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Rural Scale Torrefaction of Eucalyptus and Acacia wood: Effect on yield and functional group modification

Heena Saini[a], Oisik Das[a,*] , Sampan Kashyap[a], Manpreet Sandhu[a], Anil K. Sharma[a], Vipin Saini[b] and Pratima Labroo[c]

[a] Department of Biotechnology, College of Engineering, Maharishi Markandeshwar University, Mullana, Ambala
[b] College of Pharmacy, Maharishi Markandeshwar University, Mullana, Ambala
[c] Biological Engineering Department, Utah State University, Logan, UT, USA

Abstract

The depletion of fossil fuels lead to the investigation and development of renewable resources. Among them torrefaction is an attractive technique that increases the energy density of the biomass, makes it hydrophobic and enables the straight chain polymers to be more crystalline. Torrefaction of Acacia and Eucalyptus wood yielded blackened material and the conversion rate was higher in Eucalyptus due to lack of thick bark. From the FT-IR spectra, it was seen that the lignin monomer became prominent with torrefaction and increase in torrefied material percentage in the blends. This is attributed to the reduction in degree of polymerization of cellulose which in turn increases the dominance of guaiacyl in the torrified material and blends with higher percentage of torrefied material.

Keywords: Torrefaction, biomass, FT-IR, thermo-chemical conversion

Introduction

Energy is one of the most important building blocks in human development, and is a key factor in determining the economic development of any nation [1]. High economic growth would create much larger demand for energy and this would present the country with a variety of choices in terms of supply possibilities [2 ,3]. With the growing concern of environmental problems, the possibility of using renewable resources to meet our energy needs for fuels, chemicals and materials is receiving increasing attention. Most studies say that the global warming is a consequence of large production of the greenhouse gases from burning of fossil fuels. Economic advancement of developing nations and exhaustion of the fossil oil reserves has huge impact on the balance of demand and supply. The use of biomass aptly fits into the need for using renewable sources to drive our economic development [4, 5].

Biomass is readily available throughout the world and is used extensively for power generation. In light of many problems associated with usage of fossil fuels biomass becomes an attractive fuel because of its carbon neutral nature [4, 5]

Eucalyptus is a tall evergreen tree with the height of more than 300 feet. Juvenile shoots are opposite, sessile, cordate-ovate and covered with a bluish white bloom while the adult ones are alternate, lanceolate and are 6-12 inches long and 1-2 inches broad. The flowers of the tree are in cymose panicles and are cream in color. Its bark consists of long fibers and can be pulled off in long pieces. Eucalyptus grows well on sandy soil and it requires water before and after plantation and availability of full sunlight for growth. It is widely grown in Tamil Nadu, Andhra Pradesh, Gujrat, Haryana, Mysore, Kerala and in the Nilgiri Hill [6].

Acacia (kikar) is the small thorny tree and it grows to the height of 7 - 12 meter. The leaves are light green and fern like having 120mm length and 50mm width. Its flowers are yellow and round which are nectar less. The bark is red -brown to blackish and rough. Acacia can be grown on any type of soil but requires cold temperature for proper growth. It is widely found in the state of Haryana in India. It can also be found in the Ranthambore National Park of India [7].

India being an underdeveloped country depends on extracting energy from biomass by application of crude techniques. Also, India reverted back to wood energy due to recent energy crisis [8]. Torrefaction is a technique of thermo-chemical conversion of wood which is gaining

*Corresponding author:
Oisik Das
Assistant Professor,
Department of Biotechnology, College of Engineering,
Maharishi Markandeshwar University, Mullana, Ambala.
Email : oisik_das@wsu.edu

increased popularity due to accessible technology and valuable end product. In this process, biomass is degraded at a temperature of 200-300°C at an oxygen depleted environment causing partial decomposition of woody polymers. The torrefied solid is 30% more energy dense than the starting raw material.

Torrefied biomass has excellent combustion properties. The fuel can be readily co-processed with other biomass and/or coal, and further act as raw material for subsequent thermo-chemical conversion reactions. Moreover, the transportation of torrefied biomass is more lucrative than non- torrefied biomass. Torrefied biomass is reported to be more hydrophobic than normal coal and biomass and hence is easier to store for longer period of time. Finally, torrefied biomass is easier to grind and pulverized when compared with coal.

In an effort to reduce SO_x and NO_x co-processing of coal, biochar and biomass is applied which would reduce pollution, utilized renewable resources and offset some conventional fossil fuels. The study would provide insights on the torrefaction yields of commonly used biomass in India as well as modification of functional groups associated with blending of torrefied solid with its own raw material.

Materials and Methods

Torrefaction of biomass

Two biomass namely Eucalyptus wood and Acacia wood were torrefied in a rural scale reactor. The reactor consisted of a clay dome with holes made for the introduction of oxygen. 2 Kg of the biomasses were introduced into the reaction zone after which the reactor was sealed. The reactor was heated to a temp of 250°C and the reaction was continued for seven days. During the whole process oxygen was fed into the system from the environment through the holes.

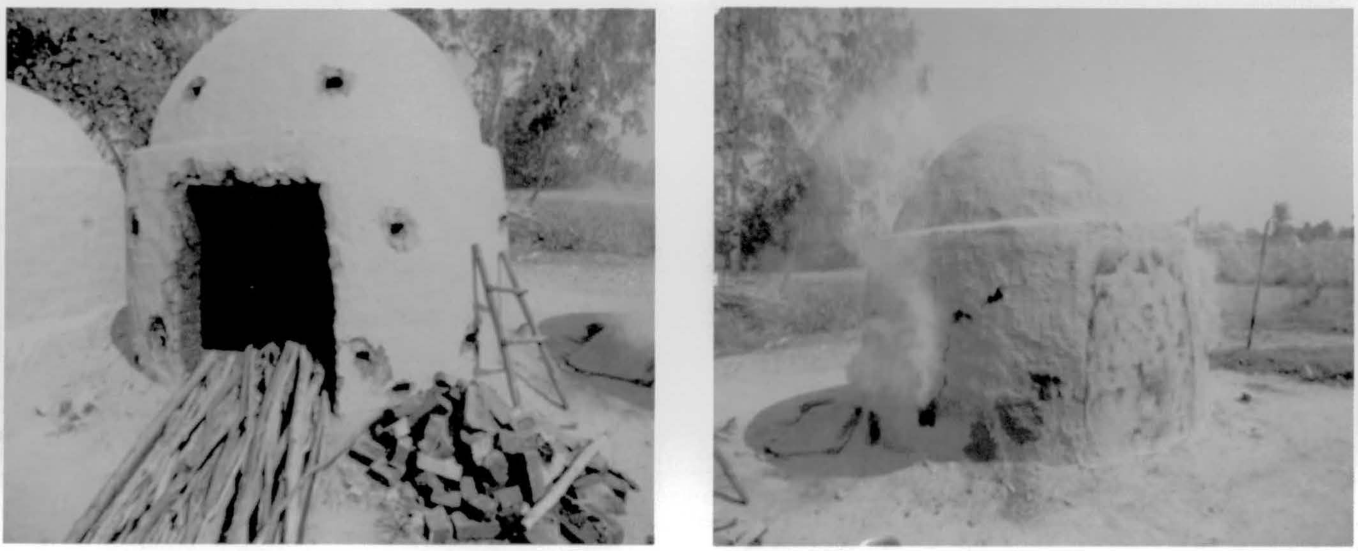

Figure 1. Torrefaction Facility

Grinding and blending

Both the biomass and their subsequent torrefied solids were ground by mortar pestle and passed through a 2 mm sieve. The blends were made between the torrefied solid and the biomass in the ration of 100:00, 70:30, 50:50, 30:70, 00:100.

Moisture content analysis

The 5g of blended samples were put into an oven at 105°C for 14 hrs. The dried sample weight was measured. Moisture content was determined based on the following formula:((Wet- Dry)/Wet) *100

Ash analysis

The blended samples were introduced in muffle furnace and were combusted at 800°C. The ash content was analyzed based on dry basis using the formula: ((Weight of blended sample-Weight of ash) / Weight of blended sample) * 100

FT-IR

The infrared spectra of the biomass, torrefied solid and the blends were collected in an IR Affinity-1 instrument with a Pike Miracle ATR compression clamp. The software used was IR solutions. For each reading 64 scans were done and average from 400 cm^{-1} to 4000 cm^{-1}.

Results and Discussion

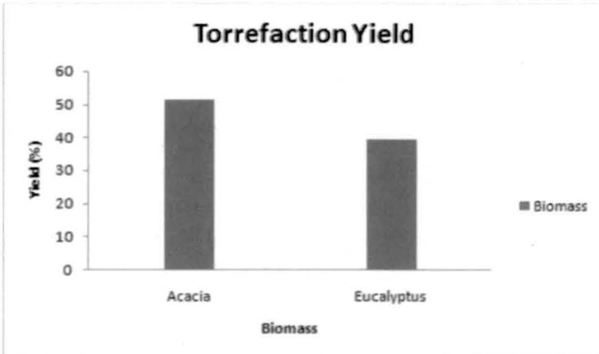

Figure 2. Torrefaction yield of Acacia and Eucalyptus wood.

Torrefaction yield

Acacia and Eucalyptus woods were torrefied and the resulting yield so observed was 51.2% for acacia and 39.3% for eucalyptus. It is clear from the graph that acacia yield was higher than the eucalyptus, however, the acacia wood didn't undergo complete conversion due to the presence of thick bark. The air space between the bark and the wood was a poor conductor of heat. In case of eucalyptus, the bark was very thin and hence it facilitated efficient propagation of heat. Hence, even though eucalyptus has lower yield it has been completely torrefied. As the temperature of the biomass particle rises, the pyrolysis decomposition reactions start to take place on a cylindrical reaction front which progresses toward the centre of the particle. However, this progress is hindered due to the absence of conducting material. As a result, the acacia wood experiences less conversion than eucalyptus wood [9].

Moisture analysis

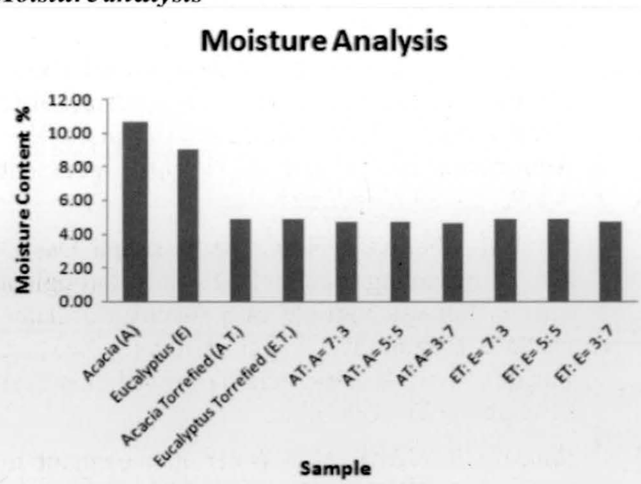

Figure 3. Moisture of Samples and Blends

From Fig. 3, it was observed that Acacia wood has highest moisture content (10.7 %) among other biomass torrefied solids and blends. The moisture content of the Eucalyptus wood was also comparable to moisture content of the Acacia wood. It was found out that the moisture content of the blends had an additive effect.

Ash analysis

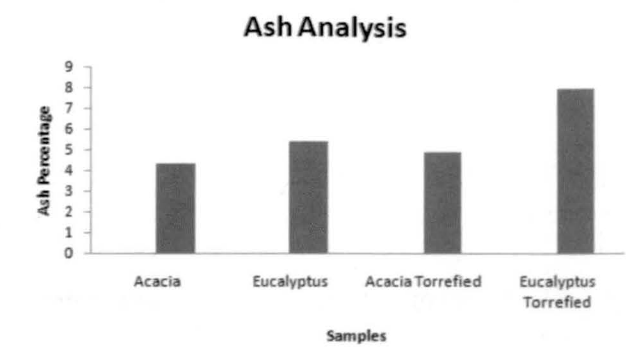

Figure 4. Ash content of Samples

From Fig. 4, it was found that the ash of Acacia was lower than the Eucalyptus by 1%. When the biomasses are torrefied the ash percentage of Acacia still remains lower than the ash percentage of torrefied Eucalyptus.

FT-IR analysis

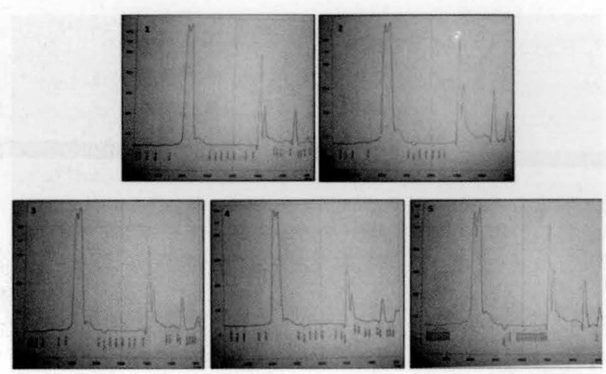

Figure 5. FT-IR spectra of Eucalyptus (E), Torrefied Eucalyptus (T.E), T.E.:E::5:5, T.E.:E::3:7, T.E.:E::7:3

The FT-IR spectra of the samples for Eucalyptus, torrefied Eucalyptus and their blends are presented in Fig. 5. It is evident that each of the samples has O-H peaks at about 3000cm^{-1}; esterified acetic acid peaks at 1500 cm^{-1} and guaiacyl monomer peaks at 700 cm^{-1}. The O-H peaks are an indication of the presence of sugars and guaiacyl peaks are indication of the presence of lignin. As cellulose, hemicellulose and lignin are present in all the samples, they exhibit similar FT-IR spectra.

During torrefaction the degree of polymerization of cellulose decreases and as a result makes the guaiacyl stretching more prominent. This is observed when the spectra of raw Eucalyptus were compared with the torrefied one. Also, in the blends, the guaiacyl became more prominent with increasing percentage of torrefied material. Hence, the straight chain polymers are more susceptible to thermo-chemical degradation.

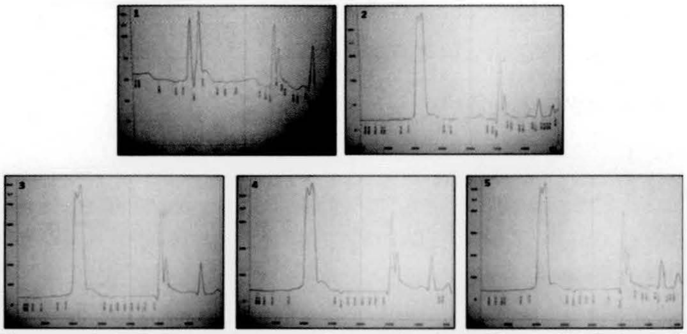

Figure 6. FT-IR spectra of Acacia (A), Torrefied Acacia (T.A), T.A.:A::7:3, T.A.:A::5:5, T.A.:A::3:7

The FT-IR spectra of the samples for Acacia, torrefied Acacia and their blends are presented in Fig. 6. It is evident that each of the samples has O-H peaks at about 3000cm^{-1}; esterified acetic acid peaks at 1500 cm^{-1} and guaiacyl monomer peaks at 700 cm^{-1}. The O-H peaks indicate the presence of sugars and guaiacyl peaks indicate the presence of lignin. As cellulose, hemicellulose and lignin are present in all the samples, they exhibit similar FT-IR spectra.

The FT-IR spectrum of Acacia follows the same trend like the spectra of Eucalyptus where due to decomposition of cellulose lignin monomer becomes more prominent.

The study provides an insight into the modification of the functional group that takes place in both Acacia and Eucalyptus after torrefaction. It also gives a picture of the arrangement of the functional groups after the torrefied material has been blended with the respective raw biomass. It was observed that the lignin monomer becomes dominant with torrefaction and increase in amount of torrefied material in blends. This concludes that the Lignin is more resistant to the thermo- chemical process of torrefaction where as Cellulose is more susceptible [10].

Conclusion

The rural scale torrefaction yield more torrefied material from Acacia wood than Eucalyptus wood. However, the quality of torrefied material from Eucalyptus wood is higher than the torrefied material from Acacia wood. This is due to the presence of bark in Acacia wood which hindered heat propagation and lead to incomplete conversion.

The bound moisture content of acacia wood and Eucalyptus wood are similar to each other. It was also seen that the bound moisture of Acacia torrefied and Eucalyptus torrefied is similar to each other. The moisture content of all the blends is around 4.5% and they are additive of the initial samples. The ash amount in both Acacia and Acacia torrefied is lower than Eucalyptus and Eucalyptus torrefied.

From the FT-IR spectra, it was comprehended that due to reduction in chain length of cellulose during torrefaction, the lignin monomer became more prominent. Hence, the functional group for guaiacyl was modified after torrefaction in both Acacia and Eucalyptus. This study leaves scope for further investigation into the dynamics of torrefaction as observed through FT-IR for different biomass that are economically viable.

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