

Affect of Particle Size and Temperature on the Yield of Pongamia Pinnata Bio-Oil in Pyrolysis Process

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Abstract: Globally, bio-fuels are needed for the current automobile needs and fuel consumption. Bio-oils are an alternative to crude oil products like diesel and petrol considering the need to replace them. In this study, cold compressed pongamia pinnata cake is treated for pyrolysis to yield bio-oil from it. To determine whether particle size and temperature have an impact on the yield and viscosity of bio-oil, a slow level pyrolysis process was conducted. An orthogonal L9 Taguchi array was used in the present study for the design of experiments. To optimize parameters for better yield, three factors with three levels of design are run with experimentation. There were three levels of particle sizes in this study: 0.5-0.75mm, 0.75-1.0mm, 1.0-1.25mm, temperatures 350°C, 400°C, 450°C, and nitrogen gas flow rates 6, 8, 10 LPM. The optimal parameters for best yield and viscosity are particle sizes between 0.5-0.75mm, a temperature of 450°C, and a gas flow of 8 LPM. An ANOVA solver has been used in Mini-tab to optimize the Taguchi prediction.

Keywords: Pongamia Pinnata, Bio-oil, Pyrolysis, Particle size, Temperature, Taguchi, ANOVA.

1. Introduction

Biomass fast pyrolysis bio-oils (also called biomass pyrolysis oils, and bio-crude oils) from lignocellulosic biomass are very different fuels from fossil oils with regard to both their physical properties and chemical composition [1]. These liquids typically have high water content and may have substantial levels of suspended solids and also have a density higher than conventional fossil fuels. They are acidic, have a heating value of less than half of that of mineral oils, and they tend to polymerise when heated. Chemically, they are highly polar, containing about 35–40 wt% oxygen (dry basis), while mineral oils contain oxygen only at ppm levels [2]. Hence, bio-oils are not soluble in mineral oils or other bio-oils, like biodiesels. The need for energy is increasing sharply due to the rapid increase in the world's population and developing technologies, while the current energy resources with limited reserves are decreasing. Biomass (plant materials) has been recognized as a major world renewable energy source to supplement declining fossil fuel resources [3]. It is composed mainly of carbohydrate compounds (cellulose, hemicellulose, lignin and minor amounts of other organics) which are determined as the elements of carbon, hydrogen and oxygen and possess a high energy content [4]. Biomass energy is destined to play an important role in the future energy systems of the world. Bio-oil known as pyrolysis oil, bio-fuel oil, pyrolytic oil and liquid wood [5] that was produced by

pyrolysis of biomass. Generally, it can be found in a dark brown organic liquid form [6]. The bio-oil contains hundreds of organic compounds that belong to alkanes, aromatic hydrocarbons, phenol derivatives and little amounts of ketones, esters, ethers, sugars, amines and alcohols with H/C molar ratio higher than 1.5 [7]. It is produced by high thermal decomposition (pyrolysis) method without the additional of O₂/air. The pyrolyze bio-oils can be directly used as fuels in boilers or subsequently upgraded to produce fuels and bulk chemicals using several methods such as zeolite cracking [8], hydrogenation and aqueous phase processing [9]. type of biomass use in the production of bio-oil by various research work and the type of biomass obtain for this study

2. Literature Review

Patra et al. [10] studied pyrolysis of *Delonix regia* seed and investigated the effects of temperature on composition and yield of bio-oil. At a temperature of 600 °C, a maximum oil yield of about 48% was reported. The bio-oil composition was studied with FTIR and GC-MS; and amides, nitriles, aldehydes and ketones were found to be the main components. Sun et al. [11] performed flash pyrolysis of rice husk and sawdust at 700–1000 °C in a flow reactor. The authors observed a rise in gas and reductions in char and liquid fractions as the temperature increased. Punsuwan et al. [12] examined the influences of temperature and particle size on the decomposition of palm kernels, palm shells and cassava pulp. They noticed that smaller particles and higher temperatures lowered the char yield and raised the gas yield. Natural materials in raw and modified forms, such as termite hill and anthill, have also been used as Pyrolysis for enhanced bio-oil

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yield from the decomposition of waste biomass and production of biodiesel from edible and non-edible oils. Nisar et al. [13] used termite hill as the catalyst for enhanced bio-oil production from peanut shell waste, and conditions were optimized for maximum oil yield. In another study, Olubunmi et al. [14] successfully applied iron supported anthill for biodiesel yield from waste cooking oil. In yet another study, Harreh, D [15] investigated the catalytic behaviour of alkaline modified anthill for biodiesel yield from *Chrysophyllum albidum* seed oil. Agarwal AK, Dhar et al. [16] were reported that the treatment of biomass before convert to bio-oil will be produce high quality of products. In fact, by acid treatment method, the oxygen content was slightly reduced influence by oxygen-rich compound removal during treatment. K, M.P., Somasundaram [17]. This review is the first of a kind in throwing light on the energy and exergy analysis of the pyrolysis process. Pyro-oil has an increased amount of oxygen content which has to be upgraded for further use. Pyrolysis also serves as an efficient tool for converting plastic waste into energy. Raquel Escrivani Guedes [18] This review was written with a focus on parameters that influence the process, such as temperature, reaction time, heating rate, gas flow rate, feed rate, particle size and biomass composition and discusses the effect of these parameters on the yield and quality of bio-oil.

3. Methodology

Pyrolysis means to heat a substance to a specific temperature in an inert atmosphere (no oxygen). As a result, it was necessary to determine the temperature at which groundnut cake could be effectively pyrolyzed. To reduce the air space in the reactor, flakes of cake were ground up in a coffee grinder. This was done to maximize cake utilization. The moisture, volatile matter, ash, and fixed carbon contents have all been measured using proximate analysis according to ASTM D3172-07a. A thermo-gravimetric analyzer, the DTG60, was used to conduct thermo-gravimetric analysis (TGA) on a sample cake. After being heated to 800 degrees Celsius with a 1-minute residence time, a sample cake weighing 20-30 milligrams was allowed to cool to room temperature. Two parallel measurements were made, one in air and one in nitrogen, both at 200 C/min. Within a narrow temperature window, the de-oiled cake made from *Pongamia pinnata* deteriorates.

A 10 g sample of biomass was placed in a quartz tubular reactor measuring 30 cm in length and 2.47 cm in diameter with an internal diameter of 2.47 cm. The vapors coming out of the reactor were condensed by a condenser attached to its outlet. A container was used to collect the condensed liquid at the end of the condenser. We carried out the experiments at 350 ,400, 450 with a temperature increment of 20°C/min, under a constant nitrogen flow

rate of 100 ml/min. By weighing liquid products and char, yields were calculated. Differences were used to determine the amount of gas. Aqueous and organic phases make up the liquid product; acids, sugars and other highly polar organic compounds compose the aqueous phase. A similar amount of diethyl ether was used to extract the organic phase. A rotary evaporator at 30°C was used to evaporate the diethyl ether fraction (organic phase) obtained after drying over sodium sulfate, filtering, and drying over sodium sulfate was carried out. The bio-oil fraction was weighed, bottled and referred to in the present study as bio-oil. To determine the temperature at which maximum liquid product is produced, 30 grams of cake were pyrolyzed at intervals of 50°C within the temperature range established. Data such as reaction time, char yield, and liquid yield were recorded during sample runs. Temperature-dependent variations in char yield, liquid product yield, and gas yield (volatiles). Yield with temperature was plotted for the better temperature findings. Standard procedures were utilised to calculate the bio-oil's calorific value, specific gravity, viscosity, condensed carbon, flash point, fire point, pour point, cloud point, sulphur content, distillation boiling range, and cetane index. A 0.035-micron filter was used to final-stage filter the oil. Table 1 displays the *pongamia pinnata* oil's physicochemical characteristics.

3.1 Taguchi Method

Taguchi method is a statistical tool for analysing the performance of the design process and product with the considerable reduction of time on investigation and cost. it employs the concept of orthogonal array, which defines the set of well-defined experiment and signal to noise (S/N ratio) ratio. Taguchi defines three quality characteristics, such as lower the better, the larger the better and the nominal the best. also, a statistical analysis of variance (ANOVA) can be used to identify the most influencing factor affecting the quality characteristics. a three level three parameter L9 orthogonal array with nine experiments was conducted. the S/N ratio used for the larger better is given in Eq. (1).

$$S/N(db) = -10 \log_{10} \left[\frac{1}{n} \sum_{i=1}^n \frac{1}{y^2} \right] \dots (1)$$

Where, i = 1, 2 ,....n, and y is the response value for an experimental condition repeated in 'n' times.

- The input process parameters are identified, which influencing output response of the process.
- suitable orthogonal array selected to perform the experiments.
- The results are examined to identify the optimum parametric condition

3.1.2 Design of experiments:

Variable 1- 0.5 -0.75mm, 0.75- 1mm, 1- 1.25 mm – particle thickness

Variable-2- 350, 400, and 450°C, - Temperatures (T1, T2, T3)

Variable 3- 6, 8, and 10 LPM - flow rates (F1, F2, F3)

Taguchi array [L9: 3*3]

Factors: 3, Runs: 9

Columns of L9 [3*4] Array = 1, 2, 3

Table: 1 Columns of L9 (3³) array: 1 2 3

↓	C1	C2	C3
	A	B	C
1	1(0.5-0.75)	1(350)	1(6)
2	1(0.5-0.75)	2(400)	2(8)
3	1(0.5-0.75)	3(450)	3 (10)
4	2(0.75-0.1)	1(350)	2(8)
5	2(0.75-0.1)	2(400)	3(10)
6	2(0.75-0.1)	3(450)	1(6)
7	3(1-1.25)	1(350)	3(10)
8	3(1-1.25)	2(400)	1(6)
9	3(1-1.25)	3(450)	2(8)

Pyrolysis proces of pongamia pinnata bio-oil using different particle sizes and the optimization carried out with respect to the yield of bio-oil, char and other volatile

materials. Slow pyrolysis process has been carried out to get maximum yield with above designed parameters.

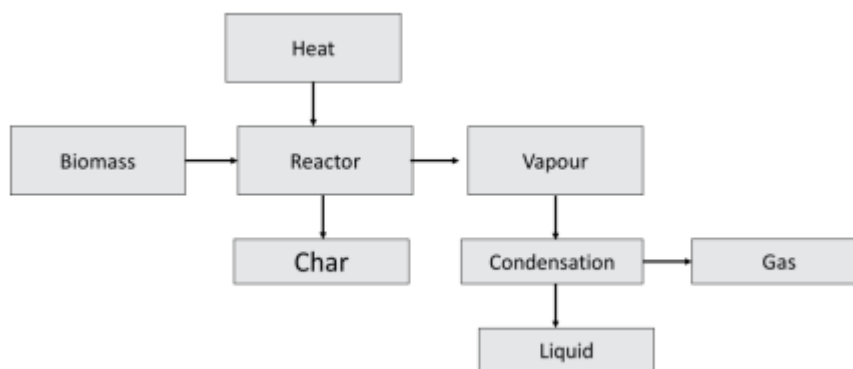


Fig 1: Schematic diagram of slow pyrolysis

A K-type thermo-couple was installed to measure the reactor's actual temperature. A proportional integral derivative (PID) temperature controller managed the maximum working temperature of this reactor up to 450°C. One kilogram of the dried seed cake with different particle sizes of <1.25 mm was charged into the reactor to start the pyrolysis process. Within three different reaction times (120 min, 107 min, and 120 min, respectively), for the temperature of the pyrolysis experiment was 350°C, 400°C, 450 °C by varying the gas feed rate. As the bio-oils were condensed in a series of condensers during the pyrolysis process, they were collected at room

temperature in a liquid sample port. A gravimetric weight was then determined for the bio-oil and it was stored in a closed glass jar for further investigation. Because less than 2% of char was contained in the pyrolysis liquid, the amount of bio-oils did not rise significantly as a result of the collecting of char in the reactor, on top of the sand, and in the charpot. Optimal conditions for producing the highest bio-oil yield were 450°C and 4.2°C/min, which provided the highest higher heating value (HHV). Thermal decomposition of feed stocks and bio oils was examined using thermo-gravimetric analysis (TGA).

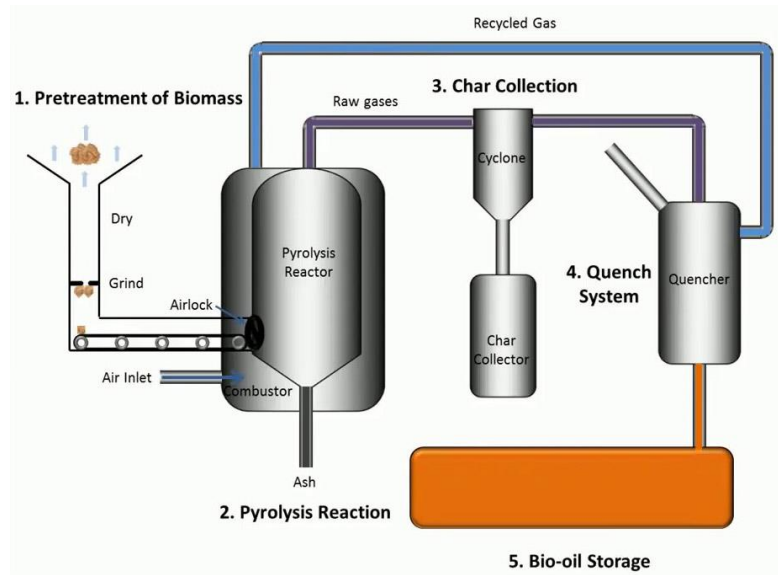


Fig 2: Layout of slow pyrolysis process

4.0 Results and Discussions

Experimentation has been carried out to check the percentage of yield at different combinations to optimize final pyrolysis parameters from selected DOE.

Table: 2 Experimentation results of yield and viscosity

S.no	C1	C2	C3	Yield (%)	Viscosity (mm ² /s)
	A	B	C		
1	1(0.5-0.75)	1(350)	1(6)	48	28.6
2	1(0.5-0.75)	2(400)	2(8)	54	26.8
3	1(0.5-0.75)	3(450)	3 (10)	61	25.4
4	2(0.75-0.1)	1(350)	2(8)	45	28.2
5	2(0.75-0.1)	2(400)	3(10)	51	27.9
6	2(0.75-0.1)	3(450)	1(6)	56	27.2
7	3(1-1.25)	1(350)	3(10)	46	28.5
8	3(1-1.25)	2(400)	1(6)	42	29.3
9	3(1-1.25)	3(450)	2(8)	45	28.9

The above obtained results were optimized using Mini- tab software for Taguchi prediction analysis with regression as well as factor prediction to check the factors effect on output yield and viscosity.

Level	A	B	C
1	40.63	37.38	38.52
2	39.22	38.50	37.98
3	36.62	40.58	39.97
Delta	4.02	3.20	1.98
Rank	1	2	3

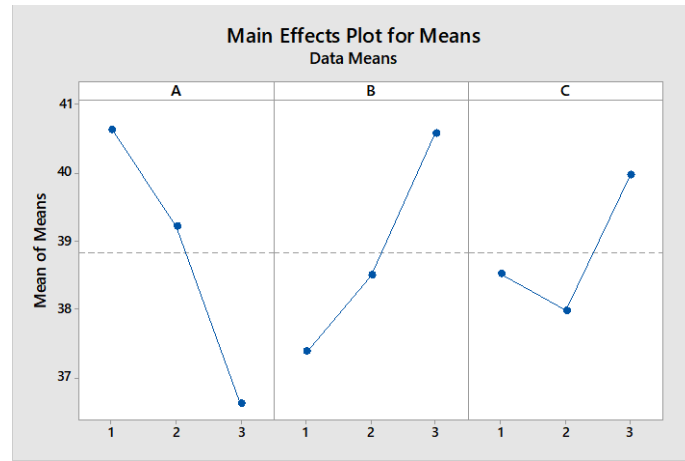
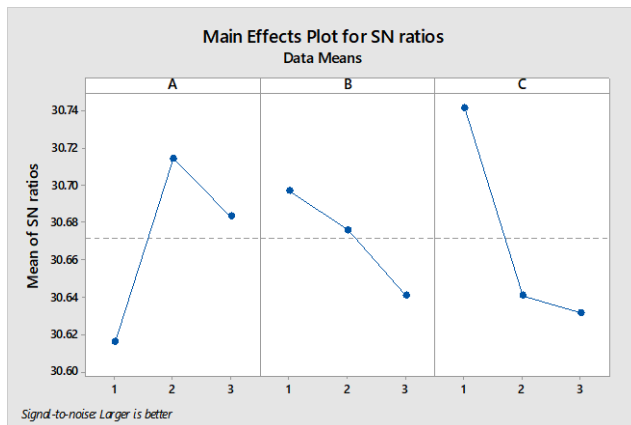


Fig 3: Factors vs yield and viscosity



Level	A	B	C
1	2.934	2.536	2.609
2	2.761	2.648	2.621
3	2.381	2.891	2.845
Delta	0.553	0.354	0.236
Rank	1	2	3

Fig 3: Factors response vs yield and viscosity

Table:3 Taguchi optimized results

EXP. No	Yield (%)	Viscosity (mm ² /s)	S/N ratio	Mean	StDev	Ln(StDev)	Rank
1	48	28.6	30.7121	38.8889	15.3992	2.69573	5
2	54	26.8	30.5898	39.4722	17.4027	2.81972	4
3	61	25.4	30.5456	43.5389	25.3223	3.28567	1
4	45	28.2	30.7097	36.9389	12.0287	2.53470	6
5	51	27.9	30.6793	40.0389	18.0155	2.87029	3
6	56	27.2	30.7548	40.6722	18.5341	2.87688	2
7	46	28.5	30.6693	36.3222	10.5437	2.37870	8
8	42	29.3	30.7585	35.9889	9.12953	2.25492	9
9	45	28.9	30.6225	37.5389	13.0658	2.50928	7

Regression Analysis: YI versus B, C, AMethod (ANOVA)

Selected factors influence on yield result optimized with Taguchi regression model for the influence of particle

size. From the above ranking table3 it is observed that increase in particle size decreasing the yield and with increase in temperature improving the yield.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	265.72	66.43	6.35	0.050
B	1	88.17	88.17	8.43	0.044
C	1	24.00	24.00	2.29	0.204
A	2	153.56	76.78	7.34	0.046
Error	4	41.83	10.46		
Total	8	307.56			

Study on particle size affect on yield with a regression model the regression equation defined for 3 levels with respect to temperature and gas flow rate has been defined. Significance showing that effect of gas flow rate lower

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	4	10.068	2.5171	5.68	0.060
B	1	2.407	2.4067	5.43	0.080
C	1	1.815	1.8150	4.10	0.113
A	2	5.847	2.9233	6.60	0.054
Error	4	1.772	0.4429		
Total	8	11.840			

Affect on viscosity with the particle size the regression equation is differed with the yield equation, most effective parameter is temperature as the viscosity decreased with higher temperature.

A			
1	YI	=	42.67 + 3.83 B + 2.00 C
2	YI	=	39.00 + 3.83 B + 2.00 C
3	YI	=	32.67 + 3.83 B + 2.00 C

with lower temperature and particle size between 0.75-1mm given moderate results and improvement in particle size decreases the yield value.

A			
1	VI	=	29.300 - 0.633 B - 0.550 C
2	VI	=	30.133 - 0.633 B - 0.550 C
3	VI	=	31.267 - 0.633 B - 0.550 C

The factorial analysis on yield and viscosity continued with the selected variants observed with anova based linear analysis.

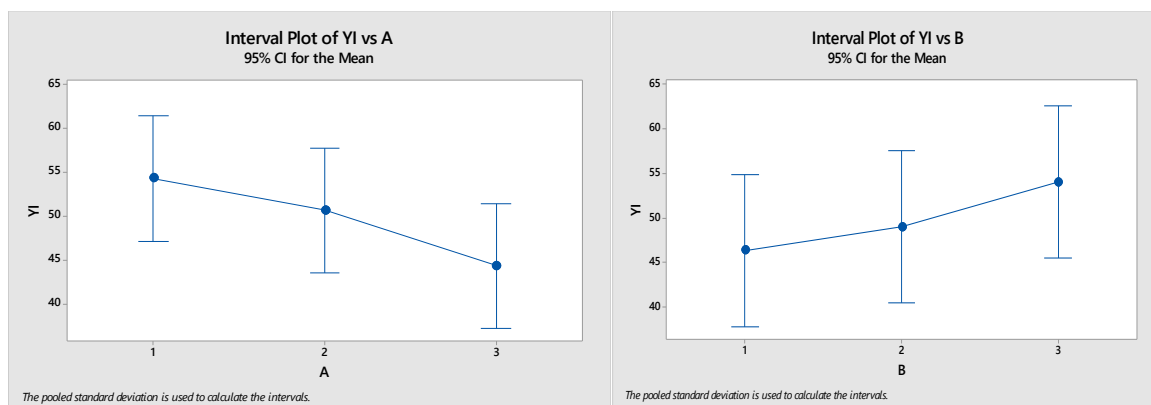


Fig 4: Yield vs particle size, Yield vs Temperature

Above graphs showing that with linear optimal analysis on yield when particle size increases the yield decreases with an approximation of 20% variation, with temperature increment the yield improved by 20%. By this it can be estimated that low particle size with high temperature

yield will be good as shown in figure 4. A medium decrease with gas flow rate with medium particle size, yield increases with maximum gas flow rate as shown in figure 5.

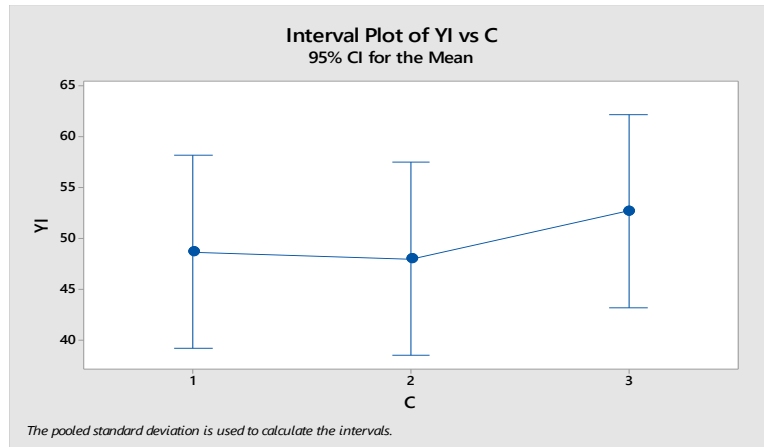


Fig 5: Yield vs Gas flow rate

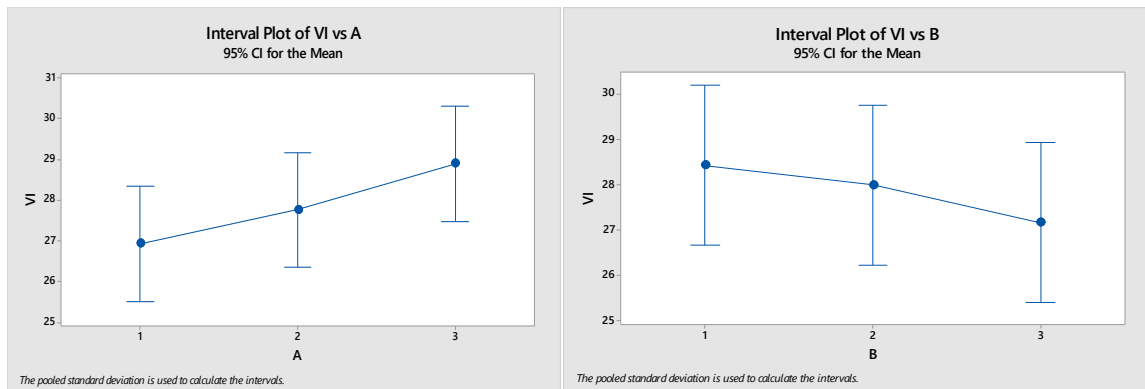


Fig 6: viscosity vs particle size, viscosity vs Temperature

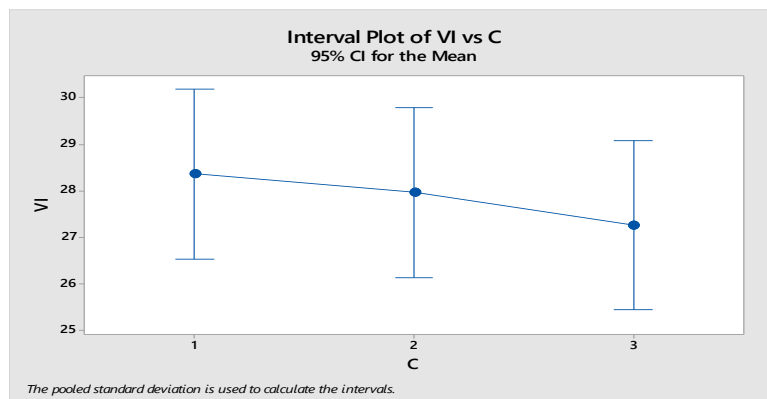


Fig 7: Viscosity vs Gas flow rate

The viscosity values obtained after the pyrolysis process when particle size increases viscous nature increased and when temperature increased the viscous value decreased

as shown in figure7. the viscous value decreased with increase of gas flow rate as shown in figure 7.

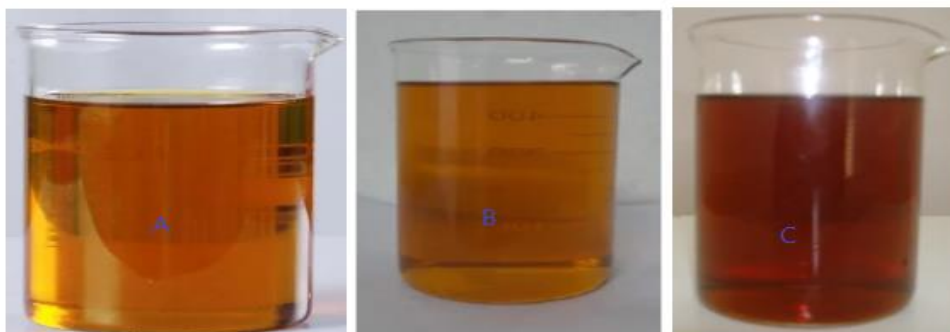


Fig 8: Bio-oil images at different particle sizes

5. Conclusions

Slow pyrolysis process has been carried out to get the maximum yield from pongamia pinnata seed cake. Three important parameters observed and we drawn the following conclusions after optimizing the parameters.

- The best particle size for getting maximum yield is in between 0.5mm -0.75mm.
- Best temperature to achieve good yield is 450°C.
- Best gas flow rate is 8 LPM by compare standard deviation results.
- Viscosity low at temperature of 450 and low particle size with medium gas flow rate are optimized conditions.
- Optimization done in Mini-Tab given better optimized results in selected parameters.

References

- [1] A. Res, itoglu, K. Altinis ik, and A. Keskin, "The pollutant emissions from diesel-engine vehicles and exhaust afertreatment systems," *Clean Technologies and Environmental Policy*, vol. 17, no. 1, pp. 15–27, 2015.
- [2] Nagarhalli M. V., Nandedkar V. M. and Mohite K.C. pongamia pinnata biodiesel and its blends in a C.I. engine and it's economics. *AJEAS*. Feb 2010.
- [3] Shashi Kumar Jain, Sunil Kumar, and Alok Chaube. Technical Sustainability of Biodiesel and Its Blends with Diesel in C.I. Engines: A Review. *IJCEA*. April 2011.
- [4] M.P.Sudesh Kumar, B.Shunmuga Raj, D.Venkatakrishnan, J.Sai Kiran. Vegetable derived biodiesel fuel as an alternate fuel for diesel engines- a review. *ICRAMET*. 2015
- [5] Raghavendra Prasada S.A., K. V. Suresh. Pongamia Pinnata (pongamia pinnata) Biodiesel as an Alternative fuel for Diesel Engine: A Review. *AEAS-URJ*. 2014.
- [6] R.Sattanathan. Production of Biodiesel from Castor Oil with its Performance and Emission Test. *IJSR*. 2013.
- [7] J B Galchar Production of biodiesel using Nano Catalysts, Review study, © 2017 *IJEDR* | Volume 5, Issue 1 | ISSN: 2321-9939
- [8] Mookan Rangasamy, Krishnasamy Anbalagan, Sundaresan Mohanraj, Velan Pugalenth. Biodiesel Production from Pongamia pinnata Oil using Synthesized Iron Nanocatalyst. *IJCR*. Sept. 2014.
- [9] Singh Y., Singla A. Comparative analysis of jatrophha and pongamia pinnata-based biodiesel properties, performance and exhaust emission characteristics in an unmodified diesel engine. *Pollution* 1(1): 23-30. Winter 2015.
- [10] G. Joshi, D. S. Rawat, B. Y. Lamba et al., "Transesterification of Jatrophha and pongamia pinnata oils by using waste egg shell derived calcium based mixed metal oxides," *Energy Conversion and Management*, vol. 96, pp. 258–267, 2015.
- [11] S. Ismail, S. A. Abu, R. Rezaur, and H. Sinin, "Biodiesel Production from Castor Oil and Its Application in Diesel Engine Biodiesel Production from Castor Oil and Its Application in Diesel Engine," *Renewable Energy*, vol. 31, no. 2, p. 90, 2016.
- [12] S. Gangil, R. Singh, P. Bhavate, D. Bhagat, and B. Modhera, "Evaluation of engine performance and emission with methyl ester of pongamia pinnata oil," *Perspectives in Science*, vol. 8, pp. 241–243, 2016
- [13] V. S. N. Ijayan and S. R. Ubha, "Effect of Process Parameters in the Production of Biodiesel through Transesterification – A Review," *Canadian Chemical Transactions*, vol. 3, no. 3, 2015.
- [14] M. Subbiah, "Experimental analysis of combustion ignition engine using bio-diesel," *International Journal of Innovative Science, Engineering and Technology*, vol. 2, no. 6, pp. 527–532, 2015.
- [15] Dewi Harreh , A. A. Saleh, A. N. R. Reddy , and S. Hamdan An Experimental Investigation of pongamia pinnata Biodiesel Production in Sarawak, Malaysia *Hindawi Journal of Engineering* Volume 2018, 8 pages <https://doi.org/10.1155/2018/4174205>
- [16] Balaji Panchal, Qin Shenjun, Wang Jinxi, Bian Kai, Tao Chang. Biodiesel Synthesis with Iron Oxide Nano-Catalyst Catalyzed Pongamia Pinnata Seed Oil and Dimethyl Carbonate, *American Journal of Energy Engineering*. Volume 6, Issue 3, September 2018 , pp. 21-28.