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Interpretive Structural Modeling (ISM) for Recovery of Heat Energy

Kuldip Arun Rade[1], Vilas A. Pharande[2] and Daulat. R. Saini[3]

[1]Mechanical Engineering Department, B.V.D.U. College of Engineering, Pune-satara Road, Pune-46, Maharashtra, India.
[2]Mechanical Engg Department SET, Arvind Gavali college of Engineering, Varye, Satara-15, Maharashtra, India.
[3]Chemical Engg Department, National Chemical Laboratory, Dr. Homi Bhabha Road, Pune-08, Maharashtra, India.

Abstract

In this paper twenty nine factors responsible for heat transfer in the recovery of heat from hot dyeing waste slurry and its Interpretive Structural Modeling (ISM) has been developed. In this systematic approach of ISM, first of all a concept model of the problem has been formulated, followed by the formulations of Structural Self Interaction Matrix (SSIM) and Reachability Matrix. The level of significance of each factor has been derived by level partitioning. The initial digraph is prepared on the basis of the canonical matrix. ISM based model is finalized after checking for conceptual inconsistency and necessary modifications. The MICMAC analysis is also conducted with the help of driving and dependence diagram, which states that factor 4 (mass flow rate of working medium (water)) and factor 5 (Inlet temperature of working fluid (slurry)) are the major parameters for heat recovery and needs more attention.

Keywords- Heat transfer; Heat recovery; dyeing slurry; ISM.

INTRODUCTION

For optimization of energy in dyeing process number of experiments was performed based on the various process parameters in research industry and readings were taken by varying process parameters such as mass to liquor ratio, process temperature and process time etc. [1]

At the time of conducting these experiments for all batches it was found that the slurry of temperature 62^0C was directly drained to the atmosphere which will create the problems such as local heating and increased pollution. Accordingly discussion was carried out with experts from Industry and scientists from Solid and Hazardous Waste Management Division NEERI, Nagpur. As per suggestions received, it is necessary to develop a heat recovery system which can extract the possible amount of lost heat from the slurry. Here the heat recovery system is developed to recover available waste heat from the slurry. This waste heat captured in normal water is used for next dyeing process, so one can get preheated water around 34^0C for dyeing process. For this setup it is proposed to use shell and tube heat exchanger. [2]

There are number of different parameters which can affect the rate of heat transfer, directly and indirectly. The 'Interpretive Structural Modeling (ISM)' approach is used to develop a model which will logically identify the relation between these factors and also estimate the level of significance of each of one of them.[3] Therefore in this paper twenty nine factors which will affect on rate of heat transfer have been enumerated and its Interpretive Structural Mode (ISM) has been developed. In this systematic approach of ISM, first of all a concept model of the problem has been formulated, followed by the formulations of Structural Self Interaction Matrix (SSIM) and Reachability Matrix. The level of significance of each factor has been derived by level partitioning. The initial digraph is prepared on the basis of the canonical matrix. ISM based model is finalized after checking for conceptual inconsistency and necessary modifications.

THE METHOD

ISM falls into the soft operations research (OR) family of approaches. It is a computer-assisted learning process that enables individuals or groups to prepare a map of the complex relationships between the many elements involved in a complex situation. Its basic idea is to use experts' practical experience and knowledge to decompose a complicated system into several sub-systems (elements) and construct a multilevel structural model. ISM is frequently used to present fundamental understanding of complex situations, as well as to set together a course of action for solving a problem. ISM can be used for finding and analyzing the relationships among specific factors/parameters, which define a problem or an issue [3-9].

CONCEPT MODEL

Figure 1 depicts the concept model in the form of contextual relationship for developing ISM based model of heat transfer by using Shell and Tube Heat exchanger and to indicate the factors responsible for it.

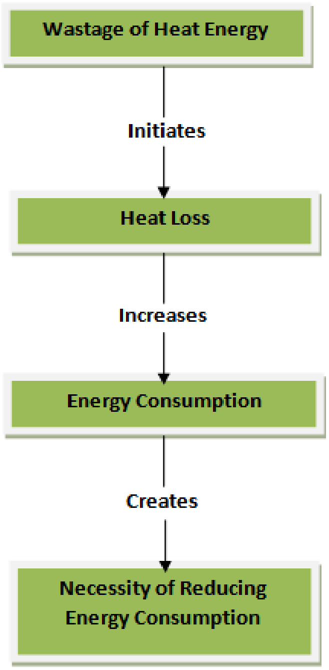

Fig.1: Concept Model

IDENTIFICATION OF ELEMENTS

In view of the concept model and in the light of results available in the literature and having discussions with the expert from the industry and academics, twenty nine factors responsible for the heat transfer have been selected and have been categorized in four groups, I to IV for the integrated total objective Recovery of Heat Energy (Refer Table I)

Table I: Selected Twenty Nine Factors Contributing to Heat Transfer Rate

I. Inlet (A) Working medium (Water)			
1	Temperature	3	Thermal Conductivity
2	Viscosity	4	Mass Flow Rate
I. Inlet (B) Working Fluid (Dyeing Slurry)			
5	Temperature	7	Working Fluid Content
6	Viscosity	8	Mass Flow Rate

<table>
<tr><td colspan="6">II. Outlet (A) Working Medium (Water)</td></tr>
<tr><td>9</td><td>Temperature</td><td colspan="2">11</td><td colspan="2">Thermal Conductivity</td></tr>
<tr><td>10</td><td>Viscosity</td><td colspan="2">12</td><td colspan="2">Mass Flow Rate</td></tr>
<tr><td colspan="6">II. Outlet (B) Working Fluid (Dyeing Slurry)</td></tr>
<tr><td>13</td><td>Temperature</td><td colspan="2">15</td><td colspan="2">Mass Flow Rate</td></tr>
<tr><td>14</td><td colspan="5">Viscosity</td></tr>
<tr><td colspan="6">III. Heat Exchanger Parameters</td></tr>
<tr><td>16</td><td colspan="2">Tube Diameter</td><td>21</td><td colspan="2">Number of tubes</td></tr>
<tr><td>17</td><td colspan="2">Tube Length</td><td>22</td><td colspan="2">Shell Diameter</td></tr>
<tr><td>18</td><td rowspan="2">Tube Material</td><td>Copper</td><td>23</td><td colspan="2">Shell Length</td></tr>
<tr><td>19</td><td>Aluminum</td><td>24</td><td rowspan="2">Shell Material</td><td>Mild steel</td></tr>
<tr><td>20</td><td colspan="2">Insulation</td><td>25</td><td>PVC</td></tr>
<tr><td colspan="6">IV. Working Condition</td></tr>
<tr><td>26</td><td colspan="2">Atmospheric Pressure</td><td>28</td><td rowspan="2">Heating Method</td><td>Direct</td></tr>
<tr><td>27</td><td colspan="2">Atmospheric Temperature</td><td>29</td><td>Indirect</td></tr>
<tr><td colspan="6">V. (30) Integrated Total Objective
Recovery of Heat Energy</td></tr>
</table>

The variables (factors) are selected for analyzing the interactions; a contextual relationship is established among variables using Structural Self-Interaction Matrix (SSIM).

STURCTURAL SELF INTERACTION MATRIX

It is developed for factors, which shows pair wise relationships among factors of the system under consideration. This matrix represents the respondent's perception of element to element directed relationship. By considering the contextual relationship for each factor four symbols are used to represent the type of relationship that can exist between two elements of the system under consideration. These are:

V: Factor i will help achieve factor j

A: Factor i will be achieved by factor j

X: Factor i and j will help achieve each other

O: Factor i and j are unrelated

TABLE III shows Structural Self Interaction Matrix (SSIM) developed for the problem under consideration using above relationship rules.

Table III: Structural Self-Interaction Matrix (SSIM)

FACTOR	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
1	V	O	O	O	O	X	X	X	X	V	V	V	V	X	X	A	X	X	O	O	X	A	O	X	X	X	O	O	X	
2	V	X	X	A	O	O	O	O	O	O	A	O	O	O	O	A	O	X	X	A	X	X	O	O	O	X	X	O		
3	O	V	V	V	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	A	X	O	O	O	O	O			
4	O	O	O	O	O	O	O	O	O	O	X	O	X	X	X	O	O	O	X	X	X	O	O	O	A	X				
5	V	X	X	X	O	O	O	O	O	X	O	A	A	O	O	O	A	O	O	O	A	O	O	X	X					
6	V	X	X	A	O	O	O	O	O	O	O	O	O	V	V	X	O	A	O	O	O	A	X	X						
7	V	A	A	O	O	O	O	O	O	O	O	O	O	O	A	X	A	O	O	O	O	O	X							
8	X	O	O	X	O	O	O	O	O	A	O	O	O	X	X	O	X	O	O	O	O	O								
9	V	A	A	A	O	A	A	A	A	A	A	O	O	O	O	O	X	X	O	A	V									
10	A	A	A	V	O	O	O	O	O	O	A	O	O	O	O	O	O	X	V	X										
11	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O											
12	X	O	O	O	O	O	O	A	A	A	O	O	O	O	O	O	X	V												
13	V	X	X	A	O	O	O	O	O	A	A	A	A	A	A	O	X													
14	V	A	A	A	O	O	O	O	O	O	O	O	O	V	V	X														
15	V	O	O	O	O	O	O	O	O	O	O	O	V	V	X															
16	V	O	O	O	O	O	V	A	O	A	O	O	O	X																
17	V	O	O	O	O	O	O	X	O	X	O	X	X																	
18	V	X	X	O	O	O	O	O	O	X	O	O																		
19	V	X	X	O	O	O	O	O	O	X	O																			
20	V	X	X	A	O	V	V	V	V	O																				
21	V	O	V	O	O	O	O	O	O																					
22	V	X	X	O	O	X	X	X																						
23	V	X	X	O	O	X	X																							
24	V	A	A	A	A	O																								
25	V	A	A	A	A																									
26	O	O	O	X																										
27	O	V	V																											
28	V	O																												
29	V																													
30																														

REACHABILITY MATRIX

Based on the SSIM, a binary matrix that reflects the directed relationships between the variables is created. SSIM is transformed into binary matrix, called the initial reachability matrix by substituting of V, A, X, O relationship by 1 and 0 as per the case. The rules for the substitution of 1 and 0 are as follows;

- If (i, j) entry in the SSIM is V, then, (i, j) entry in the reachability matrix becomes 1 and the (j, i) entry becomes 0
- If (i, j) entry in the SSIM is A, then, (i, j) entry in the reachability matrix becomes 0 and the (j, i) entry becomes 1
- If (i, j) entry in the SSIM is X, then, both (i, j) and (j, i) entries in the reachability matrix become 1.
- If (i, j) entry in the SSIM is O, then, both (i, j) and (j, i) entries in the reachability matrix become 0.

Following these rules, initial reachability matrix is obtained. The final reachability matrix for the problem under consideration is obtained by incorporating transitivity's in initial reachability matrix and is shown in Table IV.

Table IV: Final Reachability Matrix

FACTOR	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	Driving Power ↓
1	1	1	0	0	1	1	1	0	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	20
2	1	1	0	1	1	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	13
3	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	1	1	1	0	8
4	0	1	0	1	1	0	1	1	1	1	1	1	0	0	0	1	1	1	0	1	1	0	0	0	0	0	0	0	0	0	14
5	1	1	0	1	1	1	1	0	1	1	0	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0	1	1	1	1	17
6	1	0	0	1	1	1	1	1	1	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	1	14
7	1	0	0	1	1	1	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	9
8	0	0	0	1	0	1	1	1	1	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	1	1	1	12
9	1	1	1	1	1	1	0	0	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	23
10	1	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	10
11	0	1	0	1	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
12	0	1	0	1	0	0	0	0	0	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	7
13	1	1	0	0	0	0	0	0	1	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	10
14	1	0	0	0	1	0	0	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	13
15	1	1	0	0	0	1	1	0	1	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	1	13
16	1	0	0	1	0	0	1	1	0	0	0	0	1	0	1	1	1	0	0	0	0	1	0	1	0	0	0	0	0	1	11
17	1	0	0	1	0	1	0	1	0	0	0	0	1	1	0	1	1	1	1	0	1	0	1	0	0	0	0	0	0	1	13
18	0	0	1	1	1	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0	1	1	1	10
19	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	1	1	1	9
20	0	1	0	1	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	1	0	1	1	1	1	0	0	1	1	1	13
21	0	0	0	0	1	0	0	1	1	0	0	1	1	0	0	1	1	1	1	0	1	1	1	0	0	0	0	1	1	1	15
22	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	0	0	0	1	1	1	1	1	1	0	0	1	1	1	13
23	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	1	1	0	0	1	1	1	1	1	1	0	0	1	1	1	14
24	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0	1	1	1	9
25	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	0	0	1	1	1	9
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	4
27	0	1	0	0	1	1	0	0	1	0	0	0	1	1	0	0	0	0	0	1	0	0	0	1	1	1	1	1	1	0	13
28	1	1	0	0	1	1	1	1	1	1	0	0	1	1	0	0	0	1	1	1	0	1	1	1	1	0	0	1	0	1	19
29	0	1	0	0	1	1	1	0	1	1	0	0	1	1	0	0	0	1	1	1	0	1	1	1	1	0	0	0	1	1	17
30	1	1	0	1	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	26
Dependence	18	15	5	15	16	12	11	10	21	14	4	9	18	12	6	15	15	13	11	12	12	12	12	13	10	4	7	19	19	24	

LEVEL PARTITIONING

Level partitioning is done in order to classify the elements into different levels of the ISM structure. For this purpose, two sets are associated with each element Ei of the system: a Reachability Set (Ri), which is a set of all elements that can be reached from the element Ei, and an Antecedent Set (Ai), which is a set of all elements that element Ei can be reached by.

The reachability and antecedent set for each factor is obtained from final reachability matrix. The reachability set for a particular variable consists of the variable itself and the other variables, which help the variable itself and to form the reachability set. The antecedent set consists of the variable itself and the other variables, which may help in achieving it. Subsequently, the intersection of these sets is derived for all variables. After the identification of the top-level elements, these are discarded from the other remaining variables. This iteration is continued till the levels of each variable are obtained. Table II show the different factors representing the various levels of the final model for the problem under consideration.

Table II: Factors Indicating Their Level of Hierarchy in ISM Model

Level	Factors
I	2,3,4,5,9,10,11,13,14,22,23,29
II	2,3,10,14,22,29
III	3,10,14,
IV	6,12
V	--

DEVELOPING CANONICAL MATRIX

Canonical Matrix is developed by clustering factors, at the levels achieved, across rows and columns in the final reachability matrix. The resultant matrix has most of its upper triangular elements as 0, and lower triangular elements as 1. This matrix is then used to prepare a digraph. Directional graph (Diagraph) is a graphical representation of the elements, their directed relationships, and hierarchical levels. The initial digraph has been prepared on the basis of the canonical matrix, for the problem under consideration.

ISM BASED MODEL

Based on the relationships given in the final reachability matrix and the determined level for each variable, a directed graph is drawn and the transitive links are removed.

The resultant diagraph is converted into an ISM by replacing variable nodes with statements. The ISM therefore, gives a very clear picture of the system of elements, and their flow of relationships. The developed ISM based model of Recovery of Heat Energy is reviewed to check for conceptual inconsistency and to make necessary modifications. Figure 2 show a final ISM model of Recovery of Heat Energy

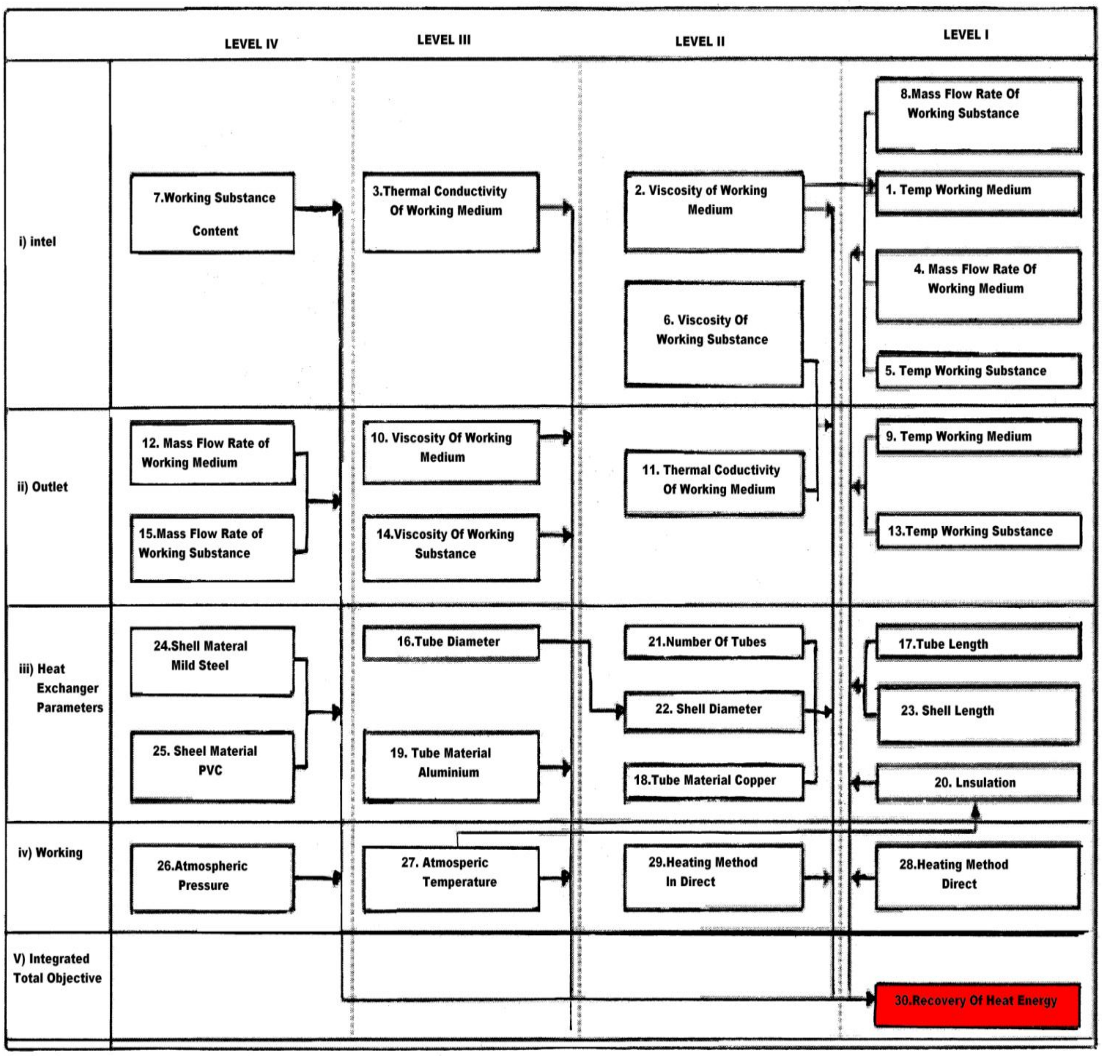

Fig. 2: ISM Model for Recovery of Heat Energy

MICMAC ANALYSIS

The objective of the MICMAC Analysis is to analyze the driving power and the dependence of the variables. It is also known as Driving and Dependence diagram as shown in Figure 3.

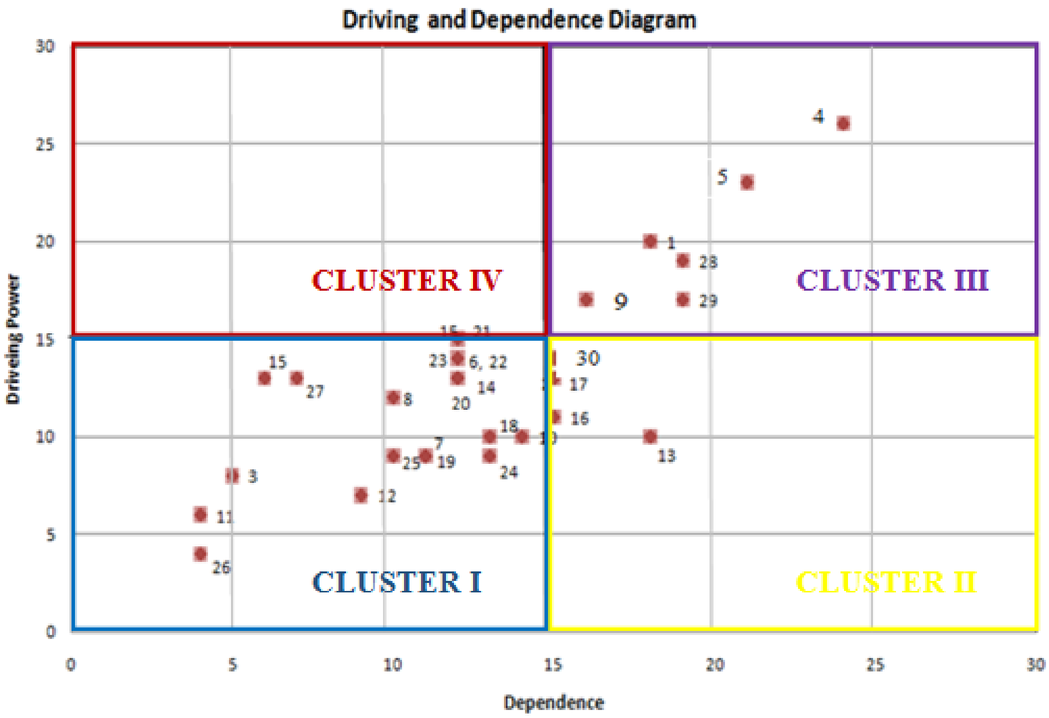

Fig.3: Driving and Dependence Diagram for Recovery of Heat Energy

The derived variables are classified into four clusters (Refer Figure 3). The **first cluster** consists of the autonomous variables that have weak driving power and dependence. Factors 2, 3,6,7,8,10,11,12,14,18,19,20,22,23,24,25,26 and 27 belong to this cluster. **Second cluster** consists of the dependent variables that have weak driving power but strong dependence on other variables. Factors 13, 16, 17 and 30 come under this category. **Third cluster** has the linkage variables that have strong driving power and also strong dependence. Factor 1, 4, 5, 9, 28 and 29 are in this group. **Fourth cluster** includes the independent variables having strong driving power but weak dependence. Factors 15 and 21 are pertaining to this cluster.

The variables, which lie in third cluster, need special attention and proactive consideration, since these have high driving power but they are also dependent on other variables.

Thus from the MICMAC analysis it has been observed that the **factor 4** (mass flow rate of working medium (water)) and **factor 5** (Inlet temperature of working fluid (slurry)) falls in cluster 3, which needs special attention. In ISM methodology, the contextual relation among the variables always depends on the users' knowledge and their familiarity with the system, its processes, and its application. Therefore the bias of the person who is judging the variables might influence the final result.

CONCLUSIONS

The ISM based model of the problem is a graphical representation. To analyze the driving power and the dependence of twenty nine factors enumerated in Table I, the MICMAC analysis has been carried out. From MICMAC analysis it has been observed that the **factor 4** (mass flow rate of working medium (water)) and **factor 5** (Inlet temperature of working fluid (slurry)) have the major contribution in Recovery of Heat Energy. These factors should be given more attention at the time of Recovery of Heat Energy. From ISM Approach, mass flow rate of water/MFR water (m_w), mass flow rate of slurry/MFR slurry (m_s), temperature of slurry (T_s) and Mass to Liquor Ratio (MLR) were selected for the further experimentation of heat recovery.

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