Study of Effect of Temperature on Yield of Bio-Oil, Bio-Char and NCG from Soybean Stalk in Continuous Feed Bio-oil Reactor

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Abstract- The effect of temperature on the yield of bio-oil, bio-char and NCG (Non condensable gases) +bio-oil vapor was studied in continuous feed bio-oil reactor. The effect of temperature on recovery of bio-oil, bio-char and NCG+bio-oil vapor were studied at different temperatures i.e. 450, 500, 550 and 600^{o}C. In condition 1 the yield of bio-oil was increased from 6 (wt.) per cent to 8 (wt.) Per cent while the final temperature of pyrolysis increases from 450 ^{0}C to 550 ^{O}C. After that temperatures it was found that the yield of bio-oil started decreases i.e. At a temperature 600oC yield of bio-oil was 7.5 (wt.) per cent. In condition 2 the yield of bio-oil was increased from 11 (wt.) per cent to 13 (wt.) per cent while temperature increases from 450^{o}C to 500^{o}C. After that temperatures it was found that the yield of bio-oil was decreased until the temperature of bio-oil reactor reactor increases. The yield of bio-char was starting the decreases while pyrolysis temperature increases. The yield of NCG (Non-condensable gas) +bio-oil vapor increases with increase in temperature of bio-oil reactor.

Keywords- Soybean stalk, Bio-oil, Pyrolysis, Continuous feed bio-oil reactor.

1. Introduction

Soybean crop (*Glycine max*), known as a ‘miracle crop’ with over 40 per cent protein and 20 per cent oil, originated in China and was introduced to India centuries ago through the Himalayan routes. Soybean has been traditionally grown on a small scale in Himachal Pradesh, the Uttaranchal, Eastern Bengal, the Khasi Hills, Manipur, the Naga Hills, and parts of central India covering Madhya Pradesh [1]. The biomass power potential of India to be 16,000 MW from agro-residues; 45,000 MW from plantation biomass from 20 million ha of wasteland yielding 10 metric tonnes/ha/year with 30 per cent efficiency [2]. India’s energy security would remain vulnerable until alternative fuels to substitute/supplement Petro-based fuels were developed based on indigenously produced renewable feed stalks. In bio-fuels, the country has a ray of hope in providing energy security. Pyrolysis is a conversion technique in which biomass is transformed to gaseous, liquid and solid products that can be used as improved fuels or intermediate energy carriers. The pyrolysis process carried out at lower temperature, the liquid yield is low due to the less sufficient pyrolysis reaction, which will produce a high content of the char at the same time. Likewise, the excessive temperature will also lead to liquid yield decreased resulting from the increase of gas product. In order to achieve high liquid yield, the pyrolysis reaction temperature was better to controlled around 500^{o}C in the vapor phase for most forms of woody biomass. Vapor residence time was also important to the liquid yield of pyrolysis reaction [3].

The aim of the study reported here was to investigate effects of temperature on yield of bio-oil, bio-char and NCG+bio-oil vapor in the continuous feed reactor. The continuous feed reactor design and developed for soybean crop residues at Central Institute of Agricultural Engineering Bhopal, India. Which converts the solid fuel (Soybean stalk) to liquid fuel (bio-oil).

2. Material and Methodology

2.1. Principles of Fast Pyrolysis

Fast pyrolysis is a high temperature pyrolysis process in which the feedstock is rapidly heated in the absence of air, vaporizes and condenses to a dark brown mobile liquid which has a heating value of about half that of conventional fuel oil. The essential features of a fast pyrolysis process were given below[5]

- It required Very high heating and heat transfer rates
- biomass feed (typically less than 3 mm);
- Carefully controlled temperature of around 500^{o}C;
- Short hot vapor residence times of typically less than 2-3 s;
- Rapid cooling of the pyrolysis vapor

2.2. Raw Material

The soyabean was major edible oil crop cultivated in major part of India. The crop residues left after harvesting and threshing of the crop was burned openly or used for feed for animals. The open burning cause an environmental hazard as well as loss of energy. That reason, the current research work was followed by soybean crop residues, which was procured, from the local market of Bhopal (MP) [1].

2.3. Selection of Particle Size

The selection of particle done according the requirement as well as reactor condition. The particle for carrying out research work was selected, which could suspend in the reactor for 1-5 s after falling from the auger. The selected particle size for research $\leq$ 0.2 mm.

2.4. Experimental Set-up

The bio-oil reactor was designed at Central Institute of Agricultural Engineering Bhopal. The main constructional parts of the bio - oil reactor were hopper, a screw feeder, an electric heater, a reactor chamber, a cyclone separator, a condenser, and motor with gear box attachment, as well as some thermocouples and digital temperature controller. The feeding of soybean residues was done on top of the reactor chamber by screw feeder. The screw conveyor rotates by means of an electric motor of 0.25 hp with gear box attachment. The rotation speed of motor has 30 rpm. Heating was done by 10 kW heating elements. The rate of heating was controlled by digital temperature controller. Char particle which carried by vapor was removed by cyclone separator. The condenser was used for cool the hot vapor released from cyclone separator. For removing bio-char from reactor chamber the arrangement provided at bottom of the reactor.

2.5. Temperature of profile of reactor chamber

The temperature inside the reactor was not same it varies according to the radius of the reactor and the height of the reactor chamber. There for two condition's were defined for observation i.e.

- Condition 1: Set and regulate the temperature of the reactor chamber segment where thermocouple showed the maximum temperature at any particular setting of temperature.
- Condition 2: Set and regulate the temperature of the reactor chamber segment where thermocouple showed the minimum temperature at any particular setting of temperature.

The first condition creates the reactor thermal environment in such a way that the temperature of the reactor was either equal or lower to the temperature fixed in digital controller. The second condition creates the reactor thermal environment in such a way that the temperature in the reactor was either equal or higher to the temperature fixed in the controller

2.6. Recovery of Bio-oil, Bio-char and NCG

The experimental device was installed at Energy Enclave, Central Institute of Agricultural Engineering Bhopal. Feeding rates of the system was kept 1 kg/h. The soybean stalk powder less than 0.2 mm was fed continuously into the reactor. The pyrolysis experiments using soybean stalk powder were performed at 450, 500, 550 and 600 ºC. In our experiment, the heat exchanger was operated in cool water with a condensation temperature of 27 ºC.

Besides bio-oil, two byproducts, namely bio-char and NCG+bio-oil vapour were also being obtained when soybean stalk is pyrolyzed. The yield of the bio-oil could be determined from the condensed liquid and the feedstock used. The yield of NCG could be determined from the fact that the sum of the three product yields should equal 100 per cent.

2.7. Experimental Procedure

The experimental procedure to run the system and collecting analysis sample given below

a) Turn on the electric heater and turn on the motor of the feeder to prevent jamming the feeding system by the raw material.
b) When the temperature of the fluidized bed reactor reaches the expected or set temperature, transport

soybean stalk powder at a rate of 1 kg/h into the continuous feed bio-oil reactor.

c) After 60 minutes, stop transporting soybean stalk powder into the continuous bed reactor.

d) Turn off the electric heater and the water circulating pump.

e) Collect the bio-oil, bio-char and NCG+bio-oil vapor for the experiment.

f) Perform the experimental steps (a-f) again with varying the temperature range 450, 500, 550 and 600 ^{OC} respectively.

g) Repeat this experiment three times for individual temperature and use the average value of respective experiment.

3. Result and Discussion

3.1. Effect of Pyrolysis Temperature on Yield of Bio-oil

The yield of bio-oil was increased from 6 (wt.) per cent to 8 (wt.) per cent while final temperature of pyrolysis increases from 450 ^{0}C to 550 ^{o}C. After that temperature increases the yield of bio-oil started decreases i.e. at temperature 600 ^{o}C yield of bio-oil was 7.5 (wt.) per cent. In condition 2 the yield of bio-oil was increased from 11 (wt.) per cent to 13 (wt.) per cent while temperature increases from 450 ^{o}C to 500 ^{o}C. After that temperature the yield of bio-oil were decreases until temperature of reactor increases i.e. at temperature 550 ^{o}C (10 per cent bio-oil) and 600 ^{o}C (9 per cent bio-oil). From above discussion it concludes that the pyrolysis temperature 550 ^{OC} and 500 ^{OC} suitable for maximum yield of bio-oil at condition 1 and condition 2.

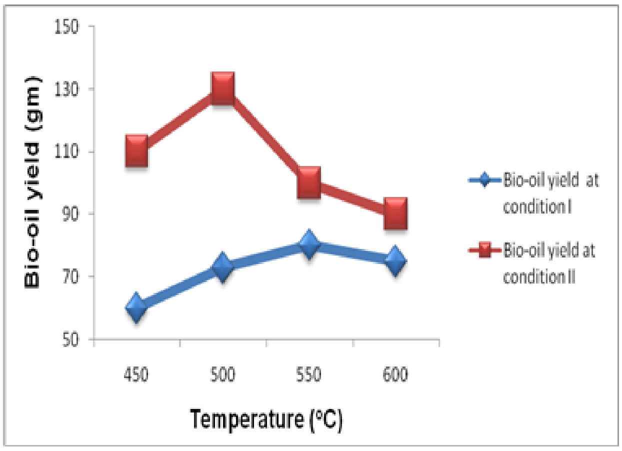

Fig.1. Effect of temperature on yield of bio-oil

3.2. Effect of Pyrolysis Temperature on Yield of Bio-char

The effect of pyrolysis temperature on yield of bio-char in condition 1 and condition 2 was studying it found that the yield of bio-char was starting the decreases while pyrolysis temperature increases. The yield of bio-char at temperature 450, 500, 550 and 600 ^{o}C was given as 75, 69, 66 and 64 (wt.) per cent respectively. The highest yield obtained on condition 1 was due to the fact that owing to lower temperature in reactor some unpyrolyzed material also mixed with bio-char. In condition 2 it shows that the yield of bio-char was starting the decreases while pyrolysis temperature increases. The yield of bio-char at temperature 450, 500, 550 and 600 ^{o}C were given as 40, 37, 35 and 32 (wt.) per cent. From the above discussion it shows that the yield of bio-char was inversely proportional to the pyrolysis temperature.

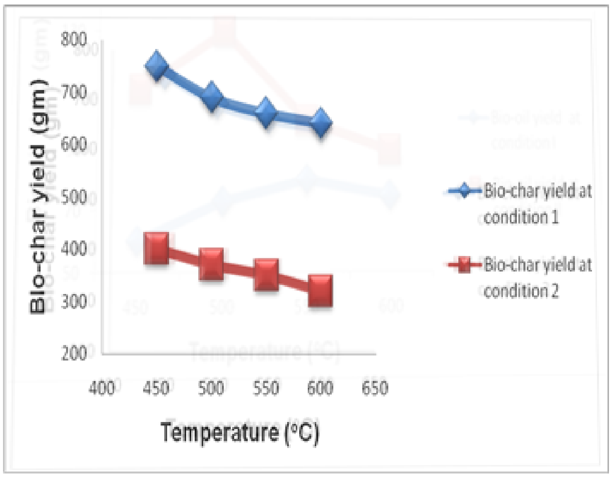

Fig.2. Effect of temperature on yield of bio-char

3.3. Effect of Pyrolysis Temperature on Yield of NCG+Bio-oil vapor

Fig.3 shows the effect of temperature on yield of NCG+bio-oil vapor at condition 1 and condition 2. It found that yield of NCG+bio-oil vapor increases with increase in temperature of bio-oil reactor chamber.

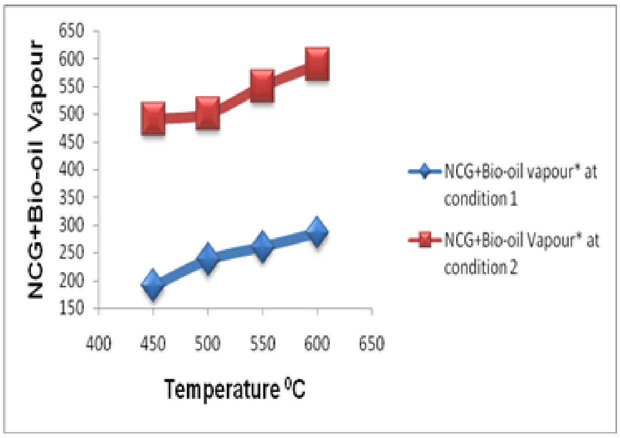

Fig.3. Effect of temperature on yield of NCG+bio-oil vapor

4. Conclusion

1. It concludes that the pyrolysis temperature 550 ^{OC} and 500 ^{OC} suitable for maximum yield of bio-oil at condition 1 and condition 2.
2. The yield of bio-char was starting the decreases while pyrolysis temperature increases.
3. It found that yield of NCG+bio-oil vapor increases with increase in temperature of bio-oil reactor chamber

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