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Research Article

PERFORMANCE EVALUATION OF BIO-OIL REACTOR FOR MUSTARD CROP RESIDUE

WASU G.H.[1] AND KALBANDE S.R.[2]
Department of Unconventional Energy Sources and Electrical Engineering, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Krishi Nagar, Akola, 444104, Maharashtra, India
Professor & Head, Department of Unconventional Energy Sources and Electrical Engineering, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola, 444104, India
*Corresponding Author: Email- ghwasu@gmail.com

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Abstract- Pyrolysis liquid is a potential source of revenues for motor vehicles or lubrication purpose. Fast Pyrolysis bio-oil from agriculture crop residues is one of the alternatives to replace fossil fuels. Once produced, bio-oils may be shipped, stored and utilized much like conventional liquid fuels once their specific fuel properties are taken into account. The mustered crop residue was selected for carrying out research work. Size of particle play important role during the design of bio-oil reactor. It was suitable for satisfying the condition of fast pyrolysis. The screw feeding method was used to feed the raw material in reactor chamber. Temperature throughout reactor was not same. It varies according to height and also, with the distance from wall of the reactor chamber. For determination of temperature profile of reactor, it was found that temperature at middle region of reactor chamber was higher than that of top and bottom regions of reactor chamber. The performance of reactor was taken at different temperature of 450, 500, 550 and 600 ^{0}C respectively. The feeding rate of pyrolysis unit was kept constant *i.e.*, 1 kg/h. The highest recovery of bio-oil from mustered crop residues was found as 11 (wt.) percent at temperature of 550 ^{0}C. The highest recovery of bio-char was found 40 (wt.) per cent at temperature of 450 0C. The highest yield of NCG + Bio-oil was estimated 28.5 percent at temperature of 600 ^{0}C.

Keywords- Biomass, biochar, bio-oil, pyrolysis, proximate and ultimate analysis

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Introduction

Biomass is becoming the most popular raw material among new renewable energy sources day after day. Biomass sources including wood and wood wastes, energy crops, aquatic plants, agricultural crops and their waste by-products, and municipal and animal wastes can be considered as potential sources of fuels and chemical feed stocks [1]. Biomass can be treated in numerous ways to produce gases, liquids or solids, but one of the technologies that has the best industrial perspectives is pyrolysis (thermal decomposition in absence of oxygen or with a low concentration of oxygen without affecting the process to a large extent) since the process conditions can be optimized to maximize the yields of liquid, solid (char or biochar) or gases products [2]. Biomass, the most abundant renewable energy resource in the world, has also been receiving considerable attention. Biomass fuels account for approximately 14% of the worldwide energy consumption [3]. Currently, some researchers are concentrating on developing alternative and renewable sources of liquid fuels which are "environmentally friendly." Plant/vegetable-derived oil is attracting increased interest in this respect [4]. 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. Vapor residence time was also important to the liquid yield of pyrolysis reaction [5]. The aim of reported here was to investigate effects of temperature on yield of bio-oil, bio-char and gases (bio-oil vapor) in the continuous feed reactor in which mustard stalk used as fuel, with the objective of determining the important condition and key variable. The research investigated the impact of reactor temperature on bio-oil yield and another parameter. Study the proximate and ultimate properties of mustard stalk. Effects of mustard stalk particle size and reactor temperatures on bio-oil yield.

Methodology

Pyrolysis process

Pyrolysis is one of the best methods to convert all biomass materials into bio-oil, char and volatiles. Pyrolysis is the process of heating of organic materials the absence of air or oxygen at high temperature of 500 – 1100 ^{0}C. The bio-oil obtained by this process contains 10-20% water. Bio-oil is produced by rapidly and simultaneously depolymerizing and fragmenting the cellulose, hemicelluloses, and lignin components of biomass. In a typical operation, the biomass is subjected to a rapid increase in temperature followed by an immediate quenching to "freeze" the intermediate pyrolytic products. Rapid quenching is important, as it prevents further degradation, cleavage, or reaction with other.

Collection of mustered crop residues

The mustered crop residue was collected from Dr. PDKV farm and store in department of UCES & EE. Mustered crop residue was chopped and dry by using sunlight for a week before being grinded to reduce its particle size.

Size reduction of mustered crop residue

Particles have to be very small to fulfil the requirements of rapid heating and to achieve high liquid yields. Feed specifications range less than 2 mm for fluid beds and less than 6 mm for transported or circulating fluid beds. The size reduction of mustered crop residue was done by grinding machine.

Selection of particle size

Sieving

The sieving was done for separating different size of particle from residues comes from the hammer mill. The particle retained on sieve and percent weight retained on sieve was determined by following formula:

$$\text{Partical retained on sieve, g} = W_1 - W_2$$
$$\text{Percent weight retained on sieve, \%} = \frac{W_1 - W_2}{W} \times 100$$

Where,
W = Weight of sample taken, g
W1 = Total weight (Sample + Sieve), g
W2 = Sieve weight, g

Moisture content: Electric oven was used to determine the moisture content. Moisture content was determined by heating 1 g of air dried biomass samples to 105 ^{0}C to 110 ^{0}C for 1 h and calculating the loss in weight as percentage.

Volatile matter: Volatile matter was determined by heating 1 g of air dried biomass sample exactly for 7 minutes in translucent silica crucible of specified dimensions at a steady temperature of 925 ^{0}C in a muffle furnace. The loss in weight calculated as percentage minus the percentage moisture gives the percentage volatile matter.

Ash content: Ash content was determined by heating biomass samples at 400 ^{0}C. A known quantity of powdered sample until most of the carbonaceous matter is burnt off and then heating for 1 h at 750 ^{0}C to complete the combustion. The weight of the residue reaming in the crucible corresponds to the ash content of the biomass, which was reported on percentage basis.

Fixed carbon: The sum total of the percentages of moisture, volatile matter and ash was subtracted from 100 to give the percentage of fixed carbon.

Ultimate analysis: The ultimate analysis determines the elements analysis containing carbon, hydrogen, oxygen, nitrogen and sulphur. The elemental analysis of the sample was done CHN analyzer. The known quantity of sample was placed in analyzer and data of carbon, hydrogen, oxygen, nitrogen and sulphur was recorded.

Pyrolysis unit

Pyrolysis reactor developed and fabricated at Department of Unconventional Energy Sources and Electrical Engineering Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola. Pyrolysis of mustard stalk was performed in a continuous feed reactor unit. The unit was composed of strip heater, hopper, screw conveyor, cyclone separator, condenser and bio-char and bio-oil collection unit. The reactor was made from a MS pipe 100 mm diameter and 2-meter height. The reactor was heated by strip heater by providing electrical supply of 7.5 Kw 5 Nos. of stripper heater having 1.5 Kw output each are fitted around the outer body of reactor pipe. Thermal insulation was accomplished with adiabatic material around the reactor and the immediate vicinity to minimize heat losses. The temperature of the experimental system was adjusted using temperature controllers and was monitored using J-type thermocouples. The pyrolysis vapour produced was cleaned up in cyclone separators and a hot filtration unit prior to condensation. Pyrolysis vapour was condensed into liquid product by a water coon heat exchanger and ice/cold water in condenser unit.

Pyrolysis unit experiments

There were 4 levels of the setting temperature including 450 ^{0}C, 500 ^{0}C, 550 ^{0}C and 600 ^{0}C. The biomass particle size was 2 mm. The feed rate of each experiment was around 1 kg/h. Air strip heater was used for heating the reactor and temperature control by automatic temperature controller with the help of J-type thermocouple and temperatures is display on digital temperature indictor. The total time of each test run was approximately 1 hour. To achieve the goal of these variables, a total of 3 experimental runs were performed.

Mass balance calculation

The main products from fast pyrolysis process are liquid bio-oil, solid char and non-condensable gases. The yields of each product were calculated by weighing the output of liquid yield, solid yield and Non condensable gases. The bio-oil yields were the combined weight of liquid from the product collection unit. The char yields were the combined weight of solid from the reactor at outlet. The gas yields were calculated by difference.

Result and Discussion

Selection of particle size

The sieving was done for particle separation from raw material. [Table-1] shows that the per cent weight retains on each sieve. The material retains on sieve Diameter >2.00, 2.00, 0.60, 0.50, 0.30, 0.02, 0.15, 0.08 mm were biomass retained 51.3, 9.3, 11.4, 14.3, 4.7, 4.5, 2.7, 0.7, and 1.1 per cent respectively. The highest materials retain on sieve diameter > 2mm *i.e.*, 51.3 per cent. The particle size less than 0.2 mm shows lowest falling velocity and it remains for falling 2.30 sec in reactor. The particle size less than 0.2 mm was suitable for satisfying the condition of fast pyrolysis *i.e.*, these remains maximum time (1-5 s) in reactor chamber during free falling.

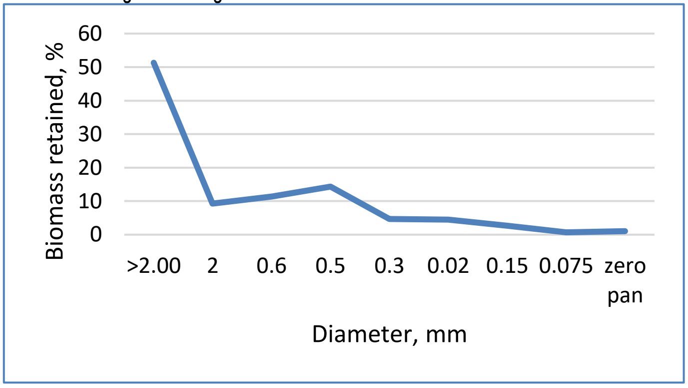

Fig-1 Sieve analysis of mustard stalk

Characterization of mustard stalk sample

The proximate and ultimate analysis of mustard stalk are given in Table 1 which shows that the raw materials contains higher per cent of volatile matter 69.73 per cent and less amount of moisture and ash content 6.23 per cent, 12.60 per cent whereas fixed carbon content in sample was found that 11.44 per cent. Volatile matter evolves in the form of gas, hydrocarbon and tars. Higher volatile matter of the biomass makes it more acceptable for bio-oil generation. Ash content and moisture content affect the heating value of bio-oil. Ash content depends upon the plant and soil condition in which the plant grows. There characteristics of raw material shows Mustard stalk has ability to produces bio-oil. The bulk density of mustard stalk was 97.50 kg/m3 and calorific value of mustard stalk *i.e.*, HCV and LCV were 16.19 and 14.89 MJ/kg respectively. High calorific value indicates good characteristics for pyrolysis and gasification, because higher heat generated during combustion leads to high temperature in reaction zone.

Table-1 *Proximate and ultimate characterization of mustard stalk sample*

Properties	Mustard stalk
Bulk density, (kg/m^3)	97.50
Calorific value, (MJ/kg) HCV LCV	 16.19 14.89
Proximate analysis	
Moisture content, (%)	06.23
Volatile matter content, (%)	69.73
Ash content, (%)	12.60
Fixed carbon content, (%)	11.44
Ultimate analysis	
Carbon, (%)	42.55
Hydrogen, (%)	05.89
Oxygen, (%)	37.62
Nitrogen, (%)	00.79
Sulphur, (%)	00.55

Ultimate analysis represents the elemental analysis which belongs to carbon, hydrogen, oxygen, nitrogen and sulphur. Mustard stalk was higher in carbon content and less in hydrogen, oxygen, nitrogen and sulphur content. For thermochemical process, carbon is the most important element in the fuel as it has direct influence on the heating value according to same, higher the carbon content (42.55 %) of mustard stalk represents higher heating value of fuel. Kim, *et al.*, (2006) studied the ultimate analysis of palm kernel shell and reported the carbon, hydrogen, oxygen, nitrogen and sulphur content 44.56, 5.6, 49.77, 0.4 and 0.05 %, respectively.

Preheating of bio-oil reactor for different temp

Preheating is the time required for archiving the desire temperature. When the desired temperature achieves the relay is cut off the electric supply and when temperature goes down it start the electric supply with the help of automatic relay system. Time required for different temperature *i.e.*, 450, 500, 550 and 600 0C. Time required for achieved desired temperature is shown in table 2. The maximum time required for achieved 600 0C temperatures was 17 min. and minimum time required for achieved 450 0C temperatures was 13 min.

Table-2 *Time required for preheating of bio-oil reactor for different temperature*

Time (Min)	Temperature achieved (for 450 ^{0}C)	Temperature achieved (for 500 ^{0}C)	Temperature achieved (for 550 ^{0}C)	Temperature achieved (for 600 ^{0}C)
Start	27	29	28	31
01	29	36	32	36
02	48	53	51	54
03	74	84	82	81
04	135	118	116	115
05	190	163	168	169
06	223	212	214	215
07	257	274	272	277
08	286	301	302	305
09	334	332	323	329
10	362	380	363	372
11	402	429	432	445
12	437	463	472	470
13	450 (Relay out)	492	485	490
14	487	500 (Relay out)	514	516
15	542	540	534	539
16	552	554	550 (Relay out)	559
17	584	586	580	600 (Relay out)

Temperature profile of reactor

The reactor was designed to maintain the desired temperature uniformly throughout the chamber. As the radial heating was used for heating up the system, the uniformity in temperature inside the reactor could not be maintained experimentally. It was due to fact that the existing air in the reactor at initial stage (under no load condition) under through convective heat transfer.

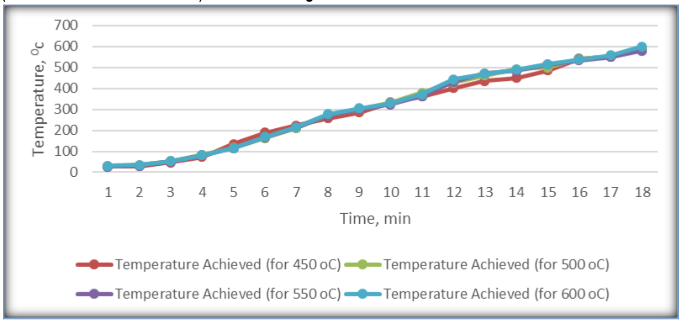

Fig-2 Time required for preheating of bio-oil reactor for different temperature

The temperature of middle zone of reactor was found to be higher than the top and bottom region of reactor. Measurement conducted to find out the radial temperature gradient, it was found that center portion of the reactor was high in comparison to the location close to periphery wall of reactor.

Recovery of bio-oil and bio-char

Recovery of bio-oil and bio-oil and bio-char was studied and explained in table 3. During the study the feeding rate kept constant *i.e.*, 1 kg/h. Table 3 shows the recovery of bio-oil and bio-char. The recovery of bio-oil at temperature of 450, 500, 550 and 600 0C were found to be 9, 10, 11, and 9.5 (wt.) per cent respectively. It showed that highest recovery of bio-oil was obtained at temperature 550 0C.

Table-3 *Recovery of bio-oil at different condition*

Sr. No.	Temperature (^{0}C)	Bio-oil (g/h)	Bio-Char (g/h)	NCG + BV (g/h)
1	450	90	540	370
2	500	105	510	385
3	550	110	595	295
4	600	95	360	545

The recovery of bio-char at temperature 450, 500, 550 and 600 0C found to be 54, 51, 59 and 36 (wt.) per cent respectively. These higher values of char production may be due to presences of some un-charred raw material in experiment conducted due to lower temperature regime inside the reactor. The yield of Non-condensable gases + bio-oil vapour at temperature of 450, 500, 550 and 600 0C found that 37, 38.5, 29.5 and 54.5 (wt.) per cent respectively at feeding rate 1 kg/h. it showed that highest yield of Non-condensable gasses + bio-oil vapor was obtained at temperature 600 0C. It also showed that yield of Non-condensable gases + bio-oil vapor was high at higher temperature.

Conclusion

The mustered crop residue contains higher per cent of volatile matter 66.66 per cent and less amount ash content 13.33 per cent. Whereas fixed carbon content in sample was found to be 10.00 per cent. Temperature in the system set were 450, 500, 550 and 600 ^{0}C then maximum temperature gradient seen at bottom of reactor chamber were 98, 140, 175 and 117 ^{0}C respectively and maximum temperature gradient seen at top region of reactor were 63, 85, 116 and 100 ^{0}C respectively. The feeding rate of system kept constant during recovery of bio-oil and bio-char at both condition. The recovery of bio-oil with different temperature of 450, 500, 550 and 600 ^{0}C were found to be 90, 105, 110 and 95. (wt.) percent, respectively. The recovery of bio-char different temperature of 450, 500, 550 and 600 ^{0}C were found to be 540, 510, 595 and 360 (wt.) per cent respectively. The yield of Non condensable gases + bio-oil vapour at different temperature of 450, 500, 550 and 600 ^{0}C were found to be 370, 385, 295 and 545 (wt.) per cent respectively.

Application of research: Pyrolysis from agricultural crop residue can be used for lubrication purpose in all machinery. It can replace the engine by further cleaning and heating treatment.

Research Category: Renewable Energy Sources

Abbreviations:

NCG = Non Condensable Gases
wt = weight basis
^{0}C = Degree celsius
kg/h = Kilogram per hour
% = percentage

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