Production of bio-oil from plants using pyrolysis reactor:Short Review

JaysinghGaharwar*[1], Arun Arora[2], Santosh Kumar Sar[3]

[1]Mechanical Engineering Department, BITDurg, C.G. 491001 India,
jaysingh_vnit@yahoo.co.in
[2] Mechanical Engineering Department, BIT Durg, C.G. 491001 India
[3] Applied Chemistry Department, BIT Durg, C.G. 491001 India

Abstract:

The present review report studies the pyrolysis process used for extraction of oil from plants. Bio-oil is obtained as a major product of intermediate pyrolysis. Bio-oil obtained from plants such as mahua, neem and karanja is reported to have applications as medicine. Other plants can also be used as biomass for oil extraction.Bio-oil has several other applications such as substitute of furnace oil, extraction of fine chemical. Biochar is also obtained as one of the products of pyrolysis. It can be used as a soil amendment for enhancing soil fertility and gases for thermal application. Pyrolysis converts crop residues, woody residues into carbon rich biochar. It stabilizes organic matter into soil.

Keywords: intermediate pyrolysis, biomass, bio-oil, bio-char.

Introduction:

The focus on biofuels has increased since it net zero contributor to carbon dioxide. Switching to renewable energy brings positive impacts such as reduced emissions of toxic gases, a greener environment and healthier community, as well as the promise of a sustainable future.Biomass was the chief source of fuel in the pre-industrialrevolution world and is still quiet important in any developing countries, such as India. In 1973, oil crisis and the more recent global climate change concerns brought into focus sharply the post industrial revolution conflict between economic development and energy sustainability. It has been shown again and again that the best way of resolving this conflict by promoting energy conservation and renewable energy utilization. The importance of biomass as a renewable energy resource, especially in its prevalent form of stored chemical energy, as opposed to solar and wind energy which fluctuate widely, has increased in the recent years. This can be observed not only the developing countries like India, but also in industrially developed countries, such as the Netherland, Germany, Finland and Sweden[1-8]. Pyrolysis in particular attracts high levels of interest largely because the pyrolysis liquids (bio-oils) which are produced can have a high energy content.

Literature Survey:

A number of types of pyrolysis reactor have been invented and investigated for producing biomass based pyrolysis fuels by fast pyrolysis. Fluidized bed reactors, including bubbling fluidisedbed and circulating fluidized bed, have been the most popular type owing to their simple construction and operation, good temperature control, high heating rate and high efficiency[1,3,5]. Economy of India is based on agriculture, where biomass can act as a promising alternative to meet ~16–18% of the total energy consumption with variety of possible renewable energy sources in abundance[2].

The technique that can convert raw biomass directly to an upgraded bio-oil in a single step is called catalytic fast pyrolysis (CFP). Among the many catalysts that have been applied to CFP, the most studied are the zeolites. They present the advantage of transforming the solid biomass into an upgraded bio-oil in one single step and additionally, they are solid catalyst and may impart shape selectivity due to their porous structure performed the qualitative and quantitative analysis of the bio-oil of hemicellulose, cellulose and lignin and also of a mixture of these three compounds (25.8 wt.% hemicellulose, 28.3 wt.% lignin and 45.9 wt.% cellulose) produced by fast and catalytic pyrolysis in a fixed bed reactor. However, they worked only with a standard mixture of compounds and not with real biomass residues. In addition, they employed only fixed bed reactor[3].

Biomass use as an energy resource as well as chemical resource has significanteconomic and ecological impacts with advantage of bioenergy generation, and offering solutions for soil remediation while not competing with agriculture food production[4,5, 9-11].Banana peels and boiled rice yielded the highest quantities of bio-methanol as compared to other wastes such as papaya peels, sugarcane bagasse, spinach waste etc. M. Anitha reported that the yield of bio-methanol was higher than those of previously reported studies using pyrolysis technology[11].

Two different waste biomasses (Douglas fir, a soft wood and hybrid poplar, a hard wood) were subjected to four different pre-treatments, namely hot water pretreatment, torrefacation, acid(sulphuric acid) and salt(ammonium phosphate) doping. Post pretreatments, the changes in the biomass structure, chemistry, and thermal make up were studied through electron microscopy, atomic absorption/ ultraviolet spectroscopy, ion exchange chromatography and thermogravimetry. The pretreatments significantly reduced the amounts of inorganic ash extractives, metals, and hemicellulose from both the biomass samples. Furthermore, hot water and torrefaction pretreatment caused mechanical disruption in biomass fibers leading to smaller particle sizes. Torrefaction of douglas fir wood yielded more solid product than hybrid poplar. Finally the salt pretreatment increased the activation energies of the biomass samples (especially douglas fir) to a great extent. Thus salt pretreatment was found to bestow thermal stability in the biomass [12].

Rapid pyrolysis of agricultural residues such as olive waste and straw at high temperature (800 -1000^{0}C) is studied. The effect of the treatment conditions such as heating rate, temperature and particle size on the product distribution, gas composition and char reactivity. A higher temperature and smaller particles size increases the heating rate which results in decrease in char production but favors the cracking of hydrocarbon. Wood gives more volatiles and less char than straw and olive waste. The higher ash content in agricultural residues favors the charring reaction. Chars from olive waste and straw are more reactive than chars from birch in gasification due to higher ash content[13].

Characterization of biomass and biochar in terms of proximate analysis is done in accordance to the standard ASTM methods. Moisture, ash,biochar and volatile matter content of the biomass samples were determined by ASTM methods[2]. Fixed carbon was calculated from the difference of moisture, ash, and volatile matter. The moisture content of different feedstock directly impacts the final conversion to products. Volatiles from the decomposition of hemicellulose, cellulose and lignin differ for different feedstock and hence the product distribution and properties varied. Volatiles and fixed carbon gives the measure of the ease with which biomass is burnt (McKendry, 2002). Ash content of the feedstock has a major effect on product yield and distribution as they catalyze secondary pyrolysis reactions[14,15].

Within BtVB process converts biomass (low in oil), ash-rich agricultural and forestry residues to produce heat and power. Biomass generation is done via photosynthesis at 20-25 ^{0}C. Main delivery of biomass is through algae[4]. Life Cycle Assessment (LCA) of intermediate pyrolysis is a method that is carbon neutral and also supports carbon sequestration and thus sustainable. The emission factor for such process is -1.8 compared to 1.22 kg of CO_2 /kWh in case of diesel[6].

Biomass gasification for electricity generation has greater efficiency and reduced CO_2 emission. But it has yet to consolidate its position as compared to other technology[8].Sewage sludge feedstock is taken from a treatment plant which is the final product of anaerobic digestion process. Dried sludge is finely powdered and blended with 10% water to be pelletised. De-inking sludge is a solid residue generated during the de-inking stage of recovered fibre paper products manufacture. It contains mainly fibres and inert fillers, together with small amounts of inks and pigments. It is first dried then mixed with moisture and pelletised. Pyrolysis oil production was carried out in the Pyroformer intermediate reactor. The reactor is a horizontal cylindrical unit made from carbon steel. The laboratory scale unit at Aston is 180 cm in length and has a diameter of 20 cm and compromises two horizontal co-axial rotating screws, where the inner screw conveys the feedstock passing through the reactor and the outer screw transports the product char backwards for cycling through reactor for further reaction and heat exchange. The Pyroformer is designed to make full use of the contact time of the pyrolysis vapours and bio-char for further cracking of the high molecular weight organic products. This has been shown to be effective by the good quality of produced oils

Atabaniet.al. introduces non-edible vegetable oils known as the second generation feed stocks to be used as biodiesel feed stocks. Several aspects related to these feed stocks have been reviewed which includes overview of non-edible oil resources, advantages of non-edible oils, problems in exploitation of non-edible oils, fatty acid composition profiles (FAC) of various non-edible oils, oil extraction techniques, technologies of biodiesel production from non-edible oils, biodiesel standards and characterization, properties and characteristic of non-edible biodiesel and engine performance and emission production. There is a huge chance to produce biodiesel from non-edible oil sources and therefore it can boost the future production of biodiesel.[16]

Nair et. al. reported high total ash value for tulsi in comparison with neem and karanja. This shows
high mineral content in tulsi. Karanj has lower value of moisture content which shows its high calorific value. It also shows lower ash value indicating its high energy value and potential to be a good bio fuel.[17]

Karanja (Pongamiaglabra) seeds were pyrolyzed by Nayanet. al.in semi-batch mode at a temperature range of 450–550 ^{0}C and at a heating rate of 20 ^{0}C/min. FTIR (Fourier transform infrared spectroscopy) analysis of the liquid product indicates the presence of alkanes, alkenes, ketones, carboxylic acids and aromatics rings. GC–MS (Gas chromatography–Mass spectrometry) demonstrated the presence of hydrocarbons with between 14 and 31 carbon atoms in a chain. The physical properties of the pyrolysis liquid were close to mixture of diesel and petrol.[18]

Kader et. al.reported the conversion of tamarind seeds into pyrolytic oil by fixed bed fire-tube heating reactor. The major components of the system were fixed bed fire-tube heating reactor, liquid condenser and collectors. The products are oil, char and gases. The parameters such as reactor bed temperature, running time, gas flow rate and feed particle size were found to influence the product yields significantly. The maximum liquid yield was 45 wt% at 400^{0}C for a feed size of 1.07cm^3 at a gas flow rate of 6 liter/min with a running time of 30 minute. [19]

Storage and transportation plays an important role in deciding the use of a particular bio-oil as fuel. Das et. al. reported decrease in oxidative stability of Karanja oil methyl ester (KOME) i.e. the peroxide value and viscosity increased with increase in storage time (180 days storage).the sample is more susceptible to oxidative degrading when exposed to metal or air during storage. The stability of KOME was improved by adding different antioxidants Tert-ButylatedHydroxyluene BHT), Tert-ButylatedHydroxyanisole (BHA), Pyrogallol (PY), Propyl gal ate (PrG) and Tert-Butyl Hydroxyl Quinone (TBHQ). PrG is reported to be the best antioxidant followed by BHA and BHT. [20]

Veljkovicet.al.investigated the production of fatty acid methyl esters (FAME) from crude tobacco seed oil (TSO) having high free fatty acids (FFA). The tobacco biodiesel obtained is reported to have the fuel properties within the limits prescribed by the latest American (ASTM D 6751-02) and European (DIN EN 14214) standards, except a somewhat higher acid value than that prescribed by the latter standard (<0.5). Thus, tobacco seeds (TS), as agricultural wastes, might be a valuable renewable raw material for the biodiesel production.

Methodology and procedure:

The full system as shown in Fig. 1 is comprised of a feeding hopper, the Pyroformer reactor, hot gas filter candles for removal of entrained char and solid particulates, a shell and tube water cooled condenser for condensing of the liquids and an electrostatic precipitator for aerosol removal. The Pyroformer is able to process a maximum of 20 kg/h feedstock. To produce the oil, the reactor is initially purged with nitrogen to eliminate any presence of air and is then heated to a temperature of 450 ^{0}C. The feedstock, i.e. dried sewage sludge or de-inking sludge in this study, is transferred to the reactor via a feed chute at a rate of approximately 15 kg/h. The speeds of inner and outer screws are set to 4 rpm and 1.25 rpm respectively. The feedstock residence time is estimated at 7–10 min although the vapour residence time is only a few seconds. The evolved gases and vapours pass through hot gas filter candles which are also heated to 450 ^{0}C. The condensable vapours are then cooled in a cold-water condenser to form pyrolysis oil, while the permanent gases can be flared or collected after they pass through an electrostatic precipitator.

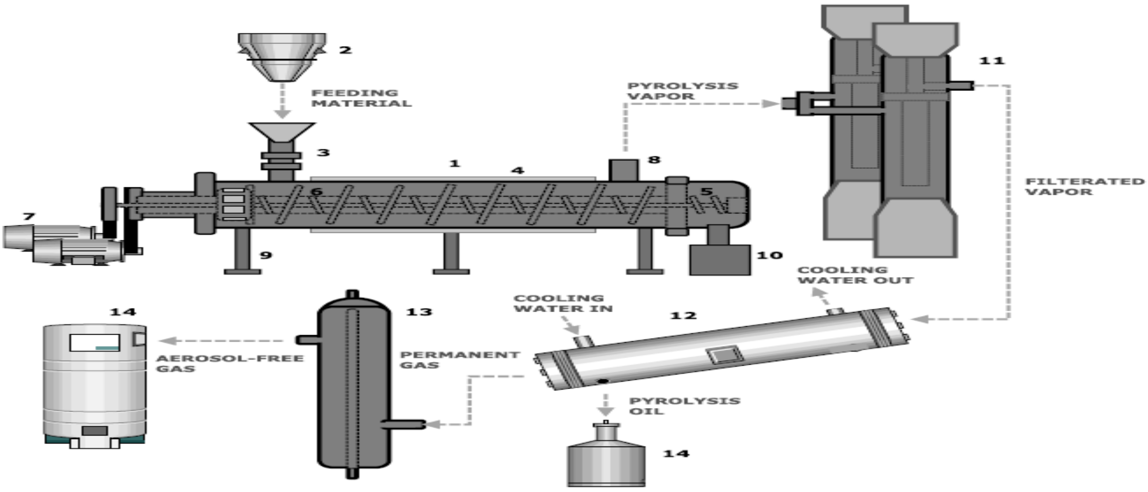

Figure 1 schematic diagram of the intermediate pyrolysis system[1].

For de-inking sludge, the corresponding yields of liquid, gas and solid product were 10 wt.%, 11 wt.% and 79 wt.% respectively. Separation of the liquid into an organic and an aqueous phase was again seen, however the organic phase in this case was 90 wt.%. The pyrolysis oils have some satisfactory characteristics for use as diesel engine fuels, but at the same time there are some characteristics that may cause deteriorated engine performance and reduced engine life. However, the negative effects of most of these characteristics for engines could be alleviated if they are blended with other better quality fuel oils, since they are theoretically in proportion to the fraction of pyrolysis oil in the blend.

Conclusion:

Preliminary investigations have found that the pyrolysis oils have some satisfactory characteristics for use as diesel engine fuels, but at the same time there are some characteristics that may cause deteriorated engine performance and reduced engine life. Banana peels and boiled rice yielded the highest quantities of bio-methanol as compared to other wastes such as papaya peels, sugarcane bagasse, spinach waste etc. Pyrolysis of selected biomass at intermediate conditions produced highest liquid yield of 47.5% with neem seed, biochar yield of 40% from straws and highest gas yield of 40.5% from Soyabean Straw. Husks, like pigeon pea and yellow pea have produced biochar with higher calorific value (28.03 MJ/kg) comparable with saw dust (29.4 MJ/kg). Channa stalk has shown similar characteristics of biomass and product comparable with Wheat Straw, hence claims a good source of bioenergy.Further studies on the controlling factors such as operational temperatures, particle size etc. needs to be done for the better yield of bio-methanol.Pyrolysis of plants such as neem, mahua, karanja etc. yields oil having medicinal properties. It also has the potential to be used as a promising biofuel. Storage and transportation of these bio-oils could be difficult but the problem can be solved with the use of antioxidants. Investigation on using the bio-oils directly as a biodiesel or as a mixture with other suitable components needs to be done.

References:

[1]. D. V. Torri , V.Paasikallio , C. S.Faccini , R. Huff , E. B. Caramão , V.Sacon , A. Oasmaa , C. A. Zini, Bio-oil production of softwood and hardwood forest industry residuesthrough fast and intermediate pyrolysis and its chromatographic characterization. Bioresource Technology 200 (2016) 680–690.

[2]. F. Tinwala , P. Mohanty , S. Parmar , A. Patel , K. K. Pant, Intermediate pyrolysis of agro-industrial biomasses in bench-scalepyrolyser: Product yields and its characterization. Bioresource Technology 188 (2015) 258–264.

[3]. V.V.N. Kishore and SN Srinivas, journal of scientific & industrial Research ,vol62(2003) 106

[4]. Y. Yang , J.G. Brammer , A.S.N. Mahmood , A. Hornung, Intermediate pyrolysis of biomass energy pellets for producing sustainable liquid, gaseous and solid fuels. Bioresource Technology 169 (2014) 794–799.

[5]. Y. Yang, J. G. Brammer, M. Ouadi, J. Samanya, A. Hornung, H. M. Xu, Y. Li, Characterisation of waste derived intermediate pyrolysis oils for use as diesel engine fuels. Fuel 103(2013)247-257.

[6]. R. A. Patel, S. Prabir, H. Singh, H Tyagi, S. Sagi, Life cycle assessment of intermediate pyrolysis of wheat straw for sustainable energy alternate and emission mitigation. International Review of Applied Engineering Research 4 4(2014) 325-330.

[7]. Hornung, A Apfelbacher, S. Sagi, Intermediate pyrolysis: Asustainable biomass-to-energy Concept-Biothermal valorization of biomass (BtVB) process. Journal of Scientififc & Industtrial Research 70 (2011) 664 – 667.

[8]. J.A. Ruiz, M.C. Juarez, M.P. Morales, P. Munoz, M. A. Mendivil, Biomass gasification for electricity generation : Review of current technology barriers. Renewable and sustainable energy reviews 18(2013) 174-183.

[9]. C. Branca, C. Di Blasi, A. Galgano, Chemical characterization of volatile products of biomass pyrolysis under significant reaction-induced overheating. Journal of Analytical andApplied Pyrolysis 119(2016)8-17

[10]. S. Sensoz, Slow pyrolysis of wood baeks from PinusBrutia Ten. And product compositions. Bioresource Technology 89(2003)307-311

[11]. M. Anitha, S.K. Kamarudin, N.S. Shamsul, N.T. Kofli. Determination of bio-methanol as intemeditae product of anaerobic co-digestion in animal and agricultural wastes. International journal of hydrogen energy 40(2015) 11791-11799

[12]. O. Das, A.K.Sharmah,mechanism of waste biomass pyrolysis: effect of physicaland chemical pretreatments, science of the total environment

[13]. R. Zanzi, K. Sjotrom and E. Bjornborn,Rapid pyrolysis of agricultural residues at high temperatures, Biomas& bioenergy, Elsevier Science, 2001.

[14]. Biomass pyrolysis and biocharcharacterization , F. Ronsse, D. Dickinson, R. Nachenius, W. Prins, 1stForebiom Workshop, 4/4/13 Vienna.

[15]. Q. Wang, P. Aparu, H. Kurogawa, K. Sugiyama, Recovery Briquetting Technologies of waste biomass and Pyrolyzed waste char produced from solid industrial and agricultural organic wastes, International Journal of sustainable development and planning, 9 (2014) 705-716.

[16]. A.E. Atabani, A.S. Silitonga, H.C. Ong, T.M.I. Mahlia, H.H. Masjuki, I. A. Badruddin, H. Fayaz, Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production, Renewable and Sustainable Energy Reviews 18 (2013) 211–245

[17]. Nair Lethika D., Sar Santosh K., Arora Arun and Mahapatra Deepak, A Comparative study on Proximate Analysis conducted on Medicinal Plants of Chhattisgarh, CG, India, Research Journal of Chemical Sciences, 2(9) (2012) 18-21

[18]. N. K. Nayan, S. Kumar , R.K. Singh , Characterization of the liquid product obtained by pyrolysis of karanja seed,Bioresource Technology 124 (2012) 186–189

[19]. Md. A. Kader, M. R. Islam, M. U. H. Joardder, Fast pyrolysis for better utilization of tarmarind seed from Renewable energy point of view, international conference on mechanical engineering and renewable energy 2011, ICMERE2011-PI-155

[20]. L.M. Das, D. K. Bora, S. Pradhan, M. K. Naik, S.N. Naik, Long-term storage stability of biodiesel produced from Karanja oil, Fuel 88 (2009) 2315–2318

[21]. V.B. Veljkovic, S.H. Lakic´evic´, O.S. Stamenkovic´, Z.B. Todorovic´, M.L. Lazic, Biodiesel production from tobacco (Nicotianatabacum L.) seed oil with a high content of free fatty acids Fuel 85 (2006) 2671–2675