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Bio-oil and char production from *Jatropha Curcus* seed cake *via* slow pyrolysis: a comparative study of thermochemical and fuzzy modeling

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Jatropha seed cake (JSC) biomass is one of the prominent feedstocks for renewable energy production through thermochemical conversion. In this work firstly slow pyrolysis was conducted to find the product yield of charcoal and bio-fuel in a fixed-bed reactor. Secondly, a fuzzy model of the operating variable was developed using ANFIS through mamdani MIMO system for thermochemical kinetic data. The proposed modeling was verified by comparing with the observed practical results obtained by thermochemical conversion under specific conditions. Results showed that the maximum oil yield was 18.42 wt.% obtained at 530ºC for the mesh size of -6+8 at a sweep gas velocity of 150 ml/min, due to the elimination of the mass and heat transfer limitations by high heating rates. At the lowest pyrolysis temperature of 500ºC high amounts of char products were obtained. Mamdani MIMO system provides a representation of the process parameters and its output is close to the experimental result.

Keywords: Biomass, thermochemical conversion, ANFIS, charcoal, bio-fuel.

INTRODUCTION

Agriculture-based residual and its availability as a waste product is a leading source of renewable energy. Amongst the many varied ways to utilise biomass as a source of energy is pyrolysis, a thermochemical decomposition process that occurs at elevated temperatures in the absence of oxygen gas. Biomass pyrolysis produces gas and liquid products and leaves a solid residue known as char [1]. The liquid product is a fuel termed as bio-oil, pyrolysis oil or bio-crude [2]. Presently, bio-oil produced from the pyrolysis of biomass can be used directly or after further physicochemical processes to heat boilers, or even drive diesel engines or turbines [3–5]. It can be stored and transported more efficiently compared to the original biomass because of its liquid state. During the combustion of bio-oil, its net-zero carbon dioxide (CO_2), as well as lesser nitrogen oxides (NOx) and/or sulfur oxides (SOx) emissions compared to fossil fuels make it a potential liquid fuel replacement [6]. The feedstock of interest is *Jatropha curcas (J. curcas)*, a drought-free inedible crop, which can be planted economically in tropical and sub-tropical regions [7]. Its seed is a source of oil that is currently used for commercial biodiesel production. Nevertheless, the extraction of oil for biodiesel production only takes up to 18 wt% of the dry fruit, but it has been reported that the remaining J. curcas fruit after biodiesel production has the potential of fuel production with twice the energy content compared to biodiesel [8]. Different parts of the J. curcas shrub can be utilised in several thermochemical processes. J. curcas seed husk could successfully be used as feedstock for open core downdraft gasifier to generate producer gas. For pyrolysis, approximately 50 wt.% of its nutshell can be transformed into bio-oil and even its wood and leaves can be valorised for fuel extraction [9, 10]. The pressed cake remaining after oil extraction can also be used as a source of bio-oil production and it was found that the main thermal decomposition occurred over the temperature range of 523.15 – 723.15 K and could be described by the three-parallel reactions model [11]. Parametric study of flash pyrolysis was conducted for Jatropha oil cake in an electrically heated fluidised-bed reactor using nitrogen. The maximum oil yield of 64.25 wt.% was obtained at a particle size of 1.0 mm, and extract source of low-grade fuel directly [12]. Comparative analysis has been performed for different mesh sizes for product composition and result shows that slow pyrolysis experiments of Jatropha curcus seed cake in a fixed-bed reactor yield 18.42 wt. % of bio-oil at a pyrolysis temperature of 500°C, particle size of -6+8 mesh number and nitrogen gas flow rate of 150 ml/min. Heterogeneous catalysts and catalytic pyrolysis pretreatment can improve bio-oil quality and yield [13-15]. Palm oil-empty fruit bunches and rice husk were pyrolyzed to produce gas and liquid fuel in a semi-batch pyrolysis reactor [16]. Mathematical model and kinetic parameters were used to describe the pyrolysis of a single solid particle of biomass [17].

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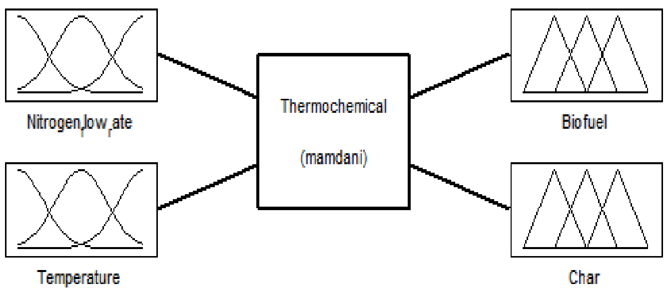
De-oiled seed cakes of African star apple and Silk cotton as a source of bio-oil were investigated using slow pyrolysis at temperatures of 300–450 °C for 60 min residence period in a nitrogen atmosphere. Maximum conversion of 72% takes place at 400 °C [18]. Pyrolysis of JC by-products adds to sustainable technology for energy production, heterogeneous catalyst and precursor of activated carbons/chemicals [19]. Response surface methodology was employed to optimum operating conditions for pyrolysis of Neem PSC. The highest liquid yield of 52.1 wt. % was achieved at 512.5 °C, 60 min and 0.5 L/min [20]. Fast pyrolysis of Jatropha was carried out in a fixed-bed batch reactor with temperature zone of 400°C to 550°C to produce liquid biofuel at an interval of 50°C. The higher temperature in the fast pyrolysis of the bio material produces maximum liquid yield [21]. Wheat straw was used as biomass material to produce bio-oil in a fluidized-bed fast reactor. The result shows that the highest bio-oil yield of 42 wt.% is obtained at a temperature of 500°C, feed particle size of 1 mm, and gas flow rate of 4 m^3h^{-1} [22]. Lignocellulosic and macro algae biomasses were used for bio char production using co-pyrolysis. It assists to change the morphological and surface composition of bio char [23]. Slow pyrolysis experiments of Jatropha curcus seed cake in a fixed-bed reactor yielded 18.42 wt % of bio-oil at a pyrolysis temperature of 500°C, particle size of -6+8 mesh number and nitrogen gas flow rate of 150 $ml.min^{-1}$ [24]. To date, while several research studies have indicated the potential of J. curcas wastes as pyrolysis feedstock, this paper is an attempt to produce quality product using slow pyrolysis and optimize the process using adaptive neuro fuzzy system.

Experimental & Fuzzy Methodology

Analysis of Jatropha seed cake after the extraction of oil indicates that seed cake has a wide potential as feed stock for anaerobic slow pyrolysis. The seed cake has high protein content of 31.5% and significant percentages of cellulose and hemi-cellulose - 15.9% and 11.4%, respectively. In our experimental setup, a fixed-bed reactor was used for slow pyrolysis of JSC. Pretreatment of biomass was performed to reduce the size and remove the moisture content. After the biomass sample reached a constant weight (250 g), it was loaded into the fixed-bed reactor, and N_2 sweeping gas developed an inert atmosphere in the reactor. After constant heating, the reactions in the reactor began to take place at 450-500^{0}C through electrical heating. On further increasing the temperature (3^{0}K/min) products were formed which passed through the condenser for the desired liquid phase. Products were obtained using different techniques of the separation process for particle size -6+8 mesh number. Fuzzy model described in this thermochemical reactor system, shown in Fig. 2, is a MIMO system with two input parameters – nitrogen flow rate, and temperature of reactor and outputs as Biofuel and Biocahr. Possible universe of discourse for the input parameters is given in Fig. 1 for mamdani fuzzy system.



Input parameters:
Nitrogen flow rate (ml/min) = 50 to 200,
Temperature (^{0}C) = 500-530

Output parameter:
Biofuel & char =
Predicted as concentrations of products (wt. %)

Figure 1. Fuzzy model of thermochemical (mamdani) showing inputs and output.

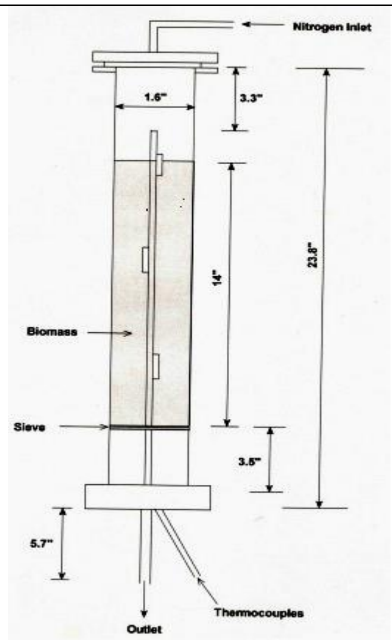


Figure 2. Lab scale reactor

Table 1. Product yields (wt. %) of slow pyrolysis of JSC *vs*. temperature

Temperature (^{0}C)	500	505	510	515	520	525	530
Bio-Oil Yield (wt. %)	17.07	16.10	16.00	15.75	16.89	18.40	18.42
Char Yield (wt. %)	43.08	43.00	42.95	42.86	41.30	40.40	39.54

RESULTS AND DISCUSSION

Table 1 shows the product yields of JSC for pyrolysis temperatures of 500-530^{0}C for the particle size of -6+8 mesh number under sweep gas velocity of 50-150 ml/min. The maximum oil yield of 18.42 wt.% was obtained at 530ºC. The yield of oil increased from 17.07 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. The lowest pyrolysis temperature of 500ºC causes a relatively slow thermochemical conversion, and char products values are high. On further increasing the temperature the char wt % decreased due to the increase in the volatile matter.

Moreover, Table 1 clearly indicates that the bio-oil yield obtained by fixed-bed pyrolysis increases with the increase of N_2 flow rate causing cooling effect. As the pyrolysis reaction proceeds the N_2 flow rate reaches an equilibrium, this delay in cracking and bonding prolonging the duration of the pyrolysis process in agreement with literature [25]. The above value of the temperature (^{0}C) used in the present investigation agrees well with the literature value of 636-800 ^{0}K for Jatropha pressed cake pyrolysis [26]. From the temperature range of 505-515^{0}C, the cellulose first breaks down, and then the lignin starts to crack down into char, water and heavy oil. This justifies the decrease in char production in favour of higher bio-oil product and these results also agree with previous work [27].

Fuzzy Modeling for Membership Functions for the Input and Output Variables: In this process, linguistic values were assigned to the variables and that was performed using fuzzy subsets and their associated membership functions. Modeling with grid partition involves three membership functions that were produced for each input variable of substitution matrices, and sequences based on ANFIS. The in1mf1, in1mf2, in1mf3 are three linguistic levels for nitrogen flow rate and in2mf1, in2mf2, and in2mf3 are for temperature as shown in Figures 3 and 4.

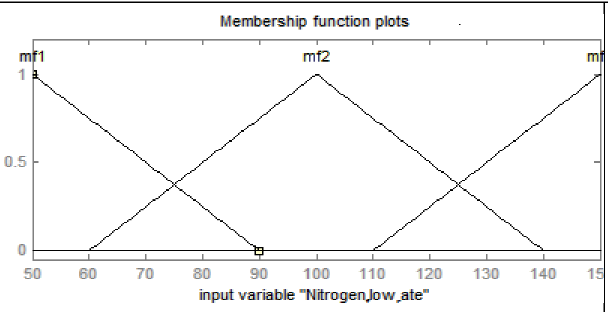


Figure 3 (a). Fuzzy model of thermochemical namdani) showing input variable nitrogen flow rate.

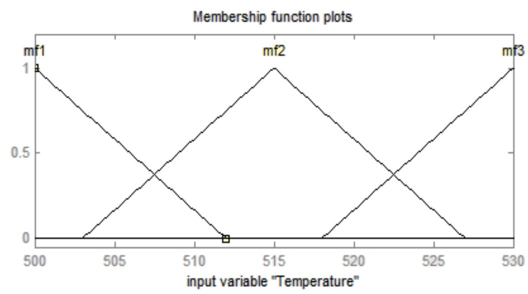


Figure 3 (b). Fuzzy model of thermochemical (mamdani) showing input variable temperature.

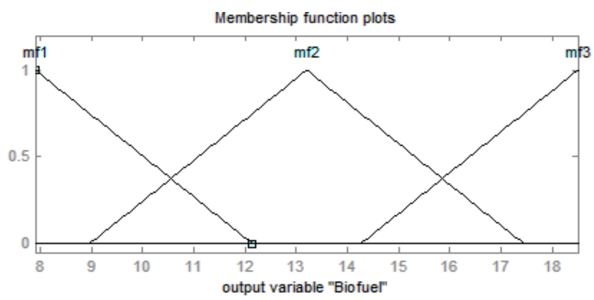


Figure 4 (a). Fuzzy model of thermochemical (mamdani) showing output variable biofuel.

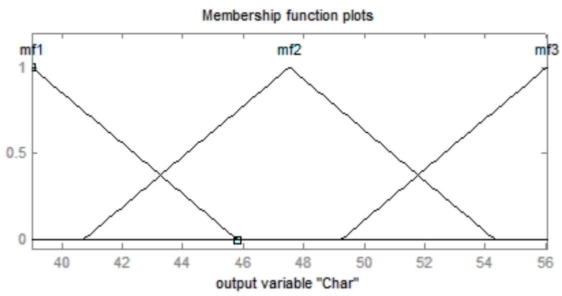


Figure 4(b). Fuzzy model of thermochemical (mamdani) showing output variable char.

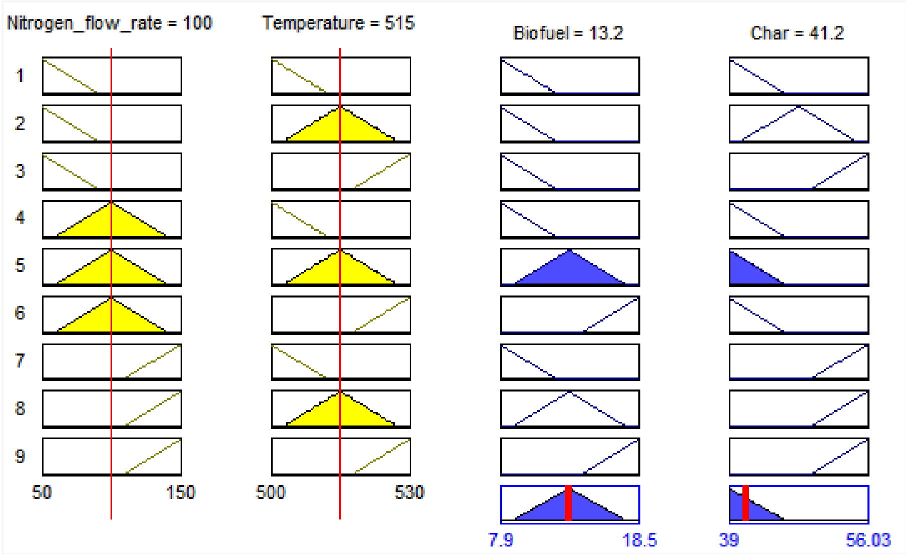


Figure 5. Ruler view of input variables (nitrogen flow rate and temperature) with output variables (biofuel and char)

Modeling for thermochemical (mamdani) involves nine membership functions that were produced for each output variable shown below:

1. If nitrogen_flow_rate is mf1 and (temperature is mf1, then biofuel is mf1 (char is mf1) (1).
2. If nitrogen_flow_rate is mf1 and temperature is mf2, then (biofuel is mf1 (char is mf2) (1).
3. If nitrogen_flow_rate is mf1 and temperature is mf3, then biofuel is mf1 (char is mf3) (1).
4. If nitrogen_flow_rate is mf2 and temperature is mf1), then biofuel is mf1 (char is mf1) (1).
5. If nitrogen_flow_rate is mf2 and temperature is mf2, then biofuel is mf2 (char is mf1) (1).
6. If nitrogen_flow_rate is mf2 and temperature is mf3, then biofuel is mf3 (char is mf1) (1).
7. If nitrogen_flow_rate is mf3 and temperature is mf1), then biofuel is mf1 (char is mf3) (1).
8. If nitrogen_flow_rate is mf3 and temperature is mf2, then biofuel is mf2 (char is mf3) (1).
9. If nitrogen_flow_rate is mf3 and temperature is mf3, then biofuel is mf3 (char is mf3) (1).

Figure 5 presents the rule viewer that shows the values of the various inputs to the model and computed outputs. Here, the biofuel and char concentration (output) can be predicted by varying the input parameters nitrogen flow rate and temperature. It shows a particular instance having input values given to the system for nitrogen gas flow rate of 100 ml/min, and temperature of 515^{0}C for analysis. The output generated by the system for biofuel concentration and char with experimental data shows similarity as 83% and 96%, respectively. This fuzzy model has generated other values of the output variable for a different set of data points in the specified range of input variables.

Figures 6 (a) and (b) show two different views of control surfaces, which are indicating the results predicted by the fuzzy model for different sets of data points. These control surfaces as shown give the interdependency of input and output parameters guided by the various rules in the given universe of discourse. It has already been finalized that there are nine rules predicting the concentration of products for MIMO fuzzy model. These rules were implemented in MATLAB environment using the sugeno type FIS of fuzzy logic toolbox. Results predicted from this fuzzy model were compared with the 70% experimental results data for its validation.

CONCLUSIONS

The experimental and ANFIS results allow to 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 char yield decreased as the nitrogen gas flow rate was increased from 50 to 200 ml/min. Moreover, the char yield can rise as particle size increases from -6+8 onwards. The yield of bio-oil increased by approximately 8% when the pyrolysis temperature increased from 500ºC to 530ºC. The char yield decreased with increasing pyrolysis temperature and the same result was depicted by the mamdani ANFIS system. This study supports that the fuzzy logic technique can be introduced as a viable alternative to analyze complex thermo-kinetic variables. Moreover, fuzzy logic allowed modeling and optimization to be treated simultaneously.

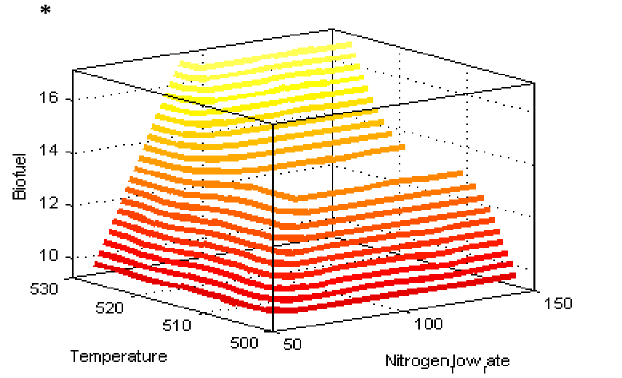


Figure 6 (a). Control surface view of the fuzzy model with nitrogen flow rate, temperature *vs.* biofuel

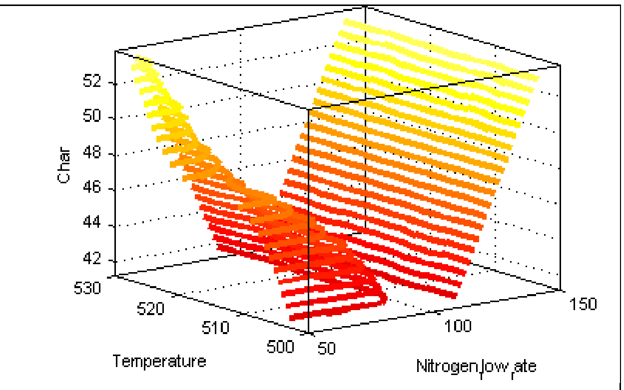


Figure 6 (b). Control surface view of the fuzzy model with nitrogen flow rate, temperature *vs.* char

REFERENCES

1. S. Yaman, *Energy Conversion and Management*, **45(5)**, 651 (2004).
2. Q. Zhang, J. Chang, T. Wang, Y. Xu, *Energy Conversion and Management*, **48(1)**, 87 (2007).
3. M. Balat, M. F. Demirbas, *Energy Sources, Part A*, **31(19)**, 1719 (2009).
4. D. Mohan, C. U. Pittman Jr, P. H. Steele, *Energy & Fuels*, **20(3)**, 848 (2006).
5. S. Kumar, R. Prakash, S. Murugan, R. K. Singh, *Energy Conversion and Management*, **74**, 323 (2013).
6. A. E. Pütün, B. B. Uzun, E. Apaydin, E. Pütün, *Fuel Processing Technology*, **87(1**), 25 (2005).
7. J. S. de Oliveira, P. M. Leite, L. B. de Souza, V. M. Mello, E. C. Silva, J. C. Rubim, P. A. Suarez, *Biomass and Bioenergy*, **33(3)**, 449 (2009).
8. R. N. Singh, D. K. Vyas, N. S. L. Srivastava, M. Narra, *Renewable Energy*, **33(8)**, 1868 (2008).
9. D. K. Vyas, R. N. Singh, *Renewable Energy*, **32(3)**, 512 (2007).
10. R. Manurung, D. A. Z. Wever, J. Wildschut, R. H. Venderbosch, H. Hidayat, J. E. G. Van Dam, H. J. Heeres, *Food and Bioproducts Processing*, **87(3)**, 187 (2009).
11. V. Sricharoenchaikul, D. Atong, *Journal of Analytical and Applied Pyrolysis*, **85(1-2)**, 155 (2009).
12. S. A. Raja, Z. R. Kennedy, B. C. Pillai, C. L. R. Lee, *Energy*, **35(7)**, 2819 (2010).
13. N. Schmitt, A. Apfelbacher, N. Jäger, R. Daschner, F. Stenzel, A. Hornung, *Biofuels, Bioproducts and Biorefining*, **13(3)**, 822 (2019).
14. H. C. Ong, W. H. Chen, A. Farooq, Y. Y. Gan, K. T. Lee, V. Ashok Kumar, *Renewable and Sustainable Energy Reviews*, **113**, 109266 (2019).
15. S. Pang, *Biotechnology Advances*, **37(4)**, 589 (2019).
16. T. D. Kusworo, W. Widayat, A. F. Mahadita, D. Firizqina, D. P. Utomo, *Periodica Polytechnica Chemical Engineering*, **64**(2), 179 (2020).
17. B. Miljkovic, B. Nikolovski, D. Mitrović, J. Janevski, *Periodica Polytechnica Chemical Engineering*, **64(2)**, 192 (2020).
18. M. A. Sokoto, B. Biswas, J. Kumar, T. Bhaskar, *Renewable Energy*, **146**, 1710 (2020).
19. R. Piloto-Rodríguez, I. Tobío, M. Ortiz-Alvarez, Y. Diaz, S. Konradi, S, Pohl, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **1**, (2020).
20. K. N. Dhanavath, S. Bankupalli, C. S. Sugali, V. Perupogu, S. V. Nandury, S. Bhargava, R. Parthasarathy, *Journal of Environmental Chemical Engineering*, **7(1),** 102905 (2019).
21. S. Saeed, I. Ashour, M. R. Ali, *Petroleum & Coal*, **61(6),** (2019).
22. A. S. Paul, N. L. Panwar, B. L. Salvi, S. Jain, D. Sharma, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, **1**, (2020).
23. O. A. Fakayode, E. A. A. Aboagarib, C. Zhou, H. Ma, *Bioresource Technology*, **297**, 122408 (2020).
24. V. K. Sohpal, R. K. Sharma, *International Journal of Energy and Power Engineering*, **7(12),** 1023 (2013).
25. S. A. Jourabchi, S. Gan, H. K. Ng, *Energy Conversion and Management*, **78**, 518 (2014).
26. J. Kongkasawan, H. Nam, S. C. Capareda, *Energy*, ***113*,** 631, (2016).
27. A. E. Pütün, B. B. Uzun, E. Apaydın, E. Pütün, *Fuel Process Technol*., **87**, 25 (2005)