



Thermo-chemical conversion of sawdust through in-situ quenching of pyro-vapor for green fuel



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ABSTRACT

This work is focused on intermediate pyrolysis of sawdust in a 100 g batch reactor at $500 \pm 10^\circ\text{C}$. The pyrolysis vapors coming from reactor were directly quenched with chilled biodiesel from jatropha oil at $4 \pm 2^\circ\text{C}$ to obtain a suitable blend for stationary engine application. Total bio-oil yield was found to be 37% (wt.). After layer separation from the resultant mixture, biodiesel miscible bio-oil phase calorific value was found to be $39 \pm 0.5\text{ MJ/kg}$, which indicated that the bio-oil/biodiesel mixture was stable within the conditions tested and hence suitable for engine applications. The overall process provides a platform for blended biofuel, biochar as substitute of sub-bituminous coal and pyro-gas for combined heating and power application.

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1. Introduction

Current global energy supply is mostly based on fossil fuels (oil, natural gas, coal), but the sources of fossil fuels are decreasing day by day. So, for meeting the growing energy demand, alternative source of energy is being explored more extensively these days. Biofuels are one such alternative source of energy that are renewable in nature and does not generate much pollution. There are several routes for producing biofuels from biomass in which thermochemical conversion is most suitable for producing the biofuels at industrial scale. Pyrolysis is one such thermochemical conversion technique, which has the potential for higher grade green fuel for transportation along with neutral greenhouse gas emissions. Liquid oil from pyrolysis, also called as pyrolysis oil or bio-oil contains more oxygenated and chemically unstable compounds. Bio-oil from various biomass such as sawdust, several husks, straws, seeds, as potential feedstock for pyrolysis have been tested for static applications such as boilers, furnaces, turbines and diesel engines for heat, power or electricity generations (Czernik and Bridgwater, 2004).

During pyrolysis, some gases are produced containing carbonaceous components that can be condensed into oil to make it suitable as an engine fuel (Demirbas, 2007). Quenching of pyrolysis vapors

to get bio-oil in an immiscible hydrocarbon solvent is widely practiced (Bridgwater, 2012). In this context, development of blends of bio-oil from pyrolysis vapors with other transportation fuels could be a viable alternative to utilize sizable fraction of these oils by improving its oxidation stability and cold flow properties of biodiesels (Garcia-Perez et al., 2010). The result from the pyrolysis blend is found to be comparable with conventional diesel fuel in terms of thermal efficiency and reusable heat. A three-cylinder indirect injection CI engine was tested with 20% and 30% de-inking sludge pyrolysis oil (DSPO), produced by intermediate pyrolysis and by blending with biodiesel. Blends containing 20% and 30% (v/v) DSPO obtained from pyroformer unit maintained at 450°C at a rate of 15 kg/h with both biodiesel and diesel (Hossain et al., 2013). A 20 kg/h pyroformer which was coupled to a direct quenching system without filtration, proven successful around 360°C and yielded the char, pyrolysis oil, and non-condensable gas fractions of 32%, 35%, and 33% respectively. The pyrolysis oil was condensed in a quenching unit using bio-diesel or diesel. The blend produced was 30% pyrolysis liquid and 70% bio-diesel. The engine was tested with the pyro-oil/bio-oil mixture over a long term on a 7 kW lister engine and related economics has been derived to assess the quality of blend oil (Hornung et al., 2014).

Pyrolysis of sawdust has been investigated by various ways such as using entrained flow reactor (Bitowft et al., 1989), conical spouted bed reactor (Olazar et al., 2000), and fixed bed reactor (Salehi et al., 2009). Salehi et al., (2009) is one of significant recent work and it has reported that pyrolysis of sawdust in fixed-bed

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tubular reactor gives char, gas, and bio-oil yield in the range of 20–27, 36–45, and 33–45 wt.%, respectively, at different process conditions. In the present work, the aim is to convert gaseous product from pyrolysis of saw dust into bio-oil using electrically heated batch reactor in which carbonaceous compounds in vapor is stabilized with less oxygenated compounds by quenching in suitable solvents like biodiesel.

2. Materials and methods

In the present study, sawdust has been supplied by M/s Shivganga Shrikishan Agrotech Farm, Akola, India. Jatropha oil was prepared at Sardar Patel Renewable Energy Research Institute (SPRERI), V.V. Nagar, by using an oil expeller that utilizes steam generated from wood based boiler. The extracted jatropha oil was then used as feedstock for preparation of biodiesel using methanol-oil molar ratio of 6:1 and 1 % NaOH as catalyst (SPRERI report, 2007). Sawdust was first kept for sun drying followed by sieving for 0.5 mm particle size and storage. The dried sawdust was used as raw material for the pyrolysis process, which was carried out at 500 °C temperature.

2.1. Analysis methods

Proximate analysis of the samples was carried out by using the methods described ASTM E872-82. Cellulose, hemicelluloses and lignin were determined according to methods suggested by (Goering and Van Soest, 1970). FTIR was employed to analyze the functional groups available in liquid products using a PerkinElmer FT-IR spectrum 100GX model. Each spectrum was an average of 128 scans in the IR range of 400–4000 cm^{-1} at 2 cm^{-1} resolution. TGA-DTG (Model No: SDT-Q600, TA Instruments) analysis of biomass and biochar sample was done to study thermal degradation of lignocellulosic biomass. The runs were performed under nitrogen flow (100 mL/min) by using heating rate of 10 °C/min upto 800 °C. The higher heating value was determined using the bomb calorimeter (model: Advance isoperibol I.P-3, Advance Instruments Ltd). Wet type gas flow meter (Cat No- GSI 031, Nova Instruments) was used

Table 1

Physicochemical properties, proximate and ultimate analysis of sawdust and the biochar derived from the pyrolysis process of sawdust.

| Properties | Sawdust-biomass | Sawdust derived-biochar |
|-------------------------|-----------------|-------------------------|
| Proximate analysis | | |
| Moisture (wt%) | 8.9 ± 1 | 3.5 ± 1 |
| Volatile matter (wt%) | 79.3 ± 2 | 25.6 ± 2 |
| Ash (wt%) | 0.7 ± 0.2 | 8.1 ± 1 |
| Fixed carbon (wt%) | 11 ± 1 | 62.8 ± 0.5 |
| Ultimate analysis | | |
| C | 43.74 | 70.71 |
| H | 5.93 | 1.68 |
| N | 0.45 | 0.73 |
| S | 0.00 | 0.06 |
| O | 49.18 | 26.82 |
| O/C ratio | 0.86 | 0.28 |
| H/C ratio | 1.63 | 0.29 |
| Calorific value (MJ/kg) | 19.12 ± 1 | 23.4 ± 0.5 |
| Cellulose (%) | 45.33 ± 0.5 | – |
| Hemi-cellulose (%) | 19.5 ± 0.3 | – |
| Lignin (%) | 21 ± 2 | – |

to measure the flow rate and total pyrolysis gas generated from the process. Weight percent of C, H, N, and S elements in biomass and biochar samples were determined through a vario MACRO cube CHNS analyzer. Gas composition and its calorific value were measured simultaneously, by using online gas analyzer (model no. ACE 9000X CGA, Ace Gas Analysers, Mumbai). The density of bio-oil was measured by using a density bottle at room temperature. Flashpoint of the samples were used using pensky marten closed cup apparatus according to ASTM D 93, pH was measured using pH meter (Eutech). Viscosity was measured by redwood viscometer.

2.2. Properties of material

Sawdust or Dustaphobek L was analyzed for several physicochemical properties as presented in Table 1. Ultimate analysis revealed that the forestry residue has high amount of carbon. More volatiles in sawdust are in agreement to higher hemicellulosic contents in the biomass. High calorific value, higher fixed carbon; low

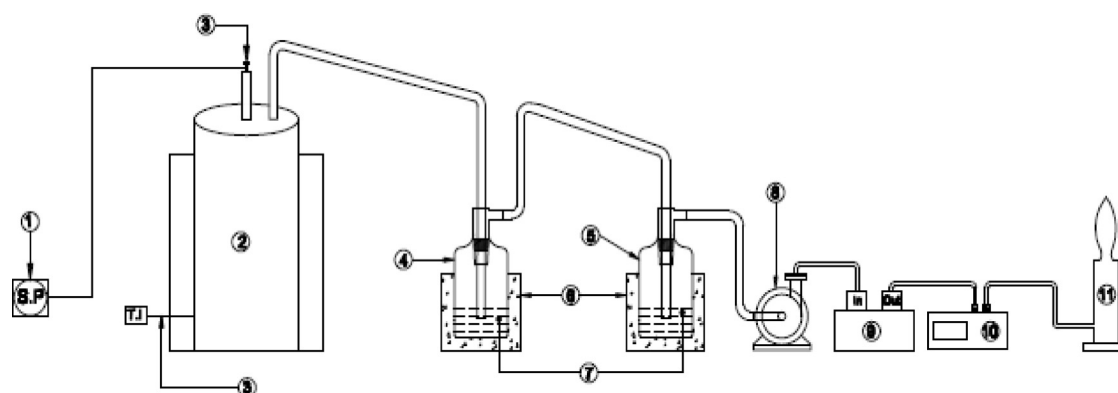


Fig. 1. Schematics for the experimental set-up for pyro-vapor quenching in jatropha bio-diesel.

1. PID Controller.
 2. Reactor.
 3. Thermocouple.
 4. Collection Bottle – 1.
 5. Collection Bottle – 2.
 6. Ice Bath.
 7. Bio-diesel.
 8. Gas flow totaliser.
 9. Gas conditioning unit.
 10. Gas analyser.
 11. Burner.
- T.I – Temperature Indicator.
S.P – Set Point.

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