American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-4, Issue-10, pp-54-59
www.ajer.org
Research Paper Open Access

Investigation of the parameters on the fast pyrolysis of wheat straw for production of bio-oil

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ABSTRACT:*Due to increase in energy demand, alternative energy resources are needed to be explored. Among these, biomass is one of the most promising, sustainable and renewable energy resources for power generation especially in agricultural countries. Several technologies are available for biomass conversion into energy but fast pyrolysis is the emerging and reliable technology among all for energy generation through biomass. Due to the continuous and abundant supply of biomass such as wheat straw, this technology is very helpful for reducing the demand and supply gap of energy. Variety of products like bio-oil, char and gases are obtained through pyrolysis of biomass. Among different type of biomasses wheat straw is selected for the study because of its abundant supply. Wheat straw is burnt in the presence of oxygen at high temperature to get pyrolysis products. The major objective of this research is to find the best and optimum temperature, particle size and heating effect at which maximum conversion of biomass into bio-oil is achieved.*

Key words*: Biomass, Wheat straw, fast pyrolysis, bio-oil, char*

I. Introduction

Biomass is a biological material obtained from living or recently living organisms. Major purpose of obtaining this biological material is to generate electricity. Due to increase in the demand and supply gap of energy especially in the third world countries, alternative sources of energy should be considered[1]. Biomass is the best alternate and renewable source of energy, having a great potential to reduce the demand and supply gap. Biomass can be grown easily within a short interval of time that is why it is known as the renewable energy source[2]. Forest (wood), Plants (crops) and animal wastes are some common examples of biomass. The history of biomass was developed gradually over the past few decades and it continues to improve until today. Now a days, biomass heaters and dryers are being used on domestic and commercial scale to obtain biofuels[3].

Biomass is mainly composed of mixture of organic molecules such as carbon, hydrogen and oxygen. Sometimes it contains traces of nitrogen, alkali and alkaline earth metals. Wheat straw is a type of agriculture biomass. It mainly consists of cellulose (40% -60%,), hemicelluloses (20% - 35%) and lignin (15 -30%). Some minerals and organic components are also present in minor proportion in the wheat straw. Cellulose exhibits a crystalline structure consisting of thousands of polymers[4]. During combustion process, cellulose usually degrades at 350^{o}C into monomers. Hemicellulose has lower thermal stability as compared to cellulose and it usually degrades at 270^{o}C. It consists of C_5 monomers. Unlike cellulose, lignin exists in amorphous form having large number of cross-linked chains of carbon atoms, therefore its degradation temperature is much higher than cellulose. The proximate and ultimate analysis of wheat straw is given in the Table 1.1.

Table 1.1.Proximate & Ultimate Analysis of Wheat Straw[5]

Description	Wheat Straw (%)
Volatile Matter	64
Fixed Carbon	26
Moisture	0.9
Ash	6

Carbon	44
Hydrogen	6
Nitrogen	0.48
Sulfur	0.15
Oxygen	44.37

Conversion process is one of the important parameters in order to attain maximum energy from bio-fuel. At present, several conversion technologies are being used to convert biomass into useful products. These include combustion, carbonization, gasification and pyrolysis. Other thermal conversion processes are combustion, carbonization, gasification and pyrolysis. In the combustion process, biomass is burned at high temperature in the presence of oxygen to achieve heat and energy. Carbon dioxide and water are produced as byproducts. Gasification is considered a better conversion technology than combustion that converts carbonaceous biomass into gaseous products such as CO and H_2 gas. It is carried out at high temperature. In this process, synthesis gases such as CH_4, CO, CO_2, H_2 and N_2 are produced which are of moderate heating value[6]. In gasification, sulfur is converted into H_2S. The sulfur compounds are usually in minor quantities. Pyrolysis is one of the efficient and cost effective methods to obtain energy from biomass[7]. Pyrolysis is classified into three types; slow, fast and flash pyrolysis. These three types of pyrolysis are differentiated by their operating conditions. In pyrolysis biomass is converted into useful products in the absence of oxygen at higher heating rates. 70-80 wt. % bio-oil is obtained in fast pyrolysis process[8].

Table 1.2: Bio oil properties[9]

QUANTITY	BIO OIL	HEAVY FUEL OIL
Volume Energy Density (GJ/m^{3})	21	39
Bio oil density (kg/m^3)	1220	963
Viscosity at 50^oC (mm^2/s)	13	351
pH	3	7
Oil water content (wt. %)	20	0.1
Ash content (wt. %)	0.02	0.03

Table 1.3: Main technology providers of fast pyrolysis in world[10]

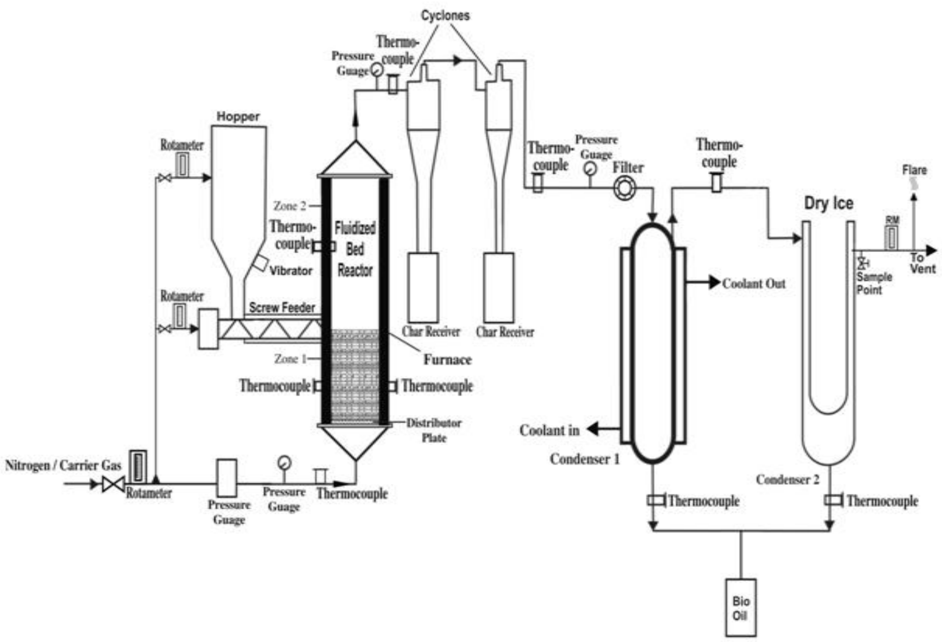
Technology provider/ trademark	Country	Scale (kg/h)	Reactor type
DynamotiveBiotherm™	Canada	400 and 4000	Fluidized bed reactor
Ensyn RTP™	Canada	1000	Circulating fluidized bed reactor
BTG	Netherlands	250	Rotating cone reactor
Pyrovac/ pyrolcycling™	Canada	50 and 3500	Vacuum reactor

II. Materials and methods

A known weight of sand is introduced into the fluidised bed reactor from the top over the distributor plate. A set point of temperature is given from the computer software system and starts the system to achieve the required temperatures. The system is initially run on air. Biomass feed is introduced from the top of hopper[11].

There is a pre-heater that heats the nitrogen gas. Nitrogen is used for purging. The nitrogen gas goes into the header from where it goes into the reactor and hopper. When the required temperature is achieved, then the feed is introduced. The screw feeder takes away the feed towards the reactor. A water cooling system is provided around the screw to prevent it from overheating[12]. As the pyrolysis reaction starts, charring of vapours take place and gases pass through the two cyclones. The char and dust is collected into the char receiver. The gases and vapours pass through the two condensers. In the first condenser water is used and in the second condenser ice is used. Bio-fuel is collected from the bottom of condenses after condensation and gases go outward from the rotameter. After the completion of the process, the bio-fuel and char are collected[13].

Fig 2.1 Schematic Diagram of Fast Pyrolysis System[14].



III. Results and Discussion

3.1 Effect of Temperature on Products

The experimental rig was operated by changing the reactor temperature between 450 and 650°C while the other parameters were kept constant. Feed (2 kg) of -30 - +60 mesh particle size and sand (2 kg) of the similar particle size were used in each run. Nitrogen gas flow rate was kept at 60 ft^3/hr in the hopper. The effect of temperature on the % age yield of products is ellaborated below in Table 3.1.

Table (3.1):-Effect of Temperature on the % age Yield of Products

Test Run	Reactor Temperature (°C)	N_2 Flow Rate (m^3/hr)	Feeder RPM	Bio oil %	Char %	Gases %
1	450	125	20	56	22	11
2	500	125	20	59	20	13
3	550	125	20	62	17	16
4	600	125	20	55	15	19
5	650	125	20	53	12	21

Fig (3.1) indicates that % age yield increases by increasing pyrolysis temperature up to 550°C and then suddenly decreases. So the maximum yield is obtained at 550°C.

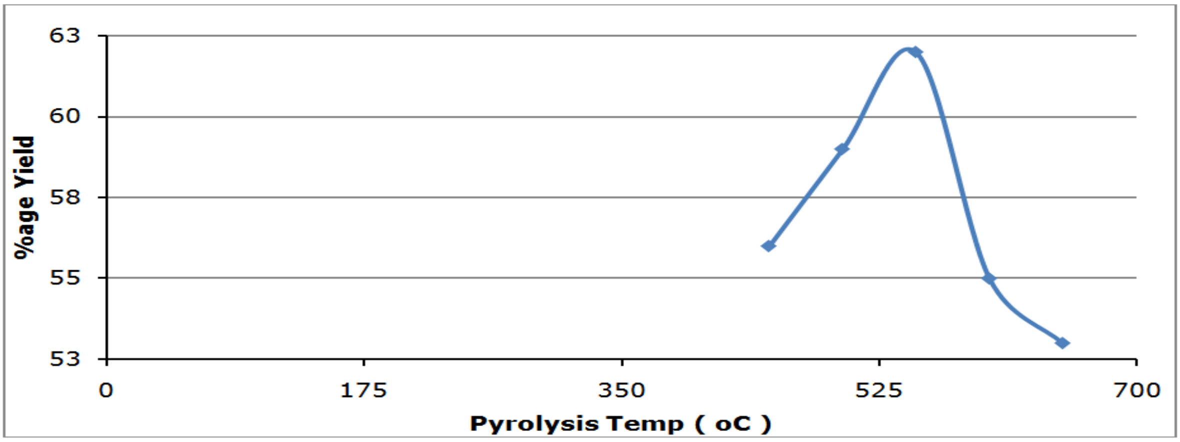


Fig (3.1):-Effect of temperature on % age Yield of Bio-oil

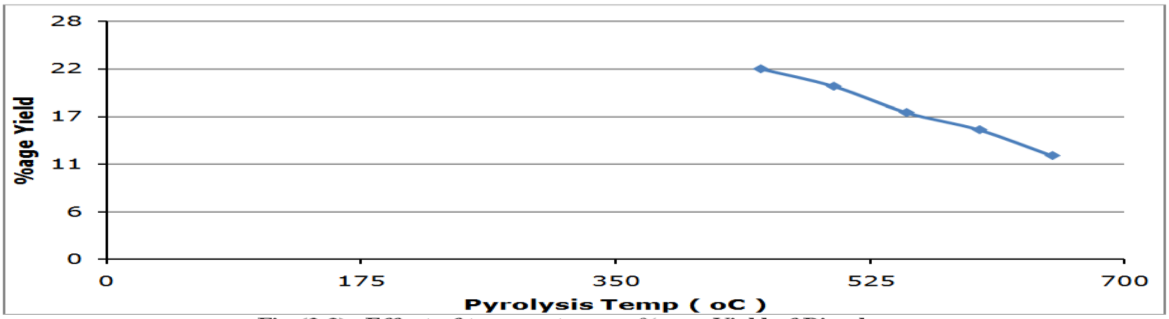


Fig (3.2):-Effect of temperature on % age Yield of Bio-char

Effect of temperature on % age yield on char is again reflected in Fig 3.2. At 450°C, the maximum yield of char is obtained at 450°C.

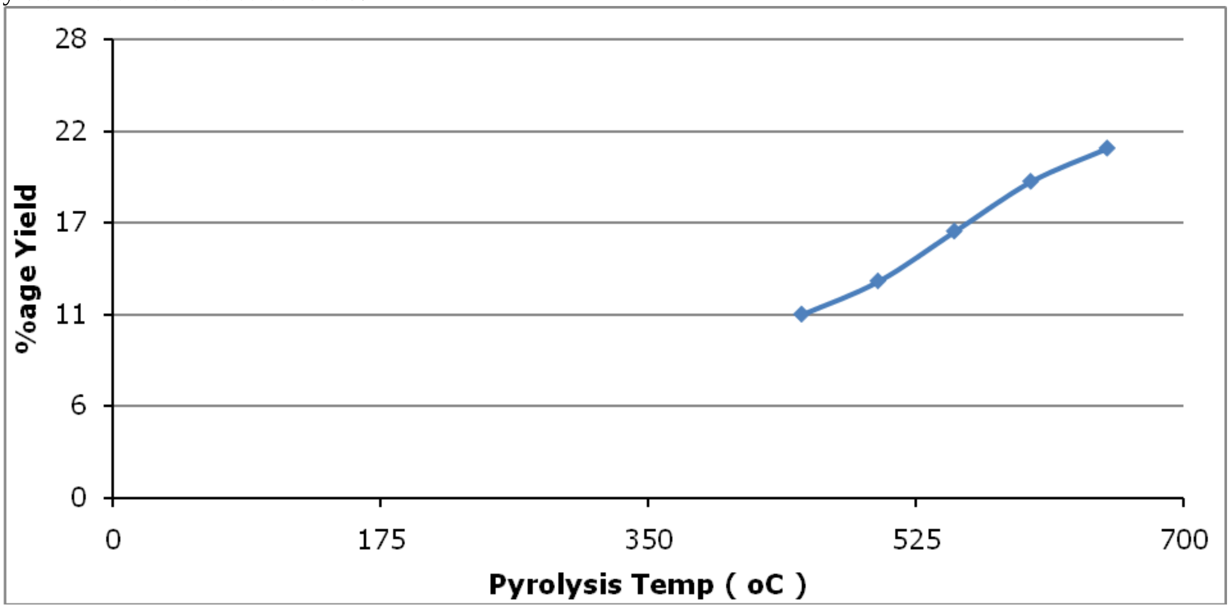


Fig (3.3):-Effect of temperature on % age Yield of gases

A linear trend is obtained in the Fig (3.3) which shows an increase in % age yield of gases with the increases in temperature in each experimental run. The maximum yield of gases is achieved at 650°C. This is because as the temperature increases, secondary reactions initiate that cause cracking and reforming. As a result formation of gases also increases.

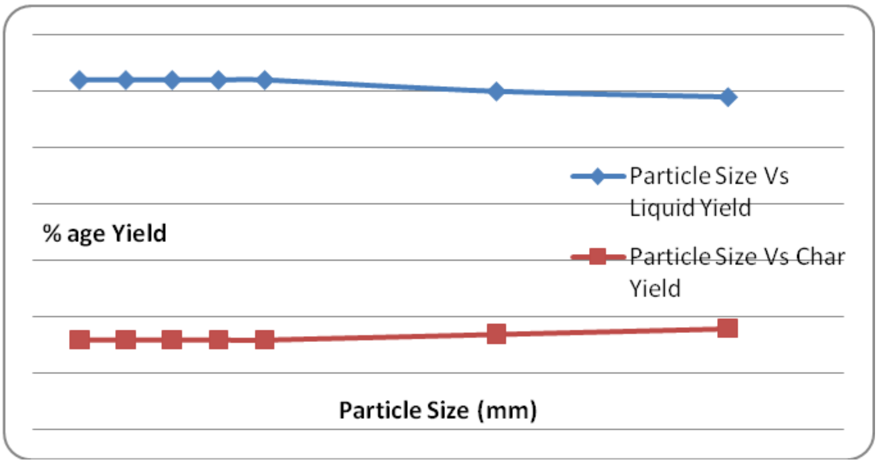
3.2 Effect of Particle Size on Products

Different runs were made to see the effect of particle size on all these products. The particle sizes were varied from 0.2-3mm, while the other parameters were kept constant.

Table 3.2. Effect of Particle size on the Products

Particle Size dp (mm)	Pyrolysis Temperature (°C)	Liquid % age yield	Char % age Yield
0.2	550	62	16
0.4	550	62	16
0.6	550	62	16
0.8	550	62	16
1	550	62	16
2	550	60	17
3	550	59	18

Fig 3.4. Effect of Particle size on the Products



This effect can be seen in Fig 3.4. The graph indicated that the liquid and char yield remains same up to 1mm dp. After 1mm, the bio-oil yield starts to decrease and bio-char yield increases. This shows that particle size also affects the product yield. The reason is that when particle size is below 1 mm, more cellulosic components are formed due to the increase in the surface area. And when the feed size is large then surface area is smaller and rate of reaction of cellulosic components decreases and thus bio-oil yield decreases.

3.3. FTIR

Fourier Transform Infrared Spectrometry (FTIR) test results of bio-oil samples were also performed during the study. The results at different wavelength showed following groups that are given below in Table 3.3

Table 3.3 FTIR results of Bio-oil

Wavelength (cm^{-1})	**Groups**
2927	Aromatics ,Cyclic enes
1636	Quinolones
1022	C-F group
1263	Hydroxyl group
3380	Imino-moiety of piperozinyl group
1702	Carbonyl of acids
1456	O-C-O group of acid
912	Amines

III. Conclusion

From the above analysis and behaviour it is concluded that maximum production of bio-oil is obtained at 550°C with minimum production of char and waste gases. Hence, for the production of bio-oil using fast pyro-lysis and wheat straw as a raw material, the optimum temperature evaluated is 550°C. The decrease in temperature causes an increase in the char yield and further increase in the temperature above 550°C increases the formation of gaseous products. Particle size also found as significant parameter which affects the products specially bio-oil and char. Bio-oil yield remains constant for biomass feed particle size less than 1mm. As particle size increases from 1mm bio-oil yield decreases and char yield increases. The ash content in char was found 13 % and calorific value of char is 14.307 MJ/kg which is in acceptable range.

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