Optimization Studies on Bio Oil Production from sweet lime Empty Fruit Bunch by Pyrolysis Using Response Surface Methodology

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Abstract — *Presently demand of fossil fuel is increasing day to day in all over the world, in developing country like India need some alternate fuel for reducing the import cost of fossil fuel and reduce the emission. Many number of researcher doing research in the field of alternative fuel from bio waste and other biomass sources. In this present work describe the production of bio oil from sweet lime empty fruit bunch by pyrolysis method and investigate the effects of various parameter particle sizes, temperature and nitrogen gas flow rate on the product yields. The optimal condition for the bio oil production was obtained by testing the effect of various parameters on the pyrolysis. The experiments are carried out in fixed bed reactor with temperature, particle size and Nitrogen gas flow rate as parameter. The parameters are optimized by response surface methodology (RSM) with a Box-Behnken (BBD). The results show the bio oil yield is 28.3% for experimental and 28.2% for statistical method at optimum temperature of 550 ºC, 4mm of Particle size and 0.3 lit/min of gas flow rate.*

Keywords: *Bio oil, Char, Pyrolysis, RSM.*

I. INTRODUCTION

Agricultural wastes and agricultural by-products has large amount of energy and it will not affect the atmospheric environment. The biomass and bio waste retains a large quantity of Cellulose, hemicelluloses and lignin. All the researchers have accepted biomass as potential source of conventional energy, as it benefits both energy recovery and environmental protection [1-2]. The main advantage of using agricultural residues is that they have little or no market value and ready for production in large quantities.

Various methods (thermo chemical conversion, biochemical conversion & fermentation) were used to convert the biomass into energy form. Among the thermo chemical conversion, Pyrolysis was one of the most efficient method to convert biomass into bio oil that can be used as alternate fuel. In fast pyrolysis method, biomass was converted into 39-74% of bio oil, 10-20% of char and rest as paralytic gas [3].

Bio oil was used in many applications, especially in alternate fuel. Thus, more researchers concentrate on improving the quantity and quality of the product yield. The fast pyrolysis was most promising method for high yield of bio oil production [3-4]. The high yield of bio oil depends on various parameters like temperature, particle size, heating rate, gas flow rate and the cooling method of the pyrolysis vapours.

It is difficult to find the optimum parameter through experiments. The number of parameter combination for which the experiments is to be conducted makes it complex. Statistical experimental design such as response surface methodology (RSM) was used to optimize the process, thus reducing the experimental process [7]. This paper discusses the effect of various parameter combinations like temperature, particle size and Nitrogen gas flow rate on the yield of bio oil from empty fruit bunch based on Box-Behnken design in RSM.

II. EXPERIMENTAL TECHNIQUE

A. *Pyrolysis procedure:*

The experiments are carried by fast pyrolysis method in 2 kg Fixed bed reactor. The reactor inner diameter is 220 mm and length of 440 mm. Nitrogen gas (sweep gas) flow is connected in bottom of the reactor. The electric furnace is used to heat the reactor and temperature measured using a K-type thermocouple. A sample of sweet line empty fruit bunch (feed stock) and photo graphic view of experimental setup is shown in figure 1 and 2 respectively. The temperatures chosen are 500 °C, 550 °C and 600 °C and the heating rate is 10 °C /min. The sweep gas flow rates of N_2 are conducted at 0.2 lit/min, 0.3 lit/min and 0.4 lit/min. The particle sizes of samples are varied in size range of 2 mm, 4 mm and 6 mm. The parameters were optimized using response surface methodology (RSM) with a Box-Behnken (BBD). RSM is carried by 15 experiments based on the three factors. The pyrolysis gas is condensed in a condenser in the form of bio oil and char was collected in the bottom of the reactor. The bio oil and char is weighted. Uncondensed gas quantity is measured by material balance. The product yield is calculated as follows:

$$\text{Liquid yield, wt \%} = \frac{\text{Liquid yield output (g)}}{\text{Sweet lime bunch input (g)}} \text{X } 100 \quad (1)$$

$$\text{Char yield, wt \%} = \frac{\text{Char yield output (g)}}{\text{Sweet lime bunch input (g)}} \text{X } 100 \quad (2)$$

$$\text{Non condensable gas yield, wt \%} = 100 \text{ wt \%} - (\text{Liquid yield, wt \%} + \text{Char yield, wt \%}) \quad (3)$$

B. Design of experiments:

In this research work, the three levels, Box-Behnken design is found to be appropriate for designing the experimental conditions. The process parameters coded are temperature (A), particle size of Empty fruit bunch (B) and flow rate of N_2 (C). Table 1 shows, the level of each parameter are assigned in low, center and high levels as -1, 0 and +1 respectively. In this work, experiments are design based on three levels and three factors with 15 runs. Performance of the regression analysis is estimated using second order polynomial.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k} \sum_{j=1}^{k} \beta_{ij} X_i X_j \quad (4)$$

Where Y is the predicted response, β_i, β_j and β_{ij} are coefficients estimated from the regression and they represent the linear, quadratic and cross products of X_1, X_2 and X_3 on response and k is the number of studied factors.

Fig. 1 sweet lime

Fig. 2 photo graphic view of fast pyrolysis plant

Table 1 Experimental conditions proposed by BBD for EFB

Variable	Real values			
	Code	-1	0	1
Temperature (°C)	A	500	550	600
Size (mm)	B	2	4	6
Flow rate lit/min	C	0.2	0.3	0.4

Table 2 BBD matrix for the experimental design and predicted responses for the oil yield

Run order	Coded Values of Variables			Actual level of Variables			Experimental	Predicted
				Temp °C	Size mm	Flow rate lit/min		
1	-1	-1	0	500	2	0.3	12	11.67
2	1	-1	0	600	2	0.3	14.8	14.67
3	-1	1	0	500	6	0.3	20	20.12
4	1	1	0	600	6	0.3	24	24.32
5	-1	0	-1	500	4	0.2	21.4	21.45
6	1	0	-1	600	4	0.2	24.6	24.45
7	-1	0	1	500	4	0.4	21.7	21.85
8	1	0	1	600	4	0.4	26.1	26.05
9	0	-1	-1	550	2	0.2	14.7	14.97
10	0	1	-1	550	6	0.2	25.1	24.92
11	0	-1	1	550	2	0.4	16.7	16.87
12	0	1	1	550	6	0.4	25.3	25.02
13	0	0	0	550	4	0.3	28.2	28.2
14	0	0	0	550	4	0.3	28.3	28.2
15	0	0	0	550	4	0.3	28.1	28.2

Table 3 ANOVA for Response Surface Quadratic model

Source	Sum of Squares	Degree of freedom	Mean Square	F Value	p-value Prob > F	Remarks
Model	400.4883	9	44.4987	423.7972	< 0.0001	Significant
A-Temperature	25.92	1	25.92	246.8571	*< 0.0001*	Significant
B-Size	163.805	1	163.805	1560.048	*< 0.0001*	Significant
C-Flow rate	2	1	2	19.04762	*0.0073*	Significant
AB	0.36	1	0.36	3.428571	*0.1233*	not significant
AC	0.36	1	0.36	3.428571	*0.1233*	not significant
BC	0.81	1	0.81	7.714286	*0.0390*	Significant
A^2	51.92308	1	51.92308	494.5055	*< 0.0001*	Significant
B^2	168.2308	1	168.2308	1602.198	*< 0.0001*	Significant
C^2	3.692308	1	3.692308	35.16484	*0.0019*	Significant
Residual	0.525	5	0.105			Significant
Lack of Fit	0.505	3	0.168333	16.83333	0.056595	not significant
Pure Error	0.02	2	0.01			
Cor Total	401.0133	14				

Standard Deviation = 0.32, Mean = 22.071, R^2 = 0.9987, Adjusted R^2 = 0.9963, C.V. % = 1.47 Predicted R^2 = 0.9997, Adequate Precision = 62.459

III. Result And Discussion

The results of the ANOVA are tabulated in Table 3. The model is significant with F value of 423.80 .The probability of large F-value is only 0.01% , which could occur due to noise. If the values of "Prob > F" less than 0.0500, then the model is significant. The model terms identified as significant here are A, B, C, BC, A^2, B^2 and C^2. If the values are greater than 0.1000, then the model was not significant. The "Lack of Fit F-value" of 16.83 implies the Lack of Fit is not significant relative to the pure error. There is a 5.66% possibility that a narge Lack of Fit F-value could occur due to noise. Non significant shown in lack of fit was good. The Predicted R^2 of 0.9987 was in rational agreement with the Adjusted R^2 of 0.9963, the difference is less than 0.2. Adequate Precision measures the signal to noise ratio. A ratio greater than 4 was attractive. The ratio of 62.459 shows an enough signal [7-8]. The experimental results are analysed using RSM. The results of the theoretically predicted outputs are given in Table 2. The mathematical expression of the relationship to the response with the variables is

$$\text{Oil yield} = 28.20 + 1.80A + 4.53B + 0.50C + 0.30AB + 0.30AC - 0.45BC - 3.75A^2 - 6.75B^2 - 1C^2 \quad (5)$$

The above equation can be used to identify the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Where A, B and C are the temperature (°C), paticle size (mm) and N_2 flow rate (lt/min), respectively. Equation 5 can be used to predict the bio oil yield within the limits of the experimental factors. Fig.3, ensures that the actual response values agree well with the predicted response values. The response surfaces and contour plots are generated for different interactions of any two independent variables, while holding the value of the other variable as constant. Such three dimensional plots give accurate geometrical representation and provide useful information about the behaviour of the system within the experimental design. The response surface curves for the overall heat transfer coefficient are shown in Fig. 4 to 6.

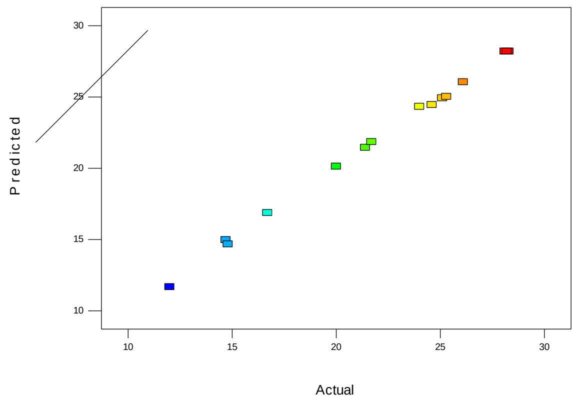

Fig 3. Actual versus predicted responses of bio oil yield

The three dimensional response surfaces which show the most important two variables temperature and particle size on bio-oil conversion at N_2 flow rate 0.3 lit/min is shown in Fig.4. The maximum bio-oil conversion was obtained at 28.3 wt %, at constant 0.3 lit/min of flow rate, 550 °C of temperature and 4 mm of particle size [5]. Fig. 5 shows the three dimensional response surfaces of the combined effects of temperature and N_2 flow rate at constant particle size 4 mm. The maximum bio-oil production 28.3 wt % was obtained at temperature 550 °C and N_2 flow rate 0.3 lit/min. Fig. 6 shows the response surface graph for the optimum yield of bio oil. The figure depicts the interaction between the N_2 flow rate and particle size in three dimensional response surfaces plots. The maximum conversion of 28.3 wt % was obtained at constant temperature 550°C.

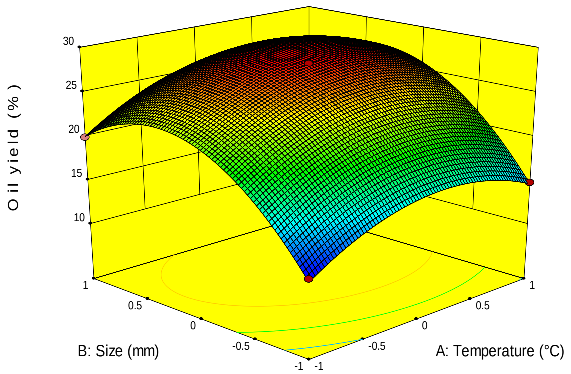

Fig. 4 The combined effect of temperature and size for the yield of bio-oil at constant 0.3 lit/min of flow rate

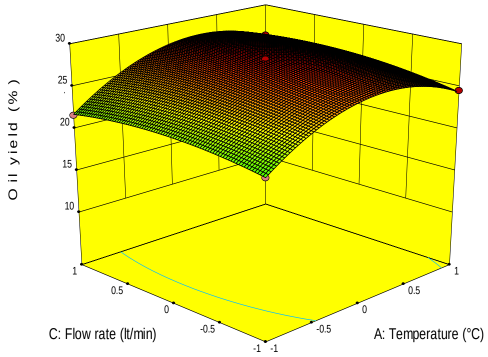

Fig. 5 The combined effect of temperature and flow rate for the yield of bio-oil at constant 4 mm of size

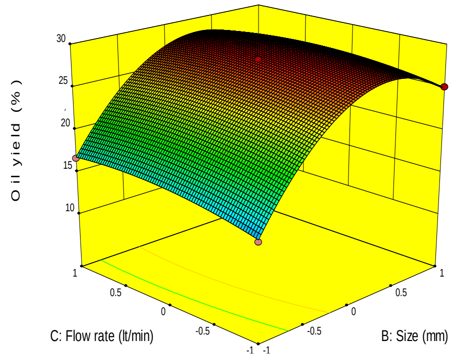

Fig. 6 The combined effect of size and flow rate for the yield of bio-oil at constant temperature

A. *Optimization of bio oil yield by response surface modeling:*

The optimum values, to obtain the bio oil yield , as inferred from the Desirability plot as shown in Fig.7. Under these conditions, the bio oil yield value predicted by the RSM design is 28.2% . To verify the accuracy of optimisation by RSM design. From the figur 5 the desirability value is 0.998 in condition of temperature 550°C, size 4mm and flow rate 0.3 lt/min is selected as optimum value and the experimental value of oil yield value is found to be 28.3%. It is observed that the RSM predicted value of bio oil is 99 % accurate to the experimental value [8].

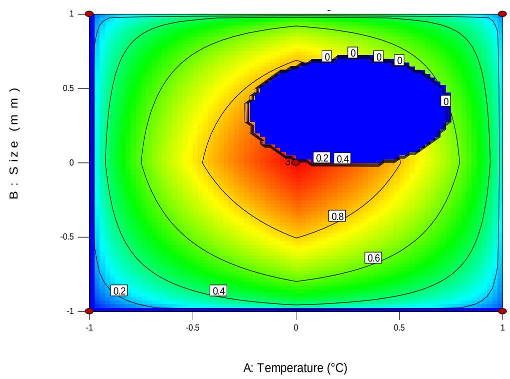

Fig 7. Desirability of tempersture and size

IV. CONCLUSION

Bio oil is produced from sweet lime empty fruit bunch by fast pyrolysis method and investigated the effects of various parameters such as particle size, temperature and nitrogen gas flow rate on the product yields. The parameters are optimized by response surface methodology (RSM) with a Box-Behnken (BBD). Mathematical model equations were built using sets of experimental data and ANOVA. The optimal conditions are obtained at pyrolysis temperature of 550 ºC, particle size of 4 mm and gas flow rate of 0.3 lit/min with the amount of bio oil yield was 28.2%.

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