Influence of Air-Nitrogen Composition on the Gasification of Palm Shells Biomass

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***Abstract*— In this work, an experimental study is carried out to investigate the gasification of biomass palm shells with air-nitrogen mixtures as gasification agent. An atmospheric pressure fixed bed reactor with 60 mm inside diameter and 280 mm height is used. Palm shells are selected as biomass feedstock due to its abundance supply in Malaysia. Nitrogen flow rate is varied in the range of 5-7 LPM and palm shells particle size of 1.180-7.130 mm. Analysis of Variance (ANOVA) indicate that the nitrogen flow rate and particle size have a significant effect on the biomass gasification index, and the produced tar, CO, and NO. The temperature results in the reactor found to vary as a function of nitrogen flow rate and the temperature found to increase from 690 to 710 ºC when nitrogen flow rate decreased from 7 to 5 LPM due to decrease of the oxygen content in the air mixture.

Keywords-ANOVA, Biomass, Oil Palm Shells, Gasification

I. INTRODUCTION

Biomass gasification is said to be one of the most promising thermochemical technologies in converting whole biomass and its residues to carbon monoxide (CO) and hydrogen (H_2) rich synthesis gas which is also known as syngas [1]. Gasification has received attention throughout the world due to the following advantages: (1) not strict limitations to the size and type of raw biomass used (for example, municipal solid wastes, agricultural wastes and forest residues); (2) convenient use of resultant gases for different applications (for instance, heat/power generation, production of syngas, methane, and hydrogen); (3) less pollution problems associated with the downstream applications compared with pyrolysis or combustion [2]. Biomass does not only provide potential source of hydrocarbon but also contributes little or no net carbon dioxide to atmosphere, hence offering biomass as an attractive feedstock for energy. Moreover, biomass is said to be an easy-to-use energy source, based on present technical level and economics resulting biomass to be the focus of most countries for sustainable energy production and also for the reduction of greenhouse gases (GHGs) emissions [2]. The Malaysian Government take efforts to promote renewable energy (RE) and energy efficiency as part of the sustainable development agenda under 9th Malaysian Plan as Malaysian progress towards Vision 2020. From this initiative taken, it clearly shows that Malaysian subscribes to the preservation of the environment and also pursuing the economic development [3]. In parallel to this, the country objectives can also secure the international agreement such as Kyoto Protocol and Montreal Protocol in reducing global CO_2 emissions which had been identified as the main culprit for causing global warming and protect the ozone layer respectively for industrialized countries.

Oil palm, or also known as *Elaeis guineensis* which belongs to the family of Palmae was initially introduced to Sumatera and Malaya area in early 1900s [4]. The growing global demand for edible oil had resulted oil palm to become today world's largest source of edible oil with 38.5 million tonnes or 25% of the world edible oil and fat production [5]. Hence, this has prompt Malaysia and Indonesia to expand oil palm plantation and becoming the world's largest producer and exporter of oil palm. Consequently, the production of oil palm biomass increased dramatically. In year 2005, about 55.73 million tonnes of oil palm biomass was recorded [6]. Due to huge amount of biomass generated yearly, Malaysia has the potential to utilize the biomass effectively to other value products such as utilization of empty fruit bunches (EFBs) to produce bioplastic, EFBs incinerated for soil conditioner, fronds converted to pulp, and palm fibres used as fillers in thermoplastics and thermoset composites [4]. Besides that, oil palm biomass can contribute a positive and promising prospect as a source of renewable energy with regards to the current state of energy crisis with the price of crude petroleum hitting record high recently and also high calorific energy content as shown in Table 1. Presently, the most conventional way of handling this biomass is to burn them with energy recovery or for landfilling [7]. However, both these methods do not contribute to net amount of carbon in the atmosphere as carbon is assimilated during plant growth resulting secondary pollution problems. An alternative in solving this problem is to implement biomass gasification technology for high efficiency power generation, heat and/or combined heat and power (CHP) applications, and can be used for the production of liquid fuels and chemical via synthesis gas (syngas). This technology is still at its infancy stage of research and gas cleaning is still the bottleneck in advanced gas utilization that limits the deployment of the use of biomass for electricity production in a gas turbine [8]. Gas turbines are highly sensitive to the quality of gas, which means only extremely low levels of contaminants, principally tars, alkali metals, sulfur and chlorine compounds can be tolerated. These contaminants can cause erosions, emission of pollutants such as nitrogen oxides (NO_x) and sulfur oxides (SO_X), hot corrosion, clog filters and deposits internally [9]. Therefore, the efficiency of a gas cleaning technology step is therefore fundamental to the successful operation of power plants.

TABLE I. CALORIFIC VALUES OF OIL PALM BIOMASS [10]

Oil Palm Biomass	**Calorific Values (kJ/kg)**

Oil Palm Biomass	Calorific Values (kJ/kg)
EFBs	18,838
Kernels	18,900
Fibres	19,068
Shells	20,108

Previous studies in the literature were carried out on different feedstock (peat, coal, wood chips) using air as gasifying agent in fluidized bed reactor [11,12]. It is reported that operation temperature of the gasifier and ratios of air to biomass have a strong impact on gasification efficiency, conversion, gas productivity, gas composition, and its low heating value (LHV) [13]. Tar concentration is mainly function of gasification temperature and tar decreases as temperature increases [14]. However, tars formed in pyrolysis that is thermally cracked will be converted to refractory tars, soots, and gases. Besides that, tar level and characteristics are also dependent on the feedstock. It is reported that tar production in wood gasification is much greater than in coal or peat gasification and the tars tend to be heavier, become more stable aromatics [15]. These may partly react to give soot which can block filters, a problem apparently peculiar to biomass gasification. The removal of ammonia from the product gas is also essential since the ammonia will be converted to NO_x during combustion. And also, the design of the gasifier plays an important role to destruct tars and the hydrocarbons released during the pyrolysis stage of the gasification [16].

Although many researches had been carried out in this area, however studies related to the used of biomass palm shells are still limited. Abdullah et al. [17] studied on the combustion characteristics of palm shells in a fluidized bed combustor using air staging technique to control and reduce the emissions from the combustion of biomass. The gaseous emissions studied include $NO_{x,}$ and CO. The study was carried out based on the ratio of the secondary air to the total combustion air which was varied from 0 to 0.4 and by taking into consideration of the percentage of air. They concluded that significant reductions in NO_x emissions were obtained for the staged operation when compared to the un-staged operation. The CO emission was mostly affected by the percentage of excess air. Ghani et al. [7] investigated on the characteristics of gasification of biomass palm kernel shell in terms of gasification temperatures, fluidization ratio, static bed height, and equivalence ratio (ER) on gas composition, gas yield and gas heating value using bench-scale fluidized bed gasifier with 60 mm diameter and 425 mm height. It is found that among the gasification parameters tested, the equivalence ratio appeared to have the most pronounced effect on the reactor temperature, the gas composition, the gas yield, and the heating value. It is found that the influence of equivalence ratio on the performance of a gasifier could be regarded as the effect of reactor temperature as the reactor found to be equivalence ratio dependent. The fluidizing velocity and static bed height showed minor effect during the gasification process.

Due to limited research in this area used of biomass palm shells, an experimental study is carried out to investigate the gasification of palm shells with air-nitrogen mixtures as gasification agent in a laboratory scale atmospheric pressure fixed bed reactor with 60 mm inside diameter and 280 mm height. Palm shells are selected as gasification feedstock due to its high calorific value compared to other oil palm biomass. Main operating variables studied are nitrogen flow rate (5-7 LPM), and average biomass palm shells particles size (1.180-7.130 mm) on the effect of biomass gasification index, tar content, CO, NO, and SO_2 production.

II. EXPERIMENTAL SECTION

A. *Feedstock Material*

The palm shells collected from a local palm mill is fed into the gasifier. Three average palm shells particle sizes (1.180 mm, 4.155 mm, and 7.130 mm) are selected for tests. Some of its properties are listed in Table 2. The quantity of palm shells used for each run of experiments is 130 grams.

TABLE II. FEEDSTOCK (PALM SHELLS) [18]

Proximate Analysis (air dry weight %)		Ultimate Analysis (weight %)	
Volatiles	68.8	Carbon	55.35
Fixed Carbon	20.3	Hydrogen	6.43
Moisture	8.4	Nitrogen	0.37

Ash	2.3	Oxygen	38.01

B. *Experimental Setup*

The experimental set-up shown in Figure 1 consists of three main parts: (i) fixed bed reactor, (ii) tar collection section and (iii) gas sampling section. The reactor is made of stainless steel 304 with an inner diameter of 60 mm and a height of 280 mm. Asbestos is used to insulate outside the reactor to minimize heat dissipated to the surrounding. Two K-type thermocouples (T1 and T2) are installed on the reactor to detect temperature of the dense bed, defined as gasification reaction zone (at the height of 20 mm above the distributor) and freeboard zone (at the height of 140 mm above the distributor) respectively.

C. *Gas and Tar Sampling*

The main sampling point for the gas analyses is located at the gas outlet point as it passes through the stainless steel probe of the combustion analyzer (Eurotron UniGas 3000+ Mk3). The combustion analyzer is used to measure CO, NO and SO_2 in terms of parts-per-million (ppm). The temperature of the sampling measured is at approximately 33°C.

The tar sampling section consists of four condenser traps (300 mL) containing approximately 250 mL of distilled water. Condenser traps are washed with water and rinsed using acetone prior to use. The four condenser traps are immersed in water at room temperature. During sampling, tars are condensed and trapped in the water and formed an inhomogeneous phase since the mixture of tar and water is insoluble. The mixture is separated using Advantec filter paper (125 mm diameter, 6μm particle retention) and evaporated under room for at least 3 hours to remove any excess water. The weight of the tar produced is measured in order to calculate the concentration of the tar. Tar concentration, C_t is generally defined as the total weight of tars per unit volume of syngas shown in Eq. (1).

$$C_t = \frac{W_t}{V_s} \qquad (1)$$

where

W_t = Weight of tars in syngas (mg)
V_g = Normal volume of syngas (Nm^3)

Biomass gasification index, BG is defined as the ratio of the biomass weight differences to the initial weight of the biomass used in the process as shown in Eq. (2).

$$BG = \left(\frac{W_i - W_f}{W_i} \right) \times 100\% \qquad (2)$$

where,

W_i = Initial weight of palm shells before experiments (g)
W_f = Final weight of palm shells after experiments (g)

D. *Experimental Procedures*

At the start-up of each experiment run, a fixed amount of palm shells is weighed (130 grams) prior placing into the reactor. The reactor is then heated up externally to a temperature approximately 250°C since the volatiles of the palm shells is released. The ratio of the air to nitrogen gas is set and supplied into the reactor. The gas leaving the reactor is cooled in a series of four absorption traps containing distilled water (250 mL each), where most of the tars are collected. Gas composition is determined by means of a combustion analyzer at the gas outlet. Tars are accumulated into the series of absorption traps. Gas compositions data are taken in every 10 minutes interval. Experiment is stopped when the temperature decreased to 500°C. Experiments are repeated 3 times for each set.

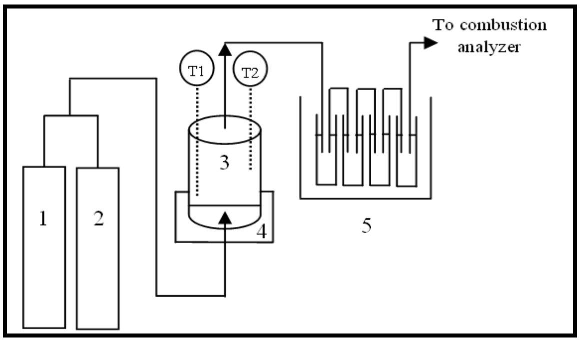


Figure 1. Experimental set up (1: compressed air; 2: nitrogen gas; 3: reactor; 4: heater; 5: absorption traps).

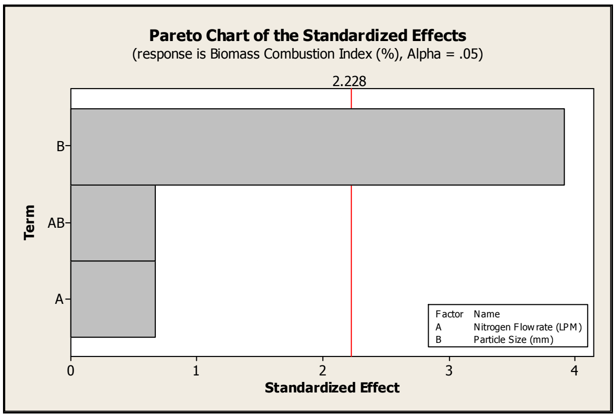
III. RESULTS AND DISCUSSION

The experimental results obtained for each response variable is analyzed statistically using Minitab (v. 15). In a first stage, the standardized Pareto's diagram is used to observe the estimated effects of these variables and their possible interactions. A pareto chart is a special type of bar chart where the values plotted are arranged in descending order [19]. Analysis of variance (ANOVA) is then used to study the influence of the variables and their possible interactions on the biomass gasification index and tar, CO, NO, SO_2. The observed variance is partitioned into components due to different explanatory variables [20]. The basis of the comparison of the variance caused by the variation of each studied factor (nitrogen flow rate, and particle size) is the variance caused by experimental error, which is calculated from the replicates of center points for each response variable. In order to consider that one factor has a statistically significant influence on a response variable, the variance caused by the factor is divided by the error variance. F-test is used with a 95% confidence level.

A. Influence of Nitrogen Flowrate and Particle Size on Biomass Gasification Index

According to Pareto's standardized chart, if any affects that extend beyond the reference line is said to be significant at the default level of 0.05. It is observed from Figure 2a that the palm shells particle size has a significant effect on the biomass gasification index in the range of variable studied. Figure 2b shows the interaction plot on the effect of different palm shells particle size on its gasification index.

(a)



(b)

The authors wish to thank Shell Malaysia Limited for the support and funding of this project.

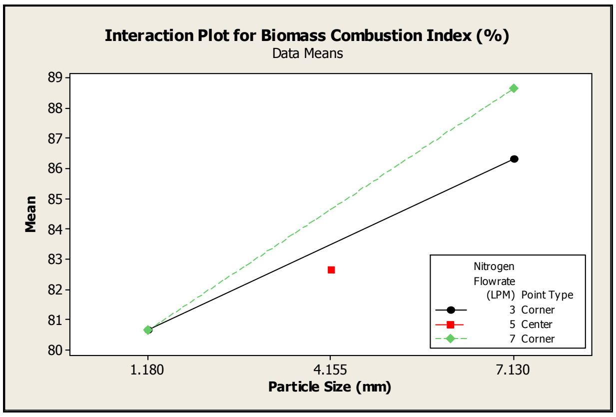


Figure 2. (a) Pareto's standardized chart: effect of the nitrogen flow rate and particle size of palm shells on biomass gasification index. (b) Interaction plot for biomass gasification index on the effect of the nitrogen flow rate and palm shells particle size.

Using palm shells particle size between 1.180 and 7.130 mm, the biomass gasification index varied between 80% and 89% when nitrogen flow rate of 5-7 LPM and constant air flow rate, 5 LPM are used. It is observed from Figure 2b in order to obtain higher biomass gasification index, a bigger palm shells particle size are the most suitable to be used in this system. It is observed from experiments that especially palm shells particle size, 1.180 mm tends to agglomerate in the reactor compared to the two other bigger palm shells particle size (4.155 and 7.130 mm). As the results, it reduces the surface area of the particle size, 1.180 mm and gives slower heating rate and lower biomass gasification index compared to the two other particle sizes. In another words, bigger palm shells particle size are easier to be burnt compared to smaller palm shells.

B. Influence of Nitrogen Flowrate and Particle Size on Tar Content

Figure 3a shows that nitrogen flow rate and palm shells particle size have a significant effects on the tar production. It is observed from Figure 3b that tar production will increased if nitrogen flow rate is increased or bigger palm shells particle size are used. Using particle palm shells size between 1.180 to 7.130 mm and nitrogen flow rate (5 to 7 LPM), tar produced will be between 100 to 3000 mg/Nm^3. Figure 3c shows that flow rate of nitrogen has effect on the grate temperature as the air flow rate remained constant at 5 LPM. As the ratio of nitrogen to air increased, this will decreased the oxygen content during the pyrolysis process. As the result, a lower temperature is produced in the process which will leads to an increased of tar content. The results of the effect of temperature on the tar concentration are in good agreement with data published elsewhere on biomass gasification [21,22,23] and could be explained by the fact that higher temperature could improve the cracking reactions of the tar in the reactor [20].

As for the palm shells particle size, it is observed that particle size, 1.180 mm produce the least tar amount compared to the two other particle sizes. According to Padban et al. [24], they assumed an influenced of the particle size on the tar characterization: small particles produce heavier tar compounds, while larger particle size produces lighter PAHs. These authors explained that this influence could be due to the fact that a small particle suffers reaction in the upper side of the bed, where the atmosphere is more reducing. In this way, the diffusion of the volatiles from smaller particles is faster and the cracking process becomes less severe than in the case of particles with a smaller size.

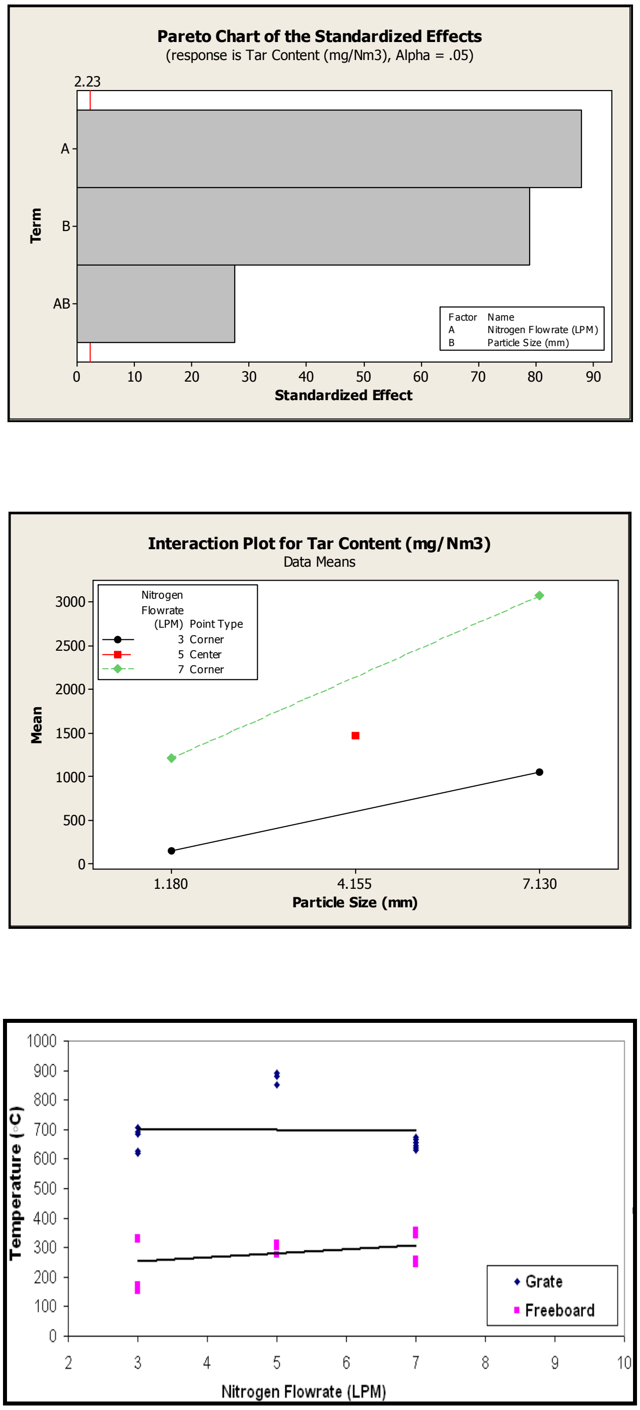
C. Influence of Nitrogen Flowrate and Particle Size on CO Production

It is illustrated in Figure 4a that nitrogen flow rate has the most significant effects on the CO production compared to palm shells particle size. It is observed that lower nitrogen flow rate increases the CO production. As mentioned earlier, lower nitrogen flow rate will increased the temperature of the system. This is in good agreement with Bourdard reaction Eq. (3) which is an endothermic reaction. As the temperature increases, the CO production increases. This is accordance with Le Chatelier's principle which states that temperature favors the reactants in exothermic reactions and meanwhile endothermic reactions favor the products.

Boudouard Reaction

$$C + CO_2 \rightarrow 2CO \quad (\Delta H = +172\, MJ/kmol) \qquad (3)$$

(a)

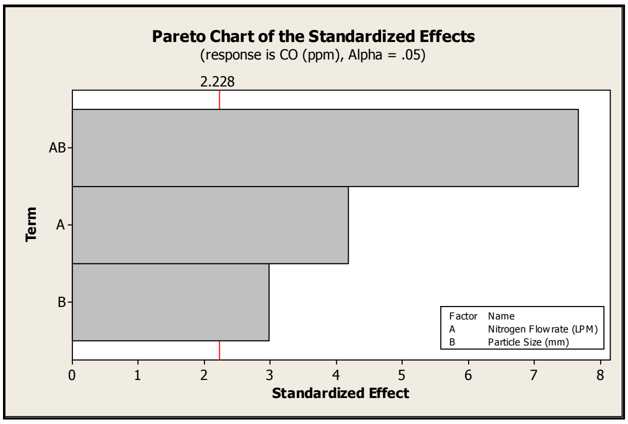


(b)

(c)

Figure 3. (a) Pareto's standardized chart: effect of the nitrogen flow rate and particle size of palm shells on tar content. (b) Interaction plot for tar content on the effect of the nitrogen flow rate and palm shells particle size (c) Effects of grate and freeboard temperature on nitrogen flow rate (5-7LPM).

(a)



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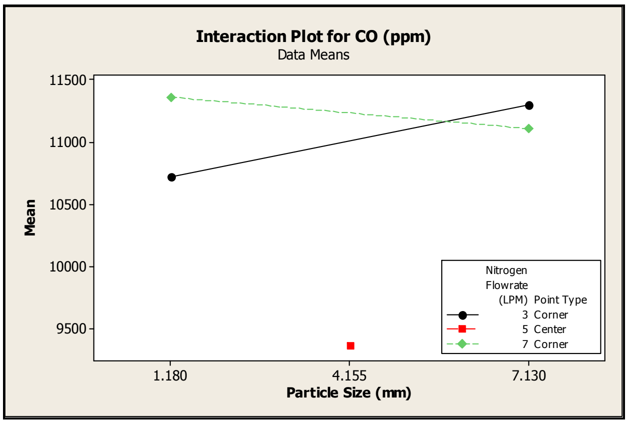


Figure 4. (a) Pareto's standardized chart: effect of the nitrogen flow rate and particle size of palm shells on CO production. (b) Interaction plot for CO production on the effect of the nitrogen flow rate and palm shells particle size.

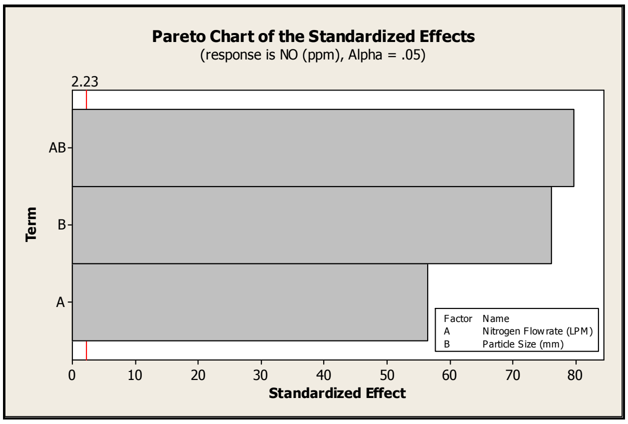
D. Influence of Nitrogen Flowrate and Particle Size on NO Production

Figure 5a shows that nitrogen flow rate has the most significant effects on the NO production compared to palm shells particle size. Generally, if the nitrogen flow rate increases, the content of NO production increases too. And also, part of the fuel nitrogen is released from the palm shells during the devolatilization stage [25,26]. However, it is observed from Figure 5b that only NO production increased when nitrogen flow rate of 7 LPM has been supplied with increasing palm shells particle size. And at lower nitrogen flow rate of 3 and 5 LPM, the NO production maintained almost constant regardless on the palm shells particle size.

E. Influence of Nitrogen Flowrate and Particle Size on SO_2 Production

Figure 6a shows that different nitrogen flow rate and palm shells particles size does not have any significant effects on the SO_2 production. According to Bridgwater [14], sulfur is not generally considered to be a problem, since biomass feeds have very low sulfur contents.

(a)



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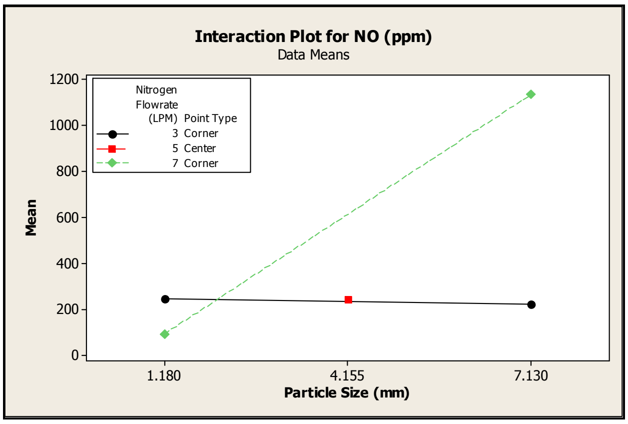


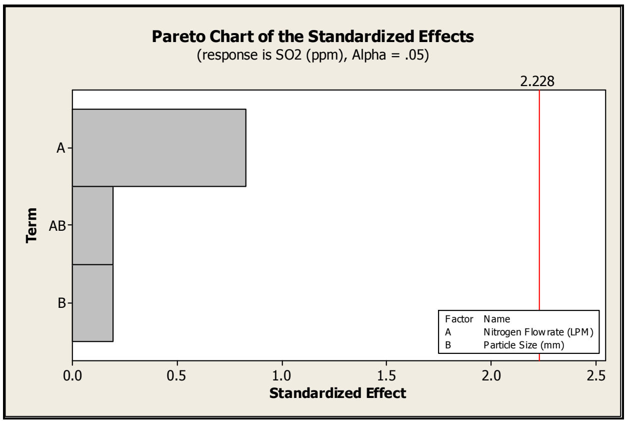
Figure 5. (a) Pareto's standardized chart: effect of the nitrogen flow rate and particle size of palm shells on NO production. (b) Interaction plot for NO production on the effect of the nitrogen flow rate and palm shells particle size.

CONCLUSION

In this study, experimental results are presented concerning the influence of different nitrogen flow rate and palm shells particle size on the effect of biomass gasification index, tar content, CO, NO, and SO_2 production in a laboratory scale fixed bed reactor using biomass palm shells with mixtures of nitrogen and air as gasifying agent. The experimental conditions examine ranges of average palm shells particle size and nitrogen flow rate of 1.180-7.130 mm and 5-7 LPM respectively. The air flow rate is kept constant at 5 LPM to the inlet of the reactor.

Of the two operating variables analyzed in this study, the results obtained from the ANOVA analysis indicate that the nitrogen flow rate has a significant effect on biomass gasification index, tar content, CO, and NO production. Meanwhile, particle size has a significant effect on the tar content, CO and NO production. Besides that, the study also revealed that the effect of the temperature in the reactor varies as a function of nitrogen flow rate when air flow rate is kept constant. The temperature increased when the nitrogen flow rate decreased as the oxygen content in the mixture of gas reduced.

(a)



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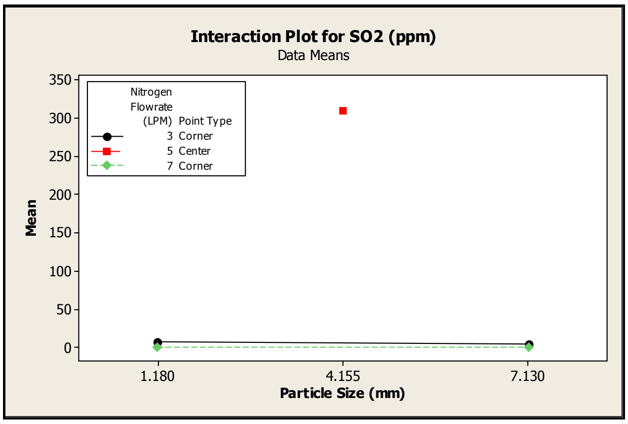

Figure 6. (a) Pareto's standardized chart: effect of the nitrogen flow rate and particle size of palm shells on SO_2 production. (b) Interaction plot for SO_2 production on the effect of the nitrogen flow rate and palm shells particle size.

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REFERENCES

[1] K.J. Ptasinski, M.J. Prins, A. Pierik, "Exergetic evaluation of biomas gasification," Energy, vol. 32, pp. 568-574, 2007.

[2] G. Chen, J. Andries, H. Spliethoff, M. Fang, P.J. van de Enden, "Biomass gasification intergrated with pyrolysis in a circulating fluidised bed," Solar Energy, vol. 76, pp. 346-349, 2004.

[3] N.M.A. Wahab, N.M. Mokhtar, N.A. Ludin, "Option and tools for renewable energy implementation in Malaysia," Seminar on Harmonised Policy Instruments for the Promotion of Renewable Energy and Energy Efficiency in the ASEAN Member Countries and Energy Efficiency in the ASEAN Member Countries, Shah Alam, Malaysia, Sept 2005.

[4] S.H. Shuit, K.T. Tan, K.T. Lee, A.H. Kamaruddin, " Oil palm biomass as a sustainable energy source: a malaysian case study," Energy, vol. 34, pp. 1225-1235, 2009.

[5] C.H. Teoh, The palm oil industry in Malaysia-from seed to frying pan, Malaysia: Plantation Agriculture, WWF from http://assets.panda.org/downloads/oilpalmchainpartaandb_esri.pdf

[6] Katmandu, Nepal.Workshop on utilization of biomass for renewable energy from http://www.apo-tokyo.org/biomassboiler/D1_downloads/presentations/Nepal_Program_DEC2006/Country_Papers/Malaysia_CP.doc

[7] W.A.W.A.K. Ghani, R.A. Moghadam, M.A.M. Salleh, A.B. Alias, "Air gasification of agricultural waste in a fluidized bed gasifier: hydrogen production performance," Energies, vol. 2, pp. 258-268, 2009.

[8] M. Kaltschmitt, C. Rösch, Research Report AIR CT94-2284, IER, Universität Stuttgart, p.47, 1998.

[9] A. Giampaolo, "Gas turbine handbook principles and practices," *CRC Press,* Taylor & Francis Group, 3rd Edn, 2005.

[10] S. Sumathi, S.P. Chai, A.R. Mohamed, "Utilization of oil palm as a source of renewable enery in Malaysia," Renewable Sustainable Energy, vol. 12, pp. 2404-2421, 2008.

[11] E. Kurkela, P. Ståhlberg, “Air gasification of peat, wood and brown coal in a pressurized fluidized-bed reactor. I. Carbon conversion, gas yields and tar formation,” Fuel Processing Technology, vol. 31, pp. 1-21, 1992.

[12] J. Leppälahti, E. Kurkela, “Behaviour of nitrogen compounds and tars in fluidized bed air gasification of peat,” Fuel, vol.70, pp. 491-497, 1991.

[13] Z. Wu, C. Wu, H. Huang, S. Zheng, X. Dai, “Test results and operation performance analysis of a 1-MW biomass gasification electric power generation system,” Energy & Fuels, vol. 17, pp. 619-624, 2003.

[14] A.V. Bridgwater, “The technical and economic feasibility of biomass gasification for power generation,” Fuel, vol. 74, pp. 631-653, 1995.

[15] P. Hasler, Th. Nussbaumer, “Gas cleaning for IC engine applications from fixed bed biomass gasification,” Biomass and Bioenergy, vol. 16, pp. 385-395, 1999.

[16] P. McKendry, “Energy production from biomass: Part 3. Gasification technologies,” Bioresource Technology, vol. 83, 2002, pp. 55-63.

[17] H.B. Abdullah, M.N.B.M. Jaafar, F.N.B. Ani, “Combustion characteristics study of biomass in a fluidized bed combustor”, Research Vote No. 75121, University Teknologi Malaysia, 2007.

[18] M.N. Islam, R. Zailani, F.N. Ani, “Pyrolytic oil from fluidised bed pyrolysis of oil palm shell and its characterisation,” Renewable Energy, vol. 17, pp. 73-84, 1999.

[19] N.H. Kutner, C.J. Nachtsheim, J. Neter, W. Li, “Applied linear statistical model,” McGraw-Hill, Boston, 2004.

[20] M. Aznar, J.J. Manyà, G. García, J.L. Sánchez, M.B. Murillo, “Influence of freeboard temperature, fluidization velocity, and particle size on tar production and composition during the air gasification of sewage sludge,” Energy & Fuel, *Article in press.*

[21] E. Kurkela, P. Ståhlberg, “Air gasification of peat, wood, and brown coal in a pressurized fluidized-bed reactor. I. Carbon conversion, gas yields and tar formation,” Fuel Processing Technology, vol. 31, pp. 1-21, 1992.

[22] R.J. Evans, R.A. Knight, M. Onischak, S.P. Babu, “Process performance and evironmental assessment of the Renugas process,” Proc. Conf. Energy from Biomass and Wastes, Institute of Gas Technology, Washington DC, 1986.

[23] D.C. Elliot, “Relation of reaction time and temperature to chemical composition of pyrolysis oil,” Pyrolysis oils from biomass, Am. Chem. Spc. Symp. Series 373, Washington DC, pp. 55-56.

[24] N. Padban, W. Wang, Z. Ye, I. Bjerle, I. Ordenbrand, Energy Fuels vol. 14, pp. 603-611, 2000.

[25] T. Mäkinen, J. Leppälahti, E. Kurkela, Y. Solantausta, “Electricity production from biomass by gasification and a solid oxide fuel cell,” Proc. 8th European Conference on Biomass for Energy, Environment, Agriculture, and Industry, Vienna, 3-5 October 1994.

[26] J. Leppälahti, T. Koljonen, “Nitrogen evolution from coal, peat and wodd during gasification: literature review,” Fuel Processing Technology, vol. 43, pp 1-45, 1995.