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Production of renewable fuels and chemicals by combining hydrothermal pretreatment with thermochemical conversion of woody biomass towards solid waste management

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Finding an ecologically and economically viable technique of processing biomass to produce biofuel is a vital one. Upgrading biomass for thermochemical processes using high temperature water (HTW) treatment is discussed in this study. In the present investigation, *Ficus religiosa* biomass is pretreated with HTW and pyrolyzed at temperature ranges from 350 °C to 550 °C. A fixed bed pyrolysis system is employed to convert raw biomass into valuable liquid and solid products. The liquid oil and char obtained through the pyrolysis process are characterized using different physical analysis. The chromatographic technique of gas chromatography mass spectroscopy (GC-MS) is also employed for the analysis of end products. The HTW treatment has been found to stimulate the synthesis of high energy value char and boost the product yield. The pretreatment is also more effective towards the production of aliphatic compounds.

Keywords: Biomass, Char, Hydrothermal pretreatment, Liquid oil, Pyrolysis

Introduction

The search for alternate and sustainable energy sources has become necessary due to the increased cost of fossil fuels and their continuous depletion. There are many different types of biomass, which have drawn significant interest as a carbonaceous resource. It is utilized to produce fuels, heat, power and chemicals[1]. Agricultural outcomes, forest wood, algae, municipal wastes and sludge are some of the important biomass used for producing fuels and chemicals[2,3]. The only carbon-containing renewable energy source is lignocellulosic biomass, which is obtained from agricultural and forestry waste. They have three main components, such as lignin, cellulose and hemicellulose, with a minimum quantity of extractives and inorganic ash. They are the main reason for the rigid structure of the biomass material[4]. Compared to coal, biomass is a solid fuel having higher moisture and volatiles when it is heated, causing its mass breakdown and energy-rich products.

Biochemical and thermochemical processes are the effective processes that can transform any biomass material into fuels and chemicals. Methane and alcohol are the important products obtained through fermentation and digestion processes. Pyrolysis is the heating of an organic substance like biomass without oxygen. It is the novel method to convert lignocellulosic material into energy rich product. It is the only method to yield three types of products such as solid, liquid and gas. Pyrolysis is the primary thermochemical conversion process that aids in decomposing organic compounds into fuels and chemicals in an air-free environment[5]. The distribution of the solid, liquid, and gaseous products is highly influenced by the characteristics of the selected material and operating parameters. Fast pyrolysis at higher heating rates with shorter residence time can yield up to 75 wt% of the pyrolysis liquid[6]. The explanation regarding the pyrolysis reaction is a principally challenging one since it evolves an unlimited number of physiochemical transformations to produce a variety of products. Many authors[7-9] studied and published the pyrolysis process model, process kinetics, and product distributions in various regions and times. In addition to that, different reactors, different feedstock, techniques and measurements have been employed in their work. In this respect, pyrolysis has been elaborated as an effective process to transform

any organic matter into energy-rich products[10]. Among three pyrolysis products, pyrolysis liquid is deliberatedas good rank and predicted as a future fuel, while the char obtained through pyrolysis can be utilized as a soil amendment[11]. When compared to traditional fossil fuels, pyrolysis liquid can be viewed as a good environmentally friendly fuel due to the extremely low levels of toxic emissions. These liquids can be further utilized for producing electricity and heat. However, these pyrolysis products are considered unsuitable for some applications due to poor qualities such as higher oxygen, lower carbon and hydrogen content etc[12]. In order to enhance the product qualities, various physical and chemical methods are adopted. These techniques can be used at several stages, including pre and post-pyrolysis.

Various types of biomass with a variety of techniques have been utilized to improve the quality of pyrolysis products[13,14]. In this connection, Ennaert *et al.* used zeolite catalyst for the conversion of biomass into energy-rich biofuel[15]. Dhanalakshmi *et al.* used Nano-HZSM-5 Zeolite to convert cotton shell and plastic waste into biofuel[16]. The feedstock with catalyst produced 4.21% more pyrolysis oil than the conventional pyrolysis method. Sujith *et al.* blended ZSM-5 with sugarcane bagasse to produce pyrolysis oil[17]. The authors demonstrated higher pyrolysis oil through the catalytic process than through the traditional non-catalytic process. Based on the selection of catalysts, a variety of chemical processes, including cracking and condensation, take place during pyrolysis[18]. The catalyst in the pyrolysis process supplies the necessary space for catalytic reforming in order to get the desired end product. In many cases, the pyrolysis oil is upgraded to high grade fuel through various chemical processes. During upgradation, the oxygen molecules present in the oil have been removed to produce high-energy liquid products. It is also necessary to alter some of the other properties, such as viscosity, chemical instability and corrosiveness[19]. Catalytic cracking is one kind of upgrading process that eliminates oxygen as water and carbon dioxide with the aid of zeolite[20]. Hydrodeoxygenation is another upgrading technology that has drawn a lot of interest in order to turn unprocessed pyrolysis oil into biofuel. According to Hassan *et al.*, it causes higher molecular components to break down into smaller ones[21]. The problems related to lower heating value, higher viscosity and poor stability can be rectified through transesterification of pyrolysis oil[22]. According to Wang, the esterified oils have decreased acid numbers, water levels and viscosities[23]. Furthermore, the esterification produces significant phenol residues. There has been a significant amount of research on esterifying bio oil to improve its characteristics[24].

Pretreatment of biomass feedstocks has been investigated by various researchers to enhance the characteristics of pyrolysis oils[25-27]. Acid and alkali treatment, wet torrefaction, ammonia fiber expansion, steam explosion, hydrothermal and biological methods are the various types of pretreatment used for treating pyrolysis feedstocks. Pretreated raw materials used for pyrolysis enhance the production of pyrolysis oil by minimizing volatile matters and ash and also significantly influence the structure of the char and its basic characteristics. Physical, chemical and biological methods are the common types of pretreatments. Torrefaction, steam explosion and washing have been used for the pyrolysis process. These processes can produce more pyrolysis oil with fewer inorganic traces[28]. Torrefaction before pyrolysis increases the generation of aromatics while reducing water and acids. It is possible that acid-leaching the biomass before pyrolysis increased the catalyst's lifespan. This is due to irreversible deactivation during pyrolysis. It is essential to interfere in the pyrolysis reaction in order to improve the properties and maximize the quality of the products. At present, pretreatment of feedstocks, process management, and upgrading are the three major strategies[29]. Water treatment and acid washing are the most popular biomass treatment methods. Chemical pretreatment further reveals that the distribution of products from pyrolysis can be considerably improved by eliminating naturally existing alkaline metals[30]. The biological pretreatment procedure has some significant drawbacks, including a very long retention time and a high investment cost[31]. The cost of chemicals and their byproducts, on the other hand, are the two most significant issues with chemical pretreatment procedures[32]. Compared to other types of pretreating techniques, treating biomass with HTW reduces the amount of pollutants as well as the cost. It is the most effective way since it needs low energy input. Previously, wells and their teams treated Napiergrass and energycane with hot water to increase the yield of sugar[33]. Due to HTW treatment, the maximum glucose yield was achieved by napiergrass and this yield was anticipated to rise with increased temperature and enzyme loading. Zhang *et al*. applied liquid hot water treatment to dislocate

the structural arrangement of rice straw to enhance degradation rate[34]. During this process, the methane yield was reduced considerably, with improved nutritive value. Recently, Alayont and their teammates applied HTW treatment for treating wild mustard biomass[35]. The treated biomass was utilized for pyrolysis, and the pyrolysis oil products were characterized. During their investigation, the HTW treatment considerably affected the formation of mono aromatics in the pyrolysis oil. Based on these results, it was decided that more research should be done on biomass pretreatment for pyrolysis.

In this study, *Ficus religiosa* was utilized as material for the pyrolysis towards the production of high-performance liquid and char products. Considering the previous literature, the HTW treatment method was adopted to treat the raw material. The HTW treatment was chosen for this study due to its economic viability and efficiency. Pyrolysis is preferred for this investigation over other thermochemical conversion methods because it is less expensive to implement and has significantly more stable operating conditions.

Experimental Section

Biomass selection

The *Ficus religiosa* plant was selected for this study. The plant belongs to the Moraceae family native to India and China. The tree can grow up to 100 feet in height. The tree is grown throughout India. It is mainly grown in State of Haryana, Bihar, Kerala and Madhya Pradesh. It grows in all seasons throughout the country. The tree has a lifespan of roughly 1000 years. The residues of the tree were collected in the residential area of Coimbatore, India. The tree produced a huge amount of residues every year. The residues are commonly used for household cooking. The open burning of these residues is creating huge emissions to the environment. These residues were cut into small pieces and dried with the aid of a furnace to remove their moisture. The precursor is then kept in a separate bag to conduct a characterization study. The same material was utilized for a flash pyrolysis experiment by one of the co-authors and reported in the literature[36]. Proximate and ultimate analysis of the material was done to find its characteristics shown in Table 1. From the table, it was found that the material has higher volatile matters with a low level of moisture. The ultimate analysis of the sample was done on ash free basis. The higher the volatile matter, the better is the pyrolysis reaction for producing biofuel. The characterization study was done by keeping ASTM protocol. The lignocellulosic content of *Ficus religiosa* includes lignic (38.6%), α-cellulose (35.1) and hemicellulose (26.3%).

Reactor arrangement

The treated and non-treated biomass materials were pyrolyzed with the help of a fixed bed reactor. The reactor, 50 mm in diameter, is placed in an electric heating furnace. In order to resist the heat loss from the reactor, the reactor is perfectly insulated with the insulating material (Chromel alumel and mineral wool). Two K type thermocouples have been attached within the reactor to measure the temperature of the bed. In order to keep the constant temperature throughout the experiment, the temperature of the reactor was controlled by an auto transformer and cut off unit. For each batch of experiments, 50 g of material was loaded. To load the biomass into the reactor, the reactor is opened manually and closed tightly. The height of the reactor bed is 150 mm. In order to avoid entering the atmospheric air within the reactor, it is completely sealed. The experiments were performed by varying the temperature of the reactor. The reactor was designed to pyrolyze the lignocellulosic material up to the maximum of 1100°C. The temperature was fixed based on the TGA report. The samples were pyrolyzed for up to 30 min and the evolved gas was condensed in a water-cooled condenser. The condenser was circulated with ice water maintained at the temperature of 5°C. The condensable volatiles passing through the condenser will be condensed and converted into liquid. The cooled char sample was collected and stored for further analysis.

Initially the experiments were conducted using non-treated biomass. For this 50 g of feedstock were loaded in the reactor. The temperature of the reactor was changed from 350°C to 550°C. The size of the

Table 1 — Properties of *Ficus religiosa*

Content (wt%)	Volatile matter	Fixed carbon	Moisture	Ash	C	H	N	S	O[¥]	HHV
Value	72.4	16.3	6.1	5.2	48.1	6.3	2.0	0.4	43.2	17.04
ASTM standard	D3175	By difference	D3173	D3174	D5373	D5373	D5373	D5373	By difference	D445

[¥]By difference

particle loaded inside the reactor was kept less than 1.0 mm. The heating rate of the reactor for all the experiments were fixed as 20 °C/min. After conducting the experiments with non-treated biomass, the HTW treated samples were kept inside the reactor and the experiments were carried out.

Pretreatment

The hydrothermal pretreatment method used by HTW is frequently carried out between 150 and 250°C. This process is very simple and does not require any special types of reactors. It is regarded as more inexpensive and straightforward. This process is primarily used to change the structure of the cell wall, hemicellulose and lignin content to breakdown into soluble components. The biomass was treated by following the procedure mentioned in the literature[37]. For treating, 500 g of samples were placed in a flask with 6 L of deionized water and processed in a high-pressure autoclave device kept at 175 °C for 1 h. After that, the biomass was then heated to 100°C for 5 h in a hot air oven to eliminate any remaining moisture.

Results and Discussion

Thermal degradation study

Thermal degradation behaviour of the *Ficus religiosa* shown in Fig. 1 has been explained in the literature and further elucidated in this section[36]. The analysis was performed using TGA701 (LECO Corporation, Michigan) analyzer. For TGA and DTG analysis, the material was heated to 800°C at 20 °C/min. The thermal decomposition manifests gradually and follows a definite course, as seen by the curves. Generally the biomass will be stable till it reaches 150°C with no major weight loss. This stage represents the evaporation of moistures and extractives. Hemicelluloses typically break down into acetic acid and furan from 200 to 250°C. The first peak, related to the breakdown of hemicellulose, appeared at 260°C. The hemicellulose in the sample breaks down at this stage to produce condensable volatiles and solid products[38]. The second peak begins to form, signifying the breakdown of cellulose. The breakdown of the whole material is essentially over at a temperature of 420°C. The decomposition of lignin exhibits a slight mass loss at high temperatures. The greatest mass loss was observed from 370 to 470°C. It is due to the breakdown of cellulose and hemicellulose content of the biomass. The decomposition of these two components represent the greater mass loss during the temperature period. The greatest mass loss was observed from 370 to 470°C. The TGA curve displays a char yield of about 20 wt%.

Pyrolysis of untreated sample

Pyrolysis of untreated biomass and its product distribution with respect to temperature is revealed in Fig. 2. The production of char decreased as the bed temperature increased. Increasing temperatures may cause more primary breakdown or secondary decomposition of char leftovers, which would result in a drop in char production. At 350°C, the char yield was 40.3 wt%, but it dropped to 23.8 wt% at 550°C. The higher output of char at moderate temperatures is due to the partial pyrolysis of untreated biomass[39]. The yield of liquid increased slowly from 30.1 wt% to 35.6 wt%. At 450 °C, a maximum yield of liquid was observed (39.2 wt%). The primary reactions are more prevalent at lower temperatures. As reaction temperatures rise, more vapour is formed, which leads to more condensed vapour collection. However, as the temperature rises, the secondary reaction within the reactor reduces the liquid yield[40]. The gas yield is increased slowly regarding increased pyrolysis temperature. The gas yield increased by 37.16% at 550°C when compared to 350°C. The yield of liquid increased with temperature, although at elevated

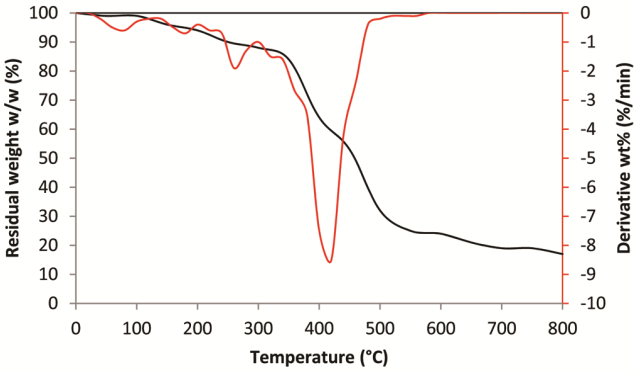

Fig. 1 — Thermal degradation characteristics of *Ficus religiosa*

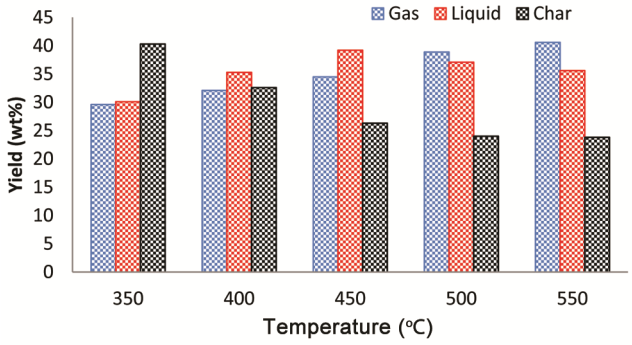

Fig. 2 — Product distributions from untreated sample

temperatures, the opposite reaction is recorded, as seen in the earlier research[41].

Pyrolysis of treated sample in HTW treatment

The experimental yields during pyrolysis of HTW treated biomass are represented graphically in Fig. 3. The figure illustrates how temperature affects the yield of liquid, char, and gas. The best option for cellulose hydrolysis is the use of water as the process medium because it avoids the requirement to dry wet feedstock. Additionally, the existence of water makes it possible for polar sugars and furan to dissolve at higher levels, giving it a significant gain over alternative nonpolar chemical solvents[42]. As a reactive solvent and medium for pyrolysis, water further exemplifies its remarkable qualities[43]. In particular, the breakdown of polar bonds by water is exposed to increased reaction[44]. During the normal decomposition process, the lignocellulosic content of the biomass attains three consecutive steps, such as the formation of free radicals, dissolution and decomposition. From the previous section, it was noticed that temperature is the significant parameter that determines product yields. Further the temperature of the process affects the pretreated raw material. The pretreatment considerably alters the structure of the lignocellulosic biomass. From Fig. 2, it is shown that pretreatment affects the product yields of different reaction processes. As observed in the previous section, temperature-dependent behaviour was also observed for the pretreated biomass. It was discovered that HTW pretreatments affected the production of liquid and char. The highest liquid production was observed as 37.6 wt% through treated biomass. At 450°C the yield of liquid was 37.6 wt% which is 4.08% lesser than the liquid obtained from original biomass. At the same temperature, the yield of char was increased by up to 8.75%.

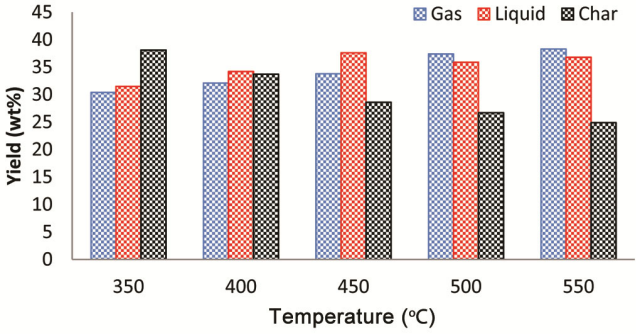

Fig. 3 — Product distributions from HTW treated sample

Characterization study

Component analysis

The elemental analysis of the liquid and char produced at 450°C from nontreated and treated biomass were analyzed. To identify the elements, the CHNS Analyzer (N2410650, Perkin Elmer Ltd., US) is used. Along with the elemental compositions, the heating value of the products was also analyzed using a thermometric calorimeter. Table 2 illustrates the results of the analysis of liquid and char. From the analysis, it came to know that the energy value of both liquid and char produced from treated material was more than non-treated material. The higher energy values of the liquid and char are 18.94 and 14.77 MJ/kg, respectively. Parr- 6772 (Parr Instrument Company, Moline) bomb calorimeter is used for the analysis of heating value of the samples. The HHV was increased by up to 6.17% and 21.86% for liquid and char products by utilizing treated biomass. The increased carbon content and reduced oxygen level with the HTW treated product is the cause of increased heating value. The liquid with HHV can be used as fuel for heating purpose. The char with higher carbon can be utilized as an absorbent and a fuel[45,46].

GC-MS analysis

Gas chromatography (GC) is a very useful separation technique that is widely employed for detecting thermally stable components. Mass spectrometry (MS) combined with GC offers explicit characterization information. GC can be used to quantify more accurately with higher sensitivity. Helium gas was employed for this analysis as the carrier gas, and the flow rate through the column was set at 1 mL/min. A DB-35 column was used for the separation. The oven's

Table 2 — Properties of the products

Product	Method	C	H	N	S	O	H/C	O/C	Empirical formula	HHV
Liquid	Non-pretreatment	45.12	8.30	0.83	0.21	45.54	2.191	0.757	$CH_{2.191}N_{0.015}O_{0.757}$	17.84
	Pretreatment	46.07	8.41	0.84	0.22	44.46	2.175	0.724	$CH_{2.175}N_{0.015}O_{0.724}$	18.94
Char	Non-pretreatment	54.14	1.56	0.76	0.09	43.45	0.343	0.602	$CH_{0.343}N_{0.012}O_{0.602}$	12.12
	Pretreatment	59.31	1.74	0.81	0.08	38.06	0.349	0.481	$CH_{0.349}N_{0.011}O_{0.481}$	14.77
ASTM standard		D5373	D5373	D5373	D5373	By difference	-	-	-	D445

isothermal program had a starting temperature of 60°C and was raised to 270°C using a standard increment of 7 °C/min. The mass spectrometric electronic ionisation spectra are compared to NIST library spectra to determine the structural information of the chemical[47]. Quantification by GC has a number of advantages and is regarded as being extremely precise[48]. Several researchers have reported using GC-MS to determine the concentration of the pyrolysis liquid obtained from biomass[49,50]. The GC-MS analysis of the pyrolysis liquid obtained from non-treated and HTW treated biomass is listed in Table 3. The procedure mentioned in our previous literature has been adopted for this study[51]. The analysis was done with the help of THERMO GC-TRACE ULTRA VER: 5.0, THERMO MS DSQ II. The liquid produced at 450°C was used for GC-MS analysis. The components of the mixture are separated and quantified using this technique based on the differences in molecular masses. In the column, the mixture is transported in a fixed phase together with helium. The result showed that both the pyrolysis liquids had different chemical compounds such as alcohol, acid, phenols, furan and esters, and it is noted that the quantity of these components in both liquids varied considerably. The produced compounds with pretreated material have

Table 3 — GC-MS analysis of the pyrolysis liquid product

S. N	Compound Name	Formula	Non treated	HTW
1	2-Furanmethanol	$C_5H_6O_2$	0.72	0.51
2	Hexadecanenitrile	$C_{16}H_{31}N$	–	0.99
3	Ethanol,2-[2-(4-pyridyl)ethylamino]-	$C_9H_{14}N_2O$	1.26	–
4	4,5,6,7-Tetrahydrophthalimidine	$C_8H_{11}NO$	3.48	2.77
5	4-Methyl-5H-furan-2-one	$C_5H_6O_2$	–	0..64
6	2,4-Dihydroxy-6-methoxy-acetophenone	$C_9H_{10}O_4$	2.10	–
7	Stigmasterol	$C_{29}H_{48}O$	1.22	–
8	Tridecane	$C_{13}H_{28}$	1.48	1.97
9	Phenol	C_6H_6O	10.34	12.53
10	2,6-dimethyl-6-(8-methyl-4-methylene-7-nonenyl)-2-cyclohexene-1á-methanol	$C_{20}H_{34}O$	0.94	1.01
11	2,3,4,5,6-Pentakis(pyrazol-1'-yl)pyridine	$C_{20}H_{15}N_{11}$	0.78	–
12	Pyrrolidine, 1-(1-cyclopenten-1-yl)-	$C_9H_{15}N$	–	2.33
13	Vanillin	$C_8H_8O_3$	0.90	0.57
14	Phenol, 3,4-dimethyl-	$C_8H_{10}O$	4.40	4.93
15	2-Isopropyl-2,5-dihydrofuran	$C_7H_{12}O$	2.18	–
16	9-Octadecenoic acid (Z)-,methyl ester	$C_{19}H_{36}O_2$	3.07	2.41
17	5-(Benzyloxymethyl)uracil	$C_{12}H_{12}N_2O_3$	1.14	–
18	Phenol, 2,6-dimethyl	$C_8H_{10}O$	3.42	3.76
19	Dodecane, 2,2,4,9,11,11-hexamethyl-(CAS)	$C_{18}H_{38}$	1.27	0.98
20	Octadecanenitrile	$C_{18}H_{35}N$	–	1.09
21	Acetic acid	$C_2H_4O_2$	3.44	3.72
22	2-methoxy phenol	$C_7H_8O_2$	4.57	3.50
23	Cholan-24-oic acid, 3,12-bis(acetyloxy)-, methyl ester	$C_{29}H_{46}O_6$	–	0.25
24	oleic acid	$C_{18}H_{34}O_2$	0.88	–
25	1,4-Dimethoxybenzene	$C_8H_{10}O_2$	2.57	–
26	Isosorbide	$C_6H_{10}O_4$	–	1.00
27	Asarone	$C_{12}H_{16}O_3$	–	1.74
28	2,7-Di-tert-Butyl-3,6-diphenylbiphenylene	$C_{32}H_{32}$	0.81	–
29	ç,ç-Dimethylallenyl - 1-ButynylSulfide	$C_9H_{12}S$	0.74	–
30	5-Tert-Butyl-1,3-dimethylpyrazole	$C_9H_{16}N_2$	2.17	1.57
31	2-Cyclopenten-tone 2-methyl	C_6H_8O	1.02	–
32	3-(4'-Bromophenyl)-5,6-diphenylimidazo[2,1-b]thiazole	$C_{23}H_{15}BrN_2S$	0.80	0.29
33	3á(-Dimethylphenylsiloxy)-5à,13à-androstane-17-one	$C_{27}H_{40}O_2Si$	0.94	–
34	Phenol, 3,5-dimethyl-	$C_8H_{10}O$	4.25	4.55
35	1-Methyl-1,3,3-triphenylindan-2-one	$C_{28}H_{22}O$	3.21	1.24
36	4-ethyl-2 methoxy-phenol	$C_9H_{12}O_2$	2.10	2.14
37	3-Acetoxy-24-methyl-5-cholest-5,22-dien-7-one	$C_{31}H_{48}O_3$	0.58	–
38	1,2-Benzendiol	C_6H_6O	0.97	1.50
39	(5à,6à)-4,5-Epoxy-17-methyl-3-phthalimidomorphinan-6-ol	$C_{25}H_{24}N_2O_4$	0.54	0.22
40	9-Octadecenamide	$C_{18}H_{35}NO$	2.10	–

(*Contd.*)

Table 3 — GC-MS analysis of the pyrolysis liquid product — (*Contd*.)

S. N	Compound Name	Formula	Non treated	HTW
41	Phenol, 2-methoxy-	$C_7H_8O_2$	3.33	3.78
42	Stigmast-5-en-3-ol, oleate	$C_{47}H_{82}O_2$	2.10	1.75
43	Benzhydryl vinyl ether	$C_{15}H_{14}O$	2.09	1.54
44	2H-Pyran, 2-(2 heptadecynyloxy)tetrahydro-	$C_{22}H_{40}O_2$	1.04	–
45	3-Hydroxy-4-methoxybenzoic acid	$C_8H_8O_4$	1.77	1.56
46	Pyrogallol 1,3-dimethyl ether	$C_8H_{10}O_3$	2.08	–
47	Piperidine-2,5-dione	$C_5H_7NO_2$	1.76	–
48	Kaempferol	$C_8H_8O_4$	–	0.88
49	1-Methyl-5-t-butyluracil	$C_9H_{14}N_2O_2$	–	0.71
50	2,3,5-Trimethoxytoluene	$C_{10}H_{14}O_3$	1.32	–
51	10-Chlorodanuphylline	$C_{24}H_{25}ClN_2O_8$	2.58	1.70
52	Butanoic acid	$C_{24}H_{34}O_6$	3.40	2.41
53	Nonadecane	$C_{19}H_{40}$	0.91	1.30
54	2,5-Pyrrolidinedione, 1-methyl	$C_5H_7NO_2$	1.55	–
55	2-Methoxy tetra hydro furane	$C_5H_{10}O_2$	1.27	1.11
56	4-Ethyl-2-methoxy phenol	$C_9H_{12}O_2$	4.56	3.47

unique characteristics. There are 56 different categories of compounds that were identified through this analysis. The majority of these substances are combinations of monoaromatics and oxygenated elements. In both liquids, phenols and their derivatives were identified more. Phenol, Phenol, 2,6-dimethyl, Phenol, 3,4-dimethyl, Phenol, 3,5-dimethyl, 4-ethyl-2 methoxy-phenol, 4-ethyl-2-methoxy phenol, and acetic acid are the common elements identified in both the liquid products. It is perceived from the table that the pretreated biomass produced lower acidic and oxygenated components than raw biomass. Phenols identified in the liquid can be used for food and pharmaceutical industries. It can be used for vaccine preservation, oral analgesics and antiseptic purposes. Apart from phenolic elements, 4,5,6,7-tetrahydrophthalimidine and 2-isopropyl-2,5-dihydrofuran is also used for chemical industries. The vanillin present in the liquid is used as a flavourings agent for food and perfumes. The acetic acid present in the liquid is used for making photographic chemicals and rubber.

Conclusion

The novel *Ficus religiosa* lignocellulosic biomass was revealed to be a promising feedstock for liquid and char production. The HTW pretreatment of the biomass at 175°C was performed in this study for the pyrolysis process. The pretreatment was directed to the solubilisation of hemicellulose and lignin content. The liquid and char products obtained from raw and pretreated biomass were analyzed. Pretreated biomass produced more char than raw biomass pyrolysis at an optimum temperature of 450°C. The pretreatment of the biomass considerably changed the properties of the liquid and char products. The carbon content and heating value of the liquid and char were increased due to pretreatment. The heating value of the liquid and char was increased by up to 6.17% and 21.86% by utilizing treated biomass. The GC-MS analysis of the liquid showed the presence of acidic and oxygenated components. The pyrolysis liquid and char with a higher heating value can be used as fuel for industrial applications. The results showed that char produced with treated biomass can be utilized as an absorbent for treating water contaminants.

Conflict of interest

The authors declare no conflict of interest.

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