Asian Review of Mechanical Engineering
ISSN: 2249-6289 (P)
Vol.12 No.1, 2023, pp.1-8

DOI: https://doi.org/10.51983/arme-2023.12.1.3607

Production of Charcoal Through Partial Combustion in a Wood Stove

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***Abstract* - Philippines is a country rich in natural resources that can be converted into biomass fuels, such as charcoal. This study aims to determine the viability of producing charcoal through partial combustion using Mahogany and Ipil – Ipil wood in a wood stove before burying the charred wood samples in clay soil. Sample preparation was done by machining pruned branches into a size of 1-in diameter by 6-in length, then drying them until their moisture content was below 20%. The dry wood samples were then charred in a wood stove at different residence times. After reaching the residence time of a trial, the charred sample was wrapped in tin foil and buried in clay soil to cool for 24 hours. Afterwards, proximate analysis and bomb calorimetry were done on the charcoals produced. Results of the tests show that with longer residence time, charcoal yield decreased; moisture content increased due to increase in charcoal hygroscopicity; volatile matter decreased due to devolatilization; and fixed carbon content increased. Also, ash content increased for Mahogany charcoals while in Ipil-Ipil, it hardly varied. Furthermore, Ipil-Ipil charcoals were found to have greater calorific values than Mahogany charcoals due to Ipil-Ipil wood having greater calorific value.**
***Keywords:* Mahogany, Ipil-Ipil, Partial Combustion, Charcoal, Wood Stove**

I. INTRODUCTION

The growing demand for energy resources is a truth this world is facing. Rising income, urbanization, and increased access to electricity has led to the rise in the demand for energy. In the recently released International Energy Outlook 2019 reference case, the U.S. Energy Information Administration (EIA) projects that world energy consumption will grow by nearly 50% between 2018 and 2050. On the lead in the increase of energy consumption is the Asian region, whose demand is strongly influenced by its economic growth [1]. To support this, an article titled, "Southeast Asia Energy Outlook 2019" stated that the influence of the Association of Southeast Asian Nations (ASEAN) countries in the growing energy demand of the world started to gain weight due to the member countries' rapidly growing population and economies [2]. The Philippines is a member of ASEAN.

The Philippines is a tropical country teeming with natural resources and diverse biological wildlife. Furthermore, it is recognized as an agricultural country as 47% of its total land area is devoted to agricultural crops. Thus, the country naturally produces biomass resources that can be used as biomass fuels (biofuels) [3]. It is therefore only logical for the country to take advantage of these natural resources and use them for energy production. Unfortunately, biomass, which the country is in abundance of, only accounts for 1.09% of fuel being used for energy production. Part of this percentage is wood, which is one of the earliest fuels used in history and is still being used to this day. In fact, it accounts for 50% and 90% of fuel used in both local and industrial sectors, respectively [4]. By converting wood into charcoal, it was discovered that charcoal fuel is lighter and higher in energy content than wood [5].

About 30% of the total population of the Philippines, particularly the underprivileged, depend upon forest resources for their survival [6]. Energy harnessed from fuelwood sources may be used for electrical and non-electrical energy production. In the country, non-electrical energy produced using fuelwood and charcoal are utilized for residential end uses, particularly cooking and ironing. Over the years, consumption of fuelwood and charcoal is notably highest in the household sector, followed by the commercial and industrial sector. In relation to this, it has also been observed that the use of fuelwood and charcoal has declined in favor of the use of other types of fuel (i.e., LPG). This observation may also be used to explain why the percentage of biomass in Figure 1 is small compared to the percentage of other fuel types. Though the use of fuelwood and charcoal may have declined over the years, the fact remains that these fuel sources still find uses in the different sectors of the country [7].

In the Philippines, most charcoal makers make use of traditional "ham-ak" and "tinabonan" method for charcoal production. Though inefficient, these methods are still relied upon by charcoal makers to produce charcoal. Currently, there are not much research done on improving these traditional charcoal making methods since most studies are geared towards industrial fuel supply; and the demand for this low - quality traditional charcoal is quite low as charcoal made from traditional methods are commonly used in rural areas and in households to perform small - scale processes such as cooking and ironing. Furthermore, household consumers are the least demanding market of charcoal, quality - wise, since these consumers give more importance to the economical and practical aspect of charcoal – accessibility, availability, and its selling price [8].

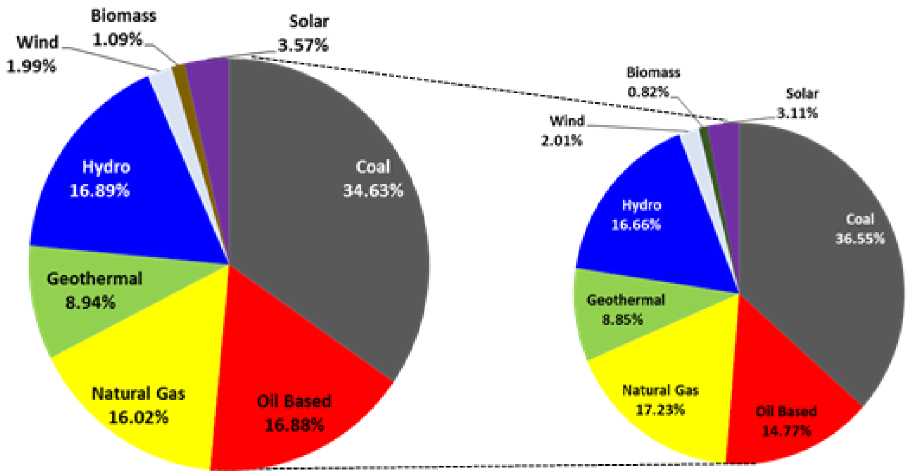

Fig. 1 Energy Fuel type used in the Philippines in 2016 [13]

Though the given reasons above are sound, the fact that the Philippines is abundant in biomass resources and people continue to use wood and charcoal fuel despite the emergence of other fuel sources should be reason enough for the Philippine research community to give attention in conducting more studies on the improvement of the production of these fuel resources.

II. EXPERIMENTAL METHODS

A. Experimental Setup

Mature branches were pruned from Mahogany and Ipil – Ipil trees located within the University of San Carlos (USC) - Talamban campus. Acquired branches were then turned to approximately 1-in diameter and cut to lengths of approximately 6 inches; the samples' barks were removed in the process. The machined samples were then sun-dried until they contained a moisture content below 20%. After drying, the samples were weighed using an analytical balance and their readings were recorded.

To ensure that the samples were directly exposed to the flames during charring, an improvised sample holder was made using wire gauze. The sample holder was attached to a lever arm, which was also used to adjust the height of the sample holder inside the combustion chamber. To support the lever arm, a stand with fulcrum was created. The stand also has a wide base to prevent it from wiggling. A type K thermocouple was placed directly above the sample holder in the middle of the combustion chamber; the thermocouple was placed in such a way that it did not touch the walls of the container and the sample holder. The thermocouple was connected to a data logger to display the temperature within the chamber. The assembly is shown in Figure 2.

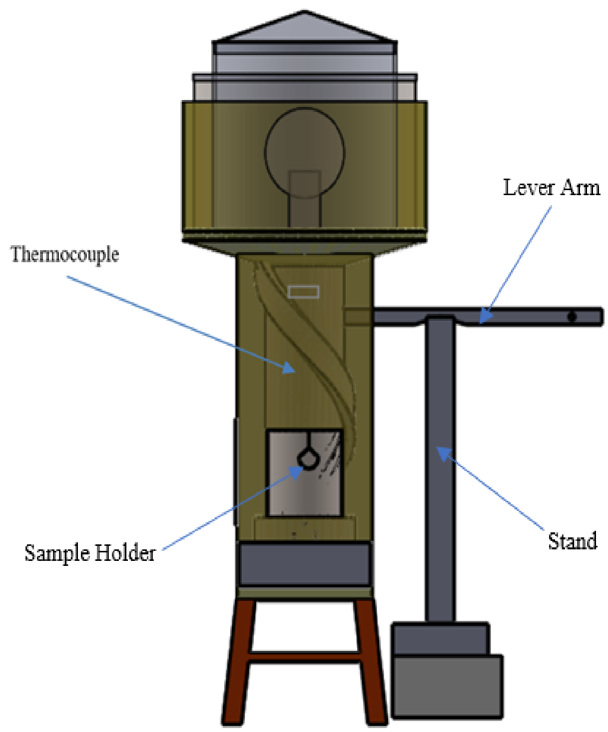

Fig. 2 Assembly of Sample Holder and Placement of Type K Thermocouple

Before the dried samples were charred, the combustion chamber of the wood stove was first preheated. This was done by placing 170 $\pm$ 4 g of wood, the species of which corresponded to the wood sample to be charred, in the wood stove. When the wood initially ignited, the blower, at 200 V setting, was switched on. This caused a temperature range of 500 to 600 °C to be reached; the researchers waited for the temperature to go down to 300 °C before starting the charring step. 300 °C was chosen since it was the temperature that retained enough wood fuel to sustain flames that would reach and ignite the wood samples placed on the holder; it was also the temperature at which volatile matter was observed to start evolving from the samples in the form of smoke.

Once the temperature within the combustion chamber reduced to 300 °C, additional 30 g of wood was added on top of the previously burning wood; this caused a slight increase in temperature which quickly returned to 300 °C. Once the temperature within the chamber returned to 300 °C, one sample was placed on the holder using a pair of tongs; the sample was positioned in a way that it was exposed directly to the flames to induce charring. The researchers then observed if smoke evolved from the sample, or if it ignited. If either or both were observed, the combustion chamber's door was shut, and the timer started. At 3-min intervals, 30 g of wood was added into the chamber to sustain the flames; the chamber's door was quickly shut after adding the additional wood.

Once the charred sample reached its designated residence time (6, 7, or 8 minutes), it was removed from the holder using a pair of tongs and was quickly wrapped using a pre – weighed aluminum foil with a size of 250 mm by 150 mm. Residence times were determined by observing at what time the wood sample started charring (6 minutes) and at what time ash started to form on the surface of the charred wood (8 minutes) in a pre-experiment. The wrapped sample was then buried in the clay soil for it to cool; the soil container's lid was shut to further ensure that no air was able to touch the sample. The sample was left to cool for 24 h. After 24 h, the wrapped sample was removed from the clay soil. The sample was carefully unwrapped to prevent any clay soil particle from sticking to the charred sample. The sample was then weighed using an analytical balance. For the succeeding residence times and their trials, steps starting from the second paragraph were repeated. There were three trials done for each residence time of each wood species.

Before conducting proximate analysis and bomb calorimetry, the samples to be tested were first prepared. This was done by reducing the produced charcoal samples into fine particles using a rubber mallet. 3 g from each powdered charcoal were set aside for the determination of heating value through bomb calorimetry; the remaining weight of the powdered samples were sent to the USC Water Laboratory for proximate analysis. Once the results were received, two-way ANOVA was done to determine if there was an interaction effect between the wood species and residence time or if there were main effects on the different parameters of the charcoals produced.

III. RESULTS AND DISCUSSION

A. Charcoal Yield

As seen in Figure 3, Mahogany charcoal yield is inversely proportional to residence time while Ipil-Ipil charcoal yield was shown to fluctuate. Charcoal yield for all trials of Ipil-Ipil at a residence time of 8 minutes are greater than the charcoal yield at a residence time of 7 minutes, opposite to the trend seen for Mahogany. This may be due to the Ipil – Ipil samples not being completely exposed to the flames due to flame movement; flames, at times, may be concentrated at either side of the combustion chamber instead of at the center, resulting to less thermal degradation of the charcoal samples produced at 8 minutes compared to those produced at a residence time of 7 minutes.

For the results of the two-way ANOVA, the p-value of the interaction effect is 0.085, which is greater than the acceptance value or significance value of 0.05. This shows that there was no significant interaction effect on the charcoal yield between the wood species and residence time. For the p-value of the Wood Species factor, it is 0.831 which is greater than 0.05; this shows that wood specie has no significant effect on the charcoal yield of the charcoal samples. This is supported by the graph in Figure 3 where Mahogany and Ipil-Ipil have a similar trend, except for the increase in charcoal yield for Ipil-Ipil at a residence time of 8 minutes.

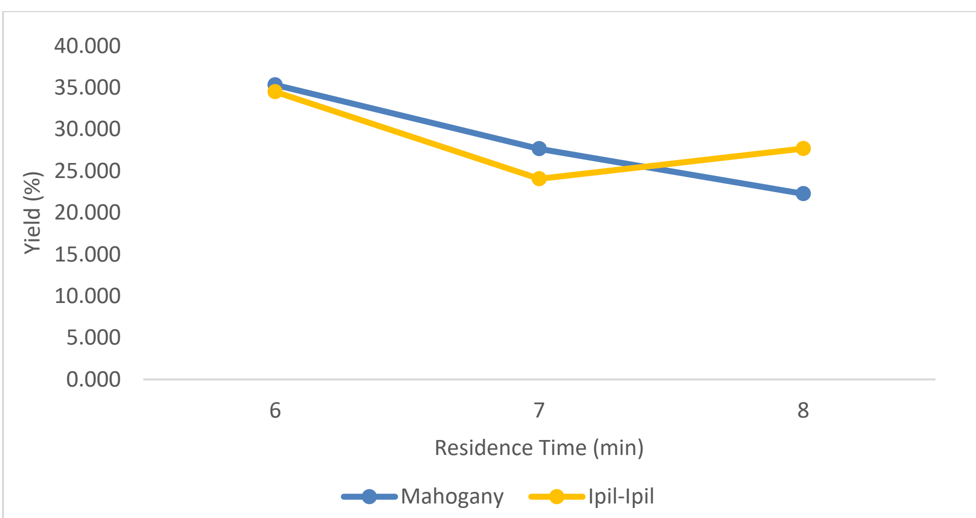

Fig. 3 Estimated Marginal Means of Charcoal Yield (%) versus Residence Time for Each Wood Species

For the Residence Time factor, the p-value is 0.000 which is less than 0.05; this means that residence time has a significant effect on the charcoal yield of the charcoal samples. This is supported by the graph in Figure 3 wherein both Mahogany and Ipil-Ipil charcoal yields differ significantly with longer residence time. Therefore, residence time has a significant effect on the charcoal yield, while the interaction effect of the two factors and wood species main effect on charcoal yield were not significant.

B. Moisture Content

As seen in Figure 4, for both Mahogany and Ipil-Ipil charcoals produced, the average moisture content increased as the residence time increased. However, Mahogany charcoal samples had a higher average moisture content in each residence time compared to the Ipil-Ipil charcoal samples. The researchers found it interesting that this trend contradicted the theory of the stages of combustion of wood in which the combustion of wood begins with drying or the evaporation of moisture trapped within the wood structure, followed by devolatilization or the evolution of water vapor and other combustible gases due to the thermal degradation of wood as heat penetrates the wood and pyrolyzes it to char. The expected outcome of the results is that moisture content would decrease with longer residence time. A possible explanation for this trend is that charcoal can act as a dehumidifying substance as it is hygroscopic; this means that it absorbs moisture in the air due to the increase in surface area of the charcoal structure from the formation of pores as cellulose and hemicellulose thermally degrades during devolatilization, allowing for more space for moisture to condense and adhere to the charcoal structure [9]. The increasing trend shows that there seems to be a limit being approached to the amount of moisture charcoals could absorb through further thermal degradation, and that limit is the amount of moisture the charcoal can absorb based on the available space it has in the structure to hold moisture.

For the results of the two-way ANOVA, the p-value of the interaction effect is 0.3063, which is greater than the acceptance value or significance value of 0.05. This shows that there is no interaction effect on the moisture content between the wood species and residence time; this is supported by the graph in Figure 4 where the lines of Mahogany and Ipil-Ipil do not intersect. For the p-value of Wood Species factor, it is 0.0193 which is less than 0.05; this shows that wood species has a significant effect on the moisture content of the charcoal samples. This is supported by the graph in Figure 4 where Mahogany has a greater moisture content in all residence times compared to Ipil-Ipil. For the Residence Time factor, the p-value is 0.0285 which is less than 0.05; this means that residence time has a significant effect on the moisture content of the charcoal samples, supported by the graph in Figure 4 where for both Mahogany and Ipil-Ipil, moisture content increased with longer residence time. Therefore, wood species and residence time have no significant interaction effect on the moisture content, but wood species and residence time have a significant effect on the moisture content.

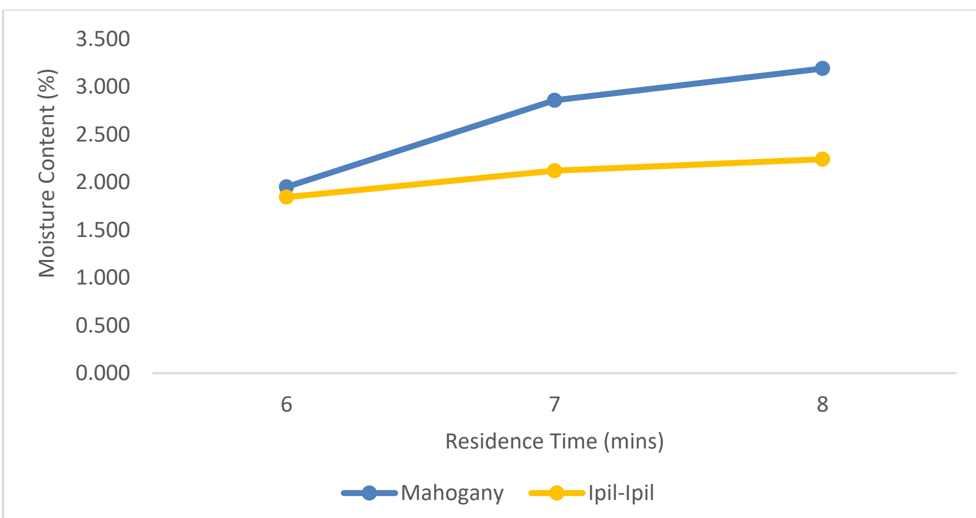

Fig. 4 Estimated Marginal Means of Moisture Content (%) versus Residence Time for Each Wood Species

C. Volatile Matter

As seen in Figure 5, the volatile matter content of the Mahogany charcoal samples has a negative relation with residence time. This trend clearly follows the stages of wood combustion wherein the longer the residence time, the further the wood gets devolatilized, lessening the volatile matter content of the wood. On the other hand, Ipil-Ipil charcoal samples have shown to have no trend; the values of the average volatile matter content fluctuated. Ipil-Ipil shows a contradiction to the expected trend because at a residence time of 8 minutes, it showed a volatile matter content greater than that of the previous two residence times. A reason for this could be that most of the flames were not consistently in contact with the Ipil-Ipil wood samples under a residence time of 8 minutes in the combustion chamber which slowed down the thermal decomposition of the Ipil-Ipil wood samples.

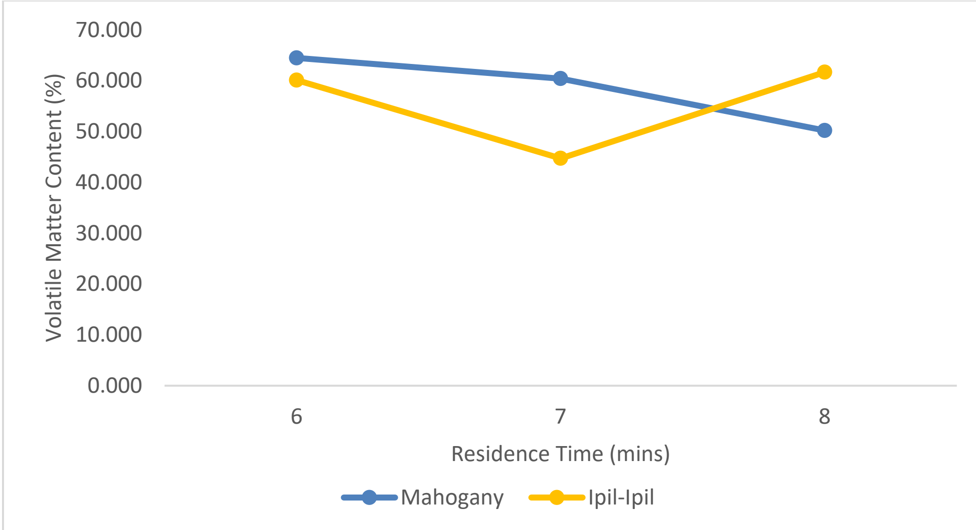

Fig. 5 Estimated Marginal Means of Volatile Matter Content (%) versus Residence Time for Each Wood Species

For the results of the two-way ANOVA, the p-value of the interaction effect is 0.0622 which is greater than the acceptance value or significance value of 0.05; this shows that there is no interaction effect on the volatile matter content between the wood species and residence time. The p-value is close to the acceptance value due to the odd behavior recorded for Ipil-Ipil under a residence time of 8 minutes which showed that instead of decreasing, it increased. For the wood species, it shows that the p-value is 0.507 which is greater than the significance value of 0.05; this means that wood species has no significant effect on the volatile matter content of the charcoal produced. Similarly, residence time has no significant effect since its p-value is 0.199 which is greater than the significance value of 0.05. Probable causes to no significant interaction effect and main effects were due to the great variance in volatile matter content between the trials of Ipil-Ipil at a residence time of 8 minutes. Though residence time has no significant effect in this study, it still established a trend that volatile matter content decreases with longer residence time, but the changes are not drastic between 6 minutes and 8 minutes; the residence times chosen were 6, 7, and 8 minutes since formation of ash at the surface of the samples were seen for residence times greater than 8 minutes. As pointed out by the studies of Sun et al., Wu et al., and Peng et al., temperature has a greater effect on the yield and proximate analysis results of charcoal [10]–[12]. Therefore, there was no significant interaction effect on the volatile matter content between wood species and residence time; wood species had no significant main effect on the volatile matter content; and residence time had no significant main effect on volatile matter content.

D. Ash

As seen in Figure 6, Mahogany charcoals produced showed that ash content increased as residence time increased. On the other hand, the average ash content of Ipil-Ipil fluctuated. The trend of Mahogany supports the study of Sun et al., Wu et al., and Peng et al., wherein ash content increases with pyrolysis temperature and residence time since it does not undergo combustion 45-47. Meanwhile, Ipil-Ipil supports the research of Sun et al., wherein residence time had little effect on the ash content of the charcoal 45.

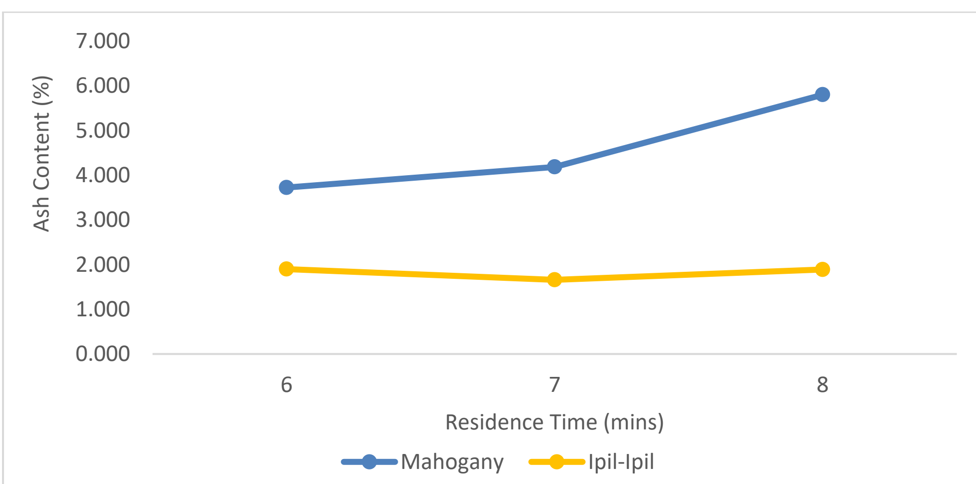

Fig. 6 Estimated Marginal Means of Ash Content (%) versus Residence Time for Each Wood Species

For the results of the two-way ANOVA, the p-value of the interaction effect is 0.595 which is greater than the acceptance value or significance value of 0.05. This shows that there is no interaction effect on the ash content between the wood species and residence time. For the wood species, it shows that the p-value is 0.006 which is less than the significance value of 0.05; this means that wood species has a significant effect on the ash content of the charcoals produced. On the other hand, residence time has no significant effect since its p-value is 0.554 which is greater than the significance value of 0.05. Therefore, there was significant interaction effect on the ash content between wood species and residence time, while wood species had no significant main effect on the ash content, and residence time had no significant main effect on ash content.

E. Fixed Carbon

As seen in Figure 7, fixed carbon content for Mahogany increases; this supports the trend of the studies of Sun *et al.,* Wu *et al.,* and Peng *et al.,* wherein increased pyrolysis temperature and longer residence time increase the fixed carbon content due to the evaporation of moisture and evolution of volatile matter content during pyrolysis [10]–[12]. On the other hand, Ipil-Ipil has shown to have extreme fluctuation on average fixed carbon content as residence time increased. This trend and the great variance between the trials for Ipil – Ipil charcoal at a residence time of 8 minutes relate to the errors that occurred during the experimentation at a residence time of 8 minutes for Ipil-Ipil.

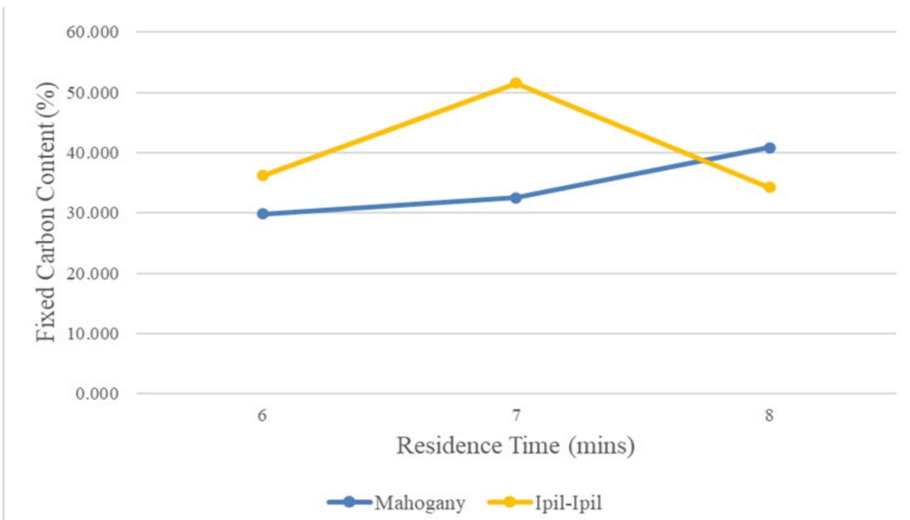

Fig. 7 Estimated Marginal Means of Fixed Carbon Content (%) versus Residence Time for Each Wood Species

For the results of the two-way ANOVA, the p-value of the interaction effect is 0.082 which is greater than the acceptance value or significance value of 0.05; this shows that there is no significant interaction effect on the fixed carbon content between the wood species and residence time. For the wood species, it shows that the p-value is 0.163 which is greater than the significance value of 0.05; this means that wood species has no significant effect on the fixed carbon content of the charcoals produced. Similarly, residence time has no significant effect since its p-value is 0.252 which is greater than the significance value of 0.05. The reason for the no significant interaction effect and main effects may be due to the great variance among the values of fixed carbon content for Ipil-Ipil at a residence time of 8 minutes. Therefore, there was no significant interaction effect on the fixed carbon content between wood species and residence time, wood species had no significant main effect on the fixed carbon content, and residence time had no significant main effect on the fixed carbon content.

F. Gross Calorific Value

As seen in Figure 8, the average gross calorific value of Mahogany showed significant fluctuation with increase in residence time. The proximate analysis results of the Mahogany charcoals produced show that the moisture content, ash content, and fixed carbon content increased with longer residence time while volatile matter content decreased with longer residence time. The proximate analysis results matched with the decreasing trend of charcoal yield for Mahogany as residence time increased. The general trend for gross calorific value or higher heating value of charcoal is that it increases with higher pyrolysis temperature and fixed carbon content, and with lower moisture, ash, and volatile matter content [10]–[12].

The average gross calorific value of Mahogany at a residence time of 7 minutes differed from the general trend as it decreased in gross calorific value when its fixed carbon content was higher, and its volatile matter was lesser compared to that at a residence time of 6 minutes. It may be inferred that the increase in moisture and ash content at a residence time of 7 minutes had contributed more to the decrease of the gross calorific value of the Mahogany charcoal samples at a residence time of 7 minutes compared to the decrease in volatile matter and increase in fixed carbon content.

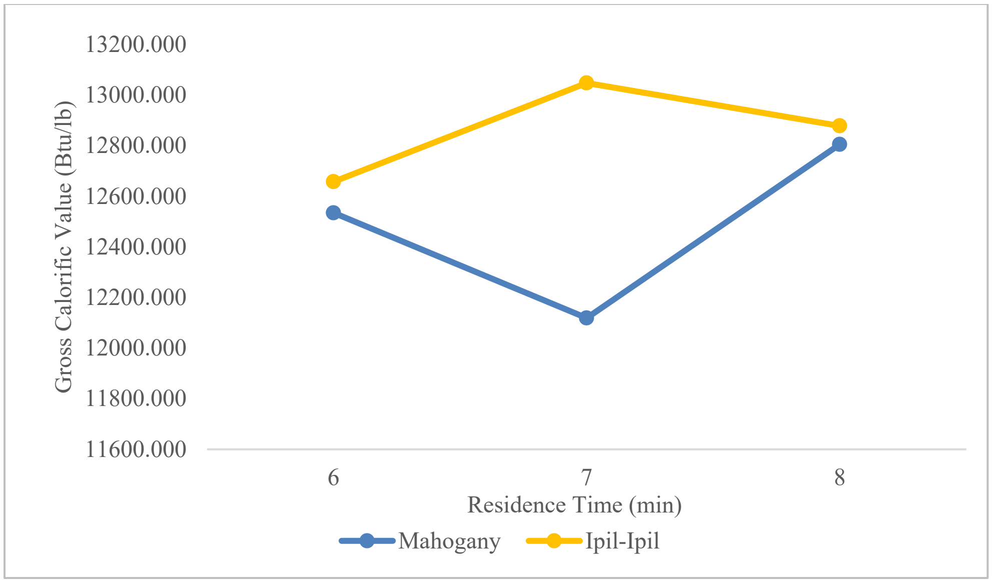

Fig. 8 Estimated Marginal Means of Gross Calorific Value (Btu/lb) versus Residence Time for Each Wood Species

On the other hand, Ipil-Ipil charcoals fluctuate less in the average calorific value, compared to the Mahogany charcoals, as residence time increased. For the proximate analysis results of Ipil-Ipil, the moisture content increased as residence time increased; volatile matter content decreased to an average of 44.70% at a residence time of 7 minutes and then increased to an average of 61.67% at a residence time of 8 minutes; ash content hardly varied as residence time increased; and fixed carbon increased to an average of 51.52% and then decreased to an average of 34.203%. In terms of yield, the average charcoal yield decreased to 24.06% at a residence time of 7 minutes and then increased to 27.69% at a residence time of 8 minutes. The charcoal yield trend explains why volatile matter content increased and fixed carbon content decreased from a residence time of 7 minutes to 8 minutes, the explanation being that at residence time of 8 minutes there was less thermal degradation that occurred due to the errors mentioned. This also explains why the gross calorific value decreased from a residence time of 7 minutes to 8 minutes due to increase in volatile matter and decrease in fixed carbon content.

For the results of the two-way ANOVA, the p-value of the interaction effect is 0.104 which is greater than the acceptance value or significance value of 0.05; this shows that there is no significant interaction effect on the gross calorific value between the wood species and residence time. For the wood species, it shows that the p-value is 0.045 which is lesser than the significance value of 0.05; this means that wood species has a significant effect on the gross calorific value of the charcoals produced. This is evident in Figure 8 where the average values of gross calorific value of Mahogany and Ipil-Ipil differ from each other and that at a residence time of 7 minutes, Mahogany increased in gross calorific value while Ipil-Ipil decreased. On the other hand, residence time has no significant effect since its p-value is 0.392 which is greater than the significance value of 0.05. Therefore, there was significant interaction effect on the gross calorific value between wood species and residence time, while wood species had no significant main effect on the fixed carbon content, and residence time had no significant main effect on the fixed carbon content.

IV. CONCLUSION

Proximate analysis results showed that moisture content increased with longer residence time due to further thermal degradation of the wood structure during the combustion of wood; this resulted to increase in hygroscopicity, allowing the charcoals produced to absorb more moisture from air. From the two-way ANOVA, it was shown that wood species had a significant effect on the moisture content as Mahogany charcoals had greater moisture content than Ipil-Ipil charcoals for all residence times. Residence time also had a significant effect on the moisture content as moisture content increased with longer residence time. For volatile matter of both Mahogany and Ipil-Ipil charcoals, it decreased with longer residence time, except for Ipil-Ipil at a residence time of 8 minutes. Due to the errors, it has resulted in no interaction and main effects for volatile matter content. For ash content, Mahogany charcoals showed an increase in ash content with longer residence time while ash content did not change significantly for Ipil-Ipil charcoals. The two-way ANOVA showed that there was an interaction effect between wood species and residence time on the ash content. For fixed carbon content, it increased as residence time increased for both Mahogany and Ipil-Ipil charcoals, except again for Ipil-Ipil charcoal produced at a residence time of 8 minutes. Due to the errors, it has resulted in no interaction and main effects on the fixed carbon content. Gross calorific value for Mahogany charcoals decreased at a residence time of 7 minutes due to the increase in moisture and ash content but then increased at a residence time of 8 minutes due to further increase in fixed carbon content and decrease in volatile matter content. On the other hand, for Ipil-Ipil charcoals, the gross calorific value increased at a residence time of 7 minutes but then decreased at a residence time of 8 minutes due to errors. Ipil-Ipil charcoals produced had greater gross calorific value than Mahogany ones; this may be attributed to Ipil-Ipil wood having a greater gross calorific value than Mahogany wood.

ACKNOWLEDGEMENT

First, we would like to thank our families and friends, and the faculty and staff of the Department of Mechanical and Manufacturing Engineering of the University of San Carlos for their support. We would also like to thank the Department of Science and Technology of the Republic of the Philippines for the financial support. Most of all, we would like to thank the Almighty Father for His guidance.

REFERENCES

[1] A. Kahan, “EIA projects nearly 50% increase in world energy usage by 2050, led by growth in Asia - Today in Energy - U.S. Energy Information Administration (EIA),” Sep. 24, 2019. [Online]. Available: https://www.eia.gov/todayinenergy/detail.php?id=41433 (accessed Apr. 28, 2021).

[2] “Southeast Asia Energy Outlook 2019,” Oct. 2019. [Online]. Available: https://www.iea.org/reports/southeast-asia-energy-outlook-2019 (accessed Apr. 28, 2021).

[3] “Biomass Industry in the Philippines - ASEAN Business News,” May 19, 2017. [Online]. Available: https://www.aseanbriefing.com/news/biomass-industry-philippines/ (accessed Apr. 28, 2021).

[4] D. Boucher, P. Elias, K. Lininger, C. May-Tobin, S. Roquemore, and E. Saxon, *The Root of the Problem: What’s Driving Tropical Deforestation Today?* Cambridge: Union of Concerned Scientists, 2011.

[5] J. D. Keita, “Wood or Charcoal - Which is Better?,” in *International Journal of Forestry and Forest Industries*, Vol. 39, 1987.

[6] I. Coxhead and S. Jayasuriya, “The Philippine Economy: Development, Policies, and Challenges,” in *The Philippine Economy: Development, Policies, and Challenges*, A. M. Balisacan and H. Hill, Eds. New York: Oxford University Press Inc., pp. 381-417, 2003.

[7] E. M. Remedio, “An Analysis of Sustainable Fuelwood and Charcoal Production Systems in The Philippines: A Case Study,” in *Criteria and Indicators for Sustainable Woodfuels: Case Studies from Brazil, Guyana, Nepal, Philippines and Tanzania*, S. Rose, E. Remedio, and M. A. Trossero, Eds. Fodd and Agricultural Organization, pp. 133-194, 2009.

[8] *Simple Technologies for Charcoal Making*, vol. 41. Rome: Food and Agricultural Organization, 1987.

[9] A. F. D. Júnior, L. P. Pirola, S. Takeshita, A. Q. Lana, J. O. Brito, and A. M. de Andrade, “Higroscopicidade do carvão vegetal produzido em diferentes temperaturas,” *Cerne*, Vol. 22, No. 4, pp. 423-430, 2016, DOI: 10.1590/01047760201622032175.

[10] J. Sun, F. He, Y. Pan, and Z. Zhang, “Effects of pyrolysis temperature and residence time on physicochemical properties of different biochar types,” *Acta Agric. Scand. Sect. B Soil Plant Sci.*, Vol. 67, No. 1, pp. 12-22, 2017, DOI: 10.1080/09064710.2016.1214745.

[11] W. Wu *et al.*, “Chemical characterization of rice straw-derived biochar for soil amendment,” *Biomass and Bioenergy*, Vol. 47, No. January 2020, pp. 268–276, 2012, DOI: 10.1016/j.biombioe.2012.09.034.

[12] X. Peng, L. L. Ye, C. H. Wang, H. Zhou, and B. Sun, “Temperature- and duration-dependent rice straw-derived biochar: Characteristics and its effects on soil properties of an Ultisol in southern China,” *Soil Tillage Res.*, Vol. 112, No. 2, pp. 159-166, 2011, DOI: 10.1016/j.still. 2011.01.002.

[13] 2016 Philippine Power Situation Report, 2016. [Online]. Available: https://www.doe.gov.ph/electric-power/2016-philippine-power-situation-report?ckattempt=3 (accessed Apr. 28, 2021).