Thermochemical Conversion: *Jatropha curcus* in Fixed Bed Reactor Using Slow Pyrolysis

Vipan Kumar Sohpal, Rajesh Kumar Sharma

***Abstract*—**Thermochemical conversion of non-edible biomass offers an efficient and economically process to provide valuable fuels and prepare chemicals derived from biomass in the context of developing countries. Pyrolysis has advantages over other thermochemical conversion techniques because it can convert biomass directly into solid, liquid and gaseous products by thermal decomposition of biomass in the absence of oxygen. The present paper aims to focus on the slow thermochemical conversion processes for non-edible *Jatropha curcus* seed cake. The present discussion focuses on the effect of nitrogen gas flow rate on products composition (wt %). In addition, comparative analysis has been performed for different mesh size for product composition. Result shows that, slow pyrolysis experiments of *Jatropha curcus* seed cake in fixed bed reactor yield the bio-oil 18.42 wt % at a pyrolysis temperature of 500°C, particle size of -6+8 mesh number and nitrogen gas flow rate of 150 ml/min.

Keywords*—Jatropha curcus*, Thermo-chemical, Pyrolysis, Product composition, Yield.

I. Introduction

PYROLYSIS is the fundamental kinetic process that is the pioneer of both the gasification and combustion of biomass and involved chemical changes occurring in the absence of oxygen when heat is applied to biomass. The products of biomass pyrolysis include water, charcoal, oils and gases. The nature of the changes in pyrolysis depend on the material being pyrolyzed, the final temperature of the pyrolysis process and the rate at which it is heated up. As typical lignocelluloses biomass materials are poor heat conductors, management of the rate of heating requires that the size of the particles being heated be quite small. Contrary of that, in massive materials such as logs, the heating rate is very slow, and this determines the yield of pyrolysis products. Depending on the thermal environment and the final temperature, pyrolysis will yield mainly char at a lower temperature (less than 400^0C) and slow heating rate. On the other hand higher temperature above than 800^0C mainly yields gases, with rapid heating rates. Main desired products such as liquid bio-oil achieved at intermediate temperature, which is just being turned to commercial applications. However, the bulk of commercial and technical pyrolysis processes are applied to the production of charcoal from biomass - a solid biofuels, which is then used as a reducing agent in metallurgy, as activated charcoal in absorption applications after chemical processing, and in domestic cooking in urban areas of the developing world.

Slow pyrolysis or conventional pyrolysis is carried out at slow heating rate 3-7^0K/min Several literatures reveal that in case of slow pyrolysis, the yield of oil is less and char yield is more. Goyal et al. [1] discussed conventional pyrolysis involves all three types of pyrolysis product. It heats the biomass at a moderate rate to a moderate temperature (~600^0C). The product residence time is on the order of minutes. The slow pyrolysis of pomegranate seeds was carried out by Suat and Selhan [2] at 400, 500, 600 and 800^0C to know the effect of temperature on the product distribution. The maximum liquid yields were obtained at the temperatures of 500 and 600^0C and the chars produced from pomegranate seeds having carbon rich fuels with high bulk densities and calorific values. H. Beis et al. [3] slowly pyrolyzed safflower seeds in fixed-bed pyrolyzed to determine particularly the effects of pyrolysis temperature, heating rate, particle size and sweep gas flow rate on the pyrolytic product yields and their chemical compositions and obtained the maximum oil yield of 44% at temperature of 500^0C, particle size range of +0.425–1.25mm, with heating rate of 5^0C/min and sweep gas (N_2) flow rate of 100 cm^3/ min. Sensoz et al. [4] obtained the maximum yield of bio-oil 36% by weight at 500^0C with a heating rate of 50^0C/ min under the sweep gas of N_2 with a flow rate of 100 cm^3/min, due to the decrease in mass transfer limitations.

Rapeseed cake was pyrolyzed by Filiz Karaosmanogi et al. [5] in a fixed bed stainless steel reactor from temperature 450-850^0C under static atmosphere at rates of 15°C/min and 25°C/min towards understanding the influence of heating rate and pyrolysis temperature on product yield. The maximum yield was obtained at 650^0C at a heating rate of 15^0C/ min. Pyrolysis experiments on soybean cake was carried out by E. Putun et al. [6] in a fixed-bed reactor under nitrogen and steam atmosphere and obtained the maximum yield of oil 33.78% at 550^0C of particle size 0.850> D_p <1.250 mm when sweeping gas (N_2) flow rate was 200 cm^3/min and the oil yield increased to 42.79% with a steam velocity of 1.3 cm/s. The gas products obtained from the pyrolysis of rapeseed oil cake carried out by Suat Ucar et al. [7] in a fixed bed reactor at 500^0C, mainly consisted of CO_2, CO, CH_4 and H_2S gas and liquid. S. Sensoz et al. [8] investigated the effect of particle size on the yields of the pyrolysis products of Brassica napus L. in a Heinze reactor under static atmosphere at a temperature of 500^0C at 40^0C/min of heating rate with a particle size of range of 0.224-1.8 mm, maximum 46 wt% oil obtained with a particle size range of 0.85-1.8 mm with a heating value of 38.4 MJ/kg. Rapeseed

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Pyrolysis were performed by Ozlem Onay et al. [9] in a free fall reactor at atmospheric pressure under nitrogen atmosphere to investigate the effect of final pyrolysis temperature, particle size and sweep gas flow rate on the yields of products and resulted that the maximum pyrolysis conversion of 7.8% at a temperature of 700^0C. The maximum bio-oil yield of 75% was obtained at a final pyrolysis temperature of 600^0C, particle size range of 0.224 to 0.6 mm and the sweep gas flow rate of 100 cm^3/ min. Ayse et al. [10] studied rapid and slow pyrolysis of pistachio shell and concluded that the highest bio-oil yield with a value of 27.7% at a temperature of 773^0K, when the heating rate and carrier gas flow rate were as 300^0K/min and 100 cm^3/ min respectively. Zandersons et al. [11] conducted slow pyrolysis of sugarcane bagasse for char production and obtained 23–28% yield of charcoal. Slow pyrolysis of cottonseed cake at heating rates of 7^0C/min in a tubular reactor was reported by Ozbay et al. [12]. Pyrolysis experiments were conducted in two reactors, Heinz retort and a well-swept tubular reactor. Sohpal et al. [13] and [14] investigated the transesterification of base oil of jatropha curcus for biodiesel production and found that biooil transesterification produces stable product of pyrolysis

II. Chemical Composition of *Jatropha curcus* Biomass

Jatropha curcus seed cake used as biomass for thermochemical conversion process. It is important to highlight that non edible oil (*Jatropha curcus*) has the requisite potential of providing a promising and commercially viable biodiesel. Analysis of *Jatropha curcus* seed shows the following chemical compositions:

TABLE I
Jatropha curcus Seed Cake Composition

Components	Weight Percentages
Moisture	6.20
Protein	18.00
Fat	38.00
Carbohydrates	17.00
Fiber	15.50
Ash	5.30

The oil content is 25-30% in the seeds and 50-60% in the kernel. The oil contains 21% saturated fatty acids and 79% unsaturated fatty acids. The composition of seed cake mentioned in Table I is the function of soil and environment conditions. Although the variation may occur in biomass obtained from *J. curcus*, but the change of weight percentage is insignificant.

III. Experimental Methodology

In our experimental setup, fixed bed reactor used for slow pyrolysis of *Jatropha curcus* seed cake. Pretreatment of biomass performed to reduce the size and remove the moisture contents. After the biomass sample reached a constant weight (250 gm), loaded into fixed bed reactor, and N_2 sweeping gas develops an inert atmosphere in the reactor. The fixed bed reactor concept for biomass pyrolysis is shown in Fig. 1. After constant heating, the reactions in the reactor begin to take place at 450-500^0C. On further increasing the temperature products, formation takes place and pass through the condenser for desired liquid phase. Products are obtained using a different technique of the separation process.

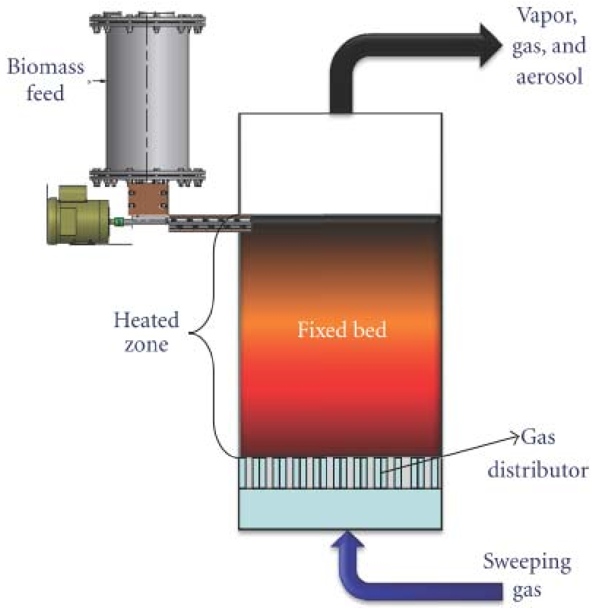

Fig. 1 Fixed Bed reactor concept for slow pyrolysis

IV. Results and Discussion

In our experiment, we conducted experiments on slow pyrolysis of Jatropha curcus biomass to investigate the affect of temperature, particle size, and sweep gas flow on the product compositions and yield. In our experimental, the temperature range consider from 500-530^0C, particle size of -6+12 mesh number and sweep gas flow rate of 50-200 ml/min

A. Influence of N_2 Sweeping Gas on Mass of Pyrolysis Products

Nitrogen gas flow rate on product yields is shown in Fig. 2, when *Jatropha curcus* particle size of -6+8 mesh number at a temperature of 500°C is used. The increase in nitrogen gas flow rate from 50 to 200 ml/min decreased the char mass from 94.88 to 87.09 gm. The bio oil, water, and gas mass production through slow pyrolysis are reciprocal of char mass production. The higher residence time of the volatiles in the reactor causes secondary decomposition of higher molecular weight products. At a pyrolysis temperature of 500°C, the maximum bio oil mass obtained 40.57gm with particle size of -6+8 mesh number at a sweep gas flow rate of 150ml/min. The maximum gas mass of 8.89 gm obtained at a sweep gas flow rate 150 ml/min. The char mass decreased by 8% (gm) when the nitrogen gas flow rate varied from 50 to 200 ml/min.

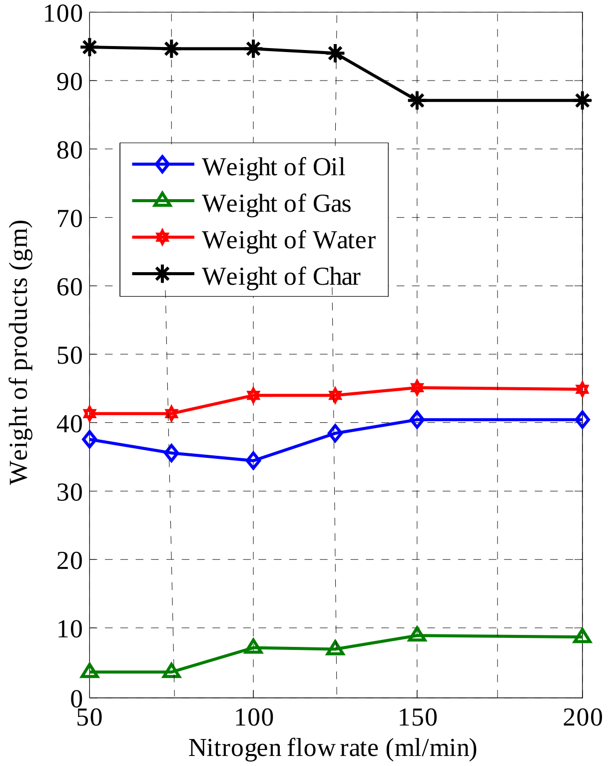

Fig. 2 Nitrogen flow rate effect on mass of products at 500^{0}C with particle size -6+8 mesh number

The experimental analysis of the present work shows that the mass of oil and non-condensable gases was affected by the nitrogen gas flow rate. The nitrogen gas flow rate had an also significant effect on the char and water mass. It is known that sweeping the retort environment with nitrogen could increase the oil yield. Because sweeping the environment shortens the residence times of the volatiles and reduces their chances of being involved with char and radical forming secondary reactions.

B. Influence of Particle Size on Mass of Pyrolysis Products

In this experiment two different sizes of particles of biomass considered to determine the effect of particle size on product mass. On varying the particle size from -6+8 to -8+12 mesh number, with the sweep gas flow rate of 150 ml/min, the mass of oil decreases from 40.57 gm to 21.28 gm. On the contrary of bio oil, char mass increases as the particle size increases from -6+8 to -8+12. This result suggested that mass and heat transfer parameters have significant with larger particle size of -8+12, resulting in minimum oil yield. The gas and water mass decreased as the particle sizes increases with sweep gas flow rate of 150 ml/min at uniform temperature. Figs. 2 and 3 show the effect particle size -6+8 and -8+12 mesh number on product mass of at uniform temperature 500^{0}C. The experimental results agree the concept that smaller the particle heated uniformly, results in high oil yield. The maximum gas yield of 40.4 gm was obtained at particle size of -6+8 mesh number. The heat transfer rate from outer to inner surface for large particle size is less, virtue of that water contents in the pyrolysis products reduced as particle size increased. Similarly reduction in heat transfer rate due to larger size of particle causes the higher mass of char production.

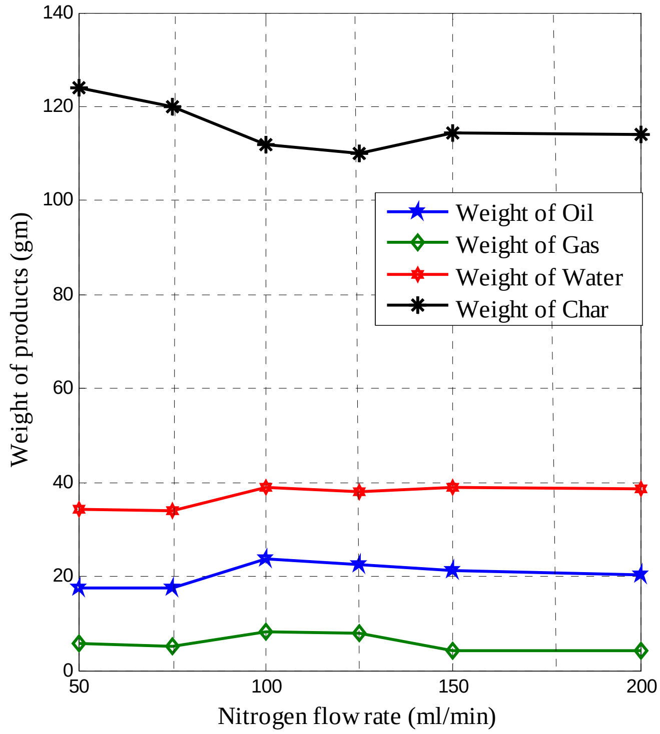

Fig. 3 Nitrogen flow rate effect on mass of products at 500^{0}C with particle size -8+12 mesh number

C. Influence of Temperature on the Yield of Pyrolysis Products

Table II, shows the product yields of *Jatropha curcus* seed cake in relation to pyrolysis temperatures of 500-530^{0}C and 520-530ºC for the particle size of -6+8 to -8+12 mesh number under a sweep gas velocity of 150 ml/min. The maximum oil yield of 18.42 wt% obtained at 530ºC. The yield of oil increases from 17.7 wt % to 18.42 wt % when the pyrolysis temperature was increased from 500ºC to 530ºC. The oil yield increased due to the elimination of the mass and heat transfer limitations by high heating rates. As shown in Table II the pyrolysis temperature affected the yield of the products significantly. In general, the yield rises to an optimum value with an increase in temperature and then fall.

TABLE II
PRODUCT YIELDS (WT %) OF PYROLYSIS OF *JATROPHA CURCUS* SEED CAKE VS. TEMPERATURE

Sr. No	Mesh Size (mesh number)	Temperature range (^{0}C)	Product Yields (Wt%) of Pyrolysis of *Jatropha curcus* seed cake				
			Oil	Water	Gas	Char	Losses
1	-6 +8	500	17.07	18.78	1.68	43.08	19.40
2		515	15.69	20.03	3.32	42.86	18.10
3		530	18.42	20.64	4.04	39.54	17.36
4	-8+12	520	7.90	15.60	2.66	56.03	17.83
5		525	10.80	17.74	3.78	50.81	16.87
6		530	9.66	17.64	2.05	51.94	18.7

The lowest pyrolysis temperature of 500ºC causes thermo chemical conversion relatively slow, and char and losses products values are high. On further increasing the temperature char wt % increased at 530ºC. The decrease in the char yield at the high temperatures is consistent with the increase in the volatile matter. From the results shown in Table II with respect to maximum oil yield, it is clear that the optimum pyrolysis temperature is 530ºC and 525^{0}C under the experimental conditions used.

V. CONCLUSIONS

The experiments results conclude that the increase in nitrogen gas flow rate from 50 to 200 ml/min increased the oil yield from 17.07 wt % to 18.42 wt %. The water and gas yield increased from 18.73 to 20.64 wt % and1.68 to 4.04 wt %. The char yield decreases as the nitrogen gas flow rate was increased from 50 to 200 ml/min. Moreover, the char yield rises 43.08 to 56.03 wt% as particle size increases from -6+8 to -8+12 respectively. The yield of bio oil increases from 17.07 wt % to 18.42 wt % when the pyrolysis temperature increased from 500ºC to 530ºC. The char yield decreases with increasing the pyrolysis temperature. The water and gas yield decreased from 20.64 to 18.78 wt% and 4.04 to 1.68 wt% respectively as the temperature raised from 500ºC to 530ºC.

REFERENCES

[1] H.B. Goyal, Diptendu Seal, R.C. Saxena, “Fuels from thermo chemical conversion of renewable resources: A review” Renewable and Sustainable Energy Reviews 2008; 12: 504–517.
[2] Suat Ucar and Selhan Karagoz, “The slow pyrolysis of pomegranate seeds: The effect of temperature on the product yields and bio-oil properties” Journal of Analytical and Applied Pyrolysis 2009; 84:2:151-156.
[3] H. Beis, O. Onay and O. M. Koçkar, “Fixed-bed pyrolysis of safflower seed: Influence of pyrolysis parameters on product yields and compositions” Renewable Energy 2002; 26: 1:21-32.
[4] Sensoz S, Angin D., “Pyrolysis of safflower seed press cake: part 1. The effects of pyrolysis parameters on the product yields” Bioresources Technology 2008; 99:13:5492-7.
[5] Filiz Karaosmanogi LU, Esin Culcuogi LU, “Pyrolysis of Rapeseed Cake”, Energy Sources 2001; 23: 377- 382.
[6] E. Putun, Esin Apaydin, Ersan Putun, “Bio-oil production from pyrolysis and steam pyrolysis of soybean-cake: product yields and composition” Energy 2002; 27: 703–713.
[7] Suat Ucar Ahmet R. Ozkan, “Characterization of products from the pyrolysis of rapeseed oil cake” Bioresources Technology 2008; 99:8771–8776.
[8] S. Sensoz, D. Angn, S. Yorgun, “Influence of particle size on the pyrolysis of rapeseed (*Brassica napus* L.): fuel properties of bio-oil” Biomass and Bioenergy 2000; 19: 271- 279.
[9] Ozlem Onay, O. Mete Kckar, “Pyrolysis of rapeseed in a free fall reactor for production of bio-oil” Fuel 2006; 85: 1921–1928.
[10] Ayse E. Putun1, Nurgu Ozbay, Esin Apaydın Varol1, Basak B. Uzun and Funda Ates, “Rapid and slow pyrolysis of pistachio shell: Effect of pyrolysis conditions on the product yields and characterization of the liquid product” Int. J. Energy Res. 2007; 31:506–514.
[11] Zandersons, J.; Gravitis, J.; Kokorevics, A.; Zhurinsh, A.; Bikovens, O.; Tardenaka, A.; and Spice, B.“Studies of the Brazilian sugarcane bagasse carbonisation process and products properties” Biomass and Bioenergy 1999; 17: 209 – 219
[12] Ozbay N, Putun AE, Uzun BV, Putun E. “Biocrude from biomass: pyrolysis of cotton seed cake” Renew Energy 2001; 24:615–25.
[13] Sohpal, Vipan Kumar, Amarpal Singh, and Apurba Dey “Fuzzy modeling to evaluate the effect of temperature on batch transesterification of Jatropha curcus for biodiesel production." Bulletin of Chemical Reaction Engineering & Catalysis 2011, 6.1: 31-38.
[14] Sohpal, Vipan Kumar, Amarpal Singh, and Apurba Dey. "A comparative study of molar ratio effect on transesterification of *Jatropha curcas* using kinetic and fuzzy techniques." International Journal of Oil, Gas and Coal Technology 2011, 4.3: 296-306.