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Optimal selection of insulating material for energy conservation in steam pipe using Analytical Hierarchy Process

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During past decades there has been an increasing trend to save the amount of heat energy lost from the steam carrying heat pipes. Improper selection of the pipe insulation materials leads to loss of energy and reduces the amount of energy content at the usage point. This in turn increases the fuel cost at the steam generation for required supply of steam. In view of the above, there is a need to conserve energy by choosing suitable insulating material. The present paper deals with optimal selection of insulating material based on multi-criteria decision making analysis using Analytical Hierarchy Process (AHP).Five different criteria (insulating materials) and five alternatives such as cost, thermal conductivity, flammability, toxicity, and noise are considered for the analysis of decision making in order to choose best insulating material for energy conservation. Ranks are given to the alternatives based on the on the criteria weights using AHP pairwise comparison matrices. The results indicate that the rockwool is the suitable insulating material for conservation of energy in stem pipe.

***Keywords*:** Insulation, Multi-criteria decision, Analytical hierarchy process, Steam pipe

1. Introduction

Steam pipes find applications in process industries, power plants and domestic house heating, etc. A lot of energy is being wasted from steam pipes to surroundings due to the improper selection of insulating materials. To retain the required thermal energy content, pressure at the user end and energy saving, energy conservation is needed. In order to conserve energy in steam pipes suitable insulating material is applied on the steam pipe. Selecting the best insulating material among different insulating materials is a challenging task to the energy planners due to the complexity in considering various facts such as technical, economic, social and environmental aspects. Several techniques have been used in the decision making analysis. Among the various decision making techniques Analytical Hierarchy process has been received high consideration in making decisions for selecting the best one in energy planning. The detail literature on implementation of AHP in the energy sector is provided below. Saaty[1] introduced the Analytic Hierarchy Process (AHP), as an effective tool for dealing with complex decision making, by reducing complex decisions to a series of pair-wise comparisons, and then synthesizing the results. Bilal Akash *et al.*[2] conducted a study on multi-criteria selection of electric power plants using analytical hierarchy process wherein a comparison among the different electricity power production options were considered. Meixner[3] in his evaluation of energy sources using Fuzzy, used AHP group decision analysis for evaluation of the energy crisis based on the energy sources. Al-Hawari *et al.*[4] conducted Analytic Hierarchy Process for selection of temperature measurement sensors. Chinese *et al.*[5] conducted a study on the multi-criteria analysis for the selection of space heating systems in an industrial building. Pramod *et al.*[6] conducted a study on multi-criteria evaluation of natural gas energy systems using graph theory and Analytical Hierarchy Process. Gary Klein[7] conducted a study on cost estimation for materials and installation of hot water piping insulation. Zhang *et al.*[8] conducted fire risk assessment of fire retardant polyurethane thermal insulation materials for exterior walls of buildings based on Analytical Hierarchy Process. Paunescu *et al.*[9] conducted Fuzzy AHP to study on pollution produced by electrical generators and the quantity of noxious substances electrically generated when thermal redundancy factors were applied. Diam and Abu Taha[10] conducted an assessment renewable energy-concluding that AHP is the most used methodology of all Multi-Criteria Decision Making (MCDM) methods. Georgiou *et al.*[11] conducted a study using the MCDM on the energy supply configuration of autonomous desalination. Lavonia and Veronica[12] conducted AHP process to select phase change material (PCM) in order to prioritize and select the proper PCMs for comfort application in buildings. Siadati and Shahhosseini[13] compared the modern structural systems using the Fuzzy AHP where of AHP was deployed to rank the best structural systems such as light steel frames. Gholami and Mahdavinejadb[14] operated AHP for selection of utilizing of nano-insulating materials in building industry. After detail literature study, it is seen that AHP based multi-criteria decision making analysis can be applied for steam carrying pipes. The present paper is motivated on the implementation of AHP methodology to evaluate the best insulating material among polystyrene, polyurethane, calcium Silicate, glass wool and rock wool against the criteria being- cost, thermal conductivity, flammability, toxicity, and noise.

2. Solution Methodology

The methodology of AHP can be explained in the following steps. Initially the structure of hierarchy (seen Fig.1) consisting of goal, criteria and alternatives is developed. Data are collected from the literature and information from the suppliers corresponding to the hierarchy structure, in a pairwise comparison of alternatives on a qualitative Saaty's scale as shown in Table 1. The comparisons are made for each criterion and converted into quantitative numbers based on the scale.

Table. 1. Saaty's scale of AHP[1]

Intensity of importance	Definition
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Very, very strong
9	Extreme importance
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j,then j has the reciprocal value when compared with i

The pairwise comparisons of various criteria generated are reorganized into a square matrix. The diagonal elements of the matrix are 1. The criterion in the i^{th} row is better than criterion in the j^{th} column if the value of element (i, j) is more than 1; otherwise the criterion in the j^{th} column is better than that in the i^{th} row. The (j, i) element of the matrix is the reciprocal of the (i, j) element. Two criteria are evaluated at a time in terms of their relative importance and index values of 1 to 9 are used. The weights of the individual criteria are calculated. First, a normalized comparison matrix is created. Each value in the matrix is divided by the sum of its column. To get the weights of the individual criteria, the mean of each row of this second matrix is determined. Priority vector or criterion weight can be calculated using mean of row method. Further, arithmetic mean is calculated for the row for obtaining the priority vector. Then the different criteria weights are obtained. Depending on each criterion, same process has to be repeated for the alternatives. The criteria's weights are used to generate final rating table, where the entire weights related to the different alternatives are entered. The transpose of the final final rating matrix is done. After the transpose the each element of the row is multiplied with the the original criteria weights. The final priorities are obtained according to the criterion weights. The The obtained priorities are ranked according to decreasing order and the one which obtained the highest priority is selected as the best alternatives among various alternatives.

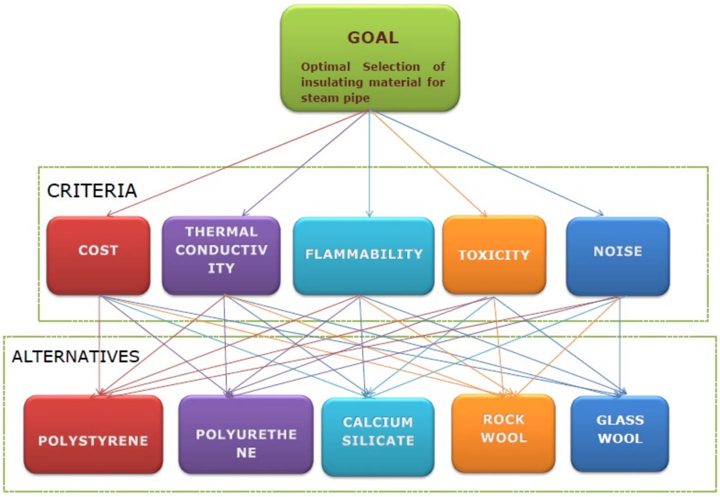

Fig.1. Hierarchy structure of the present problem

3. Results & Discussion

In order to select the most accurate insulation material for steam pipe, by considering polystyrene, polyurethane, calcium silicate, glass wool and rock wool as materials, computations have been carried out for different alternatives and criteria. Five important criteria namely: Thermal conductivity, cost, toxicity, flammability and noise have been selected based on the comprehensive analysis of the literature review. Thermal insulation is the reduction of heat transfer (the transfer of thermal energy between objects of differing temperature).When objects of differing temperatures are placed in contact with each other, heat flow is inevitable. The insulating capability of a material is measured in terms of its thermal conductivity. Lower the thermal conductivity higher is the insulating capability. The cost factor here represents which insulation material is cheaper than the other. The initial investment would be less when the cost of the insulation material is less. Industries try to obtain best insulation material at a cheaper price. The toxicity factor represents the intensity of health hazard caused to humans. The insulation materials which are used in the industries should not cause any health hazardous to the workers. Noise factor represents the level of echo caused by the insulation material. Few insulation materials have the ability to absorb the high frequency sounds coming from the machinery. Flammability represents the ease with which a material can be set to fire. The materials which are highly flammable may lead to fire hazardous in the plant. The industries which use this type of materials have to be more cautious and give more importance to fire and safety factors in the plant.

Considering the above facts related to various criteria. Computations are carried out using AHP methodology described in the section 2. Pair-wise and normalized comparison of criteria is implemented and results are tabulated in Table 2. The criteria weight can be obtained by performing average operation to each row. Depending on the criteria weight ranks will be given to the evaluated criteria's. The criteria with highest weight will be given rank one and the subsequent criteria's will be given subsequent ranks in descending order of their weights.

Table. 2. Normalization matrix for criteria

	Cost	Thermal conductivity	Flammable	Toxicity	Noise	Criteria weight
Cost	0.692	0.867	0.332	0.494	0.25	0.60
Thermal conductivity	0.077	0.096	0.295	0.439	0.222	0.227
Flammable	0.077	0.012	0.037	0.006	0.250	0.033
Toxicity	0.077	0.012	0.332	0.055	0.250	0.119
Noise	0.077	0.012	0.004	0.006	0.028	0.025
Sum	1.000	1.000	1.000	1.000	1.000	

Each alternative is pair-wised with each other based on each criterion. In order to find out the criteria weight of individual alternatives for different criteria, normalization is carried out and ranked accordingly. For better understanding the results are presented in Table 3. The highest rank is given for the highest weight criteria. From the table, it is evident that rock wool seems to be the best material based on the cost, Flammability, toxicity and noise criteria. It is also found that polyurethane received highest rank based on the thermal conductivity criteria.

Table. 3. Weight criteria for alternatives based on different criteria

Alternatives	Criteria Weight				
	Cost	Thermal conductivity	Flammability	Toxicity	Noise
Polystyrene	0.123	0.247	0.046	0.036	0.046
Polyurethane	0.072	0.531	0.046	0.036	0.037
Calcium Silicate	0.027	0.066	0.046	0.138	0.092
Glass wool	0.237	0.027	0.292	0.271	0.260
Rock wool	0.540	0.129	0.570	0.519	0.565

The final rating matrix is obtained from the normalization of the five criteria. The transpose of the final rating matrix is prepared. After obtaining final rating matrix, each element of the row should be multiplied with the criteria weight obtained in Table. 2 in order to find the final priority. The final priority for various alternatives is shown in Table 4. After obtaining final rating matrix; it found that Rockwool is the best insulating material among the other alternatives.

Table. 4. Final rating matrix

Alternative	Weight	Rank
Polystyrene	0.081162	4
Polyurethane	0.062717	5
Calcium Silicate	0.164322	3
Glass wool	0.222741	2
Rock wool	0.474722	1

4. Conclusion

The results in the present work are obtained by application of multi-criteria decision making based Analytical Hierarchy Process to the various alternatives of insulation materials (Polystyrene, Polyurethane, Calcium silicate, Glass wool, Rock wool.) so as to select the best alternative with cost, Heat load, Flammability, Toxicity, Noise as the main criteria. After the pair wise comparison of alternatives corresponding to each criterion, normalization is done and ranks are obtained for alternatives corresponding to criteria to which criteria's weights are entered to generate final rating table. From the above study, it is found that of the various alternatives present, Rock wool got the highest weight (0.474722),followed by glass wool (0.222741), Calcium silicate (0.164322), polystyrene (0.081162), polyurethane (0.0627171).The results obtained from the present study could be useful for decision makers in implementing energy conservation strategies for steam distribution networks.

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