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Selection of Heat Exchanger for Heat Operation by Multiple Attribute Decision Making (MADM) Approach

D.P. Singh [1], Abhishake Chaudhary [2], Vijayant Maan [3]
1, 2, 3 Lecturer, SCRIET, CCS University, Meerut.

ABSTRACT

Many Thermal power plants are using heat exchangers to perform repetitions difficult and hazardous task to provided heat. The selection of a suitable heat exchanger is becoming more and more difficult and complicated of the large increase in manufacture of heat exchanger, configuration and available option. In this work a methodology on Multiple Attribute Decision Making in developed for such types of selection problem. TOPSIS (Technique for Order Performance by Similarity to the ideal solution) method is used to rank the available alternative. Heat is assigned by decision maker to the different attribute according to their importance. These methods will help the decision maker to select a suitable heat exchanger according to requirement. The developed is analysed by an illustrative examples for thermal power plant with same data.

Key words: ***Heat exchanger, TOPSIS, MADM, Power plant***

Introduction

This research considers a shell and tube heat exchanger and builds a SISO model of the system with the help of experimental data available. This system also takes in to account different disturbance elements and transportation delay. First of all, a classical PID controller is implemented in a feedback control loop so as to obtain the control objectives. To further optimize the control performance, feed-forward controller is used in conjunction with the PID controller. In classical control methods different performance indices were calculated for feedback and feedback plus feed-forward control loops to achieve the desired robustness and system stability. Auto-tuning of PID controllers is also implemented and simulated in this paper. To achieve the desired control objective and implement human intelligence in controller architecture a fuzzy logic based PID controller is designed implemented.

In the past decade, heat transfer enhancement technology has been developed and widely applied to heat exchanger applications; for example, refrigeration, automotive, process industry, solar water heater, etc. The aim of augmentative heat transfer is to accommodate high heat fluxes. Up to date, there has been a great attempt to reduce the sizes and cost of the heat exchanger, and energy consumption. The most significant variable in reducing the size and the cost of the heat exchanger is a heat transfer coefficient and a pressure drop, which generally leads to less capital cost and to another advantage of a reduction in the temperature driving force, which increases the second law efficiency and decrease entropy generation. Thus, this captivates the interests of the number of researchers.

The great attempt on utilizing different methods is to increase the heat transfer rate through the compulsory force convection. Meanwhile, it is found that this way can reduce the sizes of the heat exchanger device and save up the energy. In general, enhancing the heat transfer can be divided into two groups. One is the passive method, without stimulation by the external power such as a surface coating, rough surfaces, extended surfaces, swirl flow devices, the convoluted (twisted) tube, additives for liquid and gases. The other is the active method, which requires extra external power sources, for example, mechanical aids, surface-fluid vibration, injection and suction of the fluid, jet impingement, and use of electrostatic fields.

The swirl flow devices can be classified into two kinds: the first is the continuous swirl flow and the other is the decaying swirl flow. For the continuous swirl flow, the swirling motion persists over the whole length of the tube for example twisted-tape inserts, wire coil insert, while in the decaying swirl flow, the swirl is generated at the entrance of the tube and decays along the flow path for example the radial guide vane swirl generator, the tangential flow injection device and the snail swirl generator. For the decaying swirl flow, the heat transfer coefficient and pressure drop decrease with the axial distance, while for the continuous swirl flow, the heat transfer coefficient and pressure drop keep constant.

At present, the technology of the twisted-tape insert is widely used in various industries. Insertion of twisted tapes in a tube provides a simple passive technique for enhancing the convective heat transfer by introducing swirl into the bulk flow and by disrupting the boundary layer at the tube surface due to repeated changes in the surface geometry. It has been explained that such tapes induce turbulence and superimposed vortex motion (swirl flow) causing a thinner boundary layer and consequently resulting in a high heat transfer coefficient and Nusselt number due to repeated changes in the twisted tape geometry. On consideration of the heat transfer enhancement, it can be considered through bringing the twisted-tape to insert while the pressure drop inside the tube is higher. Because of low assets and easy setting up, it is widely used, especially in a compact heat exchanger.

Solid oxide fuel cells (SOFC) of various types are capable of upwards of 60% electric conversion efficiency. However, they produce high exhaust gas temperatures of 600-1000.and require recuperates to recover this thermal energy, which otherwise be wasted. Accordingly, heat resistant material is necessary for the construction of high temperature heat exchangers. The recovered heat may be used to generate electricity in SOFC/GT hybrid power generating systems including gas turbines and HRU (heat recovery system), recently, a hybrid recuperates has been considered for use in such power systems. Hybrid recuperates consist of three pass recuperates the first is a ceramic heat exchanger with a working temperature between 600^0c and 1000^0C and the second and the third are metallic heat exchanger with working temperature under 600^0C For a sense of perspective the working temperature of heat exchangers for general use are normally less then 150^0C.

Ceramic heat exchangers offer the benefits of cheap material costs, but suffer from low thermal efficiency compared to metallic heat exchangers. In this study, the performance of a ceramic heat exchanger including three pass recuperates was analyzed so as to predict performance, heat transfer rate, effectiveness, and pressure drop.

INEEL researchers are investigating improving the condenser performance by incorporating one or both of the following two concepts. The first concept is to add properly sized and strategically located vortex generators/winglets on the fins. The second concept is to replace the circular tubes with oval tubes. Deployment of winglets on fin surfaces has been shown to enhance heat transfer through the generation of longitudinal vortices that produce localized thinning of thermal boundary layers. Jacobi and Shah provide an excellent review of heat transfer enhancement through the use of longitudinal vortices. The usage of oval tubes instead of circular tubes results in reduced form drag and increased tube-surface area for the same cross-sectional internal flow area. This strategy is not practical in all cases due to manufacturing considerations and the fact that circular tubes are inherently stronger and can therefore withstand much higher pressures with the same wall thickness. In geothermal power plants, air-cooled condensers operate at relatively low pressure, so oval tubes can be considered.

The INEEL has been performing research on these concepts for the past two years. A delta winglet (a triangle on its longer side) or rectangular winglets are the preferred shapes for the present investigation. By optimizing the shape and location of the winglets, the resulting vortices can minimize the size of the wake (stagnant flow) region behind a cylindrical tube and also improve the heat transfer downstream of the winglets. Experiments have shown that it is reasonable to expect an improvement of ~20-35% in heat transfer coefficient by adding the winglets. Additional experiments have been performed to obtain pressure drop measurements in several laboratory-scale model cases of tube bundles with and without winglets. Considering the heat transfer enhancement and pressure drop results, one or more desirable prototype cases will be chosen for further research. It is anticipated that by combining both concepts, the air-side heat transfer coefficients in binary plant air-cooled condensers can be increased without imposing additional pressure drop and fan power.

METHODOLOGY

The there stage selection procedure:-

Elimination search:-

Through all the attributes have been identified, all of them would not be important while selecting the heat exchanger for particular application. There will be few attributes, which will have direct effect on the selection procedure. This small number of attributes may be set-aside as pertinent attributes as necessitated by the particular application or the user. The threshold values of these pertinent attributes may be assigned by obtaining information from the user and the group of experts. Henceforth the selection procedure focuses solely on the pertinent attributes leaving out the rest. On the basis of the threshold values of the pertinent attributes and shortlist of heat exchangers are obtained. This may be achieved by scanning the database for pertinent attributes, one at a time, to eliminate the heat exchanger alternatives, which have one or more pertinent attribute values that fall short of the minimum required values. To facilitate this search procedure an identification system has been made for all the heat exchangers in the database.

Evaluation procedure:-

A mini-database is thus formed which comprises these satisfying solutions i.e, alternative which have all attributes satisfying the acceptable levels of aspiration. The problem is now one of finding out the optimum or best out of these satisfying solutions. The selection procedure therefore needs to rank these solution is order of merit. The first step here will be to represent all the information available from the database about these satisfying solutions in the matrix form. Such a matrix is called as decision matrix, D. Each row of this matrix is allocated to one candidate heat exchanger and each column to one attribute under consideration. There for an element d_{ji} of the decision matrix D, gives the value of j^{th} attribute in the row (non normalized) form and units, for the i^{th} heat exchanger. Thus if the number of short-listed heat exchangers is m and the number of pertinent attributes is n, the decision matrix is an m * n matrix. This evaluation procedure completes in three steps.

Step-1 Normalized specifications:-

The next step is construction of the normalized specification matrix, N, from the decision matrix, D. Normalization is used to bring the data with in particular range or scale and moreover, it provides the dimensionless magnitudes. This phenomenon is used to calculate the normalized specification matrix. The normalized specification matrix will have the magnitudes of all the attributes of the heat exchangers on the common scale of 0 to 1. It is a sort of value, which indicates the standing of that particular attribute magnitude when compared to the whole range of the magnitudes for all candidate heat exchangers.

An element n_{ij} of the normalized matrix 'N' can be calculated as

$$n_{ij} = d_{ij} \Big/ \sqrt{\sum_{i=1}^{m} d_{ij}^2}$$

Where d_{ij} is an element of the decision matrix 'D'.

Step-2 Method for Assigning Weights:-

Many methods for MADM problems require information about the relative importance of each attribute. It is usually given by a set of weights which is normalized to sum to 1. In case of n set of weights is-

$$W^T = (w_1, w_2, w_3, \ldots\ldots\ldots\ldots\ldots\ldots, w_n)$$

$$w_1 + w_2 + w_3 + w_4 + w_5 + w_6 = 1$$

$$\sum_{j=1}^{n} W_j = 1$$

Step-3 Weighted normalized specification:-

The weights obtained from the relative importance matrix have to be applied to the normalized specifications since all attributes have different importance while selecting the heat exchanger for particular application. The matrix, which combines the relative weights and normalized specification of the candidates, is weighted normalized matrix, 'V'. It will give the true comparable values of the attributes. This can be obtained as follows.

$$V = \begin{pmatrix} w_1 n_{1,1} & w_2 n_{1,2} & \ldots w_n n_{1,n} \\ w_1 n_{2,1} & \ddots & \vdots \\ w_1 n_{m,1} & w_2 n_{m,2} & \ldots w_n n_{m,2} \end{pmatrix} = \begin{pmatrix} v_{1,1} & v_{1,2} & \ldots v_{1,n} \\ v_{2,1} & \ddots & \vdots \\ v_{m1} & v_{m,2} & \cdots v_{m,n} \end{pmatrix}$$

TOPSIS (Technique for order preference by similarity to ideal solution)

The weighted normalized matrix 'V' is used to obtain the +ve and –ve benchmark heat exchangers, where the both benchmark heat exchangers are hypothetical heat exchangers, which supposed to have best and worst possible attribute magnitudes. Hwang and Yoon developed TOPSIS based upon the concept that the chosen option (optimum) should have the shortest distance from the positive benchmark heat exchangers (best possible heat exchanger) and be farthest from the negative benchmark heat exchanger (worst possible heat exchanger). The measure ensures that top ranked heat exchanger is closest to positive benchmark heat exchanger and negative benchmark heat exchanger. Here, we calculate separation measures from positive and negative heat exchangers, respectively, as S^*_I and S_i^- as follows.

The separation from the +ve benchmark heat exchanger is given by

$$S_i^+ = \left[\sum_{j=1}^{n} \left(v_{ij} - v_i^+ \right)^2 \right]^{1/2} \quad i = 1,2,3...............n$$

and separation from the –ve benchmark heat exchanger is given by

$$S_i^- = \left[\sum_{j=1}^{n} \left(v_{ij} - v_i^- \right)^2 \right]^{1/2} \quad i = 1,2,3..........n =$$

Then the relative closeness to the positive benchmark heat exchanger, C*, which is a measure of the suitability of the heat exchanger for the chosen application on the basis of attributes considered, is calculated. A heat exchanger with the largest C* is preferable.

$$C^* = S_i^- / (S_i^* + S_i^-)$$

Ranking of the candidate heat exchangers in accordance with the decreasing values of indices C* indicating the most preferred and the least preferred feasible optional solutions is done.

ILLUSTRATIVE EXAMPLE

Selection of heat exchanger for the heating operation using multiple attribute decision making (MADM) approach.

We take the example of heat exchanger selection for heating operation using MADM approach.

From the database generated, after elimination search we can find out manageable number of candidate heat exchanger and their pertinent attributes.

Candidate heat exchangers are listed below:-
Shell and Tube Heat exchange(A_1)
Gasket Plate Heat Exchanger (A_2)
Welded and other Heat Exchanger (A_3)
Spiral Heat Exchanger (A_4)
Plate Fine Heat Exchanger (A_5)
Lamella Heat Exchanger (A_6)

Pertinent attributes are listed below:-
Pressure (M Pa) (X_1)
Temperature (^{o}C) (X_2)
Surface Area (m^2) (X_3)
Thermal Efficiency (X_4)
Cost (Rs) (X_5)
Young Modulus of Materiel (N/m^2) (X_6)

Attributes for the short listed candidate heat exchangers show in (table 1)

Attributes for the short listed candidate heat exchangers.

Att.→ Alter.↓	(X_1)	(X_2)	(X_3)	(X_4)	(X_5)	(X_6)
(A_1)	100	1100	5000	95	350000	200
(A_2)	30	260	380	93	220000	210
(A_3)	20	850	15	90	300000	200
(A_4)	2.5	500	260	88	100000	190
(A_5)	85	1370	3600	96	400000	200

(A_6)	50	450	5500	91	200000	220

Here surface area and cost are the type of attribute of which is the minimum magnitude is preferable and hence the reciprocal of the values in column representing surface area should be used to form the decision matrix, ‘D’ .Table 2 shows the decision matrix obtained:

D=

Att.→ lter.↓	(X_1)	(X_2)	(X_3)	$X_4)$	(X_5)	(X_6)
(A_1)	100	1100	0.00020	95	0.0000028	200
(A_2)	30	260	0.00263	93	0.0000045	210
(A_3)	20	850	0.06666	90	0.0000033	200
(A_4)	2.5	500	0.00385	88	0.0000500	190
(A_5)	85	1370	0.000278	96	0.0000025	200
(A_6)	50	450	0.000182	91	0.0000050	220

Table 2. Decision matrix obtained

Att.→ Alter.↓	(X_1)	(X_2)	(X_3)	$(X_4$)	(X_5)	(X_6)
(A_1)	100	1100	0.00020	95	0.0000028	200
(A_2)	30	260	0.00263	93	0.0000045	210
(A_3)	20	850	0.06666	90	0.0000033	200
(A_4)	2.5	500	0.00385	88	0.0000500	190
(A_5)	85	1370	0.00028	96	0.0000025	200
(A_6)	50	450	0.00018	91	0.0000050	220

Data obtained from the above table is use in the procedure of selection of heat exchanger which is as follows:

Step 1

Formation of decision matrix “D” i.e. the matrix which will contain all the magnitudes of specifications. The rows of the matrix are the candidates heat exchangers, with their attribute values listed in columns.

$$D = \begin{bmatrix} 100 & 1100 & 0.00020 & 95 & 0.00000286 & 200 \\ 30 & 260 & 0.00263 & 93 & 0.00000455 & 210 \\ 20 & 850 & 0.06667 & 90 & 0.00000333 & 200 \\ 2.5 & 500 & 0.00385 & 88 & 0.0000500 & 190 \\ 85 & 1350 & 0.000278 & 96 & 0.0000025 & 200 \\ 50 & 450 & 0.000182 & 91 & 0.0000050 & 210 \end{bmatrix}$$

Step 2:-

Calculating the normalized specification matrix. This normalization helps to provide the dimensionless elements of the matrix.

$$n_{ij} = d_{ij} \Big/ \sqrt{\sum_{i=1}^{m} d_{ij}^{2}}$$

$$N = \begin{bmatrix} 0.689552 & 0.532010 & 0.002990 & 0.420605 & 0.056402 & 0.404639 \\ 0.206866 & 0.125748 & 0.039351 & 0.41175 & 0.089931 & 0.424871 \\ 0.137911 & 0.411098 & 0.997547 & 0.398468 & 0.065671 & 0.404639 \\ 0.017239 & 0.241823 & 0.057605 & 0.389613 & 0.986053 & 0.384408 \\ 0.586119 & 0.652921 & 0.00416 & 0.425033 & 0.049303 & 0.404639 \\ 0.344776 & 0.21764 & 0.002723 & 0.402896 & 0.098605 & 0.424871 \end{bmatrix}$$

Step 3:-

Assign weights for each attribute such that their sum will be equal to one.

$$\sum_{j=1}^{n} W_j = 1$$

$$w_1 + w_2 + w3 + w4 + w5 + w6 = 1$$

$w_1 = 0.15$ $w_2 = 0.20$ $w_3 = 0.16$ $w_4 = 0.14$ $w_5 = 0.25$ $w_6 = 0.10$

Step 4:-

Calculating the weighted normalize specification matrix. Here we incorporate the relative importance of the attributes with their normalized value to create unique parameter for the candidate heat exchanger.

$$\mathbf{V_{ij} = N_{ij}\, W_j}$$

$$V = \begin{bmatrix} 0.689552 & 0.532010 & 0.002990 & 0.420605 & 0.056402 & 0.404639 \\ 0.206866 & 0.125748 & 0.039351 & 0.41175 & 0.089931 & 0.424871 \\ 0.137911 & 0.411098 & 0.997547 & 0.398468 & 0.065671 & 0.404639 \\ 0.017239 & 0.241823 & 0.057605 & 0.389613 & 0.986053 & 0.384408 \\ 0.586119 & 0.652921 & 0.00416 & 0.425033 & 0.049303 & 0.404639 \\ 0.344776 & 0.21764 & 0.002723 & 0.402896 & 0.098605 & 0.424871 \end{bmatrix} \begin{bmatrix} 0.15 \\ 0.20 \\ 0.16 \\ 0.14 \\ 0.25 \\ 0.10 \end{bmatrix}$$

$$V = \begin{bmatrix} 0.103433 & 0.106402 & 0.000479 & 0.058885 & 0.014101 & 0.040464 \\ 0.03103 & 0.02515 & 0.006296 & 0.057645 & 0.022433 & 0.042487 \\ 0.020687 & 0.08222 & 0.159607 & 0.055786 & 0.016418 & 0.040464 \\ 0.002586 & 0.048365 & 0.009217 & 0.054546 & 0.246513 & 0.038441 \\ 0.087918 & 0.130584 & 0.000666 & 0.59505 & 0.012326 & 0.040464 \\ 0.051716 & 0.043528 & 0.000436 & 0.056405 & 0.024651 & 0.042487 \end{bmatrix}$$

This weighted normalized specification matrix, which takes care of the attribute values and their relative importance. So that matrix will be able to provide good basis for comparison with each other and with the benchmark heat exchanger. Various methods, graphical and non-graphical, explained previously can be applied for this comparison and ranking purposes.

TOPSIS method for ranking

This is the fifth step of the selection procedure. The weighted normalized attributes for the positive and negative benchmark heat exchangers can be obtained as:

$V^+ =$ 0.103433 0.130584 0.159607 0.59505 0.246513 0.042487
$V^- =$ 0.002586 0.02515 0.000436 0.054546 0.012326 0.038441

Separation of the alternatives from the ideal and negative ideal solution is as follows:

$S_1^+ = 0.282713$ $S_1^- = 0.129608$
$S_2^+ = 0.300131$ $S_2^- = 0.03117$
$S_3^+ = 0.249295$ $S_3^- = 0.170125$
$S_4^+ = 0.198969$ $S_4^- = 0.235499$
$S_5^+ = 0.283463$ $S_5^- = 0.135745$
$S_6^+ = 0.2912241$ $S_6^- = 0.054068$

Relative closeness to the ideal solution obtained as:

$C_1^+ = 0.314337$
$C_2^+ = 0.094082$
$C_3^+ = 0.40562$
$C_4^+ = 0.542041$
$C_5^+ = 0.323814$
$C_6^+ = 0.156578$

Evaluation and Ranking of the candidate heat exchangers using TOPSIS method.

Table 3. Evaluation and Ranking of the candidate heat exchangers using TOPSIS method

S. No.	Alternatives	TOPSIS-closeness to positive the benchmark heat exchanger	Rank based on C*
1	Shell and Tube Heat exchanger	0.314337	4
2	Gasket Plate Heat exchanger	0.094082	6
3	Welded and other Heat exchanger	0.40562	2
4	Spiral Heat exchanger	0.542041	**1**⟵
5	Plate Fine Heat exchanger	0.323814	3
6	Lamella Heat exchanger	0.156578	5

Arrow shows the best alternative according to user requirement.

Thus the heat exchangers are ranked in order of preference based on the attributes selected. For the purpose of a new heat exchanger, the management can use the above ranking effectively to select heat exchanger, which will be best suitable for the application and is based on the this set together with other considerations.

RESULT AND DISCUSSION

Analysis of result of heat exchanger selection for heat operation:

The result comes to solve example. This indicates that, arrow shows best alternative on table 4 and heat exchanger A4 best alternative in MADM approach.

Analysis shows of the developed for heat exchanger selection procedure on the basis of Multiple Attribute Decision Making (MADM) approach gives the result as shows in the Table 4

S. No.	Alternatives	TOPSIS-closeness to positive the benchmark heat exchanger	Rank based on C*
1	Shell and Tube Heat exchanger	0.314337	4
2	Gasket Plate Heat exchanger	0.094082	6
3	Welded and other Heat exchanger	0.40562	2
4	Spiral Heat exchanger	0.542041	**1←**
5	Plate Fine Heat exchanger	0.323814	3
6	Lamella Heat exchanger	0.156578	5

6.2 SCOPE

The model on multi-attribute evaluation is used to choose the alternative which is fairly good on all the attributes and also to be comparing a heat exchanger performance on the basis of different attributes to brief out of the soundness of heat exchanger on each of the attribute. In this work, this approach is used to select a suitable heat exchanger for a specific operation (Heat operation). But this approach can also be applied to other area like to select machinery and man power for set up an industry. The purposed technique gives the independence to the user to attach weights to the attributes as required. TOPSIS was implemented in the software which gives the performance order of the heat exchanger and relative closeness to the ideal solution.

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