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PRIMARY RESEARCH

Liquid product properties of pyrolyzed bamboo Saw-dusts

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Abstract

A pyrolyzer was fabricated for the collection of liquid products from the pyrolysis of untreated bamboo saw dust from UPV-Bamboo Enterprise Development Project. Collection and analysis of the liquid products were performed for two temperature ranges from 490-500°C and 550-560°C. Based on the generated method from the fabricated pyrolyzer, the yield ranges from 8% to 16%. The analyses included the physicochemical properties of the liquid products, such as the pH, viscosity, density, and heating value. For temperature ranges of 490-500°C and 550-560°C, mean values of pH were 4.47 and 4.30; density values were 1087.37 kg/m^3 and 1066.76 kg/m^3; viscosity values were 1.32 mm^2/s and 1.62 mm^2/s; and heating values were 1.99 MJ/kg and 2.51 MJ/kg respectively. The results showed that there was no significant difference in the pH, viscosity, calorific value, and density of the untreated bamboo saw dust with different operating temperatures of the pyrolyzer equipment using a One-Way Analysis of Variance (ANOVA) since the p-value of each test were greater than the specified α = 0.05 level of significance. The analyses of the physicochemical properties could be used in studying how the liquid product can be utilized. The results can also be bases to see if the liquid product can be used as a fuel or can be a potential ingredient for phar maceutical products.

I. INTRODUCTION

Bamboos belong to the grass family, Gramineae or Poaceae. They have woody, usually hollow culms, complex rhizome and branch systems, petiolate leaf blades and distinct sheathing organs. What sets them apart from grasses are its similar anatomical features in its leaf blades. An estimate of 1000 species of bamboo belongs to about 80 genera in the world, 200 species of these grow in Southeast Asia belonging to 20 genera [1, 2].

Seventy (70) known species of bamboo thrive in the Philippines, 53 of which are erect and 17 are climbing but only 9 are of economic importance which include kawayan tinik (*Bambusa blumeana*), bayog (*B. merrilliana*), kawayan killing (*B. vulgaris*), giant bamboo (*Dendrocalamus asper*), bolo (*Gigantochloa levis*), kayali (*G. atter*), buho (*Schizostachyum lumampao*), and anos (*S. lima*) [3].

Bamboos have been used for ages in the Philippines mainly for construction, furniture and handicraft manufacture, food, musical instruments, farm and fishing implements, pulp and paper, fuel for cooking and heating, etc. In the year 2010, the bamboo industry was formalized by virtue of Executive Order (EO) 879 which created the Philippine Bamboo Industry Development Council (PBIDC) and mandated the use of 20% of bamboo for reforestation, 25% for desk requirements of all public elementary and high schools in the country, strengthening of the bamboo industry, and intensification of research on bamboo production and utilization. The issuance of this EO demonstrates how important bamboo is for socio-economic development, environmental enhancement, and power generation [1].

Pole production and processing are the two major components of the bamboo industry in the Philippines [3]. In Thailand, instead of selling wood by-products from furniture manufacturing as fuel at a low price, wood chips are taken

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as raw materials in producing wood vinegar [4]. Similarly, in China, people paid attention to the chemical utilization of bamboo as bamboo culms were not completely used up in several processing industries. These chemical utilization methods include distilling from bamboo leaves and pyrolyzing bamboo to produce charcoal and vinegar, and the latter proved to the best and most practical way of utilizing bamboo culms [5].

Conversional pyrolysis system method is used in replacement to the traditional method in producing the liquid oil. Pyrolysis is the thermal degradation of waste in either low oxygen or an oxygen free environment. Pyrolytic products vary depending on the raw material used, these include coal, animal and human waste, agriculture waste, food scraps, paper, cardboard, plastics, rubber, and biomass. Compared to other processes, the yield of useful products is higher due to its nature [6, 7, 8].

Bambusa blumeana J.A. and *J.H. Schultes* or kawayan tinik can be found throughout settled areas of different altitudes. The exact origin of this species of bamboo is not known, but it is believed to be introduced to the Philippines in 1910's and has become the most commonly used species. It is often planted along water courses to prevent erosion, around farm houses to serve as a windbreaker, and in the field as living fences to make boundaries. This species of bamboo is also found growing neighboring countries such as Thailand, Vietnam, Malaysia and Southern China [1].

[1] described kawayan tinik as "a densely tufted sympodial bamboo, with spiny basal branches forming a densely interlace thicket 2-3 m high." The culms are erect and grow 15-25 m tall and 6-10 cm diameter. Preliminary studies done by the Department of Science and Technology–Forest Products Research and Development Institute (DOST-FPRDI) and [9], a Japanese Scientist has made a breakthrough to promote a technology which utilized species of bamboo such as "bayog", "kawayan tinik" and solid bamboo to produce good quality of bamboo charcoal and light distillate. It has been reported by Vella Atienza of the Philippine Council for Agriculture, Aquatic Forestry and Natural Resources Research and Development (PCAARRD) that bamboo charcoal can be used to clean air, purify water, as well as absorb odors in refrigerators. In the Philippines, bamboos were mainly used for construction, furniture and handicraft manufacture, food, musical instruments, farm and fishing implements, pulp and paper, fuel for cooking and heating, etc. A lot of wastes generated from these industries and processes could still be used for significant purposes – as bio-fuel, and chemical feedstock. Scientific journals have studied bamboo as a source of various products and by-products using a variety of methods.

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The main objective of this study was to analyze the properties of the liquid products from the pyrolysis of bamboo saw dusts.

Specifically, the study aims:

1. To compare the yield at different temperatures, with the use of a fabricated pyrolyzer;

2. To compare the physicochemical properties such as pH, viscosity, heating value and density of the liquid products from pyrolysis at different temperatures of untreated bamboo saw dusts from the University of the Philippines Visayas (UPV)-Bamboo Enterprise Development Project.

II. MATERIALS AND METHODS

A. Raw Materials

Bamboo wastes from UPV-Bamboo Enterprise Development Project were utilized as the biomass material converted into liquid products. The bamboo wastes used were untreated bamboo saw dusts. For the untreated bamboo saw dust, the particle size was 0.3 mm. Sieve analysis was done to assess the particle size distribution of the bamboo saw dusts. For the sieve analysis, a screen bag with an estimated mesh size of 50 with an equivalent particle size of 0.3mm [12] was used to ensure same the particle size of the untreated bamboo saw dusts. The particle size of the

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bamboo saw dusts was based on the specifications of the feedstock from Handbook of Bionergy Crops by [10]. After sieving, the bamboo saw dusts were sun dried to reach constant weight. Sun drying method retained more nutrients than the oven and smoke drying methods [13]. Hence, sun drying was used in this study.

B. Method of Pyrolysis using the Fabricated Pyrolyzer

Figure 1 shows the method for the use of the fabricated pyrolyzer after the pre-testing of the equipment. After loading the feed, the first step was the preheating of the equipment. The preheating involved 10 minutes of heating and 10 minutes of cool down. The second step included turning on of the burner, which indicated the start of the processing time.

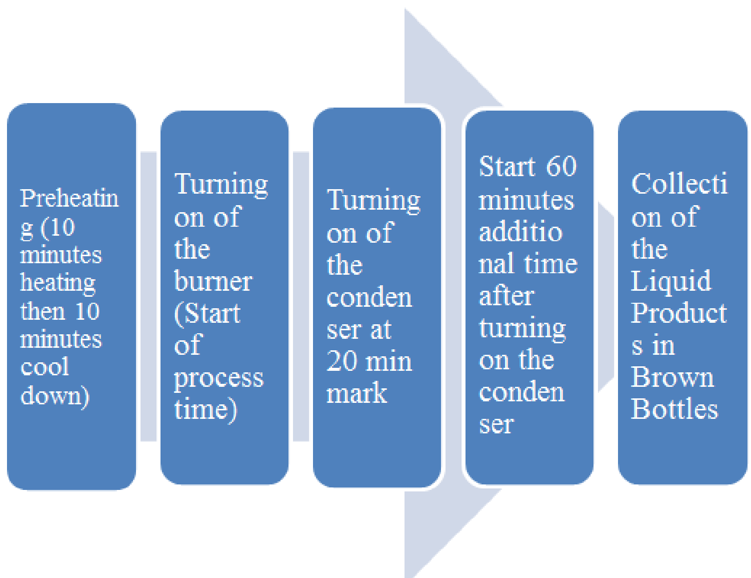

Fig. 1. Method generated in the efficient pyrolysis of the liquid products using the fabricated equipment

Third step was the turning on of the condenser after 20 minutes past the processing time. The condensing temperature was maintained at a room temperature of 25°C. The fourth step was the start of the time of pyrolysis which was additional of 60 minutes. After this last step, the collection of liquid from the condensed tube of the condenser was made. Thus, the total process time was 80 minutes and was considered constant for all trials. The generated method was used for both the temperature ranges gathered and recorded in the pre-testing of the equipment. There were two temperature ranges: a.) 490°C-500°C and b.) 550°C-560°C; and for each temperature range, there were 3 trials of the generated method. So, the total number of trials in the experiment proper totaled 6 trials. The temperature ranges were obtained using a Digi-Sense Infrared Thermometer. The fabricated pyrolyzer and its actual picture are seen in Figures 2 and 3 respectively.

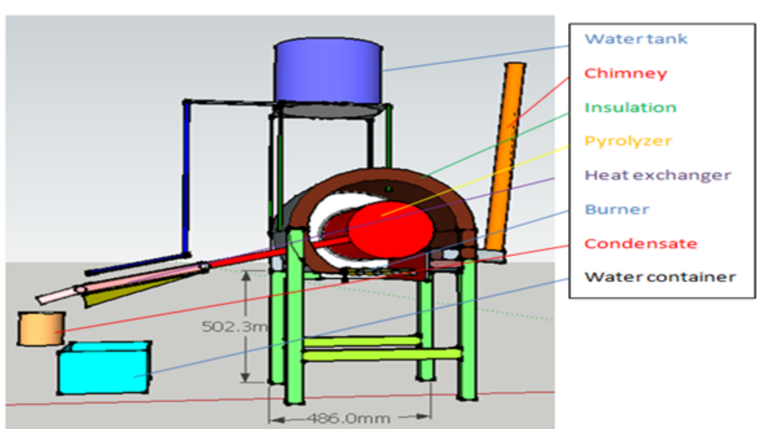

Fig. 2. Fabricated pyrolyzer labeled with parts

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Fig. 3. Actual picture of pyrolyzer unit

The feedstock was pyrolyzed by batch. The amount of feedstock used per batch was 1000 g (1 kg). The moisture content of the feedstock was measured after sun drying to reach a constant value. The moisture content determined for each batch feed was at a value not greater than 10% on weight basis. Determination of the moisture content by sun-drying includes the weighing of the initial sample and weighing of the constant-weight sample. The samples were dried under the sun until it reaches a constant weight. Constant weight was determined by weighing the sample immediately after drying and 24 hours after. The percent (%) moisture content was then equal to the loss weight of the sample divided by the initial weight of the sample multiplied by 100. The weights of the dried samples were measured using a weighing scale or the top loading balance.

C. Measurement of Yield

The efficiency of the fabricated pyrolyzer was based on the yield of liquid products in each trials conducted. The feed in each trial was constant at 1000 g of untreated bamboo sawdusts. The weights of the liquid products collected were determined using a top-loading balance. The formula used to get the % yield was

$$\%Yield \ \frac{Weight\ of\ Liquid\ Products}{Weight\ of\ Feed} \times 100$$

D. Sample Analyses

The analyses of liquid products produced in the pyrolysis include only their physicochemical properties. These physicochemical properties were pH, calorific value, density, and viscosity. The number of liquid products produced was also accounted for; it was measured by volume using a graduated cylinder and by mass using an analytical balance. The equipment used for the analyses was pH meter, bomb calorimeter, hydrometer, and Ostwald viscometer. The analyses were done in the School of Technology laboratories.

E. Determination of Viscosity

The viscosity of the liquid samples collected was determined using an Ostwald viscometer. The viscometer was calibrated using water as a reference liquid. The liquid sample was added to the viscometer, pulled into the upper reservoir by suction, and then was allowed to drain by gravity back into the lower reservoir. The time it took for the sample to pass between the upper and lower part of the reservoir was measured, and was denoted as t_1; for the water, it was denoted as t_2. The equation used to solve for the relative viscosity of the sample using the Ostwald viscometer was:

$$relative\ viscosity\ (\eta rel) = \frac{\eta 1}{\eta 2} = \frac{\rho 1 \times t1}{\rho 2 \times t2}$$

where ρ_1 and ρ_2 are the density of the liquid sample and water respectively [14].

F. Determination of Density

Density was measured by an alternative and more conventional way in solving for the density of the liquid sample using the formula: $density = \frac{mass}{volume}$. The mass of the liquid products was weighed on an analytical balance, while the volume was determined with the use of a graduated cylinder.

G. Determination of pH

A pH meter was used to measure the pH of the collected samples. The pH meter was calibrated by placing the electrode in buffers. After the reading stabilized, the electrode was washed with distilled water to prepare for the sample reading.

In reading the pH of the samples, the rinsed electrode was placed in the sample that was transferred to a 50 mL beaker. When the reading of the electrode stabilized, it was recorded as the pH of the sample.

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H. Determination of Heating Value

For heating value of the liquid product, a bomb calorimeter was used. The standard procedure used in the laboratory, was used in the analysis of the heating value of the sample. The bomb calorimeter was first calibrated using benzoic acid. After which, the heating value (Hg) of the liquid products was determined using the formula (Parr Instrument Company 2008):

$$Hg = \frac{Energy\ \ equivalent\ \ of\ \ calorimeter \times temperature\ \ rise}{mass\ \ of\ \ sample}$$

I. Statistical Analysis

In this study, the statistical analysis was carried out using a ANOVA and was analyzed using the Microsoft Excel. ANOVA was used to determine whether there was a significant effect in varying operating temperatures of the pyrolyzer equipment, in the pH, viscosity, calorific value, and density of the liquid products from untreated bamboo saw dust.

III. RESULTS AND DISCUSSION

A. Yield of Pyrolysis of Untreated Bamboo Saw Dusts

The yield of the pyrolysis of untreated bamboo saw dusts was determined for each trial as seen in Table 1. These results were the bases of the efficacy of the fabricated equipment. Lignin exhibits intermediate thermal degradation behavior from 250 to 500°C [15]. At this state, it was highly probable that the lignin in the liquid products collected was degraded since the temperature used for pyrolysis was set at 500°C and higher. The temperature ranges used in the study were categorized as fast temperature pyrolysis.

The yield for different temperatures increased with an increase in temperature. This showed that at a higher temperature more liquid products were produced in the process. Considering the method generated (Figure 1) for the pyrolysis of untreated bamboo sawdusts using the fabricated pyrolyzer, it was shown that the liquid products yield was at a range of 8% to 16%. Hence, the fabricated pyrolyzer should be operated at high temperature greater than 500°C.

TABLE 1
% YIELD AT 490–500°C AND 500–560°C

Temperature (°C)	% Yield	Mean %Yield
490–500		
Trial 1	8.41	8.05
Trial 2	7.94	
Trial 3	7.79	
550-560		
Trial 1	14.58	15.76
Trial 2	16.59	
Trial 3	16.11	

B. Physicochemical Properties

The physicochemical properties of the liquid products determined were pH, density, viscosity, and heating value. Table 2 shows the summarized data for the different properties determined.

TABLE 2
PHYSICOCHEMICAL PROPERTIES OF THE LIQUID PRODUCTS

Temperature (°C)	pH	Density (kg/m^3)	Viscosity (mm^2/s or cSt)	Heating Value (MJ/kg)
490 – 500				
Trial 1	4.60	1092.21	1.09	1.37
Trial 2	4.40	1102.78	1.29	2.72
Trial 3	4.40	1067.12	1.58	1.87
Mean	4.47^a	1087.37^a	1.32^a	1.99^a
550-560				
Trial 1	4.50	1034.04	1.34	2.90
Trial 2	4.20	1070.32	1.59	2.34
Trial 3	4.20	1095.92	1.94	2.28
Mean	4.30^a	1066.76^a	1.62^a	2.51^a

Superscripts with the same letter are not significantly different at $p > 0.05$ using ANOVA

1) pH: It was determined that the pH in both temperature ranges has values from 4.2 to 4.6 which are within the range of acidic substances [16]. As seen from Figure 4, there are no significant differences between pH at different temperature range.

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The pH of the liquid products was important because it indicates the acidity of the products. The range of pH determined in the study showed that the liquid products from pyrolysis of bamboo saw dusts were acidic and therefore could exhibit corrosiveness. The type of biomass used affects the acidity of the liquid products because of the different organic acids that can be present in the liquid products. Most liquid products produced from different types of biomass have pH between 2-4. According to [17], the acidity was also affected by the condensing temperature used.

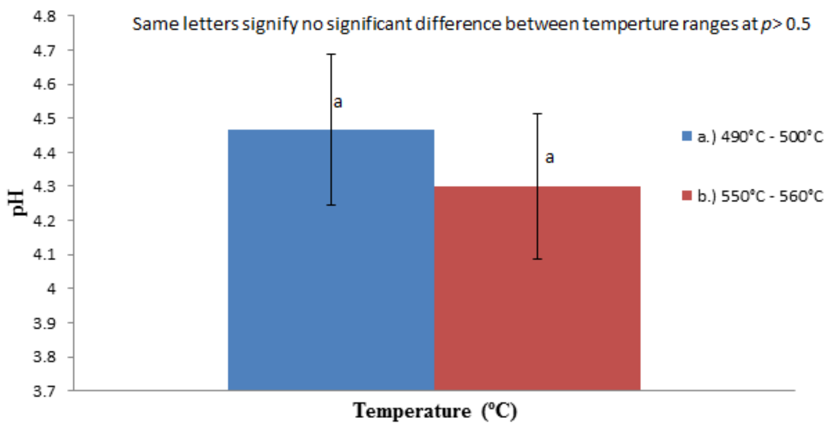

Fig. 4. Average pH of the liquid products

During the experiment, the condensing temperature was maintained at room temperature of 25°C with the use of wet linen cloth covering the condensing tube. Thus the variation in pH of the liquid products as compared to that shown in various literature could be attributed to the different organic compounds present such as acetic acid, carboxylic acid, and formic acid [16]. Differences in concentration of these organic compounds maybe due to differences in the pH range. But, results of pH of the liquid products could be useful in terms of studying the storage of the liquid products obtained. Acidic products could cause corrosion in containers; knowing the pH of the products could provide handlers with necessesary information on how to handle the samples safely. The proper storage of the liquid products could provide an adequate amount of time that will enable others to conduct future researches on the liquid products.

2) Density: The densities of the liquid products were determined using the mass over volume formula. Figure 5 shows the densities of the liquid products at different trials of different temperature ranges. The density range obtained for the first temperature range was 1.07 x 10^3 kg/m^3 to 1.10 x 10^3 kg/m^3, while the determined density range for the second temperature range was 1.0^3 x 10^3 kg/m^3 to 1.10 x 10^3 kg/m^3. ANOVA showed no significant differences in densities obtained in both temperature ranges (Figure 5).

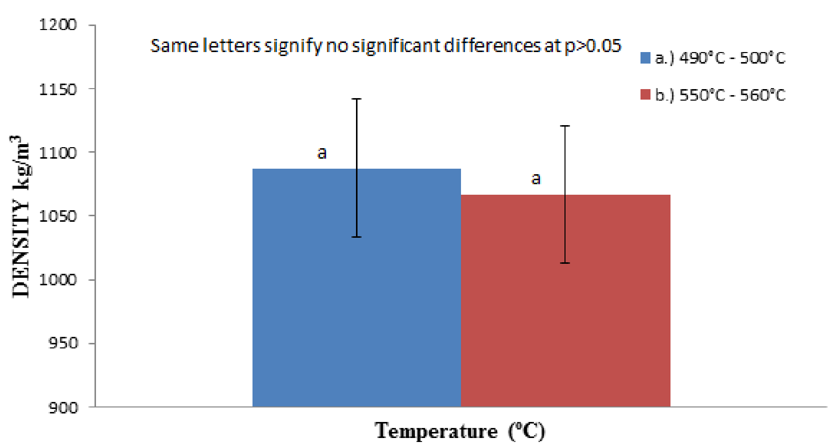

Fig. 5. Average density values of the liquid products

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The varying densities of the liquid products are linked to their energy content. As the density increases, the energy content also increases [16]. At the temperature range of 490°C-500°C the density obtained for samples 1, 2, and 3 are 1.09 x 10^3 kg/m^3, 1.10 x 10^3 kg/m^3, and 1.07 x 10^3 kg/m^3 respectively and at the temperature range of 550°C-560°C, the density readings were 1.03 x 10^3 kg/m^3, 1.07 x 10^3 kg/m^3, and 1.10 x 10^3 kg/m^3 for samples 1, 2, and 3 respectively. The values obtained in the determination of the liquid products' densities showed that it falls within the range established in pieces of literature which ranges from 1,000-1,240 kg/m^3 according to [16].

3) Viscosity: The viscosities of the liquid products were determined using an Ostwald viscometer. For the untreated bamboo saw dusts used with particle size of the feed sieved to 0.3 mm, the viscosity ranges at the temperature range of 490–500 °C was from 1.09 mm^2/s to 1.58 mm^2/s. And the viscosities for the second temperature range 550–560°C ranges from 1.34 mm^2/s to 1.94 mm^2/s. Figure 6 shows the viscosities of the liquid products at different trials for different temperature ranges.

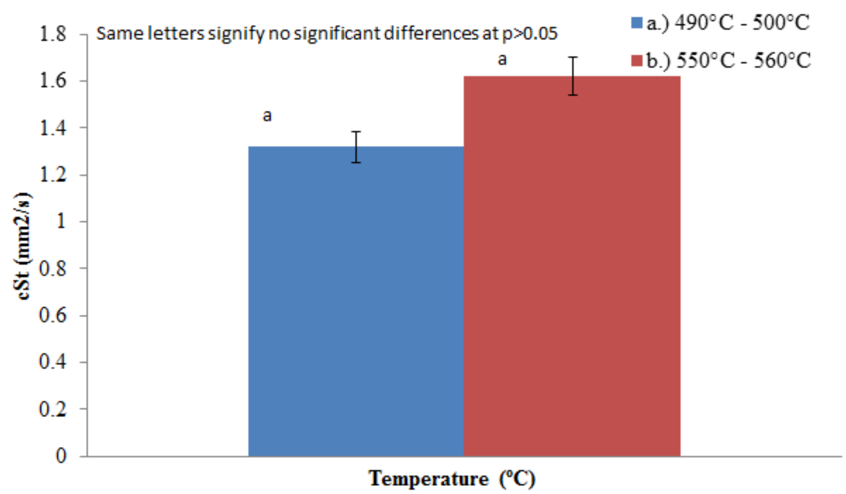

Fig. 6. Average viscosity values of the liquid products

The viscosity of the liquid products was important in determining its fluidity. According to a study by [18], biomass having particle size of 0.1 mm and 0.5 mm have their viscosity determined to be 125 mm^2/s and 138 mm^2/s respectively. The viscosity values determined were significantly lower than the values, 125 mm^2/s and 138 mm^2/s as compared with the values obtained in the literature determined by [18, 19]. Based on One Way ANOVA, there were no significant differences in viscosity at different temperature ranges at $p > 0.5$. The particle size of the biomass feedstock, water content of the oil, condensing temperature, and storage time are factors to be considered in the experiment which may have caused these differences in values from that of [18].

4) Heating value: For the first temperature range (490-500°C), the range of the heating value was 1.37 MJ/kg to 2.72 MJ/kg, while in the second temperature range (550-560°C) was 2.34 MJ/kg to 2.9 MJ/kg, as seen in Figure 7.

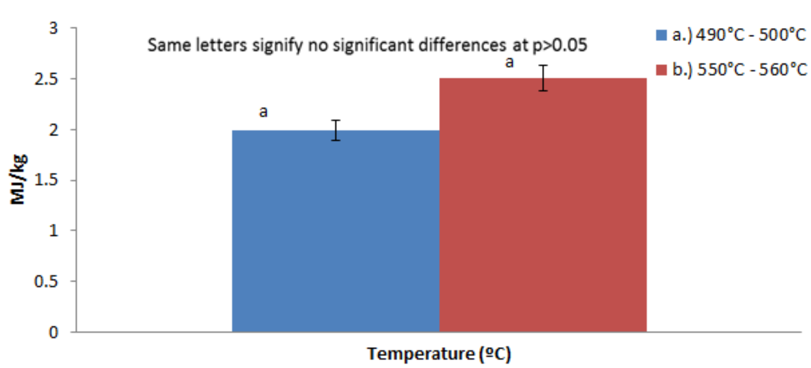

Fig. 7. Average heating values of the liquid products

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Fuels and foodstuff are commonly characterized based on its heating value which was the energy released as heat upon undergoing complete combustion. Based on [16], the determination of heating value will be a factor to be considered in identifying which type of fuel it may be. Water and oxygen content in biomass feedstock, water content in bio-oil, condensing temperature, and storage time are factors that affect the calorific value of the bio oil which was found to be far from the values of the cited literature which was the range from 15 MJ/kg to 36 MJ/kg.

In this study, the method used to generate an efficient pyrolysis of the untreated bamboo saw dusts was based on the objective of generating an efficient pyrolysis within the range of 500 to 600°C was achieved at 490-500°C and 550-560°C. The process time for all trials was 80 minutes.

The physicochemical properties of the liquid products that were determined were pH, viscosity, heating value and density. In comparison to results obtained from [16], the pH and density values obtained in this study were within the range of values found by [16] while the viscosity and heating values were outside the range of values. This variation in the viscosity values was attributed to different factors such as water content of the oil, condensing temperature, and storage time [16]. In comparison of the liquid products, the results showed that there is no significant difference in the pH, viscosity, calorific value, and density of the untreated bamboo saw dust with different operating temperatures of the pyrolyzer equipment since the *p*-value of each test were greater than the specified $\alpha = 0.05$ level of significance using ANOVA.

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