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The Selection of Amine Solvent in Gas Treating Process Considering Physical and Process Criteria Using Multiple Criteria Decision-making Techniques: A Case Study of Ilam Gas Treating Company

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Abstract

In the current work, a framework is presented for amine solvent selection in gas treating process. Since the appropriate decision making in this field affects the capital and operational costs, multi attribute decision making (MADM) techniques were used to rank alternatives. The determination of criteria and alternatives is the most important aspect in the MADM. Criteria were divided into two categories, namely physical and process, and twelve physical indexes and nine process indexes were detected. Mono-ethanol amine (MEA), di-glycol amine (DGA), di-ethanol amine (DEA), di-isopropanol amine (DIPA), and methyl di-ethanol amine (MDEA) are intended as alternatives. The importance of the criteria was expressed by weights, and the weights were determined by the analytic hierarchy process (AHP) method. The traditional Technique for Order Preferences by Similarity to an Ideal Solution (TOPSIS) method was applied to the physical criteria with crisp data. The modified interval TOPSIS technique was used to study the process criteria with interval data. The data of the criteria and alternatives were collected from Ilam Gas Treating Company, and the solution for sour gas sweetening was ranked by the proposed approach. Based on our computations, MDEA was defined as the best amine solvent with an average ranking of 1.5.

Keywords: Amine Solvent, MADM, TOPSIS, Interval Number, AHP, Gas Treating

1. Introduction

In the coming decades, the energy demand is expected to grow rapidly (Langè et al., 2015). Natural gas is a prime, clean, safe, and most useful form of energy (Kazemi et al., 2016), which has been widely used as an industrial and indoor fuel. There are impurities in natural gas which cause serious problems such as fouling and corrosion in pipelines, freezing, plugging, and erosion (Al-Lagtah et al., 2015; Gutierrez et al., 2016; Muhammad and GadelHak, 2015; Qiu et al., 2014). H_2S and CO_2 are the major impurities in natural gas which must be removed to bring natural gas to the market (Alhseinat et al.,

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2015; Cho et al., 2015). Chemical absorption by alkanol amines, bio scrubber, adsorption, membrane, and the oxidation of H_2S in an iron-chelate process have been used for the removal of these contaminates over years (Ameli Forough, 2012; Tavan et al., 2016). Amine absorption process is the most commonly used acid gas removal technology (Niu and Rangaiah, 2014). This process allows acidic gases to be dissolved in a solvent and released by regeneration at a later stage (Devold, 2013; Jassim, 2016). Amines are some compounds of ammonia (NH_3) which have replaced one or more of their hydrogen atoms with hydrocarbon groups (Arthur Kidnay, 2006). Depending on the composition and operation conditions of the raw gas streams to be treated, aqueous amines are used to meet the sweet gas specifications (Vahid Abkhiz, 2014).

Furthermore, the amines capacity for the absorption of acidic gases is an important characteristic (Momeni and Riahi, 2014). Mono-ethanol amine (MEA), di-glycol amine (DGA), di-ethanol amine (DEA), di-isopropanol amine (DIPA), and methyl di-ethanol amine (MDEA) are commonly used in the natural gas sweetening process (Shokouhi et al., 2015).

The selection of a suitable amine solution for sweetening depends on the feed condition and process objectives (Zahid et al., 2017). It can reduce capital and operating costs while providing more flexibility in achieving specific purity requirements. The specification of the required purity with respect to acidic gases (CO_2 and H_2S), equipment sizing, and operating costs are the primary concern in the gas sweetening. Amine circulation rate, reboiler/condenser size and duty, and corrosion problems are important factors to be considered in the selection of the proper amine. In the amine sweetening unit, 50 to 70% of the initial investment is related to the magnitude of the solvent circulation rate, and 10 to 20% of the initial investment is dependent on the regeneration energy requirement. In addition, about 70% of the operating costs, excluding labor, result from regeneration. Since the selection of the proper amine can greatly reduce both the regeneration energy requirement and solution circulation rate, choosing the amine or a combination of amines best suited to the conditions can have a dramatic impact on the overall costs associated with a sweetening unit (Astarita, 1983; John Polasek, 2006).

The selection of amine solvent in the process of gas treating is considered to be an important decision in gas treating companies. To this end, in the current work, MADM techniques were used for amine solvent selection for the first time. In the next section, a summary of MADM relevant literature is described.

2. Relevant literature

Multi-criteria decision-making (MCDM) is a discipline aimed at supporting decision makers which are faced with numerous and conflicting alternatives to make an optimal decision. To achieve this purpose, two critical questions should be unlocked: preference structure and weights. MCDM methods have been considered in many fields, some of which include economic, social, medical, and technical issues (Nădăban et al., 2016). To facilitate systematic research in the field of MCDM, Hwang and Yoon suggested that MCDM problems can be classified into two main categories, namely multiple attribute decision making (MADM) and multiple objective decision making (MODM), based on the different purposes and different data types (Gwo-Hshiung Tzeng and Huang, 2011). Different methods of decision analysis are illustrated in Figure 1, among which TOPSIS and AHP methods are highlighted.

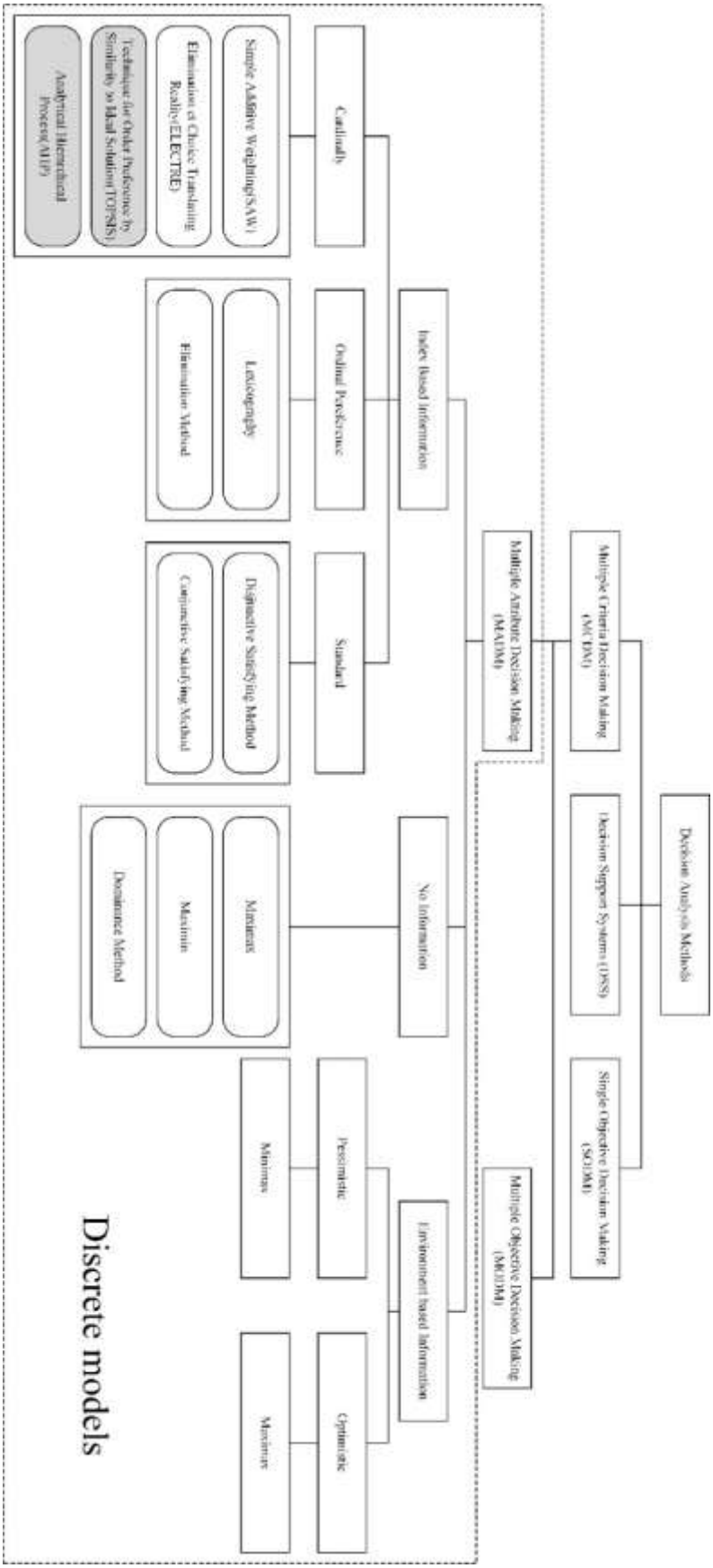

Figure 1

Decision analysis methods.

The TOPSIS method is currently one of the most frequently used methods for MCDM. Its original version was intended for dealing with real-valued data. The Technique for Order Preferences by Similarity to an Ideal Solution (TOPSIS) method was proposed by Hwang and Yoon in 1981. The main idea came from the concept of the compromise solution to choose the best alternative nearest to the positive ideal solution (optimal solution) and the farthest alternative from the negative ideal solution (inferior solution); then, the best one of sorting is chosen, which will be the best alternative (Hwang and Yoon, 1981). As a practical application of this method, we can address the works of Ansarifar et al.(2015), Barros and Wanke (2015), and Chen et al. (2015).

A new interval type-2 fuzzy multiple-attribute decision making model is developed using TOPSIS and decision making trial and evaluation laboratory (DEMATEL) by Baykasoglu et al. (Baykasolu and Glck, 2017), Hatami et al. (Hatami-Marbini and Kangi, 2017), and Runik et al. (Rudnik and Kacprzak, 2017). They have presented a general overview about the development of fuzzy TOPSIS methods. Nadaban et al. have also mentioned several works presenting some applications of fuzzy TOPSIS such as location problem, supplier selection, and sustainable and renewable energy (Nădăban et al., 2016).

In this study, for deciding on the amine solvent selection, a systematic decision-making approach was proposed. The proposed approach will be explained in the next section.

3. The proposed approach

Hierarchical structure creation, calculation of criteria weights by AHP, and selection by TOPSIS are three phases of the selection of the amine solvent. The different phases of the proposed approach are presented in Figure 2.

In the first phase, criteria and alternatives are identified using technical information gathered from Ilam Gas Treating Company; criteria are divided into two categories: physical and process, and twelve physical indexes and nine process indexes are detected. The physical criteria include 1-molecular weight, 2-boiling point, 3-freezing point, 4-critical constants, 5-density, 6-weight, 7-relative density, 8-specific heat, 9-thermal conductivity, 10-latent heat of vaporization, 11-flash point, and 12-toxicity. The process criteria are 1-acid gas pickup (m^3(GPA)/L at 38 °C), 2-acid gas pickup (mol/mol amine), 3-lean solution residual acid gas, 4-rich solution acid gas loading, 5-solution concentration, 6-approximate reboiler heat duty, 7-reboiler temperature, normal operating, 8-heats of reaction, and 9-absorption. MEA, DEA, DIPA, DGA, and MDEA are intended as alternatives. The decision hierarchical structure is depicted in Figure 3.

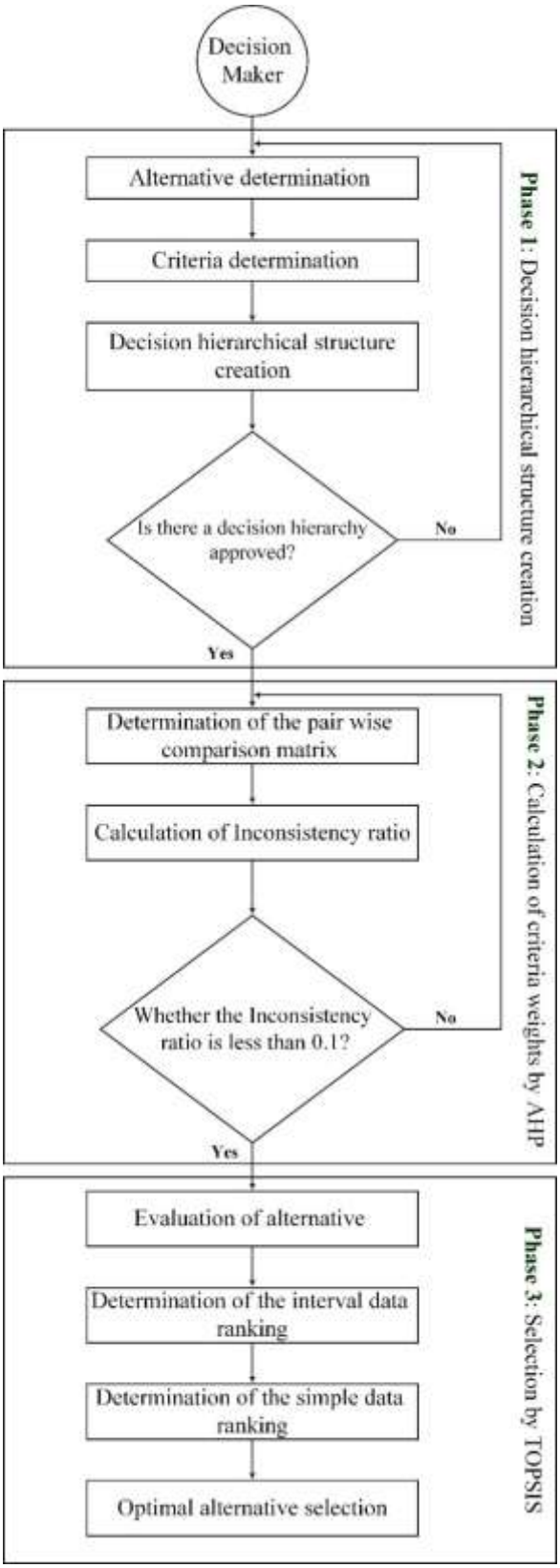

Figure 2

The proposed approach.

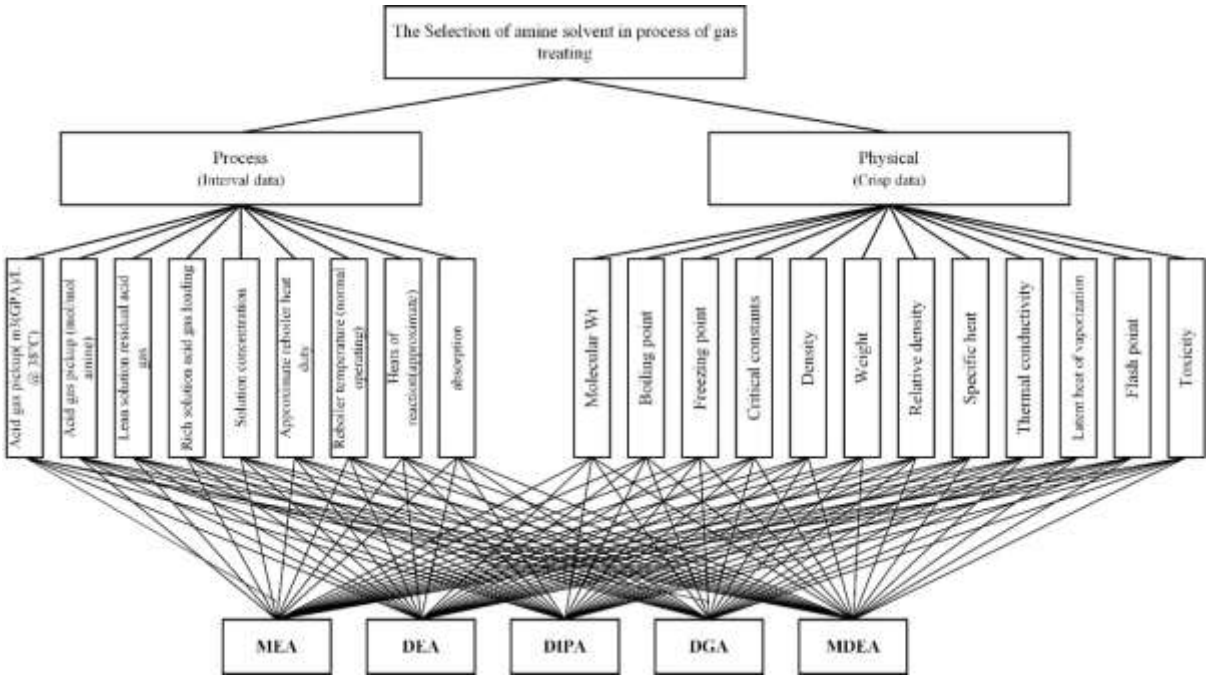

Figure 3

Decision hierarchical structure.

In the second phase, the weights of the criteria are calculated by the analytic hierarchy process (AHP), developed by Thomas L. Saaty in 1980. An advantage of the AHP is that it is designed to handle situations in which the subjective judgments of individuals constitute an important part of the decision process. Basically, the AHP is a method of (1) breaking down a complex, unstructured situation into its component parts; (2) arranging these parts, or variables into a hierarchic order; (3) assigning numerical values to subjective judgments on the relative importance of each variable; and (4) synthesizing the judgments to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation. The major steps of AHP include:

1. developing a graphical representation of the problem in terms of the overall goal, the criteria, and the decision alternatives;
2. specifying his/her judgments about the relative importance of each criterion in terms of its contribution to the achievement of the overall goal;
3. indicating a preference or priority for each decision alternative in terms of how it contributes to each criterion;
4. using a mathematical process to synthesize the information (including consistency checking) and provide a priority ranking of all the alternatives and criteria, given the information on relative importance and preferences.

Finally, in the third phase, alternative ranking is performed. Due to the different quantities of criteria (crisp and interval data), ranking procedure is performed twice. At first, amine solvents are ranked by the traditional TOPSIS method with the crisp data, and then the alternatives are ranked by the modified TOPSIS method with the interval data; ranking average is considered as the final ranking. In the following, the traditional and modified TOPSIS methods are presented.

3.1. The traditional TOPSIS method with the crisp data

Suppose that there are *n* criteria (C_1, C_2, …, C_n) which are taken into consideration among *m* alternatives (A_1, A_2, …, A_n) in an MCDM problem. Let x_{ij} be the performance of the alternative *i* at the criterion *j*. The basic principle of the TOPSIS method is that the best alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution. Its procedure is given below:

1. Calculate the normalized value n_{ij}.

$$n_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \quad i \in I = \{1,2,\cdots,m\} \text{ and } j \in J = \{1,2,\cdots,n\} \tag{1}$$

2. Calculate the weighted normalized value v_{ij}.

$$v_{ij} = w_j n_{ij}, \quad \forall i \in I, \ \forall j \in J \tag{2}$$

where, w_j is the weight of the j^{th} criterion.

3. Determine the positive-ideal solution A^+ and the negative-ideal solution A^-.

$$A^+ = \left(v_1^+, v_2^+, \cdots, v_n^+\right) = \left\{\left(\max_i v_{ij} \,|\, j \in S_B\right), \left(\min_i v_{ij} \,|\, j \in S_C\right)\right\} \tag{3}$$

$$A^- = \left(v_1^-, v_2^-, \cdots, v_n^-\right) = \left\{\left(\min_i v_{ij} \,|\, j \in S_B\right), \left(\max_i v_{ij} \,|\, j \in S_C\right)\right\} \tag{4}$$

where, S_B and S_C denote the set of benefit criteria and the set of cost criteria respectively.

4. Calculate Euclidean distance.

$$d_i^+ = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^+\right)^2}, \qquad \forall i \in I \tag{5}$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2}, \qquad \forall i \in I \tag{6}$$

5. Calculate the relative closeness to the ideal solution.

$$Cl_i = \frac{d_i^-}{d_i^+ + d_i^-}, \qquad i \in I \tag{7}$$

6. Rank the preference order.

For ranking, we can choose the best alternative with the maximum value of the relative closeness. According to the other works (Khezerloo et al., 2011; Levin, 2004; Sevastianov, 2007), the modified TOPSIS method with the interval data is described.

3.2. Modified TOPSIS method with interval data

1. Calculate the normalized interval value $N_{ij(1)} = \left[n^l_{ij(1)}, n^u_{ij(1)} \right]$ as given below:

$$n^l_{ij} = \frac{x^l_{ij}}{\sqrt{\sum_{i=1}^{m} \frac{1}{2}\left[\left(x^l_{ij} \right)^2 + \left(x^u_{ij} \right)^2 \right]}}, \qquad \forall i \in I, \quad \forall j \in J \tag{8}$$

$$n^u_{ij} = \frac{x^u_{ij}}{\sqrt{\sum_{i=1}^{m} \frac{1}{2}\left[\left(x^l_{ij} \right)^2 + \left(x^u_{ij} \right)^2 \right]}}, \qquad \forall i \in I, \quad \forall j \in J \tag{9}$$

2. Calculate the weighted normalized interval data $\bar{V}_{ij} = \left[v^l_{ij}, v^u_{ij} \right]$ defined by:

$$\bar{v}^l_{ij} = w_j n^l_{ij} \tag{10}$$

$$\bar{v}^u_{ij} = w_j n^u_{ij} \tag{11}$$

3. Identify the positive ideal solution $A^+_{(1)}$ and the negative ideal solution $A^-_{(1)}$ as follows:

$$\begin{aligned} A^+ &= \left\{ \bar{V}^+_1, \bar{V}^+_2, \cdots, \bar{V}^+_n \right\} = \left\{ \left(v^{+l}_1, v^{+u}_1 \right), \left(v^{+l}_2, v^{+u}_2 \right), \cdots, \left(v^{+l}_n, v^{+u}_n \right) \right\} \\ &= \left\{ \left(\max_i \left\{ \bar{V}_{ij} \right\} | j \in S_B \right), \left(\min_i \left\{ \bar{V}_{ij} \right\} | j \in S_C \right) \right\} \end{aligned} \tag{12}$$

$$\begin{aligned} A^- &= \left\{ \bar{V}^-_1, \bar{V}^-_2, \cdots, \bar{V}^-_n \right\} = \left\{ \left(v^{-l}_1, v^{-u}_1 \right), \left(v^{-l}_2, v^{-u}_2 \right), \cdots, \left(v^{-l}_n, v^{-u}_n \right) \right\} \\ &= \left\{ \left(\min_i \left\{ \bar{V}_{ij} \right\} | j \in S_B \right), \left(\max_i \left\{ \bar{V}_{ij} \right\} | j \in S_C \right) \right\} \end{aligned} \tag{13}$$

4. Calculate the Euclidean distance.

$$d\left(\bar{V}_{ij}, \bar{V}^+_j \right) = \sqrt{\frac{1}{3}\left(\left(v^l_{ij} - v^{+l}_j \right)^2 + \left(v^u_{ij} - v^{+u}_j \right)^2 + \left(v^l_{ij} - v^{+l}_j \right)\left(v^u_{ij} - v^{+u}_j \right) \right)} \; ; \forall \, i \in I, j \in J \tag{14}$$

$$D^+_i = \sum_{j=1}^{n} \sqrt{\frac{1}{3}\left(\left(v^l_{ij} - v^{+l}_j \right)^2 + \left(v^u_{ij} - v^{+u}_j \right)^2 + \left(v^l_{ij} - v^{+l}_j \right)\left(v^u_{ij} - v^{+u}_j \right) \right)} \; ; \forall \, i \in I \tag{15}$$

$$d\left(\bar{V}_{ij}, \bar{V}^-_j \right) = \sqrt{\frac{1}{3}\left(\left(v^l_{ij} - v^{-l}_j \right)^2 + \left(v^u_{ij} - v^{-u}_j \right)^2 + \left(v^l_{ij} - v^{-l}_j \right)\left(v^u_{ij} - v^{-u}_j \right) \right)} \; ; \forall \, i \in I, j \in J \tag{16}$$

$$D^-_i = \sum_{j=1}^{n} \sqrt{\frac{1}{3}\left(\left(v^l_{ij} - v^{-l}_j \right)^2 + \left(v^u_{ij} - v^{-u}_j \right)^2 + \left(v^l_{ij} - v^{-l}_j \right)\left(v^u_{ij} - v^{-u}_j \right) \right)} \; ; \forall \, i \in I \tag{17}$$

5. Calculate the relative closeness Cl_i as reads:

$$Cl_i = \frac{D_i^-}{D_i^+ + D_i^-}, \qquad \forall i \in I \tag{18}$$

4. Case Study: Ilam Gas Treating Company

The amine solvent selection in Ilam Gas Treating Company (IGTC) is performed using the proposed approach. The flow sheet of the plant is presented in Figure 4, and the composition and feed condition of the plant is tabulated in Table 1

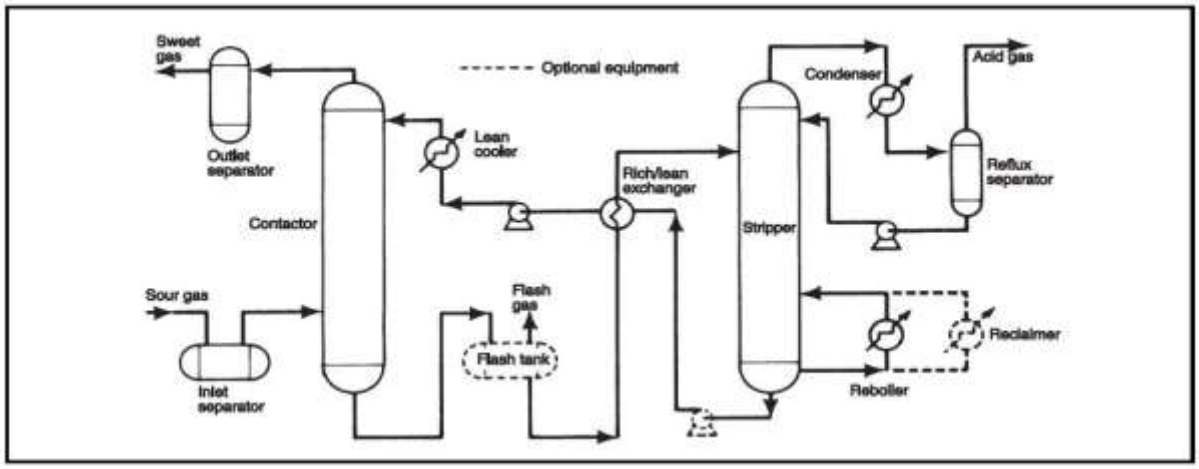

Figure 4

Amine gas sweetening flow sheet.

Table 1

Amine gas sweetening feed composition and conditions.

Feed composition			
Component	**Molar fraction**	**Component**	**Molar fraction**
H_2O	0	i-Pentane	2.09×10^{-3}
Nitrogen	1.29×10^{-3}	n-Butane	6.16×10^{-3}
H_2S	3.25×10^{-2}	i-Butane	4.37×10^{-3}
CO_2	3.74×10^{-2}	Propane	2.30×10^{-2}
MDEA	0	Ethane	5.51×10^{-2}
Piperazine	0	Methane	0.831679
n-Octane	9.94×10^{-4}	diM-Sulfide	1.26×10^{-4}
n-Heptane	5.96×10^{-4}	E-Mercaptan	2.78×10^{-5}
n-Hexane	1.29×10^{-3}	M-Mercaptan	1.30×10^{-3}
n-Pentane	2.09×10^{-3}	COS	2.29×10^{-5}

Feed flow rate and condition

Stream name	1
Vapor / Phase Fraction	1
Temperature (°C)	18.3
Pressure (barg)	76
Molar flow (kg mol/hr.)	6157.338
Mass flow (kg/hr.)	123593.3
Standard ideal LiqVol flow (m^3/hr.)	351.4239
Molar enthalpy (kJ/kg mol)	-89327.4
Molar entropy (kJ/kg mol.°C)	-124.918
Heat flow (kJ/hr.)	$-5.5\times10^{+8}$
LiqVol flow in standard conditions (m^3/hr.)	921.7805

The crisp and interval data about the physical and process criteria are listed in Tables 2 and 3.

Table 2

Physical criteria of the crisp data.

Alternatives (Amine solvent)	Physical criteria											Toxicity
	Molecular weight	Boiling point 760 mm Hg (°C)	Freezing point (°C)	Critical constants Pressure (kPa) (abs)	Density	Weight (kg/m^3)	Relative density	Specific heat	Thermal conductivity	Latent heat of vaporization (kJ/kg)	Flash point	LC50
MEA	61.08	170.5	10.5	5985	1.018	1016	1.0179	2.55	0.256	826	93	206
DEA	105.14	269	28	3273	1.095	1089	1.0919	2.51	0.22	670	138	837
DIPA	133.19	248.7	42	3770	0.999	1080	0.989	2.89	0.002	430	124	580
DGA	105.14	221	-12.5	3772	1.058	1057	1.0572	2.39	0.209	510	127	460
MDEA	119.16	247	-23	2761.36	1.04	1040	1.0418	2.24	0.275	476	127	250

Table 3

Process criteria of the interval data.

Alternatives (Amine solvent)	Process criteria																	
	C_1		C_2		C_3		C_4		C_5		C_6		C_7		C_8		C_9	
	x_{i1}^{l}	x_{i1}^{u}	x_{i2}^{l}	x_{i2}^{u}	x_{i3}^{l}	x_{i3}^{u}	x_{i4}^{l}	x_{i4}^{u}	x_{i5}^{l}	x_{i5}^{u}	x_{i6}^{l}	x_{i6}^{u}	x_{i7}^{l}	x_{i7}^{u}	x_{i8}^{l}	x_{i8}^{u}	x_{i9}^{l}	x_{i9}^{u}
MEA	0.023	0.032	0.33	0.4	0.12	0.12	0.45	0.52	15	25	280	335	107	127	1280	1560	1445	1630
DEA	0.0285	0.0375	0.35	0.65	0.08	0.08	0.43	0.73	25	35	245	280	110	121	1160	1400	1350	1515
DIPA	0.05	0.0585	0.72	1.02	0.08	0.08	0.8	1.1	25	30	245	280	110	121	1190	1190	1520	1520
DGA	0.035	0.0495	0.25	0.3	0.1	0.1	0.35	0.4	50	70	300	360	121	127	1570	1570	2000	2000
MDEA	0.022	0.056	0.2	0.55	0.005	0.01	0.4	0.55	40	50	220	335	121	127	1040	1210	1325	1390

The normalized values of the data are calculated in Tables 4 and 5.

Table 4

Normalized value of the crisp data.

Alternatives (Amine solvent)	Physical criteria											
	Molecular weight	Boiling point 760 mm Hg (°C)	Freezing point (°C)	Critical constants Pressure (kPa) (abs)	Density	Weight (kg/m^3)	Relative density	Specific heat	Thermal conductivity	Latent heat of vaporization (kJ/kg)	Flash point	Toxicity LC50
MEA	0.254	0.326	0.182	0.659	0.437	0.430	0.438	0.452	0.530	0.615	0.339	0.177
DEA	0.437	0.515	0.484	0.360	0.470	0.461	0.469	0.445	0.456	0.499	0.503	0.719
DIPA	0.554	0.476	0.726	0.415	0.429	0.457	0.425	0.512	0.004	0.320	0.452	0.499
DGA	0.437	0.423	-0.216	0.415	0.454	0.447	0.455	0.423	0.433	0.380	0.463	0.395
MDEA	0.496	0.473	-0.398	0.304	0.446	0.440	0.448	0.397	0.569	0.355	0.463	0.215

Table 5

Normalized value of the interval data.

Alternatives (Amine solvent)	Process criteria																	
	C_1		C_2		C_3		C_4		C_5		C_6		C_7		C_8		C_9	
	x_{i1}^l	x_{i1}^u	x_{i2}^l	x_{i2}^u	x_{i3}^l	x_{i3}^u	x_{i4}^l	x_{i4}^u	x_{i5}^l	x_{i5}^u	x_{i6}^l	x_{i6}^u	x_{i7}^l	x_{i7}^u	x_{i8}^l	x_{i8}^u	x_{i9}^l	x_{i9}^u
MEA	0.2496	0.3472	0.2756	0.3340	0.6216	0.6216	0.3271	0.3780	0.1692	0.2819	0.4301	0.5146	0.4007	0.4756	0.4304	0.5246	0.4073	0.4595
DEA	0.3092	0.4069	0.2923	0.5428	0.4144	0.4144	0.3125	0.5306	0.2819	0.3947	0.3763	0.4301	0.4120	0.4531	0.3901	0.4708	0.3805	0.4270
DIPA	0.5425	0.6347	0.6013	0.8518	0.4144	0.4144	0.5815	0.7995	0.2819	0.3383	0.3763	0.4301	0.4120	0.4531	0.4002	0.4002	0.4285	0.4285
DGA	0.3798	0.5371	0.2088	0.2505	0.5180	0.5180	0.2544	0.2907	0.5639	0.7894	0.4608	0.5530	0.4531	0.4756	0.5280	0.5280	0.5638	0.5638
MDEA	0.2387	0.6076	0.1670	0.4593	0.0259	0.0518	0.2907	0.3998	0.4511	0.5639	0.3379	0.5146	0.4531	0.4756	0.3497	0.4069	0.3735	0.3918

Physical index weights are determined by using the AHP method as follows:

$$W_j = (0.044, 0.132, 0.132, 0.074, 0.044, 0.044, 0.044, 0.074, 0.103, 0.103, 0.074, 0.132) \quad (19)$$

Experts proposed process index weights as follows:

$$W_j = ((0.75,1), (0.75,1), (1,1.25), (0.75,1), (0.75,1), (0.75,1), (0.75,1), (0.75,1), (0.25,0.5)) \quad (20)$$

The positive-ideal solution A^+ and the negative-ideal solution A^- are tabulated in Tables 6 and 7.

Table 6

A^+ and A^- of the physical criteria.

Alternatives (Amine solvent)	Physical criteria											
	Molecular weight	Boiling point 760 mm Hg (°C)	Freezing point (°C)	Critical constants Pressure (kPa) (abs)	Density	Weight, (kg/m^3)	Relative density	Specific heat	Thermal conductivity	Latent heat of vaporization (kJ/kg)	Flash point	Toxicity LC50
MEA	0.011	0.043	0.024	0.05	0.019	0.019	0.019	0.033	0.055	0.063	0.025	0.023
DEA	0.019	0.068	0.064	0.03	0.021	0.020	0.021	0.033	0.047	0.051	0.037	0.095
DIPA	0.024	0.063	0.096	0.03	0.019	0.020	0.019	0.038	0.000	0.033	0.033	0.066
DGA	0.019	0.056	-0.029	0.03	0.020	0.020	0.020	0.031	0.045	0.039	0.034	0.052
MDEA	0.022	0.063	-0.053	0.02	0.020	0.019	0.020	0.029	0.059	0.036	0.034	0.028
A^+	0.024	0.068	-0.053	0.048	0.021	0.020	0.021	0.038	0.059	0.033	0.037	0.023
A^-	0.019	0.056	0.096	0.022	0.019	0.019	0.019	0.029	0.000	0.051	0.033	0.095

Table 7

A^+ and A^- of the process criteria.

Alternatives (Amine solvent)	Process criteria																	
	C_1		C_2		C_3		C_4		C_5		C_6		C_7		C_8		C_9	
	v_{i1}^{l}	v_{i1}^{u}	v_{i2}^{l}	v_{i2}^{u}	v_{i3}^{l}	v_{i3}^{u}	v_{i4}^{l}	v_{i4}^{u}	v_{i5}^{l}	v_{i5}^{u}	v_{i6}^{l}	v_{i6}^{u}	v_{i7}^{l}	v_{i7}^{u}	v_{i8}^{l}	v_{i8}^{u}	v_{i9}^{l}	v_{i9}^{u}
MEA	0.1872	0.3472	0.2067	0.3340	0.6216	0.7771	0.2453	0.3780	0.1269	0.2819	0.3226	0.5146	0.3005	0.4756	0.3228	0.5246	0.1018	0.2297
DEA	0.2319	0.4069	0.2192	0.5428	0.4144	0.5180	0.2344	0.5306	0.2115	0.3947	0.2822	0.4301	0.3090	0.4531	0.2926	0.4708	0.0951	0.2135
DIPA	0.4069	0.6347	0.4510	0.8518	0.4144	0.5180	0.4361	0.7995	0.2115	0.3383	0.2822	0.4301	0.3090	0.4531	0.3001	0.4002	0.1071	0.2142
DGA	0.2848	0.5371	0.1566	0.2505	0.5180	0.6476	0.1908	0.2907	0.4229	0.7894	0.3456	0.5530	0.3399	0.4756	0.3960	0.5280	0.1409	0.2819
MDEA	0.1790	0.6076	0.1253	0.4593	0.0259	0.0648	0.2181	0.3998	0.3383	0.5639	0.2534	0.5146	0.3399	0.4756	0.2623	0.4069	0.0934	0.1959
	v_1^{+l}	v_1^{+u}	v_2^{+l}	v_2^{+u}	v_3^{+l}	v_3^{+u}	v_4^{+l}	v_4^{+u}	v_5^{+l}	v_5^{+u}	v_6^{+l}	v_6^{+u}	v_7^{+l}	v_7^{+u}	v_8^{+l}	v_8^{+u}	v_9^{+l}	v_9^{+u}
A^+	0.407	0.635	0.451	0.852	0.026	0.065	0.436	0.800	0.423	0.789	0.253	0.430	0.301	0.453	0.262	0.400	0.093	0.196
	v_1^{-l}	v_1^{-u}	v_2^{-l}	v_2^{-u}	v_3^{-l}	v_3^{-u}	v_4^{-l}	v_4^{-u}	v_5^{-l}	v_5^{-u}	v_6^{-l}	v_6^{-u}	v_7^{-l}	v_7^{-u}	v_8^{-l}	v_8^{-u}	v_9^{-l}	v_9^{-u}
A^-	0.179	0.347	0.125	0.251	0.622	0.777	0.191	0.291	0.127	0.282	0.346	0.553	0.340	0.476	0.396	0.528	0.141	0.282

The Euclidean distance, the relative closeness to the ideal solution, and the rank of the preference order for the physical criteria are presented in Table 8.

Table 8

Rank the preference order of physical criteria.

	d_i^+	d_i^-	Cl_i	Rank
MEA	0.088	0.120	0.57644	3
DEA	0.141	0.058	0.29259	4
DIPA	0.166	0.038	0.18397	5
DGA	0.047	0.140	0.74912	2
MDEA	0.029	0.174	0.85728	1

The Euclidean distance and the relative closeness to the ideal solution for the process criteria are summarized in Tables 9 and 10.

Table 9

Euclidean distance $d\left(\bar{V}_{ij},\bar{V}_j^+\right)$.

	$d\left(\bar{V}_{ij},\bar{V}_j^+\right)$									
	j=1	j=2	j=3	j=4	j=5	j=6	j=7	j=8	j=9	D_i^+
i=1	0.254373907	0.389116937	0.654891537	0.313347055	0.40637800	7 0.07692837	0.012973163	0.094300094	0.022373479	2.22468255
i=2	0.201981728	0.271287702	0.421323081	0.236115158	0.30767001	40.016627791	0.004864936	0.051770571	0.010716282	1.52235726
i=3	0	0	0.421323081	0	0.33842820	70.016627791	0.004864936	0.021842416	0.016086326	0.81917276
i=4	0.110082402	0.456511857	0.538104151	0.384646074	0	0.10788576	30.031277162	0.130742219	0.067684373	1.826934
i=5	0.140038311	0.359618514	0	0.313331248	0.16031897	20.048774853	0.031277162	0.003883096	0	1.05724216

Table 10

Euclidean distance $d\left(\bar{V}_{ij},\bar{V}_{j}^{-}\right)$.

	$d\left(\bar{V}_{ij},\bar{V}_{j}^{-}\right)$									
	j=1	*j*=2	*j*=3	*j*=4	*j*=5	*j*=6	*j*=7	*j*=8	*j*=9	D_i^-
i=1	0.004698202	0.082470161	0	0.071493636	0	0.031038543	0.022703034	0.043232156	0.045784157	0.30141989
i=2	0.056318582	0.201429981	0.233597557	0.152637483	0.099014754	0.094692474	0.026793978	0.081390301	0.057450567	1.00332568
i=3	0.258263473	0.470268902	0.233597557	0.384646074	0.070953832	0.094692474	0.026793978	0.112194772	0.051669337	1.7030804
i=4	0.149811361	0.018080847	0.116798778	0	0.406378007	0	0	0	0	0.69106899
i=5	0.150342478	0.120538982	0.654891537	0.072114432	0.247536886	0.067099769	0	0.127420335	0.067684373	1.50762879

The relative closeness to the ideal solution and the rank of the preference order for the process criteria are listed in Table 11.

Table 11

Rank and the preference order of the process criteria.

Amine solvent	***Cl*$_i$**	**Ranking**
MEA	0.11932212	5
DEA	0.39724926	3
DIPA	0.67522183	1
DGA	0.27445122	4
MDEA	0.58779908	2

As can be observed, the ranking averages are as follows: MDEA=1.5, DGA=3, DIPA=3, DEA=3.5, and MEA=4; hence, MDEA is selected as the best amine solvent. The experts in the IGTC also confirm this selection. At present, Ilam Gas Treating Company uses this kind of amine, i.e. MDEA. Therefore, it can be concluded that the TOPSIS algorithm is successfully employed in different processes. The number of applications of the basic and modified versions of TOPSIS algorithm is increasing at a faster rate, which clearly proves the potential of the TOPSIS algorithm. This method has proved to be better than other similar optimization techniques like particle swarm optimization (PSO), genetic algorithm (GA), and Taguchi method. It requires a lower number of iterations but provides higher specific results, which makes it better than others algorithms. TOPSIS has not been used in this field so far; for the first time, we used MADM techniques for amine solvent selection herein.

4. Conclusions

The selection of a suitable amine solvent for sweetening can reduce capital and operating costs. This selection is considered to be an important decision in the process of gas treating. For the first time, MADM techniques are used in this work to select amine solvents. To create a systemic approach in the amine solvent selection, the MADM techniques are recommended. The selection of amine solvent is categorized in three phases: 1-creating the hierarchical structure, 2-calculating the criteria weights by AHP, and 3-selecting the solvent by TOPSIS. The criteria were divided in two classes, namely physical and process criteria, and twelve physical indexes and nine process indexes were detected. MEA, DEA, DIPA, DGA, and MDEA were intended as the alternatives. The ranking procedure was performed twice; first, the traditional TOPSIS method with the crisp data was used to rank the amine solvents.

Second, the modified TOPSIS method with the interval data was utilized to rank the alternatives. Ranking average was considered as the final ranking. According to our computations, MDEA was introduced as the best amine solvent with an average ranking of 1.5. The process indicators were considered to be twice as important as the physical indexes. However, the top ranking did not change, and only MDEA average ranking changed to 1.67.

Nomenclature

x_{ij}	Performance of the alternative *i* at criterion *j*
w_j	Weight of the j^{th} criterion
n_{ij}	Normalized value of the performance of alternative *i* at criterion *j*
v_{ij}	Weighted normalized value of the performance of alternative *i* at criterion *j*
A^+	Positive-ideal solution
A^-	Negative-ideal solution
d_i^+	Euclidean distance between alternative *i* and the positive-ideal solution
d_i^-	Euclidean distance between alternative *i* and the negative-ideal solution
Cl_i	Relative closeness of alternative *i* to the ideal solution
$N_{ij(1)} = \left[n_{ij(1)}^l, n_{ij(1)}^u \right]$	Normalized interval value data
$\bar{V}_{ij} = \left[v_{ij}^l, v_{ij}^u \right]$	Weighted normalized interval data
$d(\bar{V}_{ij}, \bar{V}_j^+)$	Euclidean distance between alternative *i* and the positive-ideal solution according to criterion *j* with interval data
$d(\bar{V}_{ij}, \bar{V}_j^-)$	Euclidean distance between alternative *i* and the negative-ideal solution according to criterion *j* with interval data
D_i^+	Euclidean distance between alternative *i* and the positive-ideal solution with interval data
D_i^-	Euclidean distance between alternative *i* and the negative-ideal solution with interval data

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