Analytical Hierarchy process (AHP) of different pre-treatment methods used for the preparation of lignocellulose materials as raw material for ethanol production

Magesh A.*, Rajesh Kannan R. and Jayabalan K.
Department of Chemical Engineering, Annamalai University, Annamalai Nagar, Tamil Nadu, INDIA
*kannan_vrr007@yahoo.com

Abstract
This article discusses the hierarchical assessment of various pre-treatment techniques used to produce lignocellulose products as the substrate for ethanol production. Various parameters namely steam explosion (SE), lime therapy (Lime), ammonia fiber explosion (AFEX), microbial degradation (MD) are essential for studies to analyse the best one. For four different types, a mentioned level hierarchy model was planned, constructed on various principles and sub principles discussed in the preparation of lignocellulosic materials. This applies pair comparison attitude, priority generation of vectors and synthesis. It restricts reprocessing as a result of unsuccessful decisions.

This method has helped to prioritize lignocellulose materials of humble process with less input and required physicochemical properties with priority value for lignocellulosic materials. The lignocellulosic materials were prioritized by consistency verification with a minimum ruling error. This method aids reduceruns, process development and import out putrating in the preparation of lignocellulose substrate for the production of ethanol.

Keywords: Lignocellulose, ethanol, hierarchy analysis, pre-treatment methods

Introduction

This research is the alternative source for the environmental impact of fossil fuels. Biomass are the renewable sources that stores sunlight energy in its chemical bonds. Thechemical bonds are converted in the form of biofuels it may be treated either chemically or biologically.

The potential resource for ethanol is lignocellulosic biomass, which includes materials such as agricultural residues, forest waste, waste paper and other waste. Because of its availability and diverse raw materials, lignocellulosic biomass offers a better choice. Moreover, its lower requirements for agricultural inputs contribute higher net energy values of feed stocks and less green house gas emissions from ethanol combustion. It has great source for producing ethanol than other starch producing crops.

The conversion of lignocellulose biomass to ethanol is, however, stimulating than corn due to the composite structure of cell wall. Various pre-treatment methods had developed using microorganisms to improve the accessibility of enzymes to cellulosefibers[1].

All the above methods Steam explosion (SE), lime therapy (Lime), ammonia fiber explosion (AFEX), microbial degradation (MD) have their own advantage. Lime operates at mild temperatures resulting in low inhibitor production and partial lignin removal[2-6]. Steam explosion that affects hemicellulose predominantly along with transformation of lignin Microbial degradation is a low-energy process that converts both lignin and hemicellulose and does not require a corrosive resistant reactor. The disadvantage of other techniques is the costs of oxygen, temperature, alkaline catalyst, formation of degradation products, corrosion of alkaline treatment, requirements of equipment and tanks, corrosion, acid and acid recovery costs, degradation products of acid hydrolysis technique.

This study was therefore initiated to review and identify the best pre-treatment method which provides the highest cellulose to glucose conversion by applying AHP.

Material and Methods

Method of Analytic Hierarchy process: Thomas L. Saaty was the first person to develop an extensive range of AHP that includes in the research. The principle is process of AHP was the formation of Hierarchy structure, priority analysis and verification of consistency and the development of overall priority ranking[7].

Formation of Hierarchy Structure: Figure 1 Displays the analytical process steps concerned. Different criteria were descended from the objective by Hierarchy, the smallest level of subcriteria is created for a complicated choice. In the top stage, the original stage is stated to reflect the goal, display of conditions in the transitional stage. In conclusion, alternative choices are put at the lowest stage of hierarchy. Figure 1 comprehensive below for this research "Identify Alternatives (Step 1) and Develop a Hierarchical Model (Step 2).

Priority analysis: A pair-by-pair contrast matrix is set at each stage. Using a pair-by-pair comparison scale, they contrasted with the four-level hierarchy framework building alternatives as outlined in table[20]. Table 1 Shows that using the scale, the pairwise comparison is defined as essential component than supplementary. The function and performance on the options of each criterion is assessed and the priority vectors are used to fix the matrix, this method has been carried out in the priority phase. Figure 1 of this phase. Comprehensive to "Build a matrix for a pair comparison (Step 3), make a pair comparison decision (Step 4) and synthesize a pair comparison (Step 5)" for the research.

Consistency Verification and developing ranking: Evaluation of this process is found on private decisions, so there is a chance for the degree of inconsistency. The verification of consistency is conducted by using the calculation method to overcome this consistency and to ensure the judgment. Figure 1 for this method. Comprehensive sections to "Verify consistency (Step 6) and (Step 7). The conditions for consistency calculation level is carried out for the creation of general priority vector calculation for the objective. In conclusion, the options are hierarchical based on the general precedence vector. Figure 1. Comprehensive section on "Developing the general priority ranking (Step 8) and selecting the appropriate option (Step 9). To attain the objective, the alternative with the lowest rank is given priority over the other.

Problem Hierarchy: The decomposition of the complex decision problem into various levels is developed by the hierarchy of the problem. Manageable attributes or criteria are represented by each level of stage, the judgement of the lowest stageof the alternatives or criteria of the hierarchy are decided. The four levels of hierarchy are represented in figure 1. The peak level (L1) known as focus, which had only one element the wide, selecting the best technique for Lignocellulose pre-treatment is the overall objective. Six main attributes are involved in the following level, which includes Process information (PI), operational skill (OS), supplier (SUP), technical information (TEI), technical status (TES) and machine (MAC) (L2). Further, it is putrefied into Production scale (PS), Process condition (PC), etc., as an additional set of sub attributes to equivalent lower level of hierarchy (L3). The decision alternatives of the model in the lower level of hierarchy (L4) are (SE/LIME/AFEX/MD).

Data Collection: The hierarchy of the issue develops the decomposition of the complicated decision issue into different stages. Each level of hierarchy represents manageable characteristics or criteria, the judgment of the smallest level of options or hierarchy criteria is chosen. Figure 1 represents the four levels of hierarchy. Requirement of the generation of 28 pairwise comparison matrices data for the structure depicted in figure 2.

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

For example, a 4x4 matrix on each a_{ij} in the matrix (Fig. 2), it has to reach the agreement.

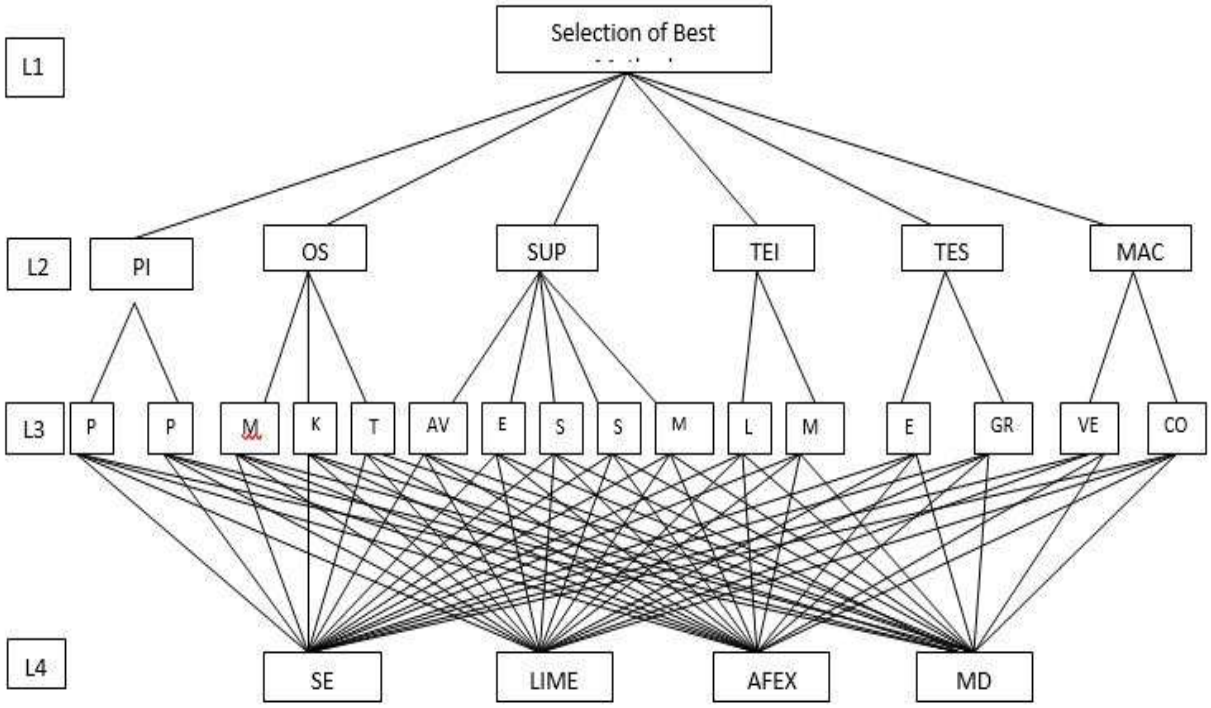

Figure 1: AHP Hierarchy structure for Lingnocellulose pretreatment technique selection

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

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

Figure 2: Pairwise comparison matrix

Establishment of the normalised weight:

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 $i = 1, 2 \ldots, n$

Since method computes was the principal matrix A,

$Aw = \lambda_{max} w$

where λ_{max} is maximum eigenvalue of A

$\lambda_{max} = n$ if A is consistent

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

A natural measure for inconsistency is obtained as yield for this method. Because $\lambda_{max} - n$ reflects the degree of inconsistency, consistency index is obtained by normalizing the measure by the size of the matrix.

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

where,

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

for $i = 1, 2, \ldots, n$

This consistency index, CI can now be compared to the consistency index Table 1. Represents the Random Indexes (RI),

CR = CI/RI.

Experimental procedure: The objectives of this study are to indicate the improved system between these mentioned alternatives; they are SE, LIME, AFEX and MD, for booming out Lignocellulose pre-treatment. A brainstorming session was conducted to identify major system evaluation criteria. The group consist of active participants were designated based on the criteria of knowledge and skill in Lignocellulose pre-treatment technique and a head of the group in brain storming technique and decision-making with good.

The group head must acquaint with AHP model. The group identified the factors/attributes after this exercise, which include in this process.

Production scale and process condition of sub-attributes information are considered. For choosing the best technique for Lignocellulose pre-treatment of AHP hierarchy is shown in figure 1. There are mentioned levels of hierarchy are represented. The focus of the problem is the peak level (L1). The set of attributes is split into PI, OS, SUP, TEI, TES and MAC equivalent to the middle level of hierarchy (L2). It turns to another level of sub attributes, includes PS, PC etc., equivalent to inferior level of hierarchy (L3), the last level of hierarchy (L4), contains PAN/SPR, is the technique for the decision alternative.

The matrix of preference numbers shown in table 3. are stated for all combination of six main attributes in figure 1 by the decision maker.

Table 2 shows the pairwise judgements. After that, computation of a vector of priorities or weighting of elements in the matrix is followed as the next step. calculating the “principal vector” (eigenvector) of the matrix and then normalising it to sum to 1.0 is termed in matrix algebra. Elements of each column is divided by the sum of that column (i.e., normalise the column) then the elements are added in the each resulting row and the number of elements in the row is used to divide the sum.

Table 1
Random Inconsistency Index (RI)

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RI	0	0	0.585	0.91	1.13	1.241	1.33	1.42	1.45	1.48	1.52

Table 2
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	1/4	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	2.003	4.801	8.676	15.414	24.333	34.000

Table 3
Normalised matrix of paired comparison of attributes 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 weight of the attributes:

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

Normalized matrixis represented in Table 3, each element is divided in Table 2 by the sum of its respective column. In Table 3, last two columns in the entry of row, the row and average of those row elements (principal vector) are comprised by the sum of the six elements. For the above pairwise comparison the consistency ratio (CR) is computed. This purpose is called as "maximum eigenvalue" and size of the matrix (called consistency index"), if the pairwise comparisons had been merely random (called "random index") it is compared with the similar values.

The calculation of CR is mentioned below:

(i) Multiply the matrix of pairwise comparisons (Table 2), call it matrix [A] by the principal vector or priority weights (right-hand column of Table 3) [B] to get a new vector [C].

$$\begin{array}{c} \\ PI \\ OS \\ SUP \\ TEI \\ TES \\ MAC \end{array} \overset{[A]}{\begin{pmatrix} PI & OS & SUP & TEI & TES & MAC \\ 1 & 3 & 4 & 6 & 7 & 9 \\ 1/3 & 1 & 3 & 5 & 7 & 8 \\ 1/4 & 1/3 & 1 & 3 & 5 & 7 \\ 1/6 & 1/5 & 1/3 & 1 & 4 & 6 \\ 1/7 & 1/7 & 1/5 & 1/4 & 1 & 3 \\ 1/9 & 1/8 & 1/7 & 1/6 & 1/3 & 1 \end{pmatrix}} \; X \; \overset{[B]}{\begin{pmatrix} 0.421 \\ 0.261 \\ 0.153 \\ 0.095 \\ 0.045 \\ 0.025 \end{pmatrix}} = \overset{[C]}{\begin{pmatrix} 2.926 \\ 1.850 \\ 1.029 \\ 0.598 \\ 0.272 \\ 0.157 \end{pmatrix}}$$

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

$$D = \begin{pmatrix} \frac{2.96}{0.421} & \frac{1.849}{0.261} & \frac{1.030}{0.153} & \frac{0.598}{0.095} & \frac{0.272}{0.045} & \frac{0.157}{0.025} \end{pmatrix}$$

$$= [6.950 \quad 7.084 \quad 6.732 \quad 6.294 \quad 6.044 \quad 6.280]$$

(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:

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

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

CR = CI/RI = 0.112/1.24 = 0.09

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

Conclusion

Analysis of the hierarchy was carried out to create the methodology for assessing and prioritize the most suitable techniques of pre-treatment used to prepare lignocellulose products as raw materials for ethanol manufacturing. The model is intended to assess the appropriate option depends on the various elements of a decision's criteria and sub criteria. This assessment helps to reduce tests, shorten development processes and improve the quality of the product.

References

1. Moiser N., Wyman C., Dale B., Elander R., Lee Y.Y., Holtzapple M. and Ladisch M., Features of promising technologies for pre-treatment of lignocellulosic biomass, *Bioresource Technology*, **96**, 673–686 **(2005)**

2. Saha B.C. and Cotta M.A., Comparison of pre-treatment strategies for enzymatic saccharification of barley straw to ethanol, *New Biotechnology*, **27(1)**, 10-16 **(2009)**

3. Sierra R., Granda C. and Holtzapple M.T., Short-term lime pretreatment of poplar wood, *Biotechnology Progress*, **25**, 323–332 **(2009)**

4. Rabelo S.C., Maciel Filho R. and Costa A.C., Lime pre-treatment of sugarcane bagasse for bioethanol production, *Applied Biochemistry and Biotechnology*, **153**, 139–150 **(2009)**

5. Maas Ronald H.W., Bakker Robert R., Jansen Mickel L.A., Visser Diana, Jong Ede, Eggink Gerrit and Weusthuis Ruud A., Lactic acid production from lime-treated wheat straw by Bacillus coagulans: neutralization of acid by fed-batch addition of alkaline substrate, *Appl. Microbiology and Biotechnology*, **78**, 751–758 **(2008)**

6. O'Dwyer J.P., Zhu L., Granda C.B. and Holtzapple M.T., Enzymatic hydrolysis of lime-pretreated corn stover and investigation of the HCH-1 model: inhibition pattern, degree of inhibition, validity of simplified HCH-1 model, *Bioresource Technology*, **98**, 2969–2977 **(2007)**

7. Saaty T.L., The analytic Hierarchy process, McGraw-Hill, New York **(1980)**.