of alternatives by identifying weights for each criterion, normalizing scores for each criterion and calculating the geometric distance between each alternatives and the ideal alternatives that is having the best score in each criterion [8]. Evaluation using TOPSIS method is expressed in these steps:

Step 1: An input Table 2 or decision matrix is created.

Step 2: Normalization of the decision matrix (Table 2) is done by using equation (2). The normalized matrix is given in Table 3.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}{}^2}} \quad (2)$$

Step 3: Construction of the weighted normalizing decision matrix by multiplying the normalized decision matrix with its associate weights. The weights of normalized values are calculated by using equation (3).

$$V_{ij} = W_{ij} r_{ij} \quad (3)$$

Step 4: Determination of the positive ideal solution (A^+) and negative ideal solution (A^-) for the weighted normalized decision matrix by using equation (4 & 5). The output is given in Table 4.

$$A^+ = \left\{\left(\frac{\max V_{ij}}{j}\right), \left(\frac{\min V_{ij}}{j'}\right)\right\} \quad (4)$$

$$A^- = \left\{\left(\frac{\min V_{ij}}{j'}\right), \left(\frac{\max V_{ij}}{j}\right)\right\} \quad (5)$$

Step 5: Calculation of the separation measures of weighted normalized decision matrix. The separations of each alternative from the positive (Si^+) and negative (Si^-) ideal solution are given by using equation (6 & 7) and reproduced in Table 5.

$$Si^+ = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_{j+}\right)^2} \quad (6)$$

$$Si^- = \sqrt{\sum_{j=1}^{n} \left(V_{ij} - V_{j-}\right)^2} \quad (7)$$

Step 6: Calculation of the relative closeness to the ideal solution from the positive and negative separation alternatives by using equation (8) and the same is tabulated in Table 5.

$$Ci^+ = \frac{Si^+}{Si^+ + Si^-} \quad (8)$$

The larger the Critical Index (Ci^+) value, the better is the performance of the alternatives.

Step 7: Ranking of relative closeness matrix is done according to the performance order, and is shown in Fig 2.

Table 2. Refrigerant properties.

R	Dielectric Strength	Thermal Conductivity	Action with oil	Action with water	Critical Temp.	Critical Pressure	Critical Vol.	Enthalpy of vaporization
11	0.089	0.11	0.25	0.34	0.346	0.205	0.2	0.12
12	0.083	0.11	0.023	0.34	0.196	0.193	0.188	0.097
115	0.083	0.134	0.117	0.087	0.14	0.151	0.186	0.069
113	0.096	0.107	0.023	0.174	0.375	0.16	0.192	0.1
22	0.24	0.139	0.117	0.174	0.168	0.234	0.216	0.131
141a	0.24	0.14	0.257	0.26	0.365	0.203	0.1	0.116
141b	0.243	0.123	0.234	0.26	0.24	0.199	0.25	0.151
502	0.07	0.112	0.117	0.087	0.311	0.191	0.08	0.174
125	0.194	0.103	0.023	0.174	0.116	0.17	0.197	0.086
134a	0.374	0.135	0.117	0.174	0.177	0.19	0.215	0.127
143a	0.385	0.118	0.117	0.26	0.128	0.178	0.256	0.121
152a	0.382	0.16	0.023	0.36	0.198	0.212	0.301	0.196
404A	0.298	0.132	0.023	0.174	0.126	0.175	0.003	0.053
407c	0.344	0.173	0.234	0.087	0.151	0.217	0.0003	0.065
410A	0.306	0.205	0.234	0.174	0.126	0.223	0.0015	0.072
AIR	0.039	0.063	0.234	0.087	0.25	0.0005	0.07	0.0318
717	0.061	0.822	0.468	0.017	0.23	0.53	0.458	0.807
744	0.062	0.163	0.351	0.017	0.054	0.34	0.11	0.154
600a	0.057	0.058	0.351	0.34	0.23	0.717	0.5	0.226
290	0.05	0.106	0.351	0.34	0.169	0.00004	0.11	0.24

III. RESULT AND DISCUSSION

Using TOPSIS- MADM technique the ranking obtained for the twenty refrigerants on the basis of 8 critical properties are shown in Fig 2. Properties like flammability, toxicity, cost, global warming potential (GWP) and ozone depletion potential (ODP) are not considered in this analysis. As it is felt that these criteria are of lesser importance, further some of these data

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may be qualitative. For a different application like domestic or mobile A/C application these criteria may be considered and this will automatically alter the rankings of the refrigerants. Use of other MADM technique like PROMETHEE, FAHP, etc. may also yield marginally different result with same set of input variables as each have distinct way of handling qualitative and quantitative data. Using TOPSIS-MADM technique it has been observed that the R717 (Ammonia) is at the highest ranking followed R152 and R134a for the selected application

Table 3. Normalized matrix.

R	Dielectric Strength	Thermal Conductivity	Action with oil	Action with water	Critical Temp	Critical Pressure	Critical Vol	Enthalpy of vaporization
11	0.0891	0.1101	0.2491	0.3388	0.3479	0.1685	0.1998	0.1203
12	0.0831	0.1101	0.0229	0.3388	0.1971	0.1587	0.1878	0.0972
115	0.0831	0.1341	0.1166	0.0867	0.1408	0.1241	0.1858	0.0691
113	0.0961	0.1071	0.0229	0.1734	0.3771	0.1315	0.1918	0.1002
22	0.2403	0.1391	0.1166	0.1734	0.1689	0.1924	0.2157	0.1313
141a	0.2403	0.1401	0.2561	0.2591	0.3671	0.1669	0.0999	0.1162
141b	0.2433	0.1231	0.2332	0.2591	0.2414	0.1636	0.2497	0.1513
502	0.0701	0.1121	0.1166	0.0867	0.3128	0.1570	0.0799	0.1744
125	0.1943	0.1031	0.0229	0.1734	0.1167	0.1398	0.1968	0.0862
134a	0.3745	0.1351	0.1166	0.1734	0.1780	0.1562	0.2147	0.1273
143a	0.3855	0.1181	0.1166	0.2591	0.1287	0.1463	0.2557	0.1213
152a	0.3825	0.1601	0.0229	0.3587	0.1991	0.1743	0.3006	0.1964
404A	0.2984	0.1321	0.0229	0.1734	0.1267	0.1439	0.0030	0.0531
407c	0.3445	0.1731	0.2332	0.0867	0.1519	0.1784	0.0003	0.0651
410A	0.3064	0.2051	0.2332	0.1734	0.1267	0.1833	0.0015	0.0722
AIR	0.0391	0.0630	0.2332	0.0867	0.2514	0.0004	0.0699	0.0319
717	0.0611	0.8225	0.4663	0.0169	0.2313	0.4357	0.4574	0.8087
744	0.0621	0.1631	0.3497	0.0169	0.0543	0.2795	0.1099	0.1543
600a	0.0571	0.0580	0.3497	0.3388	0.2313	0.5895	0.4994	0.2265
290	0.0501	0.1061	0.3497	0.3388	0.1700	0.0000	0.1099	0.2405

Table 4. Ideal positive and ideal negative solution of weighted normalized matrix.

R	Dielectric Strength	Thermal Conductivity	Action with oil	Action with water	Critical Temp	Critical Pressure	Critical Vol	Enthalpy of vaporization
11	0.0059	0.0072	0.0164	0.0223	0.0229	0.0111	0.0131	0.0079
12	0.0036	0.0048	0.0010	0.0146	0.0085	0.0069	0.0081	0.0042
115	0.0034	0.0055	0.0047	0.0035	0.0057	0.0051	0.0076	0.0028
113	0.0041	0.0046	0.0010	0.0075	0.0162	0.0057	0.0082	0.0043
22	0.0146	0.0085	0.0071	0.0105	0.0103	0.0117	0.0131	0.0080
141a	0.0164	0.0096	0.0175	0.0177	0.0251	0.0114	0.0068	0.0079
141b	0.0178	0.0090	0.0170	0.0189	0.0176	0.0119	0.0182	0.0111
502	0.0031	0.0050	0.0052	0.0039	0.0140	0.0070	0.0036	0.0078
125	0.0078	0.0041	0.0009	0.0069	0.0047	0.0056	0.0079	0.0035
134a	0.0234	0.0084	0.0073	0.0108	0.0111	0.0098	0.0134	0.0080
143a	0.0242	0.0074	0.0073	0.0163	0.0081	0.0092	0.0160	0.0076
152a	0.0248	0.0104	0.0015	0.0232	0.0129	0.0113	0.0195	0.0127
404A	0.0074	0.0033	0.0006	0.0043	0.0031	0.0035	0.0001	0.0013
407c	0.0090	0.0045	0.0061	0.0023	0.0040	0.0047	0.0000	0.0017
410A	0.0105	0.0070	0.0080	0.0059	0.0043	0.0063	0.0001	0.0025
AIR	0.0006	0.0010	0.0036	0.0013	0.0039	0.0000	0.0011	0.0005
717	0.0055	0.0743	0.0421	0.0015	0.0209	0.0394	0.0413	0.0731
744	0.0024	0.0062	0.0134	0.0006	0.0021	0.0107	0.0042	0.0059
600a	0.0046	0.0047	0.0283	0.0274	0.0187	0.0476	0.0403	0.0183
290	0.0010	0.0021	0.0071	0.0068	0.0034	0.0000	0.0022	0.0049
A+	0.0248	0.0743	0.0006	0.0006	0.0251	0.0476	0.00001	0.0731
A-	0.0006	0.0010	0.0421	0.0274	0.0021	0.0000007	0.0413	0.0005

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Table 5. Positive and negative separation alternatives along with their relative closeness.

R	Dielectric Strength	Thermal Conductivity	Action with oil	Action with water	Critical Temp	Critical Pressure	Critical Vol	Enthalpy of vaporization	S+	S-	Relative Closeness
11	0.0059	0.0072	0.0164	0.0223	0.0229	0.0111	0.0131	0.0079	0.1064	0.0465	0.3039
12	0.0036	0.0048	0.0010	0.0146	0.0085	0.0069	0.0081	0.0042	0.1106	0.0555	0.3343
115	0.0034	0.0055	0.0047	0.0035	0.0057	0.0051	0.0076	0.0028	0.1114	0.0564	0.3361
113	0.0041	0.0046	0.0010	0.0075	0.0162	0.0057	0.0082	0.0043	0.1094	0.0588	0.3495
22	0.0146	0.0085	0.0071	0.0105	0.0103	0.0117	0.0131	0.0080	0.1025	0.0531	0.3413
141a	0.0164	0.0096	0.0175	0.0177	0.0251	0.0114	0.0068	0.0079	0.1022	0.0541	0.3463
141b	0.0178	0.0090	0.0170	0.0189	0.0176	0.0119	0.0182	0.0111	0.1021	0.0457	0.3092
502	0.0031	0.0050	0.0052	0.0039	0.0140	0.0070	0.0036	0.0078	0.1065	0.0601	0.3606
125	0.0078	0.0041	0.0009	0.0069	0.0047	0.0056	0.0079	0.0035	0.1111	0.0578	0.3423
134a	0.0234	0.0084	0.0073	0.0108	0.0111	0.0098	0.0134	0.0080	0.1026	0.0554	0.3507
143a	0.0242	0.0074	0.0073	0.0163	0.0081	0.0092	0.0160	0.0076	0.1052	0.0524	0.3323
152a	0.0248	0.0104	0.0015	0.0232	0.0129	0.0113	0.0195	0.0127	0.1004	0.0567	0.3607
404A	0.0074	0.0033	0.0006	0.0043	0.0031	0.0035	0.0001	0.0013	0.1137	0.0635	0.3581
407c	0.0090	0.0045	0.0061	0.0023	0.0040	0.0047	0.0000	0.0017	0.1120	0.0612	0.3534
410A	0.0105	0.0070	0.0080	0.0059	0.0043	0.0063	0.0001	0.0025	0.1092	0.0592	0.3517
AIR	0.0006	0.0010	0.0036	0.0013	0.0039	0.0000	0.0011	0.0005	0.1181	0.0615	0.3424
717	0.0055	0.0743	0.0421	0.0015	0.0209	0.0394	0.0413	0.0731	0.0624	0.1151	0.6484
744	0.0024	0.0062	0.0134	0.0006	0.0021	0.0107	0.0042	0.0059	0.1082	0.0556	0.3394
600a	0.0046	0.0047	0.0283	0.0274	0.0187	0.0476	0.0403	0.0183	0.1068	0.0555	0.3421
290	0.0010	0.0021	0.0071	0.0068	0.0034	0.0000	0.0022	0.0049	0.1151	0.0566	0.3296
A+	0.0248	0.0743	0.0006	0.0006	0.0251	0.0476	0.00001	0.0731			
A-	0.0006	0.0010	0.0421	0.0274	0.0021	0.0000007	0.0413	0.0005			

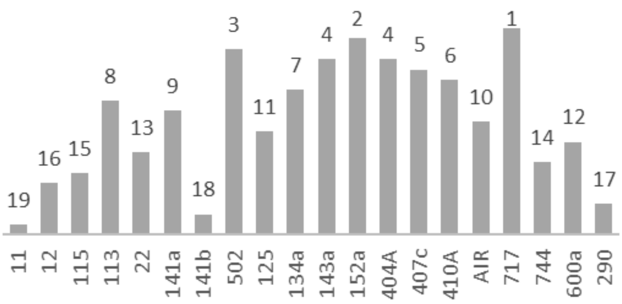

Fig. 2. Ranking of the refrigerants.

IV. Conclusions

The following conclusions are drawn:

- The critical properties (dielectric strength, thermal conductivity, critical temperature, critical pressure, critical volume, action of refrigerant with water & oil and enthalpy of vaporization) for the 20 commonly used refrigerants are traced using REFPROP 9.0 and tabulated for cold chain warehouse application.
- The quantitative data is then analyzed using TOPSIS-MADM technique to identify the most promising options, R717 is found to be having the highest prospect following R152 and R143a.

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