Feasibility study of pine needles as a potential source of bio-energy

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ABSTRACT: The abundant availability of pine needles (*Pinus roxburghii*) resulted from continuous leaf shredding in pine forests of north Himalayan region. The summer forest fire in pine forests has devastating effects on local communities, cattle, wildlife, soil flora and fauna. The local communities conventionally use pine needles for fruit packaging and cattlebedding due to its lower biodegradability. The lower biodegradability results from higher lignin content of pine needle. The lignin content of biomass is also responsible for higher biochar yield upon thermochemical conversion. Therefore, the present study analyzes the potential application of pine needles for its thermochemical conversion into bio-fuel. The study asserts the suitability of pine needles for production of pyrolysis oil and biochar through thermochemical conversion.

Key words: Biochar, bio-fuel, biochar yield, pine needles,thermochemical conversion

The chir pine (*Pinus roxburghii*) forests cover approximately 1.09 million km^2 area of north western Himalayan range i.e., spread across India and other countries. The Indian Himalayan Region is stretch across 95 districts and ten states; namely, Jammu & Kashmir, Uttarakhand, Himachal Pradesh, Sikkim, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Tripura,Assam and West Bengal. The continuous leaf shredding in consistently growing pine forests (from middle of March to July) results in abundant availability of pine needles. India alone has 6.3 t/ha annual productivity of pine needles (Bhagat *et al.,* 2009; Singh *et al*., 2016). The high lignin content of pine needles leads to poor biodegradability which restricts the natural growth of soil flora. It forms a thick layer of foliage on forest bed which is a major cause of severe summer forest fire in the concerned states. The forest fire has devastating effect on wildlife, cattles, environment and soil fauna (Dwivedi *et al*., 2016). The highly inflammable nature of dry shredded pine needle possesses the potential for burning large forest areas. The fire frequency in chir pine forests of Uttarakhand has been estimated as 3-5 years and almost every stand found to have the evidences of recent forest fire. The pine trees have experienced various alterations due to frequent forest fire exposures. These trees have thick bark to protect the cambium during forest fire and the new pine needles (leaves) can re-sprout from lower branches or stem of young trees after a fire hazard. The viable seeds are released from pine cones upon high heat exposure which leads to new seed germination. The low bult density and low calorific value of pine needles restrict its application in space heating and cooking. While it's lower bio-degradability offers application as livestock bedding and fruit packaging material.The process development for efficient utilization of pine needles will results in significant forest fire reduction and renewable energy generation. Therefore, implementation of pine needles/ residue management practices for energy generation must be done for sustainable development and employment opportunities for local communities. According to the reports of Energy Information Administration (EID) the world energy demand is continuously increasing and will have a rapid increase till 2025. The economic growth and industrialization of developing countries (i.e., India, China etc.) contributes a major proportion to this increment in energy demand (USDOE, 2005). The Himalayan region suffers a lot from seasonal power shortages due to poor electrical infrastructure and transmission. The conventional methods (direct burning of fuel and wood)are highly practiced in these regions. Pine needles have great potential for conversion into fuel due to their high calorific value as compared to other biomass. There are several ways for thermochemical conversion of pine needle biomass into fuel; the biomass can be directly used for electricity generation, used in with-binder or binderless briquetting, pyrolysis and gasification. The end products of thermochemical conversion (pyrolysis, liquefaction and gasification) process are bio-oil, biochar and producer gas (Fig. 1). The different thermochemical conversion processes results in different proportion of end products. The aim of this research is to analyze the characteristics of pine needle through its composition, proximate, ultimate analyses and empirical formula. This study also evaluates the feasibility of pine needles as a precursor for thermo-chemical conversion.

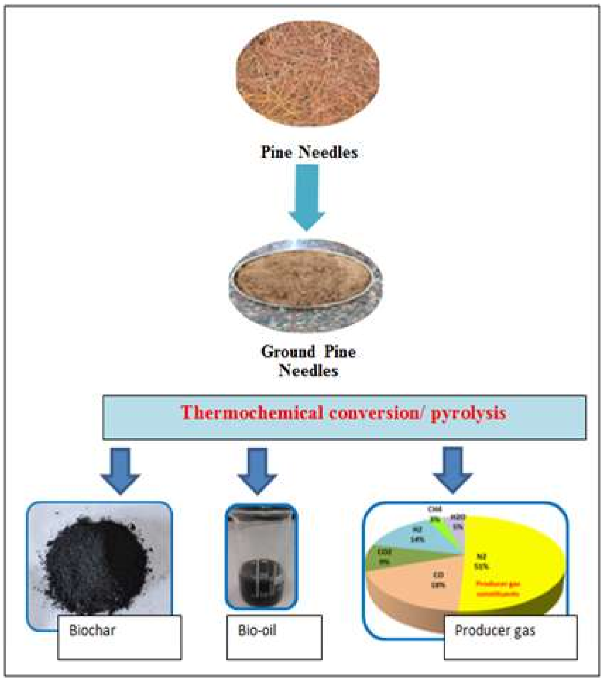

Fig.1: End products of thermochemical conversion of pine needle biomass

MATERIALS AND METHODS

The raw pine needles (*Pinus roxburgii*) biomass for the study was taken from the pine forest located in Bhowali, Nainital, Uttarakhand, India (coordinates: 29.3823°N 79.5196°E). The collected biomass was sun dried and ground to small particle size (sieve size d” 0.8 mm (I.S. sieve No. 20)) by using a hammer mill. The precursor was kept and stored in air tight containers at ambient temperature (22°C-30 °C) for analysis.

The lignin, cellulose, and hemicellulose content of biomass precursor have significant effect upon the thermal degradation process and end products. The component proportion in pine needles was determined as the method proposed by Yang *et al.* (2006). Proximate analysis was carried out to determine the moisture, volatile matter, fixed carbon and ash content of the pine needles. Moisture content, volatile matter and ash content were determined according to ASTM D 3173, ASTM D 3175 and ASTM D 3174 protocols, respectively on dry basis. The fixed carbon content was calculated by subtracting the percentage of moisture content, volatile matter and ash content from 100. Ultimate analysis (UA) refers to the procedure for determination of mass fraction of carbon, hydrogen, nitrogen and sulfur to find out the structure of biomass. Thermogravimetric analysis (TGA/DTG) of pine needles biomass was carried out under nitrogen atmosphere.

RESULTS AND DISCUSSION

Composition Analysis of Pine Needles

The extractives, hemicellulose, lignin, cellulose contents of pine needle were 16.86%, 23.27%, 31.76%, 28.1%, respectively (Table 1). Studies concluded that the biomass waste with lower extractives and higher lignin content tend to produce biochar with higher calorific value and yield (Cheng and Wang, 2018). Lignin contains higher amount of aromatic groups with greater bond energy as compared to glucose molecules series/ polysaccharide structures of cellulose.Uzun*et al*. (2007) stated that the significant weight loss of about 50% observed during heating at 200-400 °C due to quick degradation of cellulose. Though, gradual degradation of lignin observed to be spread up to 900 °C as reported by Wannapeera *et al*. (2008).

Proximate and Ultimate Analysis of Pine Needles

The moisture contents of biomass was reduced to

Table 1: Composition analysis of pine needles

Composition analysis		
Extractives (%)	:	16.86
Hemicellulose (%)	:	23.27
Lignin (%)	:	31.76
Cellulose (%)	:	28.1

7.8% (<10 wt %) by sun drying to make it appropriate for grinding and pyrolysis. Also, the water content in bio-oil increases and fuel calorific value reduces with higher moisture content of biomass. The pine needles biomass was recorded to have 2.4 % and 74.2% ash content and volatile matter, respectively. The pine needle samples found to have 2.4% ash content. Khaleel *et al*. (2015) reported that the low ash content and high volatile matter characterize any biomass as suitable precursor for pyrolysis. Ash content in the biomass affects the handling and processing costs in thermochemical conversion. The fixed carbon content was calculated as 15.6% by subtracting moisture content, ash content and volatile matter from 100. During thermochemical conversion of biomass, the significant increment in fixed carbon might be attributed to the degradation of volatile matter as suggested by Dhakate*et al*. (2019). It can be seen from Table 2 the volatile matter content in pine needle biomass is high (74.2wt%). High volatile matter of biomass facilitates better thermal decomposition and pyrolysis. The fixed carbon content was evaluated as 15.6wt%, which is similar to that of other biomass (Fernandes *et al.,* 2013).

Ultimate analysis of pine needle shows carbon, hydrogen, nitrogen, and oxygen content are 45.6, 4.8, 0.8 and 46.4 %, respectively. The results indicate that the pine needles biomass consist of substantially higher carbon content which further increases upon pyrolysis. This increment in carbon content with pyrolysis can be attributed to the volatilization and depletion of ligno-cellulosic structure of biomass as stated by Dhakate*et al*. (2019). It can also be implied from lower sulfur and nitrogen content of biomass that its thermochemical conversion process will results in minimal emissions of toxic gases (i.e.,SOx, NOx). The H/C and O/C molar ratios were calculated as 1.26 and 0.76, respectively. The H/C ratio of biomass significantly affects the yield of solid (char), liquid (bio-oil, tar) and gaseous products. The increment in H content of biomass indicates that its internal structure is more aliphatic than aromatic. The higher proportion of aromatics ensures higher yield of solid products. As it was also described in section 3.1 that high lignin content contributes to highbiochar yield. Thermochemical conversion of pinewill also result in formation of more volatiles which can be condensed efficiently as bio-oil.

Table 2: Proximate and ultimate characteristics of pine needle

Proximate analysis		
Moisture content (%)	:	7.8
Volatile matter (%)	:	74.2
Ash content (%)	:	2.40
Fixed carbon (%)	:	15.6
Ultimate analysis		
C (%)	:	45.6
H (%)	:	4.8
N (%)	:	0.8
O (%)	:	46.4
H/C	:	1.26
O/C	:	0.76
Empirical formula	:	$CH_{1.26}N_{0.05}O_{0.76}$

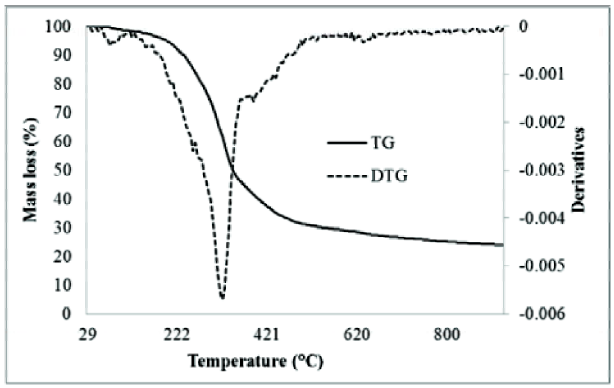

Fig. 2:Thermogrametric analysis of pine needle (*Pinus roxburghii*)

The Fig. 2 shows the TG (thermo-gravimetric), DTG (derivative thermo-gravimetric) plots of pine needles. The TG curve indicates the mass loss profile with respect to temperature and DTG curve shows the rate of mass loss with respect to temperature. The graph shows the energy change as a function of temperature during thermal decomposition of biomass (Doshi *et al.,* 2014).

The entire thermochemical conversion process of pine needles can be divided into four stages. The first stage starts at 30 °C and ends at 200 °C. The TG curve indicates relatively lesser mass loss (about 5 %) due to the removal of moisture, extractives and some of the volatile contents (Shadangi and Mohanty, 2014). The TG curve shows that the second stage ranged from 210°C to 345°C withmass loss of about 55 %. During this stage, DTG curve shows themaximum mass loss rate at 325 °C which can be attributed to the degradationof hemicellulose and cellulose. This stage is stated as active pyrolysis stage. The third stage ranged from 350°C to 500°C as evident from TG curve. As most of the mass loss took place below 500 °C temperature, it can be suggested as the central value temperature for pyrolysis of pine needle biomass.

CONCLUSION

The minimal moisture content,ash content and high volatile matter, fixed carbon of pine needle (*Pinus roxburghii*) make it a potential precursor for bio-oil production through thermochemical conversion. The lignin content, H/C ratio ensures high yield of bio-fuel and low sulfur, nitrogen content minimizes proportion of toxic emissions (SOx, NOx) in biomass/ bio-fuel combustion. An empirical formula evaluated from ultimate analysis of pine needle is given as $CH_{1.26}N_{0.05}O_{0.76}$. The thermo-gravimetric analysis suggests 200–500°C temperature range for pyrolysis of biomass. Therefore, the study concludes pine needle as a suitable precursor for bio-energy production through thermo-chemical conversion.

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