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Selection and Sensitivity Analysis of Flare Piping Materials for the Onshore Hydrocarbon Industry

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Abstract: In the hydrocarbon industry, Optimal design and development of an onshore plant depends on the correct material selection for piping systems. In the perspective of global warming, every hydrocarbon plant needs an efficient flare system. The efficiency, longevity and cost-effective design comes through proper material selection. To avoid the fatigue failure of the flare system needs a suitable piping design considering mechanical properties. In the managerial aspect, a company focuses on supply lead time and money. In this paper, a certain number of alternative flare pipes are chosen by the optimization process considering important criteria. The technical, economic and supply time is the important pillar of the designing process. Due to the entropy process and sensitivity analysis, the results are more accurate as well as the design process is smooth. The methodology of Simple Additive Weighting (SAW) and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) are implemented first time and comparative Analysis is to find out the best material for better product development.

Keywords: Flare system; Material Selection; Sensitivity Analysis; Entropy; SAW; TOPSIS; Onshore; Hydrocarbon industry

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1. Introduction

Improperly designed flares may emit methane, sulphur and other volatile organic compounds which creates the problem of our respiratory system and this impact is negatively in environment. This pressure safety device work properly when materials selection goes through scientifically. Economically and proper technically designed flare system is viable for present market scenario. Undesired flammable gases are burnt by flare system, so the essential designing is should be needed through suitable material selection. In practical world, a decision maker has to choose on one among the multiple alternative projects. Specially in piping selection process, it is very difficult task to selection and evaluation of the proposed pipe.

The material selection methodologies are reviewed for replacing the existing material to select a right candidate material of Flare system of hydrocarbon industry, the selection of material methodologies presented in this article contains important selection attributes and its applications

- ✓ Sotoodeh, K. (2022) trying to research of Flare Piping Material Selection for the Offshore Oil and Gas Industry.
- ✓ L. Anoj kumar et. al. (2014) proposed Comparative analysis of MCDM methods for pipe material selection in sugar industry.
- ✓ Ram Narayanaswamy (2017) presented the methodology of the process of materials selection for pipeline systems optimization for life cycles.
- ✓ Jamil Ahmad et. al. (2015) approaches the multi-criteria group decision making for pipe material selection: comparative analysis of hf-vikor and hf-electre ii.

2. Methodology

2.1 Multi Criteria Decision Making (MCDM)

Considering multiple conflicting criteria, selecting the best path from a set of feasible alternatives known as Multiple criteria decision making (MCDM). This process always goes through at least two alternatives and two conflicting criteria. MCDM are divided two broad categories: Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). Several useful tools for solving of MCDM problems are

- Simple Additive Weighting method (SAW)
- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
- Multi Objective Optimization Ratio Analysis (MOORA)
- Analytical Hierarchy Method (AHP)
- Analytical Network Method ANP etc.

2.2 Simple Additive Weighting (SAW)

Step 1 Formation of decision matrix

Final result of Decision Matrix comprised of a set of columns and rows as well as alternatives and criteria respectively. The decision matrix is a central structure of the MCDA/MCDM since it contains the data for comparison of decision alternatives.

$$X = \begin{matrix} \\ A_1 \\ \vdots \\ A_i \\ \vdots \\ A_m \end{matrix} \begin{matrix} \mathbf{C_1} & & \mathbf{C_J} & & \mathbf{C_n} \\ \left[\begin{matrix} x_{11} & \cdots & x_{1j} & \cdots & x_{1n} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{matrix}\right] \end{matrix}$$

x_{ij} is the performance rating of alternative ***i*** with respect to criterion ***j***,

A_j is i[th] alternative, C_j is the j[th] criterion

Step 2 Formation of Weight Matrix

Different importance weights to various criteria may be awarded by the decision makers. These importance weights form the weight as follows.

$$W = [W_1 \cdots W_j \dots W_n]$$

Step 3 Normalization of performance rating

Units and dimensions of performance ratings of columns under criteria differ. For the purpose of comparison, these performance ratings are converted into dimensionless units by normalization using following equations

$$\bar{x}_{ij} = \frac{x_{ij}}{\max_i (x_{ij})} \text{ for benefit criteria } j$$

$$\bar{x}_{ij} = \frac{\min_i (x_{ij})}{x_{ij}} \text{ for non-benefit criteria } j$$

Normalized decision matrix

$$\bar{X} = \begin{matrix} A_1 \\ \vdots \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} \bar{x}_{11} \cdots & \dots \bar{x}_{1j} \dots & \bar{x}_{1n} \\ \vdots & \vdots & \vdots \\ \bar{x}_{i1} \dots & \dots \bar{x}_{ij} \dots & \bar{x}_{in} \\ \vdots & \vdots & \vdots \\ \bar{x}_{m1} & \bar{x}_{mj} & \bar{x}_{mn} \end{bmatrix}_{m \times n}$$

Step 4 composite score

Computation of composite score (CS_i) for alternative *i*

$$CS_i = \sum_{j=1}^{n} \left(\overline{w}_j * \overline{x}_{ij} \right)$$

Step 5 Ranking and selection of best alternative:

Ranking of products in descending order of composite scores (CS_i).

2.3 Entropy

Entropy was originally a thermodynamic concept, first introduced into information theory by Shannon (see Shannon, 1948 [21]). Widely used in the engineering, socioeconomic and other fields. According to the basic principles of information theory, information is a measure of system's ordered degree, and the entropy is a measure of system's disorder degree. [Table:2]

2.4 Sensitivity Analysis

In actual situation decision-making is rather dynamic not static process. Changing with environment it varies in the continuously. In reality the value of decision-making attitude depends upon decision maker's personal choice but now a days the artificial intelligence remove the personal biases. Keeping it in mind, the proposed model for the selection of piping material has been enhanced by sensitivity analysis [Fig:2] to provide a readymade solution of the current problem under variable decision-making attitude. The governing equation of the material measure (AM) is given by

$$\boldsymbol{AM_i = \alpha(OFM_i - SFM_i) + SFM_i}$$

where, i = 1, 2…m.

OFM_i = Objective factor measure for the alternative i

SFM_i = Subjective factor measure for the alternative i

α = Objective factor decision weight/Coefficient of attitude

2.5 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS is an evaluation method that is often used to solve number of applications in practice, such as comparison of company performances, financial ratio performance within a specific industry and financial investment in advanced manufacturing systems, etc.

Algorithm of TOPSIS method under MCDM

The idea of TOPSIS can be expressed in a series of steps:

Step1 All the original criteria receive tendency treatment. We usually transform the cost criteria into benefit criteria, which is shown in detail as follows;

(i) The reciprocal ratio method ($X\ ij = 1/X\ ij$), refers to the absolute criteria;

(ii) The difference method ($X\ ij = 1 - X\ ij$), refers to the relative criteria.

After tendency treatment, construct a matrix

$$X' = [X'_{ij}]_{n\times m}, i = 1, 2 \ldots, n; \quad j = 1, 2 \ldots, m.$$

Step2 Calculate the normalized decision matrix A. The normalized value *aij* is

calculated as

$$\mathrm{A} = [a_{ij}]_{n\times m},\ a_{ij} = X'_{ij} / \sqrt{\sum_{i=1}^{n} (X'_{ij})^2} \quad i = 1, 2 \ldots, n; \quad j = 1, 2 \ldots, m.$$

Step3 Determine the positive ideal and negative ideal solution from the matrix *A*.

$$\mathbf{A}^{+}=(a_{i1}^{+},a_{i2}^{+},\ldots,a_{im}^{+}),a_{ij}^{+}=\max_{1\leqslant i\leqslant n}(a_{ij}),\quad j=1,2\ldots,m$$
$$\mathbf{A}^{-}=(a_{i1}^{-},a_{i2}^{-},\ldots,a_{im}^{-}),a_{ij}^{-}=\min_{1\leqslant i\leqslant n}(a_{ij}),\quad j=1,2\ldots,m$$

Step4 Calculate the separation measures, using the *n*-dimensional Euclidean distance. The separation of each alternative from the positive ideal solution is given as:

$$D_i^{+}=\sqrt{\sum_{j=1}^{m}W_j(a_{ij}^{+}-a_{ij})^2}$$

Similarly, the separation from the negative ideal solution is given as

$$D_i^{-}=\sqrt{\sum_{j=1}^{m}W_j(a_{ij}^{-}-a_{ij})^2}$$

Step5 For each alternative, calculate the ratio Ri as:

$$R_i=\frac{D_i^{-}}{D_i^{-}+D_i^{+}}\quad i=1,2\ldots,n$$

Step 6 Rank alternatives in increasing order according to the ratio value of *Ri* in step5.

3. Material

The selection of flare piping elements of hydrocarbon industry considering technical, economic and supply aspects. The paper involves identification of different material [Table:1] that are used in the manufacturing of flare pipe and to give a best result. Similar properties of all materials are tabulated in Table one [Table-1]. Six materials with six important properties are considered. The decision maker has to compare all the materials regarding each aspect and has to judge the best one, and this is difficult decision-making problem. So, these MCDM methods is applied to select optimal piping material in this section.

Table 1: Flare Piping materials and its properties, price & supply lead time (Days) for Haldia, WB, India location.

Material	Yield Strength (MPa)	UTS (MPa)	% of elongation - Longitudinal (Minimum)	Hardness (Brinnel)	Cost / Kg (INR)	Supply lead time (Days)
LTCS (ASTM A333 Gr. 6) (M1)	240	415	30	187	90	30
ASTM SA 312 TP316 UNS S31600 (M2)	205	515	40	217	400	30
ASTM SA 213 TP310MoLNUNS S31254 (M3)	310	655	35	220	1100	50
Inconel 625 UNS N06625 (M4)	517	930	42.50	240	3300	80
ASTM A 106 GR. A (M5)	205	330	35	241	100	20
ASTM A 106 GR. B (M6)	240	415	30	241	80	73

4. Research Gap

A flare system provided in a refinery or petrochemical plant to ensure the safe and efficient disposal of relieved gases or liquids. Maximum hydrocarbon industry is spent their money to developed an efficient flare system. This paper is projected to improve the flare system through proper material selection.

According to literature review, material selection of Flare system in hydrocarbon industry less work has been done. Although some piecemeal work on this research has been done.

Comparative analysis by various MCDM methods on Material selection process and Sensitivity analysis are implemented first to know the best material as well as the value of closeness.

5. Problem Formulation

In industrial environment, flare piping materials are made of carbon steel as well as stainless Steel. Among these six criteria- Yield strength, Ultimate tensile strength, Hardness are beneficiary, and rest of criteria are non- beneficiary.

A hydrocarbon industry has got six different materials with different specifications for flare pipe. The decision maker considered six selection criteria.

6. Experiment and Result

In entropy method, the assessment of weightage value is to be determined.

Table 2: The weighted values are:

	Yield Strength (MPa)	Ultimate tensile strength (MPa)	% of elongation - (Longitudinal)	Hardness (Brinell)	Cost / Kg (INR)	Supply lead time (Days)
weighted values	0.0823	0.1130	0.0838	0.0503	0.5105	0.1601

6.1 In the SAW method

The weighted values got from entropy method

STEP1: Determination of normalized decision matrix

Table 3: Normalized decision matrix

Material	Yield Strength (MPa)	Ultimate tensile strength (MPa)	% of elongation - (Longitudinal)	Hardness (Brinell)	Cost / Kg (INR)	Supply lead time (Days)
LTCS (ASTM A333 Gr. 6)	0.4642	0.4462	0.7059	1.0000	0.8889	0.6667
ASTM SA 312 TP316 UNS S31600	0.3965	0.5538	0.9412	0.8618	0.2000	0.6667
ASTM SA 213 TP310MoLN UNS S31254	0.5996	0.7043	0.8235	0.8500	0.0727	0.4000
Inconel 625 UNS N06625	1.0000	1.0000	1.0000	0.7792	0.0242	0.2500
ASTM A 106 GR. A	0.3965	0.3548	0.8235	0.7759	0.8000	1.0000
ASTM A 106 GR. B	0.4642	0.4462	0.7059	0.7759	1.0000	0.0274

STEP 2: Determination of weighted normalized decision matrix

Table 4: weighted normalized decision matrix

Material	Yield Strength (MPa)	Ultimate tensile strength (MPa)	% of elongation - (Longitudinal)	Hardness (Brinell)	Cost / Kg (INR)	Supply lead time (Days)
LTCS (ASTM A333 Gr. 6)	0.0382	0.0504	0.0592	0.0503	0.4537	0.1068
ASTM SA 312 TP316 UNS S31600	0.0326	0.0626	0.0789	0.0433	0.1021	0.1068
ASTM SA 213 TP310MoLN UNS S31254	0.0494	0.0796	0.0690	0.0427	0.0371	0.0641
Inconel 625 UNS N06625	0.0823	0.1130	0.0838	0.0392	0.0124	0.0400
ASTM A 106 GR. A	0.0326	0.0401	0.0690	0.0390	0.4084	0.1601
ASTM A 106 GR. B	0.0382	0.0504	0.0592	0.0390	0.5105	0.0044

STEP 3: Computation of composite score s.... by sum of all weighted normalized rows

The values of (s) are:

Table 5: Ccomposite score

Material	LTCS (ASTM A333 Gr. 6)	ASTM SA 312 TP316 UNS S31600	ASTM SA 213 TP310MoLN UNS S31254	Inconel 625 UNS N06625	ASTM A 106 GR. A	ASTM A 106 GR. B
	0.7586	0.4263	0.3419	0.3707	0.7493	0.7017

STEP 4: Arranging the final value (s) in descending order: --------->>> M1 > M5 > M6 > M2 > M4 > M3....in SAW method

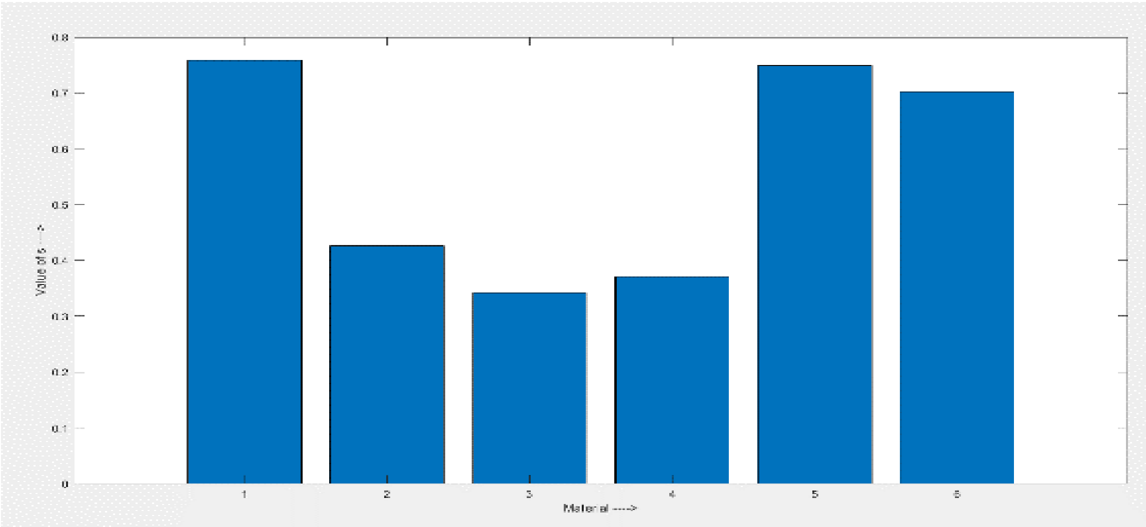

Figure 1. Material ranking in SAW

6.2 Sensitivity Analysis

Table 6: The value of closeness co-efficient in SAW method

Material	when alpha=0	when alpha=1
LTCS (ASTM A333 Gr. 6)	0.6108	0.1478
ASTM SA 312 TP316 UNS S31600	0.2522	0.1741
ASTM SA 213 TP310MoLN UNS S31254	0.1439	0.1980
Inconel 625 UNS N06625	0.0916	0.2791
ASTM A 106 GR. A	0.6075	0.1418
ASTM A 106 GR. B	0.5539	0.1478

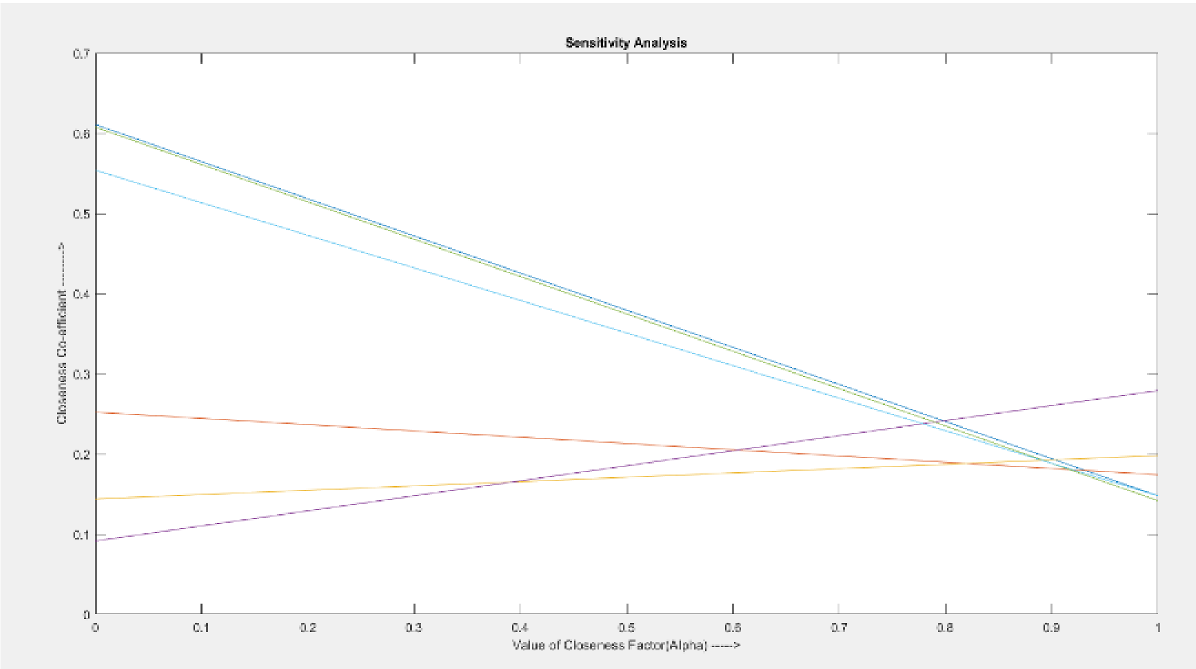

Figure 2. Sensitivity Analysis in SAW

6.3 In the TOPSIS method

STEP1: Determination of normalized decision matrix

Table 7: Normalized decision matrix

Material	Yield Strength (MPa)	Ultimate tensile strength (MPa)	% of elongation - (Longitudinal)	Hardness (Brinell)	Cost / Kg (INR)	Supply lead time (Days)
LTCS (ASTM A333 Gr. 6)	0.4642	0.4462	0.7059	1.0000	0.8889	0.6667
ASTM SA 312 TP316 UNS S31600	0.3965	0.5538	0.9412	0.8618	0.2000	0.6667
ASTM SA 213 TP310MoLN UNS S31254	0.5996	0.7043	0.8235	0.8500	0.0727	0.4000
Inconel 625 UNS N06625	1.0000	1.0000	1.0000	0.7792	0.0242	0.2500
ASTM A 106 GR. A	0.3965	0.3548	0.8235	0.7759	0.8000	1.0000
ASTM A 106 GR. B	0.4642	0.4462	0.7059	0.7759	1.0000	0.0274

STEP 2: Determination of positive ideal solution: taking the maximum values of each column from the normalized decision matrix

Table 8: positive ideal solution

Yield Strength (MPa)	Ultimate tensile strength (MPa)	% of elongation - (Longitudinal)	Hardness (Brinell)	Cost / Kg (INR)	Supply lead time (Days)
1	1	1	1	1	1

Determination of negative ideal solution: taking the minimum values of each column from the normalized decision matrix

Table 9: Negative ideal solution

Yield Strength (MPa)	Ultimate tensile strength (MPa)	% of elongation - (Longitudinal)	Hardness (Brinell)	Cost / Kg (INR)	Supply lead time (Days)
0.3965	0.3548	0.7059	0.7759	0.0242	0.0274

Table 10: Calculation of the separation measure from the positive ideal solution(di_Plus)

Material	LTCS (ASTM A333 Gr. 6)	ASTM SA 312 TP316 UNS S31600	ASTM SA 213 TP310MoLN UNS S31254	Inconel 625 UNS N06625	ASTM A 106 GR. A	ASTM A 106 GR. B
	0.2994	0.6310	0.7234	0.7606	0.3203	0.4685

Table 11. Calculation of the separation measure from the negative ideal solution(di_Minus)

Material	LTCS (ASTM A333 Gr. 6)	ASTM SA 312 TP316 UNS S31600	ASTM SA 213 TP310MoLN UNS S31254	Inconel 625 UNS N06625	ASTM A 106 GR. A	ASTM A 106 GR. B
	0.6715	0.3011	0.2051	0.3036	0.6781	0.6981

STEP 3: Calculation of R_i

Table 12: Calculation of R_i

Material	LTCS (ASTM A333 Gr. 6)	ASTM SA 312 TP316 UNS S31600	ASTM SA 213 TP310MoLN UNS S31254	Inconel 625 UNS N06625	ASTM A 106 GR. A	ASTM A 106 GR. B
	0.6916	0.3231	0.2209	0.2853	0.6792	0.5984

STEP 4: Arranging the final value in descending order:--------->>> M1 > M5 > M6 > M2 > M4 > M3

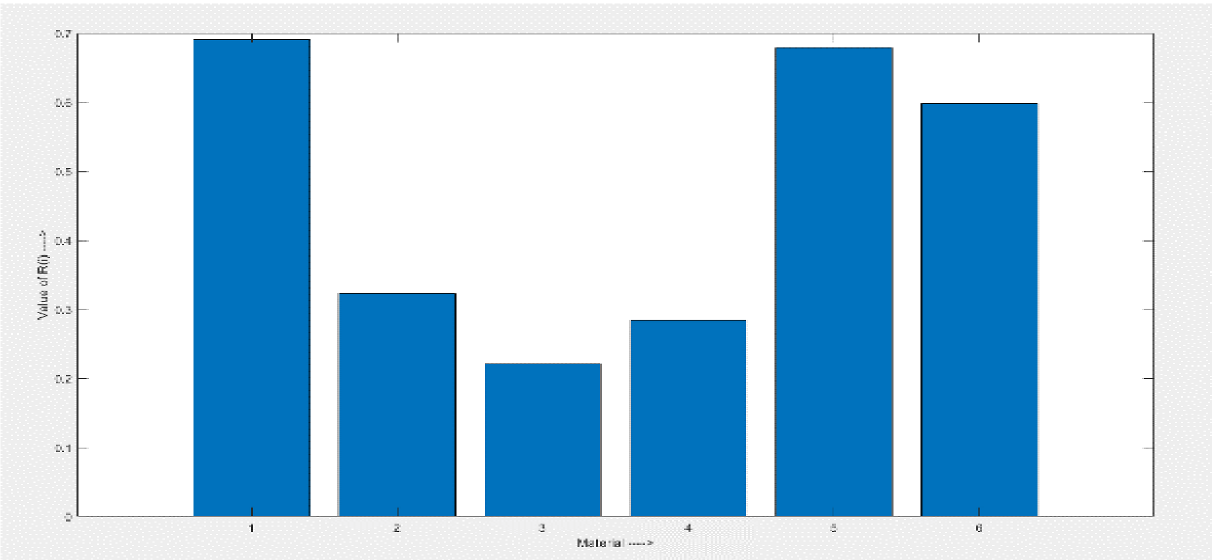

Figure 3. Material ranking in TOPSIS

Table 13. Comparative analysis of ranking of Piping materials using MCDM methods

MATERIAL	SAW (RANK)	TOPSIS (RANK)
LTCS (ASTM A333 Gr. 6) (M1)	1	1
ASTM SA 312 TP316 UNS S31600 (M2)	4	4
ASTM SA 213 TP310MoLN UNS S31254 (M3)	6	6
Inconel 625 UNS N06625 (M4)	5	5
ASTM A 106 GR. An (M5)	2	2
ASTM A 106 GR. B (M6)	3	3

7 Discussion

From the result we see that for the two different processes of MCDM, the result is same. The ranking of 1st to 6th materials are same for those two different processes. In SAW and TOPSIS methods, ranks of alternatives are given in descending order of their respective composite score. So, the ranking of alternatives of materials are as follows: **M1 > M5 > M6 > M2 > M4 >M3.** It means that Material 1 is the best as it maximizes the benefit criteria.

We have also made the sensitivity analysis with graphical representation in which we see that in SAW method. From the sensitivity analysis graph, we also get the rank of the lathes for any alpha value by drawing a vertical line from that alpha value to the straight line of the lathe in the graph. That's why for doing the sensitivity analysis our result does not depends any different decision makers with their different weighted values.

8 Conclusions

A flare system is defined as per CAPP (Canadian Association of Petroleum Producers), the controlled burning of natural gas that cannot be processed for sale or use because of technical or economic reasons. It is quite clear that selection of a proper flare piping material for a given manufacturing application goes through a large number of considerations. The use of SAW and TOPSIS methods are observed to be quite capable and computationally easy to evaluate and select the proper material from a given set of alternatives. These methods use the measures of the considered criteria with their relative importance in order to arrive at the final ranking of the alternative material. Thus, these popular MCDM methods can be successfully employed for solving any type of decision-making problems having any number of criteria and alternatives in the manufacturing domain. As a future scope, a fuzzy TOPSIS, fuzzy SAW based methodology may be developed to aid the decision makers to take decisions in presence of imprecise and incomplete data.

Declaration By Authors

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Prof (Dr) Sukhendu Samajdar serves at Maulana Abul Kalam Azad University of Technology, WB (formerly West Bengal University of Technology) as Professor and Director of the School of Natural, Applied & Social Sciences; Head of the Department of Materials Science & Technology as well as Professor-in-Charge of the Language Laboratory. Professor Samajdar has 25 years of academic and 10 years of industry/ corporate experience, of which 20 years have been in the United States of America. Upon earning his PhD from the University of Michigan, Ann Arbor, he was appointed directly as an Assistant Professor at a premier university in Ohio, USA. In that capacity he engaged in collaborative research in Materials Science with a group at MIT led by Prof John B van der Sande, the then Dean of Engineering at MIT. Prior to joining MAKAUT, Prof Sukhendu Samajdar served as the founding Pro Vice Chancellor of Kaziranga University in Jorhat, Assam and as the founding Vice Chancellor of Seacom Skills University in Santiniketan, West Bengal.