An integrated hybrid multi-criteria decision making technique for material selection in the sugar industry

L. Anojkumar*

Department of Mechanical Engineering,
Jansons Institute of Technology,
Karumathampatti – 641659,
Coimbatore, TamilNadu, India
Email: anoj83@gmail.com
*Corresponding author

M. Ilangkumaran and S. Mohamed Hassan

Department of Mechatronics Engineering,
K S Rangasamy College of Technology,
Tiruchengode – 637215,
Namakkal, TamilNadu, India
Email: maniilankumaran@gmail.com
Email: hassansitheeque@gmail.com

Abstract: Material selection is one of the most predominant activities in design process. In a successful product design, selection of material plays a vital role. As various alternatives are available, selecting the best among them which satisfies the manufacturer's requirement becomes more complex and time consuming. To choose an appropriate material with several criterion is a multi-objective task and it is a multi criteria decision making (MCDM) problem. This paper encompasses the use of preference ranking organisation method for enrichment evaluation (PROMETHEE) integrated with analytic hierarchy process (AHP) and fuzzy analytic hierarchy process (FAHP) for the successful material selection. The FAHP and AHP are used to identify the criterion weight and PROMETHEE II is employed to rank alternatives. In this work, seven attributes and five stainless steel grades are focussed for optimised selection. The obtained results are contrasted to show the effectiveness of FAHP over the traditional AHP.

Keywords: analytic hierarchy process; AHP; fuzzy analytic hierarchy process; FAHP; PROMETHEE; sugar industry; corrosion rate; material selection; multi-criteria decision making; MCDM.

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Biographical notes: L. Anojkumar is an Assistant Professor of Mechanical Engineering at the Jansons Institute of Technology, Karumathampatti, India. He completed his BE (Mechanical) from K.S. Rangasamy College of Technology, Tiruchengode in 2005. He completed his ME (Engineering Design) from the Government College of Technology, Coimbatore in 2007. He has published four papers in international journals. He has published five papers in national and international conferences. He has organised two national level seminars. He is a life member of ISTE. His research interest is composite materials.

M. Ilangkumaran is a Professor and Head of the Department of Mechatronics Engineering, K.S. Rangasamy College of Technology, Tiruchengode, India. He completed his BE (Mechanical) from K.S. Rangasamy College of Technology, Tiruchengode in 1999. He completed his ME in Industrial Engineering from Kumaraguru College of Technology, Coimbatore in 2001. He received his PhD in the area of Maintenance Management in 2010. He has published 39 papers in international journals. He has published more than ten papers in national and international conferences. He has organised two national level seminars. He is a life member of ISTE. His research interest is maintenance management.

S. Mohamed Hassan is a UG Research Scholar in Mechatronics Engineering from K.S. Rangasamy College of Technology, Tiruchengode. He has published three papers in international conferences.

1 Introduction

Modern advances in design and development of machinery components forced the industrialist and engineers to consider the material selection as a prominent activity. Nowadays, diverse materials are available with specific characteristics, applications, advantages and limitations. The selection of apt material for a particular application is a challenging task for the design engineers. In the current scenario, designers are forced into a circumstance of selecting the best suited material for the design process with attention to product functionality, high productivity and to meet customer requirement. Inappropriate material selection may lead to machine failure, causing loss and even indulge the reputation of the manufacturing organisation. In the selection of prime material, the designers have to focus on several material attributes. A clear understanding is necessary for filtering the criterion for material selection because material cannot be selected based on a single criterion. In the presence of many notable selection criterions, the material selection processes attain more complexity. There is a necessity to guide the decision makers to identify the appropriate material and the influencing criteria using simple, systematic and logical methods. Thus, a systematic and an efficient approach to material selection is necessary in order to select the best alternatives for a given application. To solve this complexity of choosing the right material with multiple alternatives and conflicting criteria, multi-criteria decision making (MCDM) method is preferred. In this paper, a MCDM method of preference ranking organisation method for enrichment evaluation (PROMETHEE) II combined with analytic hierarchy process (AHP) and fuzzy analytic hierarchy process (FAHP) are used to solve a material selection problem in sugar industry. These methods prioritise the superior to worst materials with account of different material selection attributes. The ranking order of material alternatives is obtained using AHP and FAHP-PROMETHEE II. These methods are compared with the aid of obtained results to demonstrate the applicability and effectiveness of the FAHP. The approached MCDM technique also provides the decision maker (DM) a platform for selecting the appropriate material in sugar industry.

The remainder of this paper is organised as follows: the MCDM methods in material selection are detailed in Section 2. The suggested method is presented in Section 3. In Section 4, the results obtained are discussed and contrasted for illustrating and validation of proposed method. The paper is closed in Section 5 with conclusion.

1.1 Literature review

Handful research work done by past researchers on material selection have proposed various methodologies and large number of literatures which aid in replacing the traditional ones. This section aims to review the various applications of MCDM approaches of PROMETHEE, ability of AHP and FAHP-PROMETHEE in material selection, literature review in sugar industry and describes the research gap.

1.1.1 Literature review on PROMETHEE in material selection

Kazem and Hadinejad (2015) investigated the rating of cases with the help of PROMETHEE technique to select the best radial basis functions for solving the two-dimensional heat equations. Corrente et al. (2014) reported that PROMETHEE methods are widely used in multiple criteria decision aiding (MCDA) and had applied the stochastic multi-criteria acceptability analysis (SMAA) to the family of PROMETHEE to explore the parameters with some preference information provided by the DM. Sepúlveda and Derpich (2014) employed flow sort algorithm which is derived from the classical PROMETHEE approach in solving an actual industrial application for classifying providers into categories in supply chain management. Cinelli et al. (2014) stated that the MCDA has been regarded as a set of methods to perform sustainability evaluations as a result of its flexibility. Betrie et al. (2013) implemented PROMETHEE methods to demonstrate the improved framework at a mine site. Ishizaka and Nemery (2011) have adopted multi-criteria decision aid methods PROMETHEE and GAIA in which the DM is the central actor, for the selection of a statistical distribution to describe a dataset. Goumas and Lygerou (2000) have extended PROMETHEE to deal with fuzzy input data and applied it for the evaluation and ranking of alternative energy exploitation schemes of a low temperature geothermal field. Cavallaro (2009) has applied PROMETHEE, a multi-criteria method to make a preliminary assessment of concentrated solar thermal technologies (CSP) and demonstrated that the multi-criteria analysis can provide a technical-scientific decision making tool which is able to justify its choices clearly and consistently. Albadvi et al. (2007) have solved the selection of the right stock at the right time in trade stock with the aid of PROMETHEE and applied the method at Tehran Stock Exchange (TSE) as a real case and a survey from the experts has been done in order to determine the effective criteria for industry evaluation. Parreiras and Vasconcelos (2007) have proposed that PROMETHEE has produced attractive results in the choice of the most satisfactory optimal solution of convex multi-objective problems. Halouani et al. (2009) suggested that PROMETHEE has been developed for project selection problems and the method can be applied to all kinds of decision-making problems with heterogeneous and multi-granular information.

1.1.2 Literature review on integrated PROMETHEE in material selection

Kazan et al. (2015) applied the integrated MCDM technique of AHP and PROMETHEE for the nomination of deputy candidates by taking common 15 basic criterions into consideration and determined the election of deputy candidates in a general sense. Macharis et al. (2012) have proposed an integrated approach for the decision-making problem that combines the AHP and the PROMETHEE to recommend a multi-instrumentality policy package to reduce environmental externalities. Yang and Deuse (2012) have employed a hybrid approach which integrates AHP and PROMETHEE for solving a facility layout problem (FLP). Yilmaz and Dağdeviren (2011) applied fuzzy version of PROMETHEE method in selecting equipment used in production process. Chen et al. (2011) have studied fuzzy PROMETHEE to evaluate four potential suppliers using seven criteria and four decision-makers using a realistic case study. Soltanmohammadi et al. (2010) used AHP method for determining the global weights of mined land suitability analysis (MLSA) framework attributes via pair-wise comparison matrixes composed by each individual expert. Wang and Yang (2007) proposed the use of AHP and PROMETHEE in making IS outsourcing decisions in which, AHP is used to analyse the structure of the outsourcing problem and to determine weights of the criterion, and PROMETHEE method is used for final ranking. Dağdeviren (2008) has applied an integrated approach that employs AHP and PROMETHEE together for the equipment selection problem in which the AHP is used to analyse the structure of the equipment selection problem and to determine weights of the criterion, and PROMETHEE method to obtain final ranking.

1.1.3 Literature review on sugar industry

The above cited literatures exhibited the application of PROMETHEE approach in the various selection processes, however the selection of pipeline material in the sugar factory is also one among them. Handful researches have been attempted to choose the optimum material for sugar industry equipment in order to overcome the corrosion and wear. Goel et al. (2007) reported that, U$250 million is lost due to corrosion failures in Indian sugar industries. Wu and Olson (2010) have proposed the enterprise risk management (ERM) to reduce the financial loss and compared the alternate risk management methods. Wu and Olson (2009) have stated that, risk management requires new methods and tools to control the loss with greater achievement. Wu et al. (2010) approached a three-dimensional early product development risk management by integrating graphical evaluation and review technique (GERT) and failure modes and effects analysis (FMEA) for demonstrating the risk analysis in the manufacturing sector and reported that, the decision making is varied with respect to decision-maker’s risk, value perceptions and risk preferences. Wesley et al. (2012) have observed that SS grade 444 has better corrosion performance when compared to 1010 and 304 SS grade. Singh (2011) has suggested sulphanilamide, sulphapyridine and sulphathiazole as the anticorrosive medium to reduce the corrosion of the process equipment in sugar industry. Prado et al. (2010) evaluated the effect of sugar cane juice on carbon steel roll and austenitic stainless steel welded carbon steel roll. The main wear mechanism silica is ploughing and cutting the sugar cane roller shell (Casanova and Aguilar, 2008). Zumelzu et al. (2003) have made an attempt to find out the characteristics and corrosion behaviour of high-Cr white iron. Buchanan (2012) has conducted two abrasion-corrosion tests such as Fe-Cr-C shielded metal arc welding (SMAW) hard facings used in the sugar industry and an arc sprayed Fe-Cr-based coating and concluded that the abrasion-corrosion of SMAW with high Fe-Cr-C coatings performance is lower when compared to electric arc sprayed Fe-Cr-based coating in slurry of sand and sugarcane juice. Panigrahi et al. (2007) examined the pitting corrosion in evaporator vessel using mild steel. Similarly, this paper proposes a novel MCDM technique for evaluating optimum material for pipes to reduce the corrosive wear in sugar industry.

1.1.4 Research gap

The aforementioned reviews show the importance of MCDM methods in material selection process. The selection of pipeline material in sugar industry is based on evaluation of several attributes which resembles a MCDM process. In sugar industry most of the pipe lines are corroded due to acidic nature of sugarcane juice that flows through it. Various anti corrosive medium and coating material are proposed and used on the critical equipment of sugar industry based on existing research. But the frequency of failures is not eradicated completely which drives the necessity for selection of apt material. This paper is aimed to select an optimum material for pipeline in sugar industry using PROMETHEE II integrated with AHP and FAHP whereas AHP and FAHP are employed to obtain criterion weight, PROMETHEE II is used for final ranking.

2 Materials and methods

The proposed methodology consists of four basic stages:

1 identification of the criteria and alternatives to be used in the model

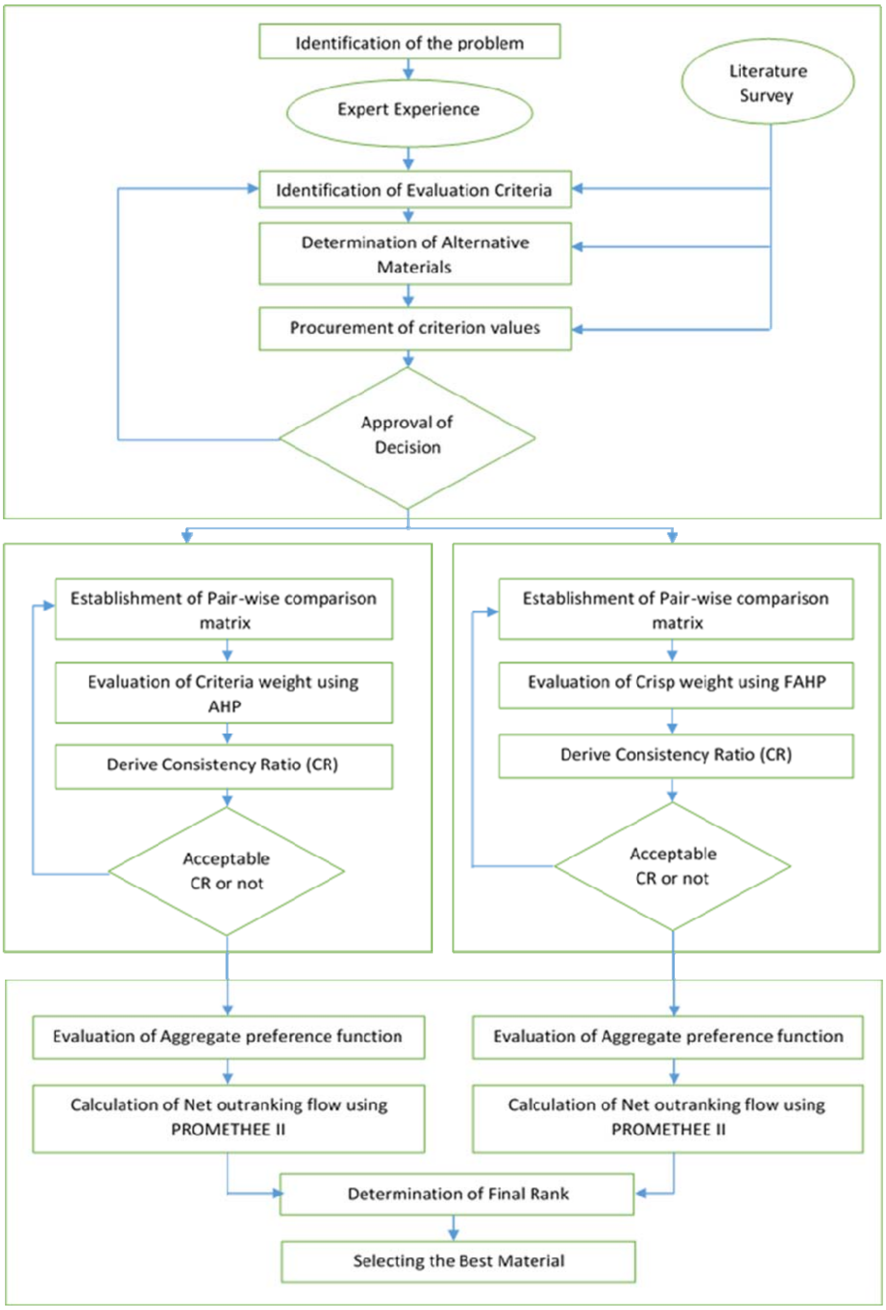
2 AHP computation

3 FAHP computation

4 ranking the alternatives using PROMETHEE II.

The diagrammatic representation of the proposed methodology for the selection of apt material is shown in Figure 1. In the first phase, alternative materials and the evaluation criteria are examined and a decision hierarchy is framed. The FAHP and AHP model are structured such that the objective is at the first level of hierarchy, criteria at the second level and the alternate materials at the third level. The decision hierarchy is approved by decision-making team at the end of the first stage. After the approval of decision hierarchy, criteria used in material selection are assigned with weights using AHP in the second stage and FAHP in the third stage. In these stages, pair-wise comparison matrices are formed in order to determine the criterion weights. The experts from decision-making team make assessments using the Saaty's scale to determine the values of the elements in pair-wise comparison matrices. The geometric mean of the values obtained from the evaluations is computed. A consensus is arrived at a final pair-wise comparison matrix that is formed. Based on this final comparison matrix, the weights of the criterion are evaluated. These weights are approved by the decision-making team towards the completion of this phase. Ranking of the material is determined by using PROMETHEE II method in the last stage.

Figure 1 Schematic diagram of the proposed model for material selection (see online version for colours)



2.1 AHP method

AHP is used to determine the relative importance of the set of criteria in MCDM. AHP is proposed by Saaty (1977). This method is employed to obtain the crisp weight of the attributes, in which the decision problem is structured hierarchically at different levels with each level consisting of a finite number of elements (Anojkumar et al., 2014). Jalao et al. (2014) employed AHP to make the decision and in computing the weight for the criteria and the alternatives. Görener et al. (2012) achieved the pair-wise comparisons among factors or criteria to prioritise them using the Eigenvalue calculation by AHP approach to enhance strengths, weaknesses, opportunities and threats (SWOT) analysis. Oztaysi (2014) has proposed AHP integrated Grey-TOPSIS method where the weights of the criterion are determined by AHP method and the alternatives are evaluated by Grey-TOPSIS in content management system (CMS). Notsu et al. (2013) have procured suitable weights for the data integration by the similarity matrix derived from the pair-wise comparison matrix using AHP. Yu et al. (2013) has applied AHP in the status evaluation index system of urban road intersections traffic congestion. Deng et al. (2014) applied the AHP process for supplier selection in supply chain management (SCM). Zuo et al. (2012) analysed the weight of each evaluation index on the basis of the AHP model. Poh and Ang (1999) used AHP planning process to identify and evaluated a set of policies. Frei and Harker (1999) employed AHP approaches to create a ranking scheme that deals explicitly with missing data and ties in the tournament scheme. Ramanathan (1997) has proposed that AHP has found a number of applications in decision making problems. Zolfani and Antucheviciene (2012) used AHP for identifying the importance of each criterion when selecting a group member. The adoption of AHP tool to identify the criteria weight and the successful application in these past applications show that AHP is an effective tool in evaluating the criterion weights. The procedural steps involved in AHP method are listed below:

Step 1 Establishment of a hierarchy structure

The hierarchy is structured on different levels from an overall objective to various criteria, sub-criteria to the lowest level (alternatives) in descending order. The objective or the overall goal of the decision is represented at the top level of the hierarchy. The criteria and sub-criteria contributing to the decision are represented at the intermediate levels. Finally, the decision alternatives or selection choices are laid down at the lowest level of the hierarchy.

Step 2 Development of comparative judgment matrices by simple pair-wise comparisons

A set of comparison matrices of all elements in a level of the hierarchy with respect to an element of the immediately higher level are constructed so as to prioritise and convert individual comparative judgments into ratio scale measurements. The preferences are quantified using nine-point scale. The meaning of each scale measurement is as follows (1 = equal importance; 3 = weak importance; 5 = strong importance; 7 = very strong importance; and 9 = extremely more importance). The intermediate values of 2, 4, 6, and 8 are allotted to indicate compromise values of importance.

Step 3 Synthesis of priorities

The pair-wise comparisons generate a matrix of relative rankings for each level of the hierarchy. The number of matrices depends on the number of elements at each level. After all matrices are developed and all pair-wise comparisons are obtained, eigen vector or the relative weights, global weights and the maximum eigenvalue ($\lambda_{\max}$) for each matrix are calculated.

Step 4 The measurement of consistency

The goodness of judgments can be evaluated by means of the inconsistency ratio. This is known as an imperative aspect of the AHP technique. Briefly, before determining an inconsistency measurement, it is necessary to introduce the consistency index (CI) of an $n \times n$ matrix defined by the ratio:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

where λ_{max} is the maximum eigenvalue of the matrix. Then the consistency ratio (CR) is calculated using the formula:

$$CR = \frac{CI}{RI} \tag{2}$$

where *RI* is a known random consistency index obtained from a large number of simulations, runs and varies depending upon the order of matrix.

The acceptable CR range varies according to the size of matrix, i.e. 0.05 for a 3 × 3 matrix, 0.08 for a 4 × 4 matrix and 0.1 for all larger matrices, 5 × 5. If the value of CR is equal to, or less than that value, it implies that the evaluation within the matrix is acceptable or indicates a good level of consistency in the comparative judgments represented in that matrix. In contrast, if CR is more than the acceptable value, inconsistency of judgments within that matrix has occurred and the evaluation process should therefore be reviewed, reconsidered and improved.

2.2 FAHP method

Yeap et al. (2014) used FAHP to evaluate the electronic word-of-mouth (eWOM) present in a personal blog, review site, social networking site and instant messaging site according to global criteria and showed that FAHP provides a non-biased and transparent assessment approach for ranking platforms. Paksoy et al. (2012) have developed the organisation strategy of distribution channel management using FAHP for an edible-vegetable oil manufacturer firm. Ho (2012) has adopted FAHP for customers to make weight assessment on evaluation indexes of Health Management Centre. Chang et al. (2003) used the FAHP method to determine the weights of criterion for performance evaluation of airports. Hwang and Ko (2005) presented the decision model for the best restaurant site selection using AHP and FAHP. Similarly, Lin and Hong (2006) applied FAHP approach for suitable site selection for airport. Hwang and Hwang (2006) proposed FAHP method for food service strategy evaluation process. Ayağ and Özdemir (2006) evaluated machine tool alternatives by applying an intelligent approach based on FAHP. Huang et al. (2008) presented a FAHP method for selecting government sponsored development projects. Khoram et al. (2007) used FAHP to prioritise the methods related to reuse of treated wastewater. Ilangkumaran and Kumanan (2009), Shyjith et al. (2008) have proposed AHP for the optimum maintenance strategy selection in textile industry. Khorasani and Bafruei (2011) developed FAHP for the selection of potential suppliers in the pharmaceutical industry. The above mentioned literature shows the importance of criteria weight obtained from the FAHP process. The steps involved in the computation of criterion weights using FAHP are described below:

Step 1 A complex decision making problem is structured using a hierarchy

The FAHP initially breaks down a complex MCDM problem into a hierarchy of inter-related decision elements (criteria). With the FAHP, the criteria are arranged in a hierarchical structure similar to a family tree. A hierarchy has at least three levels: overall goal of the problem at the top, multi criteria that define criteria in the middle and decision criteria at the bottom.

Step 2 Pair-wise comparison matrix

The crisp pair-wise comparison matrix A is fuzzified using the triangular fuzzy number $M = (l, m, u)$, where l and u represent lower and upper bound range respectively that might exist in the preferences expressed by the decision maker. The membership function of the triangular fuzzy numbers M_1, M_3, M_5, M_7, and M_9 are used to represent the assessment from equally preferred (M_1), moderately preferred (M_3), strongly preferred (M_5), very strongly preferred (M_7), and extremely preferred (M_9). This project employs a triangular fuzzy numbers (TFN) to express the membership functions of the aforementioned expression values on five scales which are used for FAHP listed in Table 1.

Table 1 Membership function of fuzzy numbers

Linguistic scale for importance	*Fuzzy number*	*TFN (L, M, U)*	*Reciprocal of TFN (1/U, 1/M, 1/L)*
Just equal		(1, 1, 1)	(1, 1, 1)
Equal importance	M_1	(1, 1, 3)	(0.33, 1, 1)
Weak importance of one over another	M_3	(1, 3, 5)	(0.2, 0.33, 1)
Essential or strong importance	M_5	(3, 5, 7)	(0.14, 0.2, 0.33)
Very strong importance	M_7	(5, 7, 9)	(0.11, 0.14, 0.2)
Extremely preferred	M_9	(7, 9, 9)	(0.11, 0.11, 0.14)
Intermediate value between two adjacent judgments	M_2, M_4, M_6, M_8		

Let $c = \{c_j \mid j = 1, 2,\ldots,n \mid\}$ be a set of criteria. The result of the pair-wise comparison on n criteria can be summarised in a $(n \times n)$ evaluation matrix A in which every element is the quotient of weights of the criterion, as shown:

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \quad a_{ii} = 1, a_{ji} = 1/a_{ij}, a_{ij} \neq 0 \tag{3}$$

Step 3 The mathematical process is commenced to normalise and find the relative weights of each matrix. The relative weights are given by the right eigen vector (W) corresponding to the largest eigenvalue, as

$$A_w = \lambda_{\max} w \tag{4}$$

It should be noted that the quality of output of FAHP is strictly related to the consistence of the pair-wise comparison judgments. The consistency is defined by the relation between the entries of A: $a_{ij} \times a_{jk} = a_{ik}$. The consistency index (CI) is

$$CI = \left(\lambda_{\max} - n\right) / (n - 1) \tag{5}$$

Step 4 The pair-wise comparison is normalised and priority vector is computed to weigh the elements of the matrix. The values in this vector sum to 1. The consistency of the subjective input in the pair-wise comparison matrix can be determined by calculating a consistency ratio (CR). In general, a CR having a value less than 0.1 is good (Saaty, 1980). The CR for each square matrix is obtained from dividing CI values by random consistency index (RCI) values.

$$CR = CI / RCI \tag{6}$$

The RCI which is obtained from a large number of simulations runs and varies depending upon the order of matrix. Table 2 lists the values of the RCI for matrices of order 1 to 10 obtained by approximating random indices using a sample size of 500. The acceptable CR range varies according to the size of matrix that is 0.05 for a 3 by 3 matrix, 0.08 for a 4 by 4 matrix and 0.1 for all larger matrices having $n \geq 5$. If the value of CR is equal to, or less than that value, it implies that the evaluation within the matrix is acceptable or indicates a good level of consistency in the comparative judgments represented in that matrix. In contrast, if CR is more than the acceptable value, inconsistency of judgments within that matrix has occurred and the evaluation process should therefore be reviewed, reconsidered and improved.

Table 2 Random consistency index

No.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
RCI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

2.3 PROMETHEE method

Preference function-based outranking method is a special type of MCDM tool that can provide a ranking, ordering of the decision options. The PROMETHEE method was developed by Brans and Vincke (1985). PROMETHEE I method can provide a partial ordering of the decision alternatives whereas PROMETHEE II method can derive the full ranking of the alternatives. Chou et al. (2004) have proposed a depression watershed method coupled with the PROMETHEE theory to determine the optimal outlet and calculate the flow direction in depressions. Tuzkaya et al. (2009) utilised a hybrid fuzzy-analytic network process and fuzzy-preference ranking organisation method for enrichment evaluations approach and provided a numerical example to foster the better understanding of the methodology and analysed the obtained results with sensitivity analyses. Ilangkumaran et al. (2013) proposed hybrid MCDM technique which involves FAHP integrated with PROMETHEE, where FAHP is used to compute the criterion weights and PROMETHEE I is used to find out the leaving and entering flows, whereas PROMETHEE II is used to find the total ranking of the material and evaluated an optimum material to be employed for manufacturing automobile bumper with five alternatives and six criteria. Abedi et al. (2012) applied PROMETHEE II technique to produce the desired mineral prospectivity mapping (MPM), validated the outputs using twenty-one boreholes that have been classified into five classes and exposed that this method shows a high performance when providing the MPM. The procedural steps involved in the PROMETHEE II method are enlisted below:

Step 1 In this step, a committee of decision makers is formed to obtain the attributes and the alternatives based on the problem.

Step 2 The appropriate crisp score is chosen for evaluating supplier alternatives.

Step 3 Based on the questionnaire, the suitable crisp score is assigned for alternatives suppliers by each decision maker. Then the decision matrix is formed.

Step 4 Normalise the decision matrix using the following equation:

$$R_{ij} = \left[X_{ij} - \min X_{ij}\right] / \left[\max X_{ij} - \min X_{ij}\right] \quad (i = 1, 2, \ldots n : j = 1, 2, \ldots, m) \tag{7}$$

where X_{ij} is the performance measure of i^{th} alternatives with respect to j^{th} criterion.

For non-beneficial criteria, equation (1) can be rewritten as follows:

$$R_{ij} = \left[\max X_{ij} - X_{ij}\right] / \left[\max X_{ij} - \min X_{ij}\right] \tag{8}$$

Step 5 Calculate the evaluative differences of i^{th} alternatives with respect to other alternatives. This step involves the calculation of differences in criteria values between different alternatives pair-wise.

Step 6 Calculate the preference function, $P_j(i, i')$. It may be very tough for decision makers to select the suitable preference function for each criterion by Brans and Mareschal proposal. In order to reduce the overburden of decision makers, the simplified preference function model is implemented here (Athawale and Chakraborty, 2010).

$$P_j\left(i, i'\right) = 0 \text{ if } R_{ij} \le R_{i'j} \tag{9}$$

$$P_j\left(i, i'\right) = R_{ij} - R_{i'j} \text{ if } R_{ij} > R_{i'j} \tag{10}$$

Step 7 Calculate the aggregated preference function taking the criteria weights into account.

Aggregated preference function,

$$\pi(i, i') = \sum_{j=1}^{m}\left[w_j * P_j(i, i')\right] / j = 1\sum_{j=1}^{m}\left[w_j\right] \tag{11}$$

where W_j is the relative importance (weight) of j^{th} criterion.

Step 8 Determine the leaving and entering outranking flows as follows:

Leaving (or positive) flow for i^{th} alternatives,

$$\Phi^{+}(i) = \frac{1}{(n-1)}\sum_{i}^{n}\pi(i, i') \quad (i \neq i') \tag{12}$$

Entering (or negative) flow for i^{th} alternatives,

$$\Phi^{-}(i) = \frac{1}{(n-1)}\sum_{i}^{n_i}\pi(i, i') \quad (i \neq i') \tag{13}$$

where n is the number of alternatives.

Step 9 Calculate the net outranking flow for each alternatives. The net outranking flow is computed through the difference between leaving flow and entering flow of each alternatives.

$$\Phi(i') = \Phi^{+}(i') - \Phi^{-}(i') \tag{14}$$

Step 10 The ranking of all the considered alternatives is determined based on the values of $\Phi(i)$. The best alternative is the one having the highest $\Phi(i)$ value.

2.4 A numerical application of the proposed model

The above mentioned methodology is applied in solving a real time problem in sugar industry. The average production of a sugar in a sugar industry is above 20,000 tonnes per year. The sugar production process involves various stages like reception, cleaning, extraction, juice clarification, evaporation, crystallisation, centrifugation, drying, storing, and packing. During these stages pipes play a vital role in transporting them. In the course of extraction process, the cane juice is mixed with lime to adjust its pH to 7 in order to arrest sucrose's decay into glucose and fructose, and to precipitate some impurities. The transportation of cane juice from this unit to other corrodes the inner surface of the pipe due to the increased pH level of the juice. This corrosion shortens the life of pipe which leads to an interruption in the production process and cause economical loss. Industrialists and experts are involved in selecting a suitable material which provides higher corrosion resistance to eradicate this loss in the sugar industry in order to increase the production scale. The engineers and designers proposed five alternative stainless steel grade materials for evaluating the optimum material and to minimise the corrosive wear.

2.5 Alternatives and criteria for selecting optimum material

The evaluation criteria for the aforementioned problem are identified through various literatures and by experts in the sugar industry. The major criterion which dominates the selection process is the corrosion rate. The other criteria are identified and the alternatives which satisfies the identified criteria and their values are tabulated in Table 3. It consists of five alternatives and seven criteria for the selection process. The criteria are explained as follows:

1 Yield strength (YS): Yield strength is an important value in piping design. It supports a force during in use and does not plastically deform.

2 Ultimate tensile strength (UTS): It helps to provide a good indication of a material's toughness and necessary to ensure the failure with range of applied load.

3 % of elongation (E): It measures the percentage change in length before fracture takes place. It is essential to withstand the operating load.

4 Hardness (H): It enables to resist plastic deformation, penetration, indentation, and scratching, when a force is applied during the working process.

5 Cost (C): The value of money that has been used to purchase the material.

6 Corrosion rate (CR): It is a natural process that seeks to reduce the binding energy in metals. It has a major role to improve the life time of the material.

7 Wear rate (WR): The ability of a metal to resist the gradual wearing away caused by abrasion and friction.

Table 3 Alternatives and values of attributes

Properties material	*Yield strength*	*Ultimate tensile strength*	*% of elongation*	*Hardness*	*Cost*	*Corrosion rate*	*Wear rate*
Units	MPa	MPa	–	HRB	Rs	mmpy	mm^3/Nm
J4	382	728	48	98	112	0.16	2.75
JSLAUS	420	790	58	97	210	0.31	2.63
204Cu	415	795	55	96	120	0.05	2.5
409M	270	455	32	78	184	0.4	4
304	256	610	60	86	89	0.01	2.59

3 Result and discussion

3.1 AHP computation

The identified alternatives are framed to form a hierarchy diagram which is represented in Figure 2. The main objective of the decision is represented at the upper level of the hierarchy and the attributes are branched to form a hierarchy diagram followed by alternatives in the third level. In the second step, the pair-wise comparison matrix is formed by comparing the attributes based on the nine point scale as described in the proposed methodology and is tabulated in Table 4. The weights of each criterion is evaluated by using the comparison matrix and their corresponding eigen vector, global weights and the maximum eigenvalue (λ_{max}) are calculated using equations (1) and (2). The criteria weight is used in the evaluation of ranking of the alternatives to obtain the best material in PROMETHEE. The exactness of the above evaluations is verified by the calculation of consistency ratio. The CR shows that the decision hierarchy matrix formed by the questionnaire and assessment provides the absolute criteria weight. The obtained relative weights, consistency index, consistency ratio of criteria are tabulated in Table 5.

Figure 2 Decision hierarchy of material selection

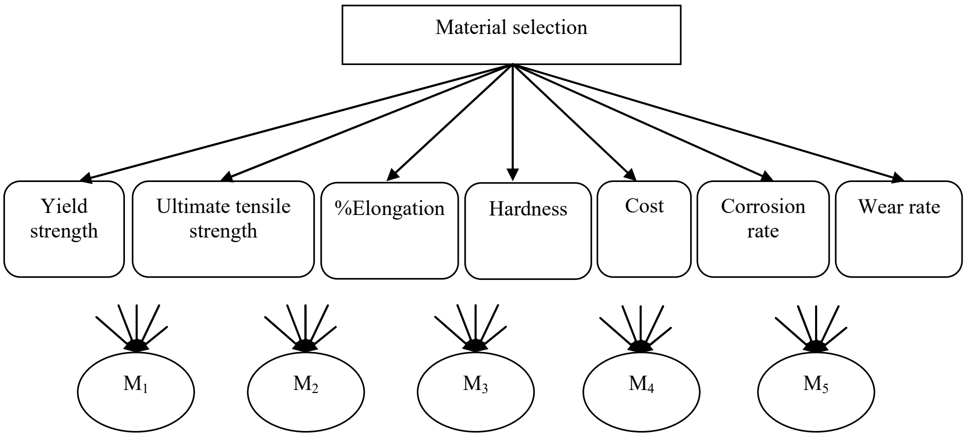


Table 4 Pair-wise comparison matrix

	YS	*UTS*	*%E*	*H*	*C*	*CR*	*WR*
YS	1	4	3	0.33	0.1666	0.2	0.25
UTS	0.25	1	0.5	0.25	0.143	0.1666	0.2
%E	0.33	2	1	0.33	0.1666	0.2	0.2
H	3	4	3	1	0.25	0.33	0.5
C	6	7	6	4	1	2	3
CR	5	6	5	3	0.5	1	2
WR	4	5	5	2	0.33	0.5	1

Table 5 Result obtained from AHP

Criteria	*Weights*	λ_{max}, *CI, RCI*	*CR*
YS	0.062	λ_{max} = 7.32	0.04004
UTS	0.028	CI = 0.05	
%E	0.039	RCI = 1.35	
H	0.107		
C	0.351		
CR	0.242		
WR	0.167		

3.2 FAHP computation

The MCDM problem for selecting the apt material for pipeline in a sugar industry is categorised to form a hierarchy diagram as categorised in the AHP in the initial stage. The main objective of the problem hierarchies the initial level of the diagram and the attributes and alternatives are represented at their next level. In the next stage, the pair-wise comparison matrix is formed by comparing the criteria with the aid of triangular fuzzy numbers and is tabulated in Table 6. The comparison is done by the industrialists and experts to obtain a greater accuracy. The comparative weights of each criterion are computed using the mathematical relations mentioned in the proposed methodology. In the next step the consistency of the comparison is defined by evaluating the inconsistency ratio using the equations (4), (5) and (6). The comparison is reviewed and reconsidered by the decision-maker by using the CR towards the completion of the phase. The attained relative weights, consistency index, consistency ratio of criteria are tabulated in Table 7. The attainment of above values is used in verifying the process done towards the identification of criteria weight. The criteria weight obtained in the FAHP is applied in the process of PROMETHEE for further attainment of ranking of the alternatives.

Table 6 Pair-wise comparison matrix for criteria

	YS	*UTS*	*%E*	*H*	*C*	*CR*	*WR*
YS	(1, 1, 1)	(1, 3, 5)	(1, 1, 3)	(0.33, 1, 1)	(0.11, 0.14, 0.2)	(0.14, 0.2, 0.33)	(0.2, 0.33, 1)
UTS	(0.2, 0.33, 1)	(1, 1, 1)	(0.33, 1, 1)	(0.14, 0.2, 0.33)	(0.11, 0.11, 0.14)	(0.11, 0.11, 0.14)	(0.11, 0.14, 0.2)
%E	(0.33, 1, 1)	(1, 1, 3)	(1, 1, 1)	(0.2, 0.33, 1)	(0.11, 0.11, 0.14)	(0.11, 0.14, 0.2)	(0.11, 0.14, 0.2)
H	(1, 1, 3)	(3, 5, 7)	(1, 3, 5)	(1, 1, 1)	(0.11, 0.14, 0.2)	(0.2, 0.33, 1)	(0.33, 1, 1)
CO	(5, 7, 9)	(7, 9, 9)	(7, 9, 9)	(5, 7, 9)	(1, 1, 1)	(1, 1, 3)	(1, 1, 3)
CR	(3, 5, 7)	(7, 9, 9)	(5, 7, 9)	(1, 3, 5)	(0.33, 1, 1)	(1, 1, 1)	(1, 1, 3)
WR	(1, 3, 5)	(5, 7, 9)	(5, 7, 9)	(1, 1, 3)	(0.33, 1, 1)	(0.33, 1, 1)	(1, 1, 1)

Table 7 Result obtained from FAHP

Criteria	*Weights*	*λ_{max}, CI, RCI*	*CR*
YS	0.060162	$\lambda_{max} = 7.35$	0.043226
UTS	0.027215	CI = 0.058355	
%E	0.036882	RCI = 1.35	
H	0.093839		
C	0.348038		
CR	0.249222		
WR	0.184642		

3.3 PROMETHEE computation using AHP

A panel of decision-makers is formed to evaluate and to select the apt material using PROMETHEE. In the next stage, a suitable crisp score is assigned to each alternatives by the DM in order to form the decision matrix based on the questionnaire. Normalisation of the decision matrix is preceded in the next stage by using the equations (7) and (8) for respective beneficial and non-beneficial factors. The beneficial attributes include factors such as yield strength, ultimate tensile strength, % of elongation and hardness whereas the non-beneficial attributes include factors such as cost, corrosion rate and wear rate. The next process evolves the evaluation of preference function of the alternatives with respect to their alternatives. The corresponding preference functions are tabulated in Table 8 using the equations (9) and (10). The aggregate preference function is evaluated by using the criterion weights attained by AHP as mentioned in equation (11) and is tabulated in Table 9. The entering and leaving flow of the alternatives are computed by the matrix formed by the aggregate preference function using the equations (12) and (13) and is tabulated in Table 10. The obtained entering flow and the leaving flow aids in calculating the net outranking flow on which the ranking of the alternatives is based. Finally the ranking of the alternatives is done by the net outranking flow calculated by using the equation (14) and the obtained results are tabulated in Table 11. The result obtained by the computation of PROMETHEE using the criteria weight of AHP shows that the 204Cu is the best material with net outranking flow of 0.662.

Table 8 Preference function of alternatives

	YS	*UTS*	*%E*	*H*	*C*	*CR*	*WR*	Σ
p1, p2	–0.23	–0.18	–0.36	0.05	0.81	0.38	–0.08	0.39
p1, p3	–0.20	–0.20	–0.25	0.10	0.07	–0.28	–0.17	–0.93
p1, p4	0.68	0.80	0.57	1.00	0.60	0.62	0.83	5.10
p1, p5	0.77	0.35	–0.43	0.60	–0.19	–0.38	–0.11	0.61
p2, p1	0.23	0.18	0.36	–0.05	–0.81	–0.38	0.08	–0.39
p2, p3	0.03	–0.01	0.11	0.05	–0.74	–0.67	–0.09	–1.32
p2, p4	0.91	0.99	0.93	0.95	–0.21	0.23	0.91	4.71
p2, p5	1.00	0.53	–0.07	0.55	–1.00	–0.77	–0.03	0.21
p3, p1	0.20	0.20	0.25	–0.10	–0.07	0.28	0.17	0.93
p3, p2	–0.03	0.01	–0.11	–0.05	0.74	0.67	0.09	1.32
p3, p4	0.88	1.00	0.82	0.90	0.53	0.90	1.00	6.03
p3, p5	0.97	0.54	–0.18	0.50	–0.26	–0.10	0.06	1.54
p4, p1	–0.68	–0.80	–0.57	–1.00	–0.60	–0.62	–0.83	–5.10
p4, p2	–0.91	–0.99	–0.93	–0.95	0.21	–0.23	–0.91	–4.71
p4, p3	–0.88	–1.00	–0.82	–0.90	–0.53	–0.90	–1.00	–6.03
p4, p5	0.09	–0.46	–1.00	–0.40	–0.79	–1.00	–0.94	–4.50
p5, p1	–0.77	–0.35	0.43	–0.60	0.19	0.38	0.11	–0.61
p5, p2	–1.00	–0.53	0.07	–0.55	1.00	0.77	0.03	–0.21
p5, p3	–0.97	–0.54	0.18	–0.50	0.26	0.10	–0.06	–1.54
p5, p4	–0.09	0.46	1.00	0.40	0.79	1.00	0.94	4.50

Table 9 Aggregate preference function using AHP criteria weight

p1, p2	0.336	p2, p1	–0.336	p3, p1	0.091	p4, p1	–0.694	p5, p1	0.073
p1, p3	–0.091	p2, p3	–0.427	p3, p2	0.427	p4, p2	–0.357	p5, p2	0.409
p1, p4	0.694	p2, p4	0.357	p3, p4	0.784	p4, p3	–0.784	p5, p3	–0.018
p1, p5	–0.073	p2, p5	–0.409	p3, p5	0.018	p4, p5	–0.767	p5, p4	0.767

Table 10 Entering and leaving flow

Material	*Entering flow*	*Leaving flow*
J4	0.2167	–0.2100
JSLAUS	–0.2038	0.2075
204Cu	0.3298	–0.3325
409M	–0.6505	0.4750
304	0.3078	–0.3200

3.4 PROMETHEE computation using FAHP

The computation and evaluation of alternatives by PROMETHEE integrated with FAHP resembles the same as of AHP. The procedural steps are followed to compute the ranking of alternatives as mentioned in the proposed methodology. The decision matrix is formed by the panel of decision-maker by assigning the suitable crisp score to each of the alternatives. In the next step, the decision matrix is normalised by using the equations (9) and (10). Further procedure is followed by computing the preference function of the alternatives. The aggregate preference function is computed for the alternatives by the criterion weights evaluated from FAHP using the equation (11) and is tabulated in Table 12. The net outranking flow of the alternatives is evaluated from the entering and leaving flow calculated using the equations (12) and (13). Finally the ranking of the alternatives is done based on the net outranking flow. The obtained entering flow, leaving flow, net outranking flow and ranking are tabulated in Tables 13 and 14. The results obtained from the evaluation of alternatives using FAHP-PROMETHEE also shows that the material 204Cu is the best suited material for the application of sugar Industry with net outranking flow of 0.663.

3.5 Discussion and comparison

The results obtained from the implementation of AHP and FAHP-PROMETHEE the selection of pipeline material is analysed and discussed in this section. The MCDM technique of AHP and FAHP integrated with PROMETHEE is applied to the selection of corrosion resistance material and the obtained results are tabulated in Tables 11 and 14. Both the computations provide similar results and rankings which provide 204Cu is the apt material for the objective and requirement based on various conflicting criteria. The evaluation of criterion weights by FAHP provides an even accurate result compared with AHP shows the effectiveness of FAHP over traditional AHP and thus FAHP integrated PROMETHEE is considered to be a viable approach in solving material selection problem. The uncertainty in the comparison matrix is mended with the aid of inconsistency ratio. The inconsistency ratio obtained from the AHP and FAHP computations accord with values in the proposed methodology denotes the exactness of the comparison matrix. The ranking order obtained by AHP integrated PROMETHEE is 204Cu = 0.662 > 304 = 0.624 > J4 = 0.427 > JSLAUS = –0.411 > 409M = –1.126 and that of obtained in FAHP integrated PROMETHEE is 204Cu = 0.663 > 304 = 0.639 > J4 = 0.422 > JSLAUS = –0.415 > 409M = –1.129.

Table 11 Ranking of alternatives

Material	*Net outranking flow*	*Rank*
J4	0.427	3
JSLAUS	–0.411	4
204Cu	0.662	1
409M	–1.126	5
304	0.628	2

Table 12 Aggregate preference function using FAHP criteria weight

p1, p2	0.336	p2, p1	–0.336	p3, p1	0.095	p4, p1	–0.692	p5, p1	0.086
p1, p3	–0.095	p2, p3	–0.431	p3, p2	0.431	p4, p2	–0.357	p5, p2	0.421
p1, p4	0.692	p2, p4	0.357	p3, p4	0.788	p4, p3	–0.788	p5, p3	–0.010
p1, p5	–0.086	p2, p5	–0.421	p3, p5	0.010	p4, p5	–0.778	p5, p4	0.778

Table 13 Entering and leaving flow

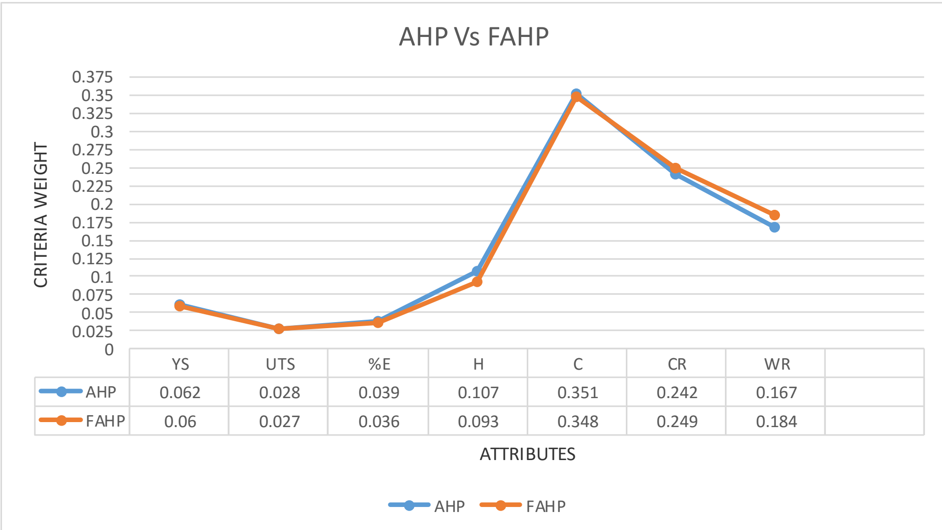
Material	*Entering flow*	*Leaving flow*
J4	0.2117	–0.2100
JSLAUS	–0.2078	0.2075
204Cu	0.3309	–0.3325
409M	–0.6535	0.4750
304	0.3186	–0.3200

Table 14 Ranking of alternatives

Material	*Net outranking flow*	*Rank*
J4	0.422	3
JSLAUS	–0.415	4
204Cu	0.663	1
409M	–1.129	5
304	0.639	2

The results of two integrated MCDM approaches are good in agreement and the assignment of values to the comparison matrix highlights the DM intervention in the selection process. The attainment of negative values in these approaches neglects the alternatives from the selection process and also provides the worst material. The process of evaluating the criteria weight in FAHP is lengthier and time consuming i.e. to reach the accurate outcome, many pair wise comparison matrix has to be made. However, it identifies the importance of the criteria and the priority of the alternatives with the aid of comparison matrix whereas the AHP only identifies the importance of the criteria which reveals the accuracy of FAHP in the material selection process. Moreover, fuzzy numbers used in fuzzy AHP helps to improve the consistency of decision making process compared to the traditional AHP approach. The criteria weight obtained from both the method are charted in Figure 3 which clearly shows that the attributes with greater importance provides higher values of criteria weight than that of less important ones in the FAHP process which clearly reveals the aforementioned statement. The criterion weights obtained from AHP and FAHP alters the net outranking flow of the PROMETHEE which provides the ranking of the alternatives. This shows that care should be taken by the DM in assigning the values of comparison matrix that determines the criteria weight. The result obtained from the method proves that the proposed method is a viable, effective, and transparent in solving a material selection process.

Figure 3 Relative weights obtained from AHP and FAHP (see online version for colours)



4 Conclusions

An integrated MCDM technique is applied in the selection of material in sugar industries, to obtain better productivity and reliability. This MCDM selection of an apt material based on various conflicting criteria has put right solution to a major issue, which affects the productivity rate and economy. Several alternatives and various criteria are selected and identified for the effective material selection. The AHP and FAHP are used for the procurement of criteria weight of the alternatives and the obtained values are integrated with PROMETHEE to select the best material. The outcome shows that 204 Cu is the best material for the application based on both the computations.

The results attained from the two approaches are compared and the accuracy of FAHP over traditional AHP is observed with respect to the values obtained. The obtained results are similar in values but the accuracy of criteria weight obtained from the two methods show the effectiveness of AHP over FAHP. The result of this study provides a way for selecting the material based on several criteria. Further research can be extended with this approached technique in selecting the suitable material for other parts of the sugar industry.

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