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Coconut Shell Feedstock Based Top Lit Updraft Gasifier for Biochar and Heat Cogeneration

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Coconut Shell Feedstock Based Top Lit Updraft Gasifier for Biochar and Heat Cogeneration

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Abstract. Biomass is not new in the field of renewable energy and has been in use for decades now. Coconut shell is one of those. It comes from the coconut tree which is a member of the palm tree family or Arecaceae. It is also used for the bio charcoal. Biochar is a carbonaceous solid that is done through the process of pyrolysis. It is a process in which the biomass feedstock is heated with little to no air in a closed container. It can be used as a soil nutrient amendment and can also be processed into briquettes for fuel. The researchers designed a coconut shell-based biochar feedstock in which the heat that is being generated during the process of pyrolysis is extracted and used for cooking means. A top-lit updraft design has been considered for the project. The components of the project such as the outer chamber which houses the whole design, the combustion chamber with slanted row holes which the vaporization process occurs and the blower fan for the vaporization period to aide with the continuous burning and to eliminate the emission of smoke. The gathered data from the experiments were analyzed and it shows that turning the coconut shells into biochar can be done in less than 2 hours with highest inside temperature of $352.32℃$ at an air flow rate of 0.013 m^3/s. The heat it produced is suitable for simple household stove usage without the emission of harmful smoke with the aid of the blower fan during the whole process. The produced coconut shell bio charcoal was later sent to Calaca Power Complex coal testing laboratories for determination of the biochar's characteristics such as its calorific value and volatile matter. The laboratory results reveal that the produced bio charcoal has a calorific value of 30.865 MJ/Kg.

1. Introduction

Biomass is an available renewable energy source that has a very high potential and is expected to play a significant role soon [1]. Studies show that biomass can be converted into a carbonaceous solid - called biochar - through the process of pyrolysis; a process of heating the biomass feedstock with little to no supply of air inside a closed container. When the process of conversion is properly done, biochar can be used as a fuel source whose potentials are comparable to high rank coals [2].Three main products are formed under pyrolysis namely Bio-oil, Biochar, and Synthetic gas [3]. The composition of the output of the process all depends on what mode of pyrolysis is done. Modes such as slow to fast pyrolysis can be chosen depending by the makers desired output composition.

The process of converting biomass into biochar depends widely on its properties, characteristics, and composition. The two (2) main types of biomass include: 1) woody biomass; which includes residues from trees and forest, and 2) non-woody biomass; including agricultural crops and residues, animal wastes, urban and industrial solid wastes [4]. Parameters such as pressure, moisture content,

chemistry of pyrolysis, feedstock type, temperature, equivalence ratio, and design may all affect the possible yield of biochar significantly. It is said that the moisture content of biomass feedstock is one of the very important parameters affecting the performance of the pyrolyzer and conversion efficiency. The amount of moisture content leads to heat loss. This is due to the evaporation of water and superheating of the vapor [5]. Through the years, people had seen the importance and the advantages of biochar and worked on different technologies which helps on the biomass-to-biochar conversion process. Several designs of reactors can be seen across different sources. These designs are usually classified as either autothermal or allothermal reactors. The difference between the two are primarily on the scale of application. Allothermal reactors require heat of reaction from an external source into the reactor which may be biomass or non-renewable fuels. These types of reactors have not found wide use for small production because of their difficulty of operation and technology required is complicated; let alone the large investment needed to implement the technology. On the other hand, autothermal reactors provide necessary heat of reaction by means partial oxidation of biomass within the reactor. These types of reactors are widely used in small scale applications. Autothermal reactor designs such as top lit updraft pyrolizer (TLUD) are easily adaptable and more operator friendly with its simplicity compared to the latter type of reactor. Though with TLUD, quality of biochar may vary with different parameters such as pressure, moisture content, chemistry of pyrolyzer, feedstock type, temperatures and equivalence ratio may all affect the possible yield of biochar significantly. Proper study of these parameters is required to find the perfect combination to make the highest quality biochar possible with the resources given [5].
Biomass cooking stove TLUD design has been an active field for decades now, and it continues to do so to aim progress towards clean and more efficient cook stove. Still in the Philippines, it is an ongoing challenge to develop a high performing, high quality, and affordable stoves that could be used by people in everyday use. Having a high abundance of feedstock, specifically coconut, the aim to utilize coconut wastes and turn it to something useful has been subject of studies. With the literatures available, study was conducted to improve stove design such as how co-generation of biochar and utilizing of heat during the process can be used and applied to stoves to make an environmentally sustainable stove that can be used by the public with ease.

2. Materials and methods

Starting with preliminary data gathering, all available information concerning the prototype were gathered. This includes how it works, issues, different designs, applications, significance and selection for the necessary feedstock was done. Feedstock may vary from rice husk, corn comb, coconut shells, and other agricultural wastes. For this study, dried coconut shells used as the main feedstock whereas dried coconut shell husk to be used as starters for fire ignition as shown in Figure 1. Further research was done to find the available materials for construction. Selection of materials can be very vital as to the strength and performance of the design. Careful checking for properties such as thermals expansion, thermal conductivity, and other properties was then done during this process.

2.1. Material selection

The researchers used locally available materials for fabricating the stove. They used the material selection matrix used by [6] with values of the properties were obtained from [7]. Based from the matrix, stainless steel 304 was chosen for the combustion chamber material whereas aluminum alloy 2024 was used for its outer frame. The researchers instead designed the prototype to be taller in order to accommodate additional coconut shells that would benefit to the yield of the bio charcoal. The researchers designed slanting row holes inclined in 45 degrees circling the lower part and top part of the combustion chamber. This is will give the same effect inside the combustion area due to cylindrical shape of the prototype. Same economic reason in choosing mild steel instead of Stainless Steel 304 as the mild steel will also serve the purpose and be better with its lighter characteristics. Addition of three 50-mm tri-feet for the combustion chamber to not have a direct surface contact to the combustion chamber. Insulation such as fiber glass to minimize the transmitted heat during the process.

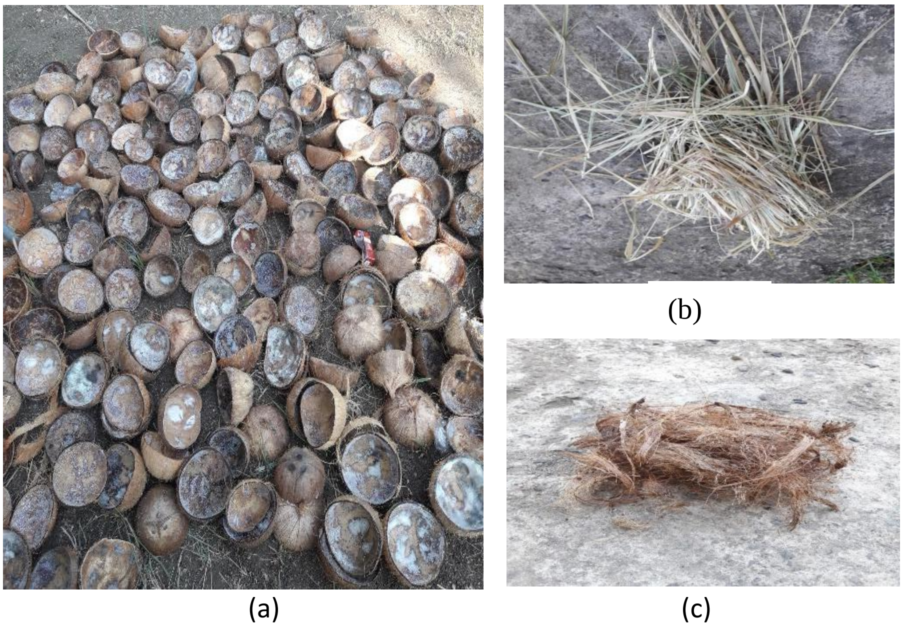

Figure 1. Actual photograph feedstock and firestarter materials. a. Dried coconut shells. b. Dried coconut shell husk to be used as starter for fire ignition. c. Dried grass used for fire ignition

2.2. Design

Based from these material selection matrices, the stove has been fabricated and the final design of the TLUD stove is seen in Figure 2 showing its exterior view and interior view where the slanted row holes were placed. The combustion chamber is the focus of the proposed design. It is the one in which is subjected to extreme heat. It is responsible for maintaining the heat inside as much as possible. This is the component of the stove where combustion zone where volatiles burn [8]. The combustion chamber is about 300mm in diameter. Burning the biomass in one chamber and housing the biomass to be charred in the annular portion of an outer chamber with diameter of 380 mm. Heat is transferred from the burning fuel on the inner chamber to the material to be charred in the outer chamber [9].
*Fixed diameter of 380 mm
Computation for Air Needed for Combustion
This is very important in determining the size of the fan or of the blower needed for the reactor in gasifying the fuel [9].
By using the formula of [10] for mass of air needed for mass of fuel,

$$m_a = \frac{100}{23}(2.67C + 8H_2 + S - O_2)\ Kg \quad (1)$$

Where:

C = 48.36%
H_2 = 0.14%
S = 0.08%
O_2 = 44.64%
(Element weight percentage values)

$$m_a = \frac{100}{23}(2.67(0.4836) + 8(0.0014) + 0.0008 - 0.4464)$$

$\mathbf{m_a = 3.725}$ **Kg of air / Kg of fuel**

Considering the 30% of total air requirement for incomplete combustion and gasification [10].

$$\mathbf{m_{a\text{ - coconut shell}}} = \frac{30}{100} \times 3.725 = \mathbf{1.118\ Kg\ of\ air\ /\ Kg\ of\ coconut\text{-}shell} \quad (2)$$

The mass of air needed per mass of feedstock is described in (2).

(a) (b)

Figure 2. The TLUD gasifier a. Exterior view and b. Interior view

The fuel will be placed on the bottom plate inside the combustion chamber. The air being pushed by the 12V DC fan into the inner walls of the frame and into the grid of the combustion chamber will create a whirl motion. An even greater performance improvement is achieved by forced ventilation via an electric fan powered by a battery [11]. The cyclone modification creates a fluid-dynamic pattern in which the flame spirals upward in a helical motion, which is conducive to better mixing between fuel and oxidizer, longer residence time in the combustion chamber, more uniform burning, and therefore a reduction in pollutant emissions [12].

3. Prototype testing

The researchers aim to evaluate the performance of the biochar cook-stove prototype; that is, to assess its effectiveness, efficiency, and feasibility. Testing and Design Evaluation via Protocols. The following test protocols from [13] that would be used to evaluate the performance of the stove are Water Boiling Test, Controlled Cooking test, and Kitchen Performance Test. These tests were selected because of its simplicity and reliability. In preparation for operating the biochar cook-stove**,** safety procedures must be conducted. First, place the stove away from all potential combustible material that can ignite accidentally during the operation. Make sure, proper safety precautions in mind and a fire extinguisher is available nearby. Check if the top-lit updraft coconut shell-based biochar stove is complete and the fan is installed well. Place the coconut shells inside the combustion chamber in a circular stack on its wall. This will create opening in the middle that will give space for the desired starter. Place desired starter on the opening in the middle of the stack of coconut shells in the combustion chamber. A hand full of desired starter is enough to start the combustion inside the combustion chamber. Turn on the fan using the control box and ignite the starter. Wait for 5 min to let the fire stabilized to avoid varying temperature of fire. As soon as the flame stabilized, cooking can now be done. Add 2-3 coconut shells every 10 min to continue cooking. After done cooking, take off the lid of the stove and remove the combustion chamber. At this time, the combustion chamber will be hot and proper safety equipment must be used such as thermal gloves. Tilt the combustion chamber and place the hot coconut shell inside the combustion. chamber to a confined container. This will stop the combustion by absence of oxygen. Let the extracted coconut shell cool in the confined container for 30 min. Used the produce char for desired application.

During the operation proper, the researchers filled the combustion chamber completely with coconut shells and the fan wasn't installed at first. This is to promote the natural draft of the air flowing through the combustion chamber. With this set-up, the prototype emitted minimal amount of smoke. In the next trials, the researchers filled the combustion chamber, again, from bottom to top. 4.5-5 kgs of dried coconut shells fill the chamber. This time, the fan was installed at a constant speed. The yield was higher during this time but still the prototype emitted smoke. Further trials include varying the air flow rate entering the combustion chamber. The researchers considered filling the chamber with dried coconut shells halfway to the top to assess the problem with smoke coming out of the chamber, acknowledging the concept of supplying proper mix of the air and fuel ratio into the combustion chamber for better combustion.

The procedures in operating the biochar cook-stove, and producing biochar are as follows: For the initial preparations, enough water supply is needed. Also, dried coconut shells as feedstock, and dried leaves as combustible materials should also be prepared. Fan, connected to a 12V DC power supply, and a voltage regulator shall be installed in the prototype as to achieve a varying flowrate supply into the combustion chamber. As for the air flow rate entering the chamber, a specific air flow rate is used per test. The researchers have used $0.013\frac{m^3}{s}$ for slow, $0.023\frac{m^3}{s}$ for medium and $0.032\frac{m^3}{s}$ for high flow rate. The coconut shells are to be placed inside the combustion chamber in such a way that all shells are properly stacked leaving the middle part of the chamber as a place for dried leaves and other elements that are easily combustible as so to ignite fire and start the pyrolysis process. The mass of the coconut shells should be recorded before placing them into the combustion chamber. As said in the procedure above, pyrolysis process starts by setting fire through the combustible elements, say, dried leaves. Pyrolysis starts when the coconut shells already caught fire. Once the previous step is done, the lid of the cookstove is placed atop it as the pyrolysis process is taking place. Here starts the Water Boiling Test which tests the efficiency of the cookstove as shown in Figure 3; water inside a pot – in the case for smaller applications, as indicated in the protocol [14], 3-5L of water is needed. This set-up has initial fuel feed of 3.5kgs, and an air flow rate of $0.013\frac{m^3}{s}$ considering the ratio of the supplied dried coconut shells and the air flow rate improved the working of the cookstove. The test started when the fire was stabilized, and boiling time of water was measured around 6 mins and 42 sec.

Figure 3. Water boiling test

This pot of water, once weigh is recorded, should then subjected atop the cookstove for water boiling. Once the pot with water is placed atop the stove, the starting time should now be recorded as the timer starts. The process is done once the water starts to continuously boil. The pot with water should now be weigh, and the weight of water is recorded. The produced biochar is placed inside sealed metal container as to completely confine it with no air, specifically, oxygen supply. This is to completely stop it from further combusting and avoid it from becoming ash.

4. Results and discussion

Figure 4. Bio charcoal produced.

After the utilization of heat by cooking, the charcoal produced can now be harvest as seen in Figure 4. This is done by taking off the lid, pulling out the combustion chamber, and placing the hot charcoal produced in an enclosed container where air can't penetrate. This would allow the stop to the continuous combustion happening and avoid making the produced charcoal into ash. As soon as it cools down, it is now ready for use as depending on the user's desired product. The study focuses solely on bio charcoal coconut shell that is freshly came out of the combustion chamber.
The results showed at Figure 5 that with lower air flow rate, the temperature inside the combustion chamber was higher, and thus, also, the efficiency of the cookstove. Efficiency ranged from 30%-36%. The highest efficiency, 36.51%, was attained at an air flow rate of 0.013 m^3/s, while the lowest efficiency was 30.16% at an air flow rate of 0.023 m^3/s as seen in Figure 5. The highest amount of water evaporated and fuel consumption were recorded both at .013 m^3/s as seen in Figures 6 and 7. The longest time of boil is 14 min at .032 m^3/s as shown in Figure 8.The highest inside temperature of 352.32℃ was met at an air flow rate of 0.013 m^3/s. At that set up, also, the highest efficiency of 36% was attained as shown in Figure 9. The lowest inside temperature, however, was at 309℃ under a higher air flow rate of 0.032 m^3/s.

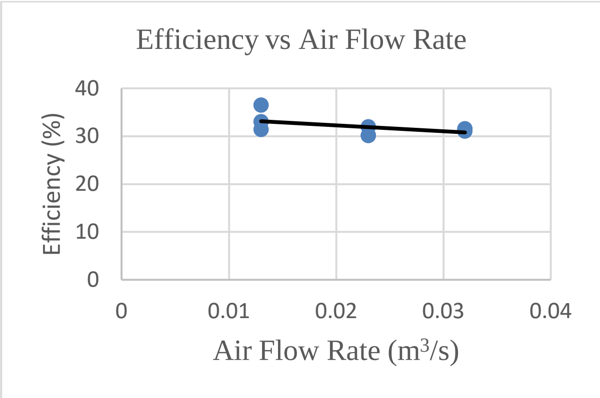

Figure 5. Efficiency and air flow rate.

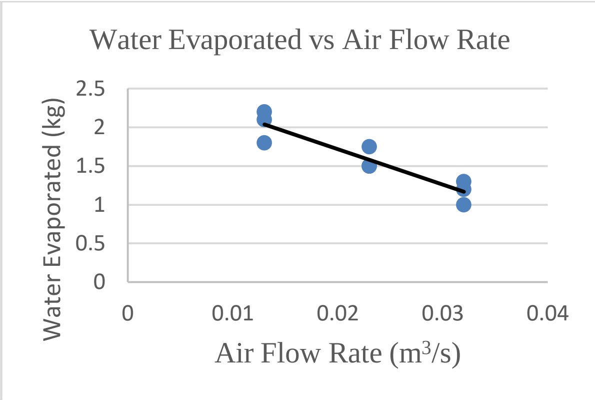

Figure 6. Water evaporated and air flow rate.

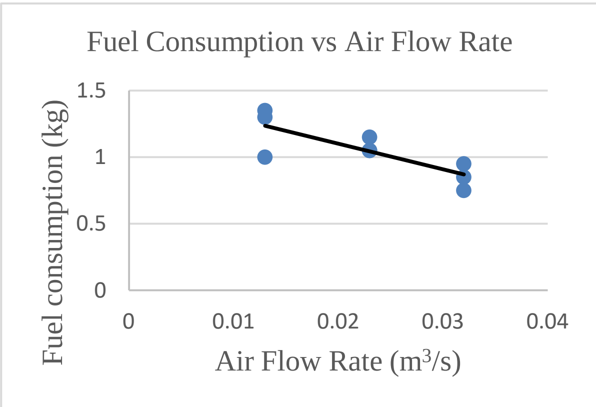

Figure7. Fuel consumption and air flow.

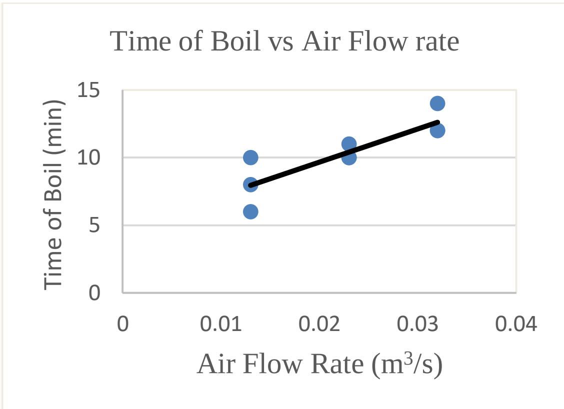

Figure 8. Time of boil and air flow rate.

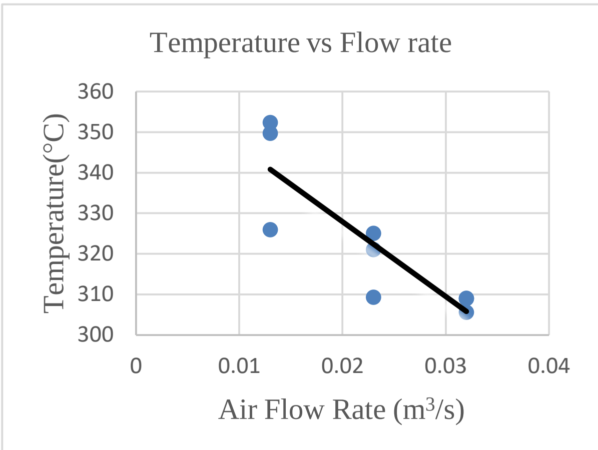

Figure 9. Time of boil and air flow rate

The biochar sample produced was delivered to the Calaca Power Complex – Chemical Operations Department to obtain its proximate analysis. The analysis revealed as shown in Table 1 that the total moisture (%TM), measured as-received, is at 10.05%. At an air-dry loss (%ADL) of 5.24%, the residual moisture (%RM) of the produced biochar is now at 5.08%. As for the volatile combustible matter (%VCM); 9.41% as received, and 9,93% air-dried. The fixed carbon

(%FC) of the biochar produced, as received, is at 77.33% and is at 81.6% air-dried. Only 3.21% amounts to the ash content (%ASH) as received, and 3.39% air-dried. Finally, the calorific value of the biochar produced is at $6991\frac{kcal}{kg}\ or\ 29.250\frac{MJ}{kg}$ as-received, and went to a higher value of $7377\frac{kcal}{kg}\ or\ 30.865\frac{MJ}{kg}$ when air-dried. The sulfur content (%S), also, is as low as 0.19% as-received, and 0.2% air-dried. This calorific value is within the range on the study obtained by [15].

Table 1. Proximate analysis of the coconut shell bio charcoal produced

AIR-DRIED BASIS							AS-RECEIVED BASIS					
%RM	%VCM	%ASH	%FC	CV (kcal/kg)	%ADL	%S	%TM	%VCM	%ASH	%FC	CV (kcal/kg)	%S
5.08	9.93	3.39	81.6	7377	5.24	0.2	10.05	9.41	3.21	77.33	6991	0.19

5. Conclusion

The coconut shell-based biochar cook stove was designed and fabricated. Dried coconut shells were used as fuel. The performance and working characteristics of the cookstove were also evaluated. The testing phase was conducted not only to evaluate the performance of the cookstove but also to assess on how to improve it. Specifically, the effect of the amount of air flow rate on the different parameters considered in the performance of the cookstove, more importantly, its efficiency, was studied and analyzed. The stove efficiency stood at 36%.

The proximate analysis of the coconut shell bio charcoal produced was also obtained for results evaluation. These results came out to be good since, as preferred, the moisture content of the biochar produced was low at 5.08%, the volatile matter decreased at a very high amount which is desirable since lower volatile matter accounts to a better charcoal, the ash content was also low at 3.39%, the fixed carbon content was admirably high at 81.6%. All these accounting to a higher calorific value of charcoal at $30.865\frac{MJ}{kg}$ as compared to raw dried coconut shells, which are only at $14-19\frac{MJ}{kg}$.

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References

[1] Ali, I., Bahaitham, H., & Naebulharam, R. (2017). A comprehensive kinetics study of coconut shell waste pyrolysis.*Bioresource Technology, 235,1–11.* doi:10.1016/j.biortech.2017.03.089

[2] Jafri, N., Wong, W. Y., Doshi, V., Yoon, L. W., & Cheah, K. H. (2018). A review on production and characterization of biochars for application in direct carbon fuel cells. *Process Safety and Environmental Protection, 118, 152–166.* doi:10.1016/j.psep.2018.06.036

[3] Laird, D. A., Brown, R. C., Amonette, J. E., & Lehmann, J. (2009). Review of the pyrolysis platform for coproducing bio-oil and biochar. *Biofuels, Bioproducts and Biorefining, 3(5), 547–562.* doi:10.1002/bbb.169

[4] Grover, S. ,Kathuria, R. S. & Kaur, M. Energy Values and Technologies for Non woody Biomass: as a clean source of Energy. *IOSR Journal of Electrical and Electronics Engineering (IOSRJEEE*) ISSN : 2278-1676 Volume 1, Issue 2 (May-June 2012), pp 10-14

[5] Nsamba, H. , Hale, S. , Cornelissen, G. and Bachmann, R. (2015) Sustainable Technologies for

Small-Scale Biochar Production—A Review. *Journal of Sustainable Bioenergy Systems,* **5**, 10-31. doi: 10.4236/jsbs.2015.51002

[6] Farag, M. M. (2015). Quantitative Methods of Materials Selection. *Mechanical Engineers' Handbook, 1–22.* doi:10.1002/9781118985960.meh115

[7] Callister W. (2017) Materials Science and Engineering an Introduction.7th Ed. NewYork, USA: John Wiley and Sons; pp A3- A36

[8] Deng, L., D. Torres-Rojas, M. Burford, T. Whitlow, J. Lehmann, and E. Fisher. 2018. "Fuel Sensitivity of Biomass." *Applied Energy 215: 13–20.*

[9] Swaminathan, R. and Amupolo, H. (2014) Design and Testing of Biochar Stoves. *Open Journal of Ap-plied Sciences, 4, 567-572.* http://dx.doi.org/10.4236/ojapps.2014.414056

[10] Preetha D.R. and Kamaraj, S. (2017). Design and Development of Updraft Gasifier Using Solid Biomass. *Int.J.Curr.Microbiol.App.Sci. 6(4):182-189. doi* https://doi.org/10.20546/ijcmas.2017.604.021

[11] Jetter, J. J., and Kariher, P. (2009). Solid-fuel household cook stoves: *Characterization of performance and emissions. Biomass and Bioenergy, 33(2), 294–305.* doi:10.1016/j.biombioe.2008.05.014

[12] Gilardoni, S., Massoli, P., Paglione, M., Giulianelli, L., Carbone, C., Rinaldi, M., … Facchini, M. C. (2016). Direct observation of aqueous secondary organic aerosol from biomass-burning emissions. *Proceedings of the National Academy of Sciences, 113(36), 10013–10018.* doi:10.1073/pnas.1602212113

[13] Harmonized Laboratory Test Protocols. (2018) Retrieved from https://www.cleancookingalliance.org/technology-and-fuels/testing/protocols.html

[14] Global Alliance for Clean Cookstoves Uganda Market Assessment International Mapping.(2012) Retrieve from https://www.cleancookingalliance.org/binary-data/RESOURCE/file/000/000/178-1.pdf

[15] Noor, M., Shariff, A., Abdullah, N. and Aziz, N. S.M. , Temperature effect on biochar properties from slow pyrolysis of coconut flesh waste. *Malaysian Journal of Fundamental and Applied Sciences Vol. 15, No. 2 (2019) 153-158*