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Application of Analytic Hierarchy Process (AHP) for Lignocellulose pretreatment Technique selection

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ABSTRACT - In cellulose-to-ethanol processes a physico-chemical pre-treatment of the lignocellulosic feedstock is a crucial prerequisite for increasing the amenability of the cellulose to enzymatic attack. It is used as a promising approach to improve the efficiency of bio ethanol production. To achieve a better efficiency, it is necessary to select the best technique for the Lignocellulose pre-treatment .This is influenced a number of factors like acid treatment, alkali treatment, etc. A study was conducted using four alternatives such as 2-step pre treatment first with acid then alkaline catalyst (TSM), alkaline wet oxidation (AWM), acid hydrolysis (AHM) and diluted acid hydrolysis (DHM). A set of alternatives were selected based on literature review, experiments, knowledge etc. The overall ranking of all techniques helps to select the best technique for the preparation of solid dispersion as a carrier Based on priority ranking 2-step pre treatment first with acid then alkaline catalyst (TSM) technique is the most suitable method to achieve bio ethanol production.

Keywords:*Multi-criteria decision making, Analytic hierarchy process (AHP), Lignocellulose, Bioethanol, pre-treatment.*

I. INTRODUCTION

A number of techniques are available forutilization of lignocellulosic biomass not only for liquid bio fuels production, notably ethanol [1] and butanol [2,3], but also for production of chemicals such as furans [4] and acetic acid [5]. Without pretreatment, the lignocellulosic biomass is too resistant to enzymatic saccharification because of the tight bonding between the polymeric constituents; cellulose, hemicellulose and lignin, and because of the crystalline nature of cellulose [6]. With pretreatment, the intention is to prepare the cellulose to become more accessible and susceptible to enzymatic hydrolysis to provide a high monosaccharide yield for the subsequent fermentation [7].In Lignocellulose pretreatment technique, the over all goal is to achieve reproducibility and consistency with good bioethanol production efficiency. This is influenced by a number of factors such as process information of the equipment and method, operation skill of the Lignocellulose pretreatment, sensitivity of the equipment etc. Hence, while choosing technique, consideration of one factor alone may not be justifiable. It is more rational and appropriate to analyse both qualitative and quantitative parameters and then to make a decision (Table 1). When two or more alternatives are in hand and one has to select the best, then the appropriate approach is to use a multi–criteria decision making (MCDM) method. It is important to incorporate all the factors that could influence Lignocellulose pretreatment in decision making process while choosing technique. In the present study analytic hierarchy process (AHP), a MCDM tool has been used to select the better technique 2-step pretreatment first with acid then alkaline catalyst (TSM), alkaline wet oxidation (AWM), acid hydrolysis (AHM) and diluted acid hydrolysis (DHM) for preparation of bio ethanol. [8].

II. MATERIALS AND METHODS

Analytic hierarchy process (AHP)

AHP developed by Saaty [9] is one of the very effective MCDM tool [10].This has been employed very successfully in many situations where a decision situation is characterized by a multitude of complementary and conflicting factors [11].

General methodology, excellent analytical-mathematical treatments of AHP are available in literature [12].

The basic steps of analytic hierarchy process model are given below: [13-15]

- Developing the hierarchy of the problem
- Collecting the data of the problem
- Establishing the priority weights or normalized weights
- Deriving the solution of the problem

Problem Hierarchy

Developing the hierarchy of the problem consists of decomposing the complex decision problem into various levels. Each level of hierarchy represents manageable attributes or criteria, by which the alternatives or decisions of the lowest level of the hierarchy are judged. Fig 1 represents four levels of hierarchy. The highest level (L1)

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called the focus, consists of only one element- the broad, overall objective namely choosing the best technique for Lignocellulose pretreatment. The next level consists of six main attributes, Process information (PI), operational skill (OS), supplier (SUP), technical information (TEI), technical status (TES) and machine (MAC) [L2]. This in turn is decomposed into another set of sub-attributes such as Production scale (PS), Process condition (PC), etc., corresponding to a lower level of hierarchy, [L3]. The lowest level of hierarchy, [L4], consists of the decision alternatives, (TSM/AWM/AHM/DHM) of the model.

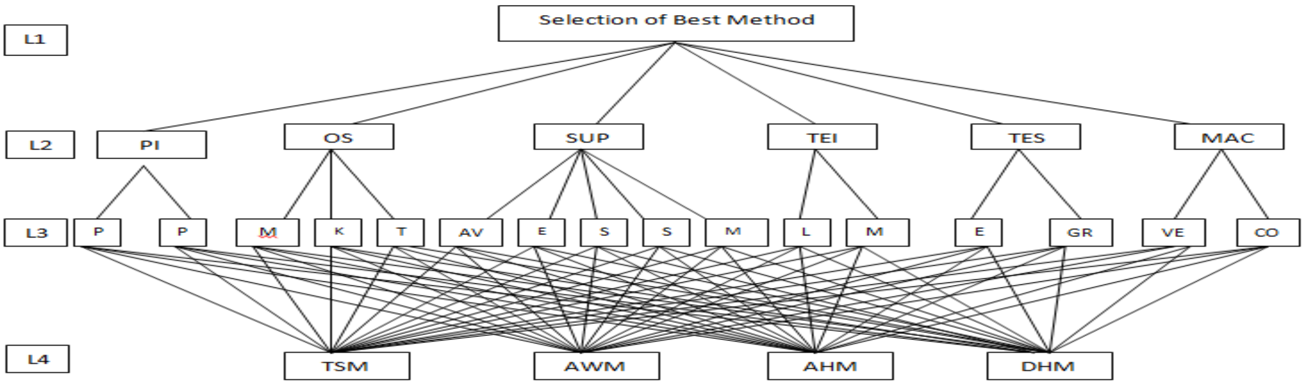

Fig.1 AHP Hierarchy structure for for Lignocellulose pretreatment Technique selection

III. DATA COLLECTION

After establishing AHP scheme, entries of data obtained are put into pairwise comparison matrices. One will assign relative values in pairwisefashion with respect to attributes of one level of hierarchy, given each of the attributes of the next higher level of the hierarchy. This process is continuedfor all levels of the hierarchy. Each relative scale in these matrices reflects the relative importance of one attribute of the pair over the other attribute of that pair. Saaty (1980) has suggested a nine-point scale that has been found highly reliable with the number code of options that respondents can handle.

The data for the structure depicted in Figure 2 requires the generation of 28 pairwise comparison matrices:

- One 6x6 matrix for the pairwise comparison of six main attributes with respect to the objectives;
- One 7x7 matrix, one 5x5 matrix, one 3x3 matrix and three 2x2 matrices for the pairwise comparison of attributes, each with respect to one of the six main criteria; and
- Twenty-one 2x2 matrices for the pairwise comparison of the two alternatives, each with respect to one of the twenty-one sub-attribute.

For a 4x4 matrix, for example, this means that the decision maker must reach an agreement on each a_{ij} entry in the matrix (Fig 2).

$$\begin{pmatrix} 1 & a_{12} & a_{13} & a_{14} \\ a_{21} & 1 & a_{23} & a_{24} \\ a_{31} & a_{32} & 1 & a_{34} \\ a_{41} & a_{41} & a_{43} & \end{pmatrix} \quad \text{A example:} \quad \begin{pmatrix} 1 & 5 & 6 & 7 \\ 1/5 & 1 & 4 & 3 \\ 1/6 & 1/4 & 1 & 1 \\ 1/7 & 1/3 & 1 & 1 \end{pmatrix}$$

where $a_{ij} = 1/a_{ji}$

Figure 2. Pairwise comparison matrix

If a matrix of pairwise comparison $A = (a_{ij})$, which is positive and reciprocal, is perfectly consistent then:

$$a_{ij} = w_i/w_j$$;where w_i is weight attribute i.

These normalized weights

w_i (with $w_i<1$ and $\sum_{i=1}^{n} w_i = 1$) can be calculated by normalizing any column j of matrix A:

$$w_i = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}}$$

for all i = 1,2 …, n

Since Saaty's method computes w as the principal right eigenvector of matrix A,

$$Aw = \lambda_{max} w$$

where λ_{max} is maximum eigenvalue of A

λ_{max} = n if A is consistent

$\lambda_{max} > n$ if A is not consistent

this method yields a natural measure for inconsistency. Because $\lambda_{max} - n$ reflects the degree of inconsistency, normalizing this measure by the size of the matrix gives us the consistency index:

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

where:

$$\lambda_{max} = \max \frac{\left(\sum_{k=1}^{n} a_{kj} w_j\right)}{w_i}$$

for i = 1, 2, …, n

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This consistency index, CI can now be compared to the consistency index of a purely randomly generated matrix, Random Indexes (RI), given in Table 1.

CR = CI/RI

If the ratio of the consistency index to the random index (called a "consistency ratio") is no greater than 0.1, Saaty suggests the consistency is generally quite acceptable for pragmatic purposes.

Table 1. Random Inconsistency Index (RI)

N	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

IV. EXPERIMENTAL ANALYSIS

The case study was conducted with an objective to choose the better system between four alternatives, namely TSM, AWM, AHM and DHM, for carrying out Lignocellulose pretreatment. To identify major system evaluation criteria, a group was constituted and a brainstorming session was conducted. The active participants of the group were selected based on their expertise and experience in Lignocellulose pretreatment technique and a group leader with good experience in brain storming technique and decision-making (in this case the group leader is well experienced and knowledgeable in Lignocellulose pretreatment technique). The group leader is also familiar with AHP model. After this exercise the group identified the factors/attributes such as Process Information (PI) of the equipment and method, Operational skill (OS) of the microencapsulator, supplier (SUP) of the equipment, technical information (TEI) about the equipment, technical status (TES) of the equipment, machine (MAC) inbuilt operational flexibility, etc. Table 2 gives an explanation for the attributes.

In Table 2, under each attribute sub-attributes were associated for example under the attribute Process Information sub-attributes such as production scale and process condition are considered since these sub-attributes contribute a lot in achieving the overall goal to formulate microspheres with reproducibility and consistency release profile. Fig 1 shows the AHP hierarchy for choosing the best technique for Lignocellulose pretreatment. It represents four levels of hierarchy. The highest level, [L1], is the focus of the problem. This is turn is split into a set of attributes, PI, OS,SUP, TEI, TES and MAC corresponding to an intermediate level of hierarchy [L2]. This in turn into another set of sub attributes such as PS, PC etc., corresponding to a lower level of hierarchy, [L3], the last or the lowest level of hierarchy, [L4], consists of the decision alternative, PAN/SPR, of the technique.

Using the AHP model the priority weights, [PR_WT], to the attributes and sub-attributes are calculated.**Table 2. Explanation for sub-attributes**

	Sub-attribute	Notation	Description
1.	**Process Information**	**PI**	
	Production scale	PS	Lab scale, Pilot scale, Industrial scale
	Process condition	PC	Temperature, Stirring speed, Ph
2.	**Operational Skill**	**OS**	
	Technique	MET	Lignocellulose pretreatment is a process where by small discrete solid particles or liquid droplets are surrounded and enclosed by an intact shall
	Knowledge	KN	Refers to Lignocellulose pretreatment theoretical background
	Training	TR	Hands on training on the technique
3.	**Supplier**	**SUP**	
	Availability	AV	How easily the machine can be procured?
	Experience	EX	Reputation of the supplier/company
	Service	SE	Servicing and maintenance facilities
	Spares	SP	Availability of spare parts
	Monopoly	MO	Vendor status: single/multi vendor
4.	**Technical Information**	**TEI**	
	Literature	LT	Scientific journals, news letters, magazines updating current trends
	Manual	MA	Operational and service manuals
5.	**Technical Status**	**TES**	
	Established technique	ET	Standing of the technique in the global level research level
	Growth	GR	Growth in the field of Lignocellulose pretreatment technique
6.	**Machine**	**MAC**	
	Versatility	VE	Operational flexibility: RPM controller, temperature, etc.
	Complexity	CO	Complexity of the machine; how easily one can handle the instrument?

Table 3 shows a matrix of preference numbers expressed by the decision maker for all combination of six main attributes in Fig. 1. After obtaining the pairwise judgments as in Table 3, the next step is computation of a vector of priorities or weighting of elements in the matrix. In terms of matrix algebra, this consists of calculating the "principal vector" (eigenvector) of the

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matrix, and then normalising it to sum to 1.0. Divide the elements of each column by the sum of that column (i.e., normalise the column) then add the elements in each resulting row and divide this sum by the number of elements in the row.

Table 4 shows the normalized matrix by dividing each element, in Table 3, by the sum of its respective column. Finally, row entries in the last two columns of Table 4 are comprised the sum of the six elements in the row and average of those row elements (principal vector), respectively.

The next step is to compute the consistency ratio (CR) for the pairwise comparison above. It is a function called the “maximum eigenvalue” and size of the matrix (called consistency index”), which is then compared against similar values if the pairwise comparisons had been merely random (called “random index”).

The CR is calculated as described below:

(i) Multiply the matrix of pairwise comparisons (Table 3), call it matrix [A] by the principal vector or priority weights (right-hand column of Table 4) [B] to get a new vector [C]

Table 3. Matrix of paired comparison of attributes

	PI	OS	SUP	TEI	TES	MAC
PI	1	3	4	6	7	9
OS	1/3	1	3	5	7	8
SUP	¼	1/3	1	3	5	7
TEI	1/6	1/5	1/3	1	4	6
TES	1/7	1/7	1/5	1/4	1	3
MAC	1/9	1/8	1/7	1/6	1/3	1
Σ	2.002	4.800	8.675	15.416	24.333	34.000

Table 4. Normalised matrix of paired comparison ofattributes and calculation of priority weights for Level 2

	PI	OS	SUP	TEI	TES	MAC	Row (Σ)	Average = Σ/6
PI	0.499	0.625	0.461	0.389	0.288	0.265	2.527	0.421
OS	0.166	0.208	0.346	0.324	0.288	0.235	1.567	0.261
SUP	0.125	0.069	0.115	0.195	0.205	0.206	0.915	0.153
TEI	0.083	0.042	0.038	0.065	0.164	0.177	0.567	0.095
TES	0.071	0.030	0.023	0.016	0.041	0.088	0.269	0.045
MAC	0.056	0.026	0.017	0.011	0.014	0.029	0.152	0.025
Σ=	1.000	1.000	1.000	1.000	1.000	1.000		1.000

Priority weights of the attributes

PI	0.421
OS	0.261
SUP	0.153
TEI	0.095
TES	0.045
MAC	0.025
Σ =	1.000

[A] [B] [C]

	PI	OS	SUP	TEI	TES	MAC		[B]		[C]
PI	1	3	4	6	7	9		0.421		2.926
OS	1/3	1	3	5	7	8		0.261		1.850
SUP	1/4	1/3	1	3	5	7	X	0.153	=	1.029
EI	1/6	1/5	1/3	1	4	6		0.095		0.598
TES	1/7	1/7	1/5	1/4	1	3		0.045		0.272
MAC	1/9	1/8	1/7	1/6	1/3	1		0.025		0.157

(ii) Divide each element in vector [C] by its corresponding element in vector [B] to find a new vector [D]

$$D = \left(\frac{2.96}{0.421} \quad \frac{1.849}{0.261} \quad \frac{1.030}{0.153} \quad \frac{0.598}{0.095} \quad \frac{0.272}{0.045} \quad \frac{0.157}{0.025} \right)$$

=[6.9507.084 6.732 6.294 6.044 6.280]

(iii) Average the numbers in vector [D]. This is an approximation called “maximum eigenvalue,” and is denoted by λmax:

$$\lambda_{max} = \frac{6.950 + 7.048 + 6.732 + 6.294 + 6.044 + 6.280}{6} = 6.558$$

The consistency index (CI) for a matrix of size n is given by the formula:

$$CI = = \frac{\lambda_{max} - n}{n - 1} \quad (6.558 – 6) / (6-1) = 0.1116$$

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Saaty, based on large numbers of simulation runs, approximated random indexes (RI) for various matrix sizes, n (Table 5). For a matrix of n = 6, RI = 1.24. The consistency ratio (CR) now be calculated using the relationship

$$CR = CI/RI = 0.112/1.24 = 0.09$$

Similarly, CR is calculated for the remaining attributes(level 2) and sub-attribute (level 3).

Table 5. Saaty's nine-point comparison scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities constitute equally to the objective
3.	Moderate importance	Experience and judgment of one over another slightlyfavour one activity over another
5.	Essential or strong importance	Experience and judgment stronglyfavour one over another
7.	Very strongly demonstrated importance	An activity is favouredvery strongly over another; its dominance demonstrated in practice
9.	Absolute importance	The evidence favouring one activity over another is of highest possible order of affirmation
2,4,6,8	Intermediate values between adjacent scale values	When compromise is needed
Reciprocals of above non zero	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**	

V. RESULTS AND DISCUSSION

The priority weights, [PR_WT], to the attributes and sub-attributes are calculated and the results are presented in Appendix I. Appendix I (A.1) gives the pairwise comparison of the attributes by the decision maker using the Saaty's 9-point scale (Table 5). It is seen here that, PI is most important (priority = 0.421) followed by OS (priority = 0.261) and so on. In Appendix I (A.1.1) factors are compared with respect to the overall objective of the problem. Here, PI is equally important when it is compared with itself and therefore assigned a value of 1 (Table 5 Saaty's nine-point comparison scale). PI is moderately important when compared with OS and therefore assigned a value of 3 and PI is extremely (or absolutely) important when compared with MAC and is assigned a value of 9. Similarly the other factors are considered. The lower half of the diagonal of the pairwise comparison matrix is the reciprocal of the upper half of the matrix. The CR for all the matrices were checked and found to be less than 0.10. On same lines,all the tables have been formulated using the expert judgment (group leader) and Saaty's nine-point comparison scale.

In the next level of comparison, sub-attributes are compared with each other with respect to an attribute at a higher level. For instance, within PI the sub-attributes PS and PC (described in Table 2) are compared (Appendix I: A.1.2). Similarly in all the other tables of Appendix I (A.1.3, A.1.4, A.1.5 and A.1.6) the priorities of the sub-attributes are computed. Appendix I (A.2.2, A.2.3, A.2.4, A.2.5 and A.2.6) give pairwise comparison of the alternatives (TSM/AWM/AHM/DHM) with respect to each of the sub-attributes.

For example, under the attribute Process information (PI) the alternatives are compared with respect to the sub-attributes PS and PC. The lower half of the diagonal of the pair wise comparison matrix is the reciprocal of the upper half of the matrix. The CR for all the matrices were checked and found to be less than 0.10. On same lines, all the tables have been formulated using the expert judgment (group leader) and saaty's nine-point comparison scale.

In Table 6 (B.3) training [TR], the comparison of alternatives on the sub-attribute, SET has been assigned a higher priority weight of 0.469 over other alternatives namely CAP with 0.247, PAN with 0.047 and SPR with 0.110.

This is assigned on the basis that SET is requires lesser training to handle the instrument compared to CAP, PAN and SPR.

The solution of the problem involves finding the composite score that reflects the relative priorities of all the alternatives at the lowest level of the hierarchy. The composite score is used for the final ranking of the alternatives.

Table 6 illustrates the calculation of composite score of alternatives with respect to Process information. Similarly composite scores are computed for alternatives with respect to other sub-attributes. Table 7 consolidates the results computed in Appendix I (A.1 and A.2) in arriving at the overall composite score of each of the alternatives (TSM/AWM/AHM/DHM).

Table 6. Calculation of composite score of SET/CAP/PAN/SPR with respect to Process information

#	Attributes	Notation	PR_WT	Sub-attributes	PR_WT	PR_WT			
1	Process information	PI	0.421			SET	CAP	PAN	SPR
				PS	0.25	0.591	0.247	0.049	0.110

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				PC	0.75	0.559	0.323	0.058	0.058

***0.282** = 0.421[(0.400 x 0.833) + (0.100 x 0.833) + (0.100 x 0.833) + (0.100 x 0.750) + (0.100 x 0.200) + (0.100 x 0.750)]
****0.097** = 0.421[(0.400 x 0.167) + (0.100 x 0.167) + (0.100 x 0.167) + (0.100 x 0.250) + (0.100 x 0.800) + (0.100 x 0.250)]

						TSM	AWM	AHM	DHM
1.	Process Information	PI	0.421						
				PS	0.25	0.591	0.247	0.049	0.110
				PC	0.75	0.559	0.323	0.058	0.058
2.	Operation skill	OS	0.261						
				MET	0.455	0.558	0.263	0.056	0.121
				KN	0.455	0.558	0.263	0.056	0.121
				TR	0.090	0.469	0.469	0.063	0.063
3.	Supplier	SUP	0.153						
				AV	0.334	0.530	0.311	0.096	0.061
				EX	0.333	0.450	0.450	0.049	0.049
				SE	0.111	0.450	0.450	0.049	0.049
				SP	0.111	0.450	0.450	0.049	0.049
				MO	0.111	0.438	0.438	0.081	0.040
4.	Technical information	TEI	0.094						
				LT	0.250	0.520	0.297	0.124	0.054
				MA	0.750	0.520	0.297	0.124	0.054
5.	Technical status	TES	0.046						
				ET	0.833	0.638	0.230	0.055	0.073
				GR	0.167	0.638	0.230	0.055	0.073
6.	Machine	MAC	0.025						
				VE	0.750	0.535	0.327	0.091	0.044
				CO	0.250	0.535	0.327	0.091	0.044
	Composite rating					**0.5216**	**0.3059**	**0.0645**	**0.0769**

Table 7. Composite rating of Techniques

VI. Conclusion

In this study, AHP technique was applied to make choice amongst alternative Lignocellulose pretreatment techniques(TSM/AWM/AHM/DHM) and thereby opt the best technique. The composite score is used for the final ranking of the alternatives. The solution of the problem involves finding the composite score that reflects the relative priorities of all the alternatives at the lowest level of the hierarchy. The composite score favored the selection of TSM (score=0.5216) over AWM (score=0.3059), AHM (score=0.0645), DHM (score=0.0769) for Lignocellulose pretreatment. Hence 2-step pretreatment first with acid then alkaline catalysttechnique is employed for the production of bioethanol.

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