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FUZZY BASED RESOURCE MANAGEMENT APPROACH FOR THE SELECTION OF BIOMASS MATERIAL

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ABSTRACT

Biomass is a renewable and sustainable composite biomaterial. It is made up of lignin, cellulose and hemicellulose with considerable amount of water, extractives and inorganic chemical compounds.The use of biomaterials and other biogenic wastes for energy recovery represent an eco-friendly way to use these natural fillers.Biomaterial selection is one of the most significantaspects for any conversion process, and it is a common outsourcing problem that includes material preparation, reactor performance, economic assessment and the calorific value of the products. Fuzzy systems can be quite useful in high-performance computing during the selection of biomaterials. In each engineering process, material selection is a crucial step since each material are having its own set of characteristics. This study presents the application of type-1 fuzzy set for the section of suitable biomaterial for yielding maximum bi-oil. This study focuses on seven locally available materials such as rice straw (M-1), sunflower shell (M-2), hard wood (M-3), wheat straw (M-4), sugarcane bagasse (M-5), corn cop (M-6) and palm shell (M-7). The study evaluated seven important properties of the materials such as lignin (P-1), cellulose (P-2), hemicellulose (P-3), volatile matter (P-4), fixed carbon (P-5), moisture content (P-6) and ash content (P-7). The findings demonstrated that sugarcane bagasse (M-5) is the best option for maximum bio-oil yield.
Keywords: Type-1 fuzzy set, property evaluation, material selection, preference score, ranking

1. INTRODUCTION

The effective handling of erroneous data and uncertainty is a critical phenomenon in any decision-making process. According to Lee et al, if the imprecision of humanity's decision-making process is mishandled, the results could be perplexing [1]. Fuzzy set theory [2] is a wonderful tool for expressing human knowledge. It is a formalised technique for scientifically conveying ambiguity and vagueness [3]. Fuzzy set theory has been used by several researchers to deal with uncertainty in a range of decision-making problems [4]. Around a century ago, Charles Peirce was the first researcher in the present era to recognise and lament that "logicians have too much disregarded the learning of vagueness, not believing the vital role it plays in numerical reasoning." [5]. Later it was also expressed by Russell [6]. Wittgenstein (1953) [7] stated that natural language concepts do not acquire an intelligible set of attributes that define them, but rather have expandable boundaries. Despite

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the fact that Lukasiewicz (1930) and his team [8] developed several valued logics with liaison truth significance(s) in the 1930s, it was the philosopher Black belongs to US (1937) who first projected the associates of fuzzy membership functions that is called"consistency profiles" to help "characterise vague symbols" [9]. Weyl (1940) considered a generalisation of the ordinary characteristic function, replacing it with a continuous characteristic function [10]. A similar type of generalisation was presented by Kaplan and Schott (1951) [11]. The term "fuzzy set" was originally used in the title of a study by Karl Menger (1951) [12].

In recent years, the use of biomaterials for the production of valuable chemicals and biofuels has gained popularity as a way to minimise emissions of greenhouse gases emitted by the combustion of fossil diesel fuels [13]. It's an organic substance with a lot of chemical energy. It has traditionally been used for energy purposes through direct burning. The annual global biomass production is expected to be 146 billion metric tonnes. It's a renewable resource that appears to offer clear environmental benefits and lower greenhouse gas emissions. Biomass burning often produces fewer air emissions than fossil fuels. Wood chips and agricultural wastes are the examples for low-value biomass feedstocks. It comprises a wide range of chemical components. Alcohols [14], organic acids [15], formic acid, and furfurals [16] are among the compounds addressed. These chemicals are then transformed into a variety of derivatives that are employed in the chemical and pharmaceutical sectors. Many researchers have published data on chemicals extracted from a wide range of biomass feedstocks, as well as specific feedstocks including carbohydrates, triglycerides, cellulose, hemicellulose, lignin [17], and furfural [18].Machine learning algorithms are designed to extract knowledge from data using classic approaches such as clustering, classification, and relationships. To create more flexible outcomes, fuzzy sets are used in combination with these approaches. In the construction of machine learning algorithms and models, fuzzy based knowledge representation and reasoning is widely used. They gave a new-fangled life to the scientific truth of machine learning which have been in a hidden stage for a long period. Fuzzy sets are used throughout the data processing stage because it may simulate partial and inaccurate data representations. In the mapping of data representation, the fuzzy extension principle was used.

The identification of suitable material for the yielding maximum biofuels and chemicals have not been examined using AHP and other MCDM approaches. This research focused on the use of fuzzy AHP to select suitable biomaterials for thermochemical conversion processes, specifically pyrolysis. Pyrolysis is a hopeful option for thermochemical conversion of lignocellulosic material because this process produces high quality liquid oil and chemicals when compared to other conversion techniques. The qualities and requirements for selecting the best biomaterial are examined using expert critiques and literature before selecting numerous materials for this study.The selected materials are available plenty and have no value. After the cultivation these materials are burnt in open atmosphere in the field itself because of its low density. Open burning of these materials causing severe impact on the environment. So appropriate recycling of these materials are essential.

2. Methodology

2.1 Type-1 fuzzy

Fuzzy sets were brought out by Professor Zadeh in 1965 as theexpansion of the conventional notion of set [19]. Here each constituent has depicted with the helpof membership function valued in the actual unit interval [0, 1]. Because of their ability to handle vagueness in preference values, fuzzy set theory has steadily gained favour in the selection of appropriate materials. This approach is frequently utilised in a variety of fields when data is partial or inaccurate [20]. The type-1 fuzzy set $\tilde{a}$ in X is a set of well-organized pair where $\tilde{a}$ is

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represented as [27] $\tilde{a} = \{(x, \mu_{\tilde{a}}(x)) | x \in X\}$ where x represents the constituents of the set X, $\mu_{\tilde{a}}$ (x) is called the membership function or the degree of membership of x.
Suppose $\tilde{a}$ is a triangular fuzzy number (TFN) (a_l, a_m, a_u)
Where a_l, a_m, a_u are the promising values of membership function shown in figure 1

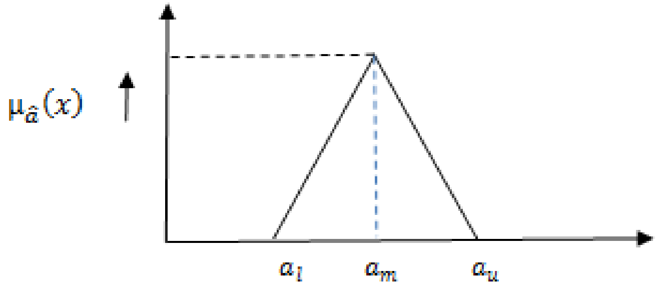

Figure 1 Illustration of triangular fuzzy set
Then the membership function is defined as

$$\mu_{\tilde{a}}(x) = \begin{cases} 1 - \dfrac{a_m - x}{a_m - a_l}, a_l \le x \le a_m \\ 1 - \dfrac{x - a_m}{a_u - a_m}, a_m \le x \le a_u \\ 0 \qquad , otherwise \end{cases}$$

Suppose $\tilde{a} = (a_l, a_m, a_u)$ and $\tilde{b} = (b_l, b_m, b_u)$ are two triangular fuzzy numbers so the mathematics operations between two type-1 fuzzy set are as follows:

$\tilde{a} \oplus \tilde{b} = (a_l + b_l, a_m + b_m, a_u + b_u)$; $\tilde{a} \ominus \tilde{b} = (a_l - b_l, a_m - b_m, a_u - b_u)$

$\tilde{a} \otimes \tilde{b} = (a_l \times b_l, a_m \times b_m, a_u \times b_u)$; $\frac{\tilde{a}}{\tilde{b}} = \left(\frac{a_l}{b_u}, \frac{a_m}{b_m}, \frac{a_u}{b_l}\right)$

$\frac{1}{\tilde{b}} = \left(\frac{1}{b_u}, \frac{1}{b_m}, \frac{1}{b_l}\right)$; $k \times \tilde{b} = (k \times b_l, k \times b_m, k \times b_u)$ where k is a crisp number

The choice of material for thermochemical conversion to produce biofuels and chemicals is a strategic and critical decision for researchers. The evaluation of many parameters is part of this selecting procedure. This approach involves evaluating a number of factors to select the best biomass source. Some studies may consider higher profits and better outcomes, however the evaluation should be focused on social and environmental issues. The majority of researchers are only interested in the biological composition of biomass. For 2nd-era ethanol, Kahr et al. [21] evaluate the lignocellulosic ethanol potential of wheat straw, rice straw, oat straw and maize stover among other potential agricultural wastes. Ciancolini et al. [22] used agglomerative hierarchical cluster analysis to assess the biomass and polyphenol production of eight cardoon genotypes. Nine capacities are tested in this study in order to find significant differences. Vaezi et al. [23] developed a numerical set of rules for biomass material selection in the gasification process. Figure 2 shows the methodology adopted for this study.

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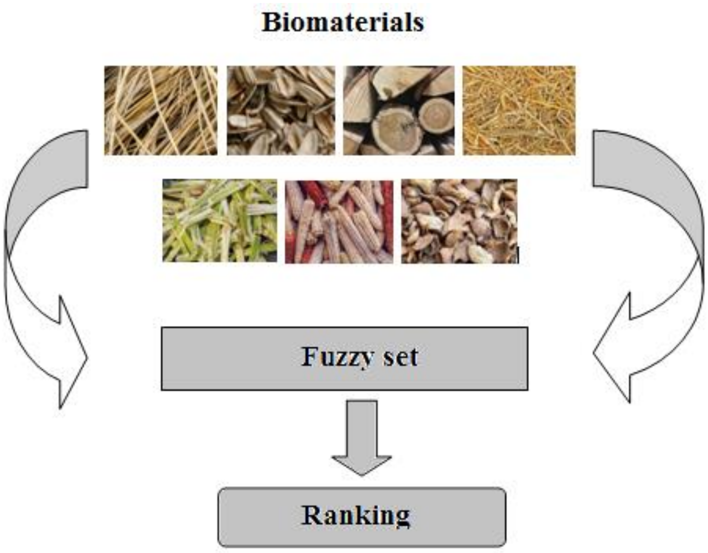

Figure 2 Methodology

3. Material Property Evaluation

Economic and environmental variables are the two most important elements that can influence biomass material choices. They are listed as follows. Various studies explain some parameters to consider in biomass selection. However, no study effectively specifies this information. Figure 3 shows the property evaluation of the biomaterials.

- Input: Cost for production and storage
- Output: Yield of biofuel
- Conversion rate: Efficiency of conversion
- Emission: Release of harmful gases
- Usage of chemicals: Properties of chemicals obtained from product
- Technological development: gap between current stage and
- Sustainable energy: Replacing fossil fuel.

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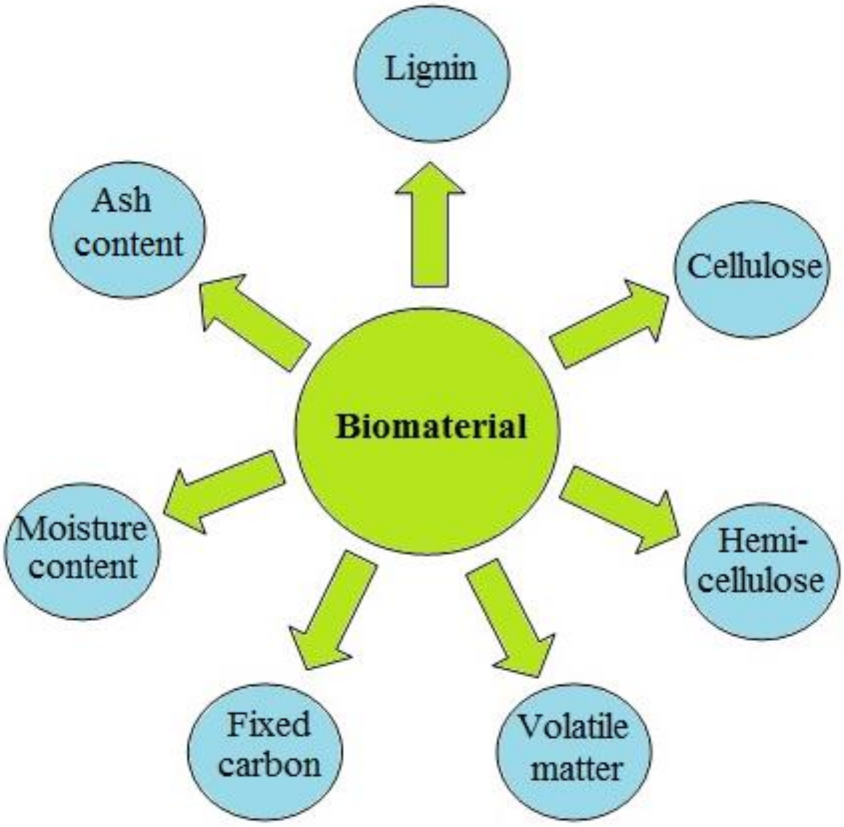

Figure 3 Biomaterial properties evaluation

4. Results and Discussion

4.1 Material Selection

Biomass material selection is mainly concerned with the biomass to biofuel conversion techniques in order to yield the maximum biofuels such as crude bio-oil, char and gas to fulfil the future energy needs. In world there are plenty of materials are available as a resource for various applications. Each material has its own unique characteristics, applications, advantages, and limitations. Earlier than the beginning of petro oil era, renewable feedstockmaterials was a major segmentfortotalenergy and chemical supplies. Biomass is a natural materialsupply chemicals and energy up todate..Among the other types of renewable materials, lignocellulosic biomass areavailable abundant, low-value materials utilized for fuels, chemicals and energy to replace fossil resources [24]. They are composite material which has cellulose, hemicellulose and lignin approximately at 50wt%, 25wt% and 25 wt% respectively [25]. The components are connectedmutually to provide structural stability. It also contains reasonable amount of water, extractives with inorganic elements. Cellulose is a linear long chain polymer that encircles mostly crystalline structures with tiny amorphous regions. They are structured in fibrils and then grouped together to form cellulose fibres, which are aware of the fibrous character of biomass cell walls. Hemicelluloses are also the amorphous polymers having shorter structure of five to six carbon sugars. It serves as a link between the cellulose and the lignin [26]. Lignin is a three-dimensional polymer made up of phenylpropane units linked together in a number of ways. The most prevalent outsourcing difficulty is material selection, which is the most important aspects of any biomass conversion process. Since different material have some unique properties and value, the

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procedurefor biomass material selection has a main role related to the conversion efficiency as well as the heating value of the biofuel [27]. This process of selection is identified to be the imperative decision-making process for biofuel conversion techniques which includes biomass preparation, performance of the reactor, economic evaluation and heating value of the biofuel products.

4.2 Evaluation of the material properties

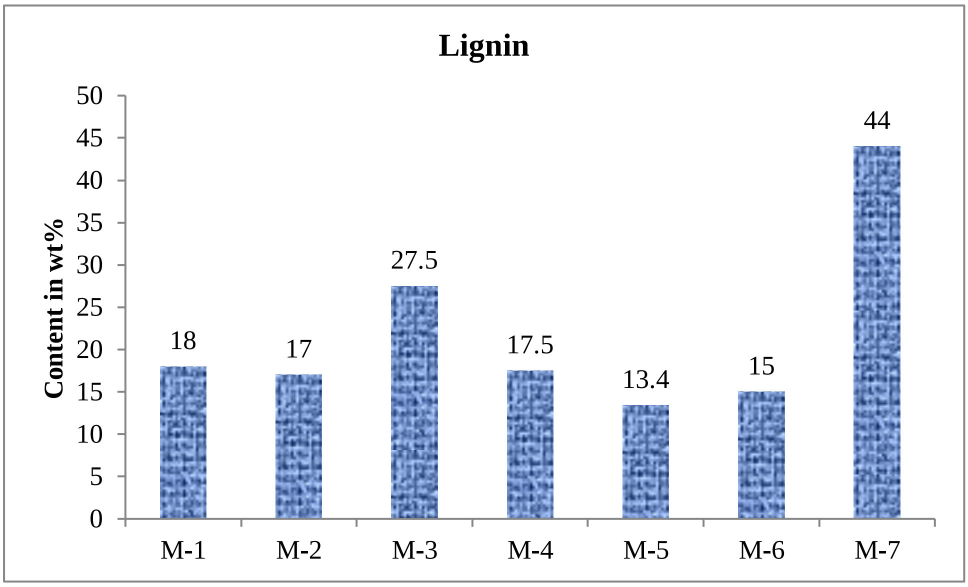

Figure 4 Lignin contents of the selected materials

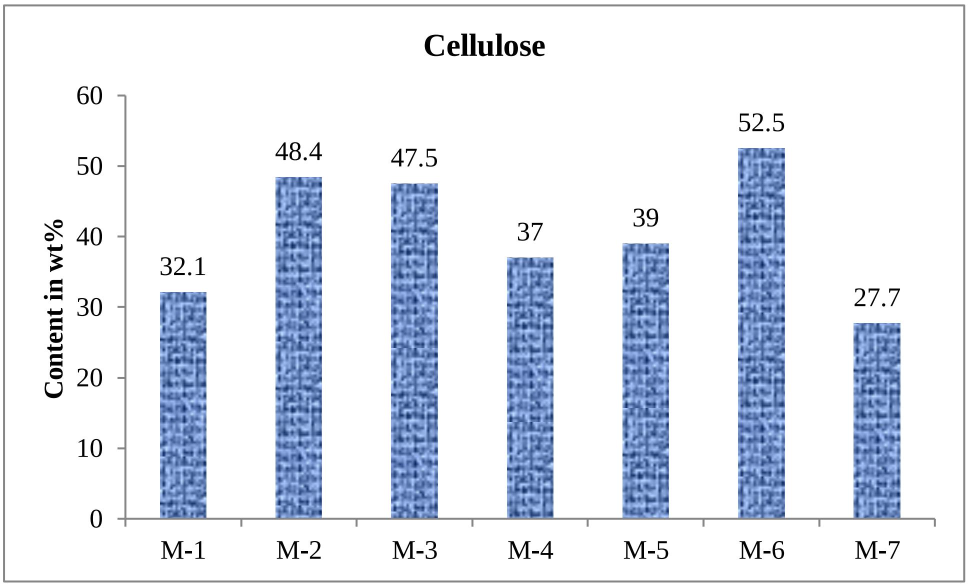

Figure 5 Cellulose contents of the selected materials

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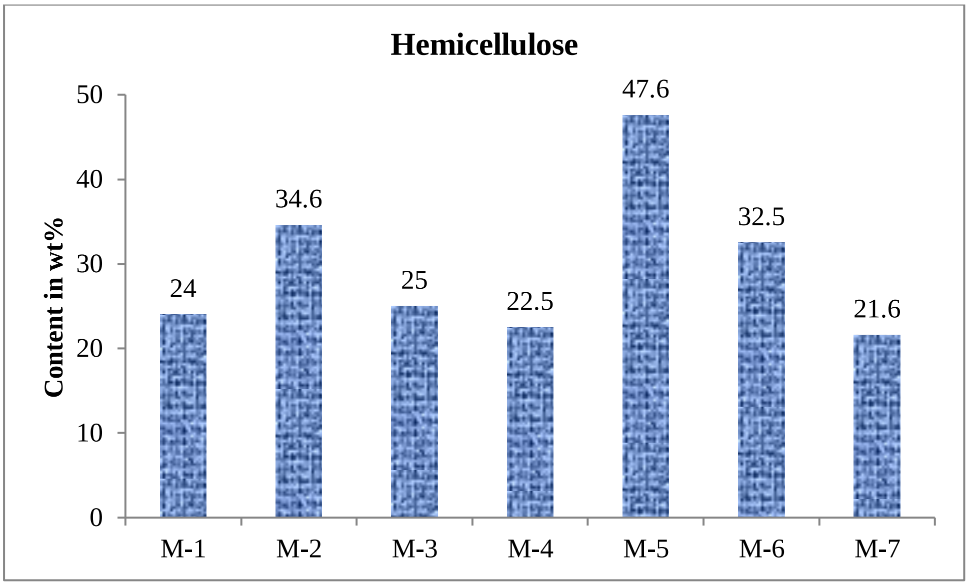

Figure 6 Hemicellulose contents of the selected material

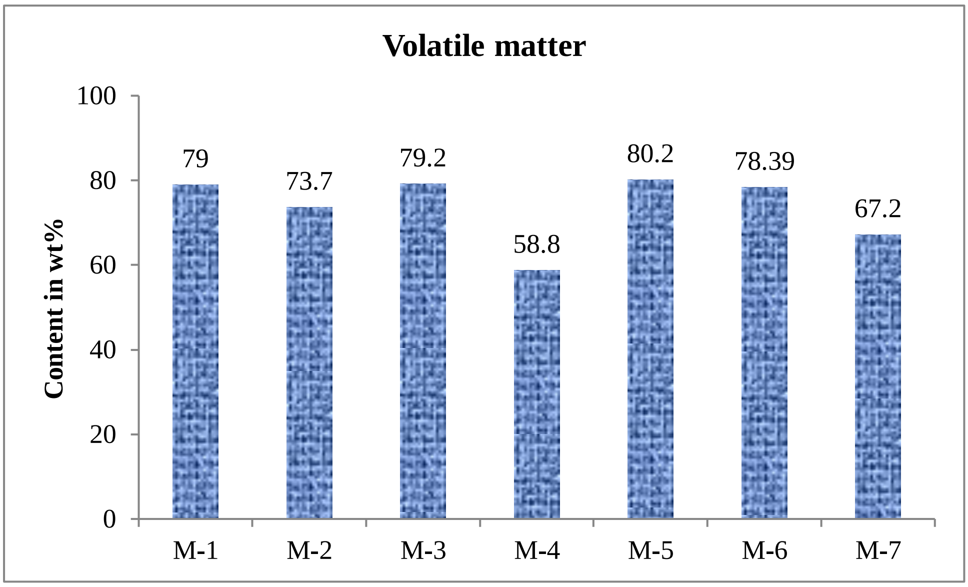

Figure 7 Volatile matters of the selected materials

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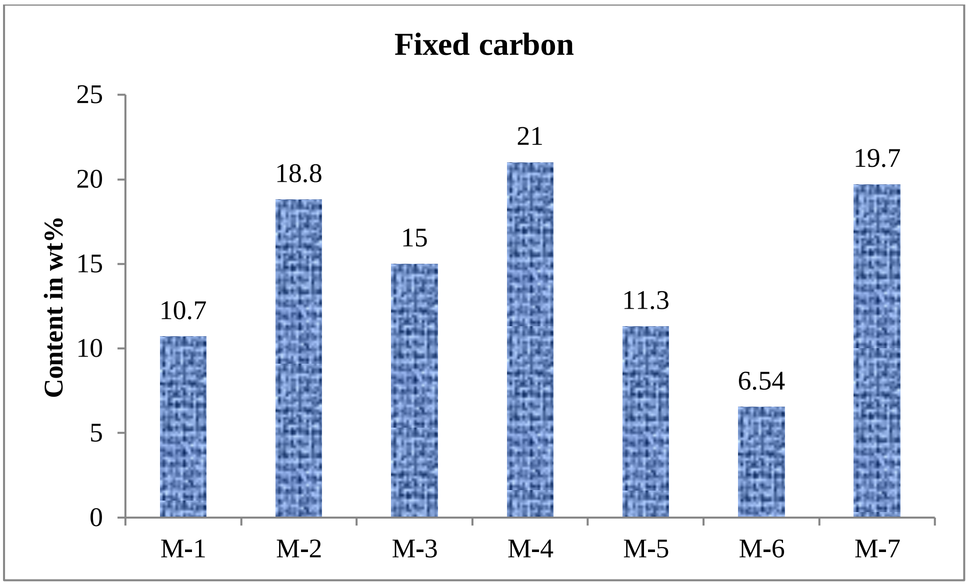

Figure 8 Fixed carbons of the selected materials

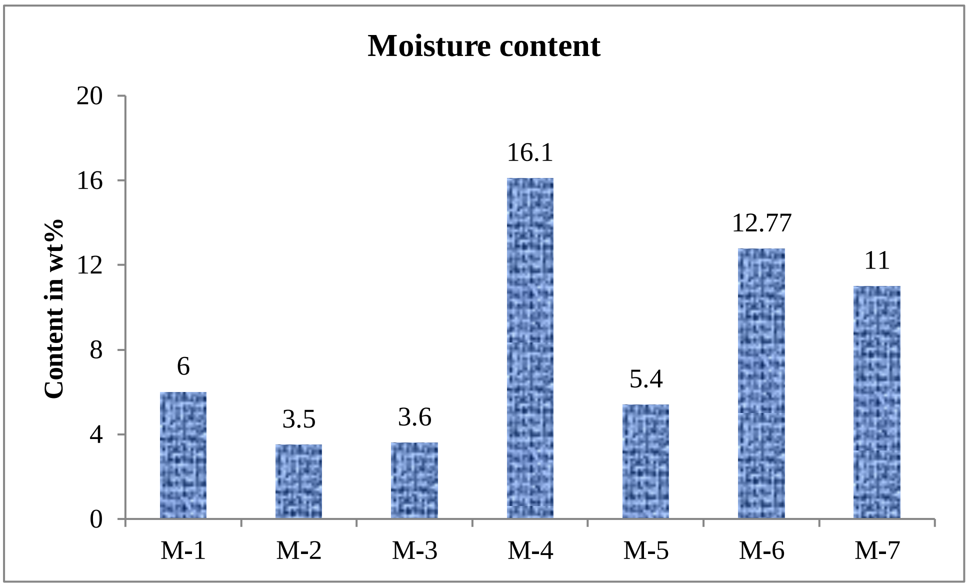

Figure 9 Moisture contents of the selected materials

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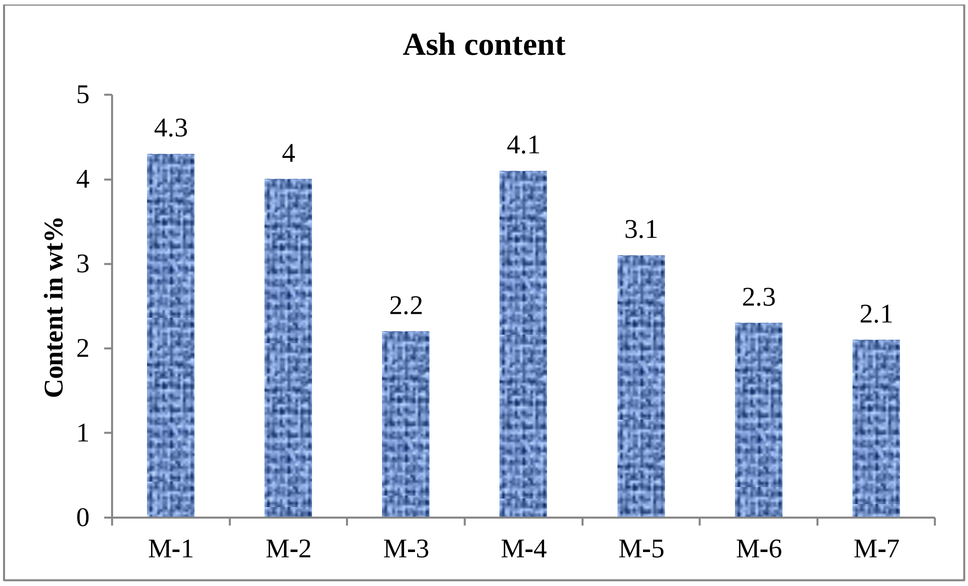

Figure 10 Ash contents of the selected materials

Different biomass materials have some unique characteristics. Analysis of material properties shown in figure 4 to 10 is very important for the selection of best biomaterial for pyrolysis. Chemical analysis biomass material is one of the most essential parts during the evaluation of reaction characteristics. In biomass, cellulose and lignin are often considered as the most important components [28]. The lignocellulosic content of materials is measured using the conventional wet chemistry technique. It is suggested as the best approach for analysis of lignocellulosic contents [29]. Figure 1 shows the lignin content and Figure 2 shows the cellulose content present in the material1 to 7. According to the data, the lignin content of the materials is varied from 13.4 wt% to 44 wt%. It can be clearly shown that M-5 has lower lignin content but M-7 has higher lignin concentrations. Generally higher lignin contents of the material slower the pyrolysis reaction yielding maximum char. The presence of cellulose in the material enhances the thermochemical conversion yielding maximum liquid products [30]. The values of cellulose in the selected materials are varies from 27.7 wt% to 52.5 wt%. The material M-6 contains the highest amount of cellulose content of all the samples and M-7 has the lowest. With reference to lignin and cellulose content, M-6 may be suggested as a suitable material, but the hemicellulose content of the material M-6 is lower than the M-2 and M-5. The presence of hemicellulose content of the material also enhances the conversion of material to biofuel during pyrolysis. The total content of the cellulose and hemicellulose is termed as holocellulose favour for the yield of biofuel. Based on the above said three properties, the favourable material for yielding maximum biofuel cannot be suggested without deep investigation. Material with more volatile contents produces more bio-oil and biogas, while material with higher fixed carbon yields more char particles. The selected sample is having more amount of volatile contents (58.8 wt% to 80.2 wt%). Based on volatile contents M-5 can be suggested as best one for maximum energy conversion. The presence of fixed carbon in the material is ranging from 6.54 wt% (M-6) to 21.0 wt% (M-4). The material's moisture content has an impact on the heat transfer phenomena during energy conversion[31]. The material with lower moisture content always yield the fuel with higher energy content [32]. According Figure 9, the moisture content of the materials is varied from 3.5 wt% to 16.1 wt%. From figure it can be shown that M-2 has lower moisture content whereas M-4 has more. The analysis was carried out in accordance with ASTM procedures to

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determine the proximate analysis (VM-ASTM D3175, FC-By difference, MC-ASTM D3173, AC-ASTM D3174). The increased moisture content in the material significantly affects the oil quality. As a result, the best material for pyrolysis should have most of volatile matter, fixed carbon, and lowest moisture and ash content. Based on the above characteristic study, the properties such as cellulose, hemicellulose, volatile matter and fixed carbon are considered as beneficial (High are better) and lignin, moisture and ash contents are considered as non beneficial (low are better).

4.3 Ranking of the material

The fuzzy pairwise comparison matrix for weight calculation using type-1 fuzzy AHP is shown in Table 1. The weights are derived using geometric mean method [33]. The type-1 fuzzy weights are defuzzified to obtain the crisp numeric weights, which are further normalised to obtain the final weights of criteria. These values are reproduced by multiplication with the evaluation matrix to get preference score. Table 2displayed the weighted normalised evaluation matrix. The graphical representations of the ranks are also shown in Figure 11. It can be seen that,sugarcane bagasseis the best alternative having rank 1. The next best material is hard wood ranked 2. The ranks are obtained based on the preference score shown in Table 3 and Table 4 shows the ranks of the selected biomaterials based on the preference score. The Lignin percentage of sugarcane bagasse is so low compared to other materials, the lower lignin level of 13.4% and greater hemicellulosic content of 47.6% forecasts the best option for optimum bio-oil production. The moisture level of the sugarcane bagasse is also quite low, at only 5.4 wt%.As a result, sugarcane bagasse provides greater quality and has a higher heating value. The quality of the oil is generally affected by the water content of the biomass feedstock [34]. Various researches have also confirmed this. One of the reasons for the superior quality of the bio-oil is the lower ash level of the sugarcane bagasse [35]. Wheat straw has higher moisture content than other biomass materials, as well as a lower cellulose content, which means it has a lesser chance of producing maximum bio-oil yield [36]. As a result, it was placed seventh among the other selected materials. During thermochemical conversion processes, there is a strong relationamong the degradation of volatile contentsand the rise in product yield [37]. The production of biofuels results in a 90 % loss of their volatile constituents [38]. Even if rice straw and sugarcane bagasse have the same quantity of volatile matter, higher level of hemicellulose and lower ash content in sugarcane bagasse may be the key reason for its ranking among other biomass materials and for the prediction of acceptable biomass.

Table 1 Type-1 fuzzy pairwise comparison matrix for weight calculation

	P-1	P-2	P-3	P-4	P-5	P-6	P-7
P-1	(1,1,1)	$\left(\frac{1}{5},\frac{1}{4},\frac{1}{3}\right)$	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$	$\left(\frac{1}{7},\frac{1}{6},\frac{1}{5}\right)$	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$	(1,2,3)	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$
P-2	(3,4,5)	(1,1,1)	(1,2,3)	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$	(2,3,4)	(2,3,4)	(1,2,3)
P-3	(1,2,3;1),	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$	(1,1,1)	$\left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right)$	(1,2,3)	(2,3,4)	(1,2,3)
P-4	(5,6,7;1)	(1,2,3)	(2,3,4)	(1,1,1)	(4,5,6)	(5,6,7)	(3,4,5)

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P-5	(1,2,3;1)	$\left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right)$	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$	$\left(\frac{1}{6},\frac{1}{5},\frac{1}{4}\right)$	(1,1,1)	(2,3,4)	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$
P-6	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$	$\left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right)$	$\left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right)$	$\left(\frac{1}{7},\frac{1}{6},\frac{1}{5}\right)$	$\left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right)$	(1,1,1)	$\left(\frac{1}{4},\frac{1}{3},\frac{1}{2}\right)$
P-7	(1,2,3)	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$	$\left(\frac{1}{3},\frac{1}{2},\frac{1}{1}\right)$	$\left(\frac{1}{5},\frac{1}{4},\frac{1}{3}\right)$	(1,2,3)	(2,3,4)	(1,1,1)

Table 2 Weighted normalised evaluation matrix

	P-1	P-2	P-3	P-4	P-5	P-6	P-7
M-1	.0449	.1255	.0689	.3577	.0420	.0251	.0533
M-2	.0476	.1892	.0994	.3337	.0737	.0431	.0573
M-3	.0294	.1857	.0718	.3586	.0588	.0419	.1042
M-4	.0462	.1446	.0646	.2662	.0824	.0094	.0559
M-5	.0603	.1525	.1367	.3631	.0443	.0279	.0739
M-6	.0539	.2052	.0934	.3549	.0256	.0118	.0996
M-7	.0184	.1083	.0620	.3043	.0773	.0137	.1091

Table 3 Preference score

Alternatives	Preference Score
M-1	0.7156
M-2	0.8433
M-3	0.8492
M-4	0.6690
M-5	0.8577
M-6	0.8429
M-7	0.6923

Table 4 Ranking of the material based on preference score

Alternatives	Rank
RS (M-1)	5
SS (M-2)	3
HW (M-3)	2
WS (M-4)	7
SB (M-5)	1
CC (M-6)	4
PS (M-7)	6

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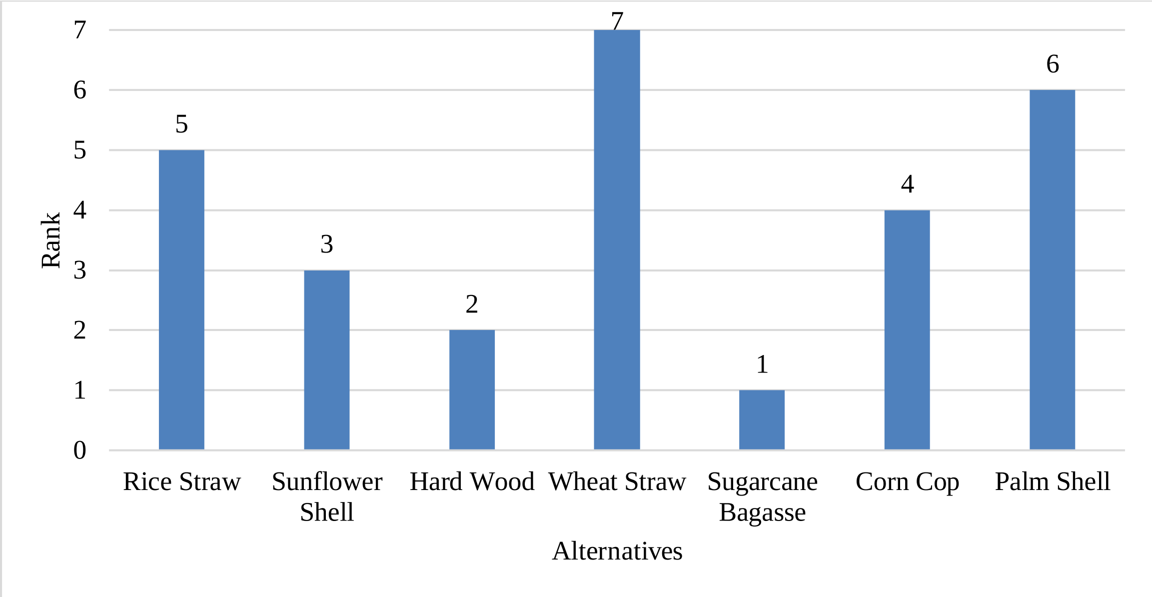

Figure 11 Rank of the biomaterial

Conclusion

In this study, type-1 fuzzy set approach was used to design a mechanism for selecting optimal biomaterial for the pyrolysis process for maximum bio-oil yield.The type-1 fuzzy set was suggested which helps in the process of selecting suitable biomass materials among a large number of available alternatives. By considering seven evaluationcriteria, this study gives the ranking order of the materialsbased on theperformance score and the order was sugarcane bagasse> hard wood> sunflower shell> corn cop> rice straw> palm shell> wheat straw.For a particular biomass material selection problem, this method considers biomass material selection qualities and their interrelationships. This method yields significant results and also establishes a link between previous studies for appropriate material selection for optimal bio-oil yield. The results provide confidence and this approach can be applied for other thermo-chemical conversion processes in order to identify the best biomaterial.

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