INVESTIGATING PERFORMANCE OF VERTICAL CARBONIZING KILN FOR BRIQUETTE PRODUCTION

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ABSTRACT

Carbonization experiments of rice husk were carried in pilot cylindrical fluidized bed carbonizing kiln using nitrogen gas as fluidization medium.

Husk was collected from rice miller, Amhara Region Wereta Town, Ethiopia and screened by standard sieves. To initate and supply the necessary heat, controlled amount of air is supplied from compressor.

Gate valve and air flow meter was installed for regulating and measuring the amount of air.K-type thermocouples and pyrometer were used to monitor progress of bed and external drum temperature distribution. Kiln performance was investigated via studying the effects of air flow rate, air contact time and particle size.

The phycochemical properties of raw material and its char were determined by proximate analysis. The results obtained demonistrate that air flow rate, air contact time and particle size have significant effect not on conversion efficiency of kiln and char composition but it affects both carbonization time and temperature distribution of kiln.

Generally, char yield varies from 24.87 to 32.49%. Furthermore, lower air flow rate, shorter air contact time and higher particle size is suitable to achiev maximum char yield with 48.63% fixed carbon. Besides, char yield were improved from 18 to 27% to the range of 24.87 to 32.49%.

Keywords - Carbonization, Rice Husk, Kiln Performance, Char Yield, Fluidization.

INTRODUCTION

Nowadays, the exploitation of renewable energy is becoming a focus area of research with main drivers being increasing price of fossil fuels and shortage of its reserve, climate change and environmental safety. Apart from this, the well accustomed news of many countries which are the result of environmental changes caused by CO_2 emissions; damages thousands live are continuing to be the main signs for the need to utilize other alternative energy sources.

Among the alternative energy sources, biomass energy takes the main role in the attempts of substituting the conventional fossil fuels, since it is renewable as well as CO_2 neutral [1]. Furthermore, it has an additional advantage of being biodegradable and great potential to continuously supply the current and future energy demands.

Globally, about half of the population uses traditional biomass energy [2]. According to the UNDP report [3] biomass provides 14% of the world's primary energy and 30-90% of the primary energy supply in the developing world. Nearly 70-90% of the primary energy supply in Africa is derived from biomass sources. In Ethiopia, it represents about 94% of the total energy consumption and 89% of which is consumed by the household sector in the form of fire wood and charcoal [3].

Daniel M. Kammen and Debra J. Lew et.al [2] reported a value of 24 million tons of charcoal was consumed worldwide in 1992. According to the authors [2] developing countries account for nearly all of this consumption, and Africa alone consumes about half of the world's charcoal production. The American Chemical Society [4] reported a worldwide value of 26 million tons in 1995.

To produce this charcoal a wide range of technologies are available. These technologies commonly employ either burning part of the feedstock loaded into the reactor or heating the reactor using external heat source or by gas recirculation in order to initiate the pyrolysis reaction of the feedstock. Another common to all the technology is that, it operates at nearly atmospheric pressure and use wood as a feedstock [4, 5].

Most of this charcoal is being produced by inefficient traditional mound or pit kilns and the technology is still widely used in many countries [3, 6]. Those traditional kilns have a conversion efficiency of 10 to 15% in not less than three week carbonization time [3, 7]. For example, traditional kilns in Madagascar and Rwanda realize efficiencies of only 8 to 9%, while elsewhere; efficiencies in the range of 8 to 36% [4]. Other kiln technologies such as the Missouri kiln which has a capacity of 180m^3 provide a charcoal yield in the range of 20 to 30% in a three week operation cycle was reported [4, 5]. The cylindrical metal kiln with nominal size of 2m^3 has a capacity to accommodate 150kg and offers a yield which varies between 20 to 30% with carbonization cycle of ten to twelve hours [7].

The low conversion efficiency of those kiln coupled with the dominating traditional energy utilization is becoming a critical challenge of deforestation which in turn contribute to the global warming. Due to this fact there is debate on the production of charcoal from wood with respect to environmental performance [3, 4]. One viable option to minimize the debate could be carbonization of agricultural residues and intensify the energy content through mechanical press. In that case production of bio- briquette from agricultural residues such as rice husks is becoming a primary candidate. Considering rice husks only, which makes up about 20% of the rice by weight, rice millers can generate more than 100 million tons of rice husks worldwide and nowadays almost 70% of the rice husks are not commercially used [8]. According to the unpublished field report of GIZ-ECO *Amhara*, dated on March 18/2011, in Ethiopia, in both *Fogera Wereda* and *Wereta* Town about 16,517 hectares of land were cultivated by rice with average yield of 65 quintal per hectare. Thus, it can generate more than twenty thousand tons of rice husks each year. Considering this potential sources and other solid waste biomass, GIZ-ECO and DLWCRC (a private institution) are now engaged in conversion of these resources to bio-briquettes using manually operated cylindrical carbonizing kiln. However, the kiln employed has low conversion efficiency in the rage of 18 to 27% and takes very long carbonization time of four to six days. Moreover the kiln has encountered the presence of un-carbonized husk and high amount of ash residues due to uncontrolled carbonization process. Thus, the present study aims to investigate the performance of a vertical cylindrical carbonizing kiln for producing a carbonaceous char from rice husk through fluidization process under restricted air supply.

MATERIALS AND METHODS

Rice husk samples as a main raw material for carbonization experiments were collected from rice miller in *Amhara* Region, *Wereta* Town, Ethiopia. After getting the husk, it was washed, dried and screened by standard sieves to obtain a uniform particle size of 1.59, 2.18 and 2.58 mm. The bulk density of the husk was determined by measuring the mass of the sample contained in a 3dm^3 containers (ELE International) and was found to be the same value of 119kg/m^3. To determine fuel properties, proximate analysis of both the raw rice husk and its carbonaceous char were done by ASTM standards reported by Sanger S.H. et.al [9], K. G. Mansaray and A. E. Ghaly [10], the American chemical society [4] and Wayne E. Moore and Edward Beglinger [11]. In addition, a pilot scale cylindrical carbonized kiln were designed and constructed to facilitate the experiment.

Description of Pilot Scale Cylindrical Metal Carbonized Kiln

A pilot scale cylindrical carbonized kiln was designed and constructed mainly from sheet metal by cut, rolled, welded and assembled together. It was designed and fabricated to suit the existing carbonizing drum of the DLWCRC with certain modifications. Air supply mechanism suitable to operate and handle during the process was introduced in the existing kiln. It consists of five main components, the main carbonizing drum, the base cone, a uniformly perforated aluminum foil, the cover lid/cap and the stand. Each part is temporally joined together by slip fitting and bolt connections so that it can be assembled during testing and disassembled if necessary. This can allow the kiln to move easily from place to place where raw materials are abundantly available. In addition, it provides an advantage for replacing the worn-out components without damaging the whole structure. In general, the pilot kiln were assembled in such a way that first the stand is slipped over the drum from bottom. Next, the uniformly perforated aluminum foil was fitted over the top of the base cone. Then, the base cone and the drum are bolted together by two bolts separated at 180°. Finally, the cover lid is slipped over the drum from top to make the complete pilot scale carbonizing kiln shown in Fig. 2.1. Each part has its own function. The main carbonizing drum where the charring process takes place is made from a 3mm thickness and 1m height sheet metal produced by rolling the sheet metal using a rolling machine with a radius of 15cm and welded the parts together. It has also a gutter/ U-shaped bracket welded around on top of the drum and is filled with water or mud to ensure air tightness during operation.

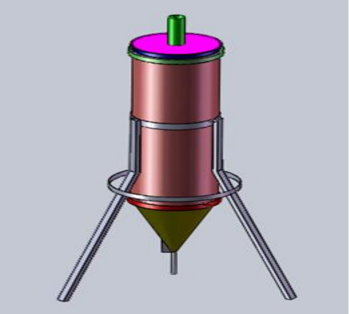


Fig. 2.1: The Pilot Scale Cylindrical Kiln

The base cone is also made from the same material as the drum except its thickness is reduced to 1.5mm. It is used to act as a diffuser so that the incoming air can expand and passed through the perforations over the entire volume of the drum. It has an overlapping lip and a ½ inch pipe each welded over the top and bottom of the base cone respectively. A bed of mud can be placed in the lip to completely seal and avoid the presence of air leakage during carbonization. The lip can also serve to support the uniformly perforated aluminum foil in place.

The uniformly perforated aluminum foil is mainly used to distribute the expanded air coming from the base cone uniformly in to the drum so that the feed stock could be pyrolyzed homogeneously inside the drum. It has perforations drilled by a 1.5mm drill bit over the entire area each separated at 4.5mm distance from its center.

The cap slides up to assist loading and charring of the raw material and moved down to seal the drum after starting ignition. It has also a central hole aligned to the center of the drum and welded with a chimney extension for discharging the exhaust gas.

The stand made from 40 mm x 20 mm x 2 mm RHS, is used to support the whole structure. It was reinforced by a circular ring so as to make strong and enhanced its life span.

Experimental Set-up

The carbonization experiment was carried out using the pilot cylindrical carbonization kiln using nitrogen as a fluidized medium. For each particle size, 7kg of raw rice husk were first introduced in to the drum and charred with a match to start ignition. To supply the necessary heat and pyrolyze the husk, a controlled amount of air was supplied from a compressor through 1/2" connecting pipes. A get valve and a flow meter was instaled along the connecting pipe for regulating and measuring the amount of air introduced in to the drum. K-type thermocouples installed at bottom, 0.4 and 0.8m height of the drum were used to monitor the progress of the bed temperature (both heating and cooling) for every 5 minutes. Moreover, a pyrometer was also used to measure the external temperature distribution of the drum. Finally, when the external temperature of the drum cooled down to the range of 40 to 30°C the carbonized husk was discharged. Fig. 2.2 shows the setup of the experiment.

Fig. 2.2: Experimental Setup for Carbonization of Rice Husk

Experimental Design

The experiment were designed to investigate the effect of operating parameters on pyrolysis performance of the pilot carbonizing kiln while converting raw rice husk in to a carbonaceous char residues.

In this study, factorial design method was employed to screen out the independent variables. The experiment was carried out taking 7kg of sample rice husk for each run with particle size of 1.59, 2.18 and 2.58 mm and supplying air at a flow rate of 0.0004, 0.0005 and 0.0006 m^3/s for 40, 50 and 60 min air contact time. That is three factors on three levels were considered and the experiment was designed in two replicas for product reproducibility. Accordingly, proximate analysis of the final char was also incorporated to characterize its quality in terms of fixed carbon content, volatile matter and ash content.

For each experiment, the final carbonaceous char yield was calculated on percentage using the relation described by FAO [6].

$$\text{Char yield } (\%) = \frac{m_{char}}{m_{rh}} * 100\%$$

Where, m_{char} is the mass of char, kg

m_{rh} is the mass of rice husk, kg

Proximate Analysis of Rice Husk and its Carbonaceous Char Residue

Moisture Content**:** The moisture content of all samples was determined by oven drying method set at 105°C until the sample attains a constant mass. During the experiment three equal samples of 1g were taken using sample holding crucibles and oven dried for 24hrs and then taken out, cooled first in desiccators and weighed the mass. Heating and cooling process was repeated at one hour time interval until the sample attains constant mass. Finally, the loss in weight is the moisture content and taken as an average value of the three individual samples in percent, wet basis [9].

$$\text{Moisture content, \% wb} = \frac{m - m_1}{m} * 100\%$$

Where, m is mass of raw samples, and m_1 is oven dried mass of both the samples, (g)

Volatile Matter **(weight, %):** For the raw rice husk, the value was obtained by heating the oven dried samples in a closed crucibles in a furnace at 600°C for six minutes and then at 900°C for another six minutes described by Sanger S.H. et.al [9]. The average weight loss of oven dried samples due to loss of volatiles was taken as the percent volatile matter in dry bases.

$$\text{Volatile Matter, \% db} = \frac{m_1 - m_2}{m_1} * 100\%$$

Where, m_2 is mass of rice husk remained in each crucible after keeping in a muffle furnace, (g)

For the carbonaceous char, the oven dried char samples were heated in closed crucibles to 950°C and held at this temperature for 6 minutes [4]. The average measured weight loss in percent is the volatile matter in dry basis.

$$\text{Volatile Matter, \% db} = \frac{m_1 - m_3}{m_1} * 100\%$$

Where, m_3 is the mass of carbonized char that remains after keeping in a muffle furnace, (g)

Ash Content**:** It was determined by heating the residue left in the determination of the volatile matter in open crucibles in an electric furnace set at 750°C for half hour and taken out, first cooled in air then in desiccators and measure its weight loss. Heating and cooling process continued till the residue attains a constant mass described by Sanger S.H. et.al [9]. The average residue that remains in each crucible was reported as the ash content of the samples in dry basis.

$$\text{Ash Content, \% db} = \frac{m_4}{m_1} * 100\%$$

Where, m_4 is mass of ash residue in grams that remains in each crucible after keeping at 750°C muffle furnace.

Fixed Carbon Content **(weight, %):** The percentage fixed carbon content of both the samples were calculated taking the difference of the sum of sample volatile matter and ash content from hundred [4, 9].

FCC, % db = 100% - % (VM + AC)

Where, FCC is the fixed carbon content, VM is volatile matter and AC is the ash content.

RESULT AND DISCUSSION

Carbonization of Rice Husk and Char Yield

During the carbonization process, at the startup it was observed that a dense white smoke was emitted from the chimney extension due to the presence of moisture and the smoke turns to bluish white with reduced in amount followed by a transparent blue color as shown in Fig. 3.1. When the feed is totally transformed into a carbonaceous char residue, the smoke becomes colorless and transparent. It was also observed that the external surface of the kiln was gradually turned to black color with the progress of the reaction downstream of the kiln.

Fig. 3.1: Color change of smoke during the carbonization process

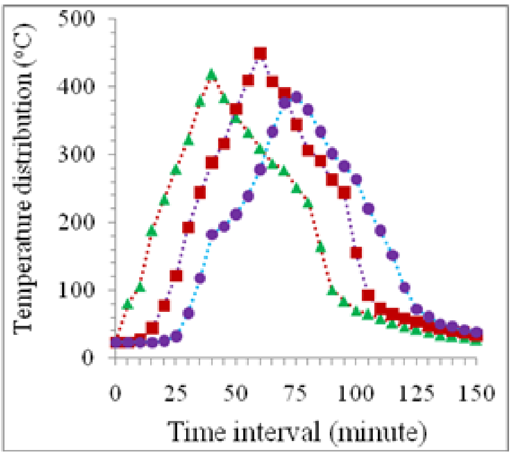
In addition, it was observed that the produced char residue looks black in color with a shining property and does not soil the fingers when we touch it as shown in Fig. 3.2. The report compiled by UNDP [3], the American Chemical Society [4] and FAO [6] states that good quality charcoal retains the grain of the wood; it is jet black in color with a shining luster in a fresh cross-section. It is sonorous with a metallic ring, and does not crush, nor does it soil the fingers. It floats in water, is a bad conductor of heat and electricity, and burns without flame.

Fig. 3.2: Sample rice husk and its carbonaceous char residue

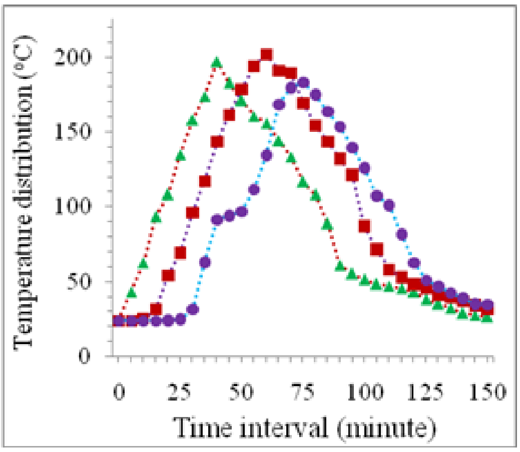
The solid carbonaceous char yield varies from 24.87 to 32.49% by weight for different pyrolysis condition. The result obtained was consistent with the report compiled by Rosa Miranda et.al. [12], from 25.5 to 33%. The highest char yield was found to be 32.49% for air flow rate of 0.0004 m^3/s, air contact time of 40 min and particle size of 2.58 mm.

As shown in Fig. 3.3, for maximum char yield the bed temperature reaches to 450 ^{o}C at 0.4 m height of the drum. Maximum bed temperature of 528 ^{o}C was also observed at 0.4 m height of the drum for higher air flow rate, longer air contact time and smaller particle size. In addition, each carbonization experiment was completed in the range of 2 to 3 hours for the different pyrolysis condition.

Looking at the existing DLWCRC cylindrical kiln, each batch was taking a carbonization time of 96 to 144 hours with conversion efficiency of 18 to 27%. Thus, it can be said that fluidizing the vertical carbonized s kiln via nitrogen medium improve efficiency by greatly reducing the carbonization time as well as improving the conversion efficiency of the kiln from 18 to 27% to the range of 24.87 to 32.49%.



a) Bed Temperature



b) Kiln Surface Temperature

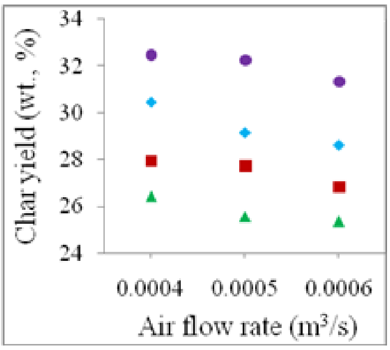
Fig. 3.3: Temperature distribution of carbonization kiln with corresponding curves for ▲0.8m height ■ 0.4m height and ● Bottom

The greater reduction in carbonization time from 96 to 144 hours to the range of 2 to 3 hours is achieved due to the increased contact surface area of solids as a result of rapid mixing of particles with the fluidizing medium. This would accelerate the heat and mass transfer rate and maintain a uniform temperature distribution inside the bed. As a result it reduces the overall carbonization time to a greater extent.

Effect of Air flow Rate on Solid Char Yield

Fig. 3.4 shows the char yield from carbonization of rice husk with particle size of 1.59 – 2.58 mm, air contact time of 40 -60 min for a wide range of air flow rate from 0.0004 to 0.0006 m^3/s. The result shows that the carbonaceous char yield were decreased from 27.96 to 26.84 % and 32.49 to 31.35 % by weight when the air flow rate was increased from 0.0004 to 0.0006 m^3/s for particle size of 2.18 and 2.58 mm, respectively, with constant air contact time of 40 min. Similarly, the char yield was also found to decrease from 26.42 to 25.36 and 30.47 to 28.62% by weight when the air flow rate was increased from 0.0004 to 0.0006 m^3/s for air contact time of 50 min and particle size of 2.18 and 2.58 mm respectively.

The decrease in solid char yield with increasing air flow rate may be due to the injection of additional oxygen which would accelerate the partial oxidation of the feed as well as the pyrolytic intermediate products released from the feedstock their by reducing the solid char yield through purging of more and more volatiles and tars.



▲d_{p1}= 2.18 mm A_{ct}= 50 min; ■d_{p1}= 2.18 mm A_{ct}= 40 min;◆ d_{p2}= 2.58 mm A_{ct}= 50 min and● d_{p2}= 2.58 mm A_{ct}= 40 min

Fig. 3.4: Effect of Air Flow Rate on Char Yield

In addition, higher oxygen concentration initiate the existence of high temperature gradient inside the kiln at a relatively short time span compared to lower air flow rate and consequently rapid pyrolysis condition of the husk would take place. High temperature coupled with rapid pyrolysis condition causes greater primary decomposition of the raw material. Thus, it reduces the char yield and increases the gas and/or liquid yield by further decomposing the volatiles and intermediates in to either gaseous or liquid products depending on how rapid the pyrolysis process is undergoing. However, as can be seen from the figure its significance is more pronounced for a longer air contact time. This demonstrated that, obviously these two parameters are synergistically inter-dependent on the pyrolysis char yield.

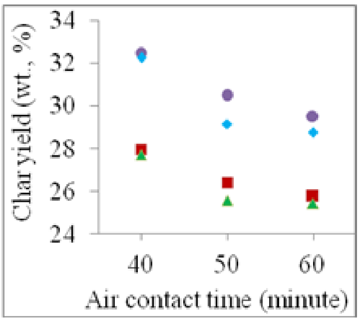
N.YubHarun, M.T. Afzal and M.T. Azizan [13] explained that higher temperature promotes higher evaporation and changes the solid to gaseous form. This is because, more cracking occurs at higher temperature resulting in higher gas yield and lower solid yield.

Wan-Fu Chiang et.al [1] investigated the pyrolysis kinetics of rice husk under inert condition, 10% O_2 (mole percent of O_2 in the mixture of O_2 and N_2) and air at heating rates of 5 K/min. The authors obtained a final residual mass of 31.69, 34.90, and 34.54% for the pyrolysis of rice husk in N_2, 10% O_2, and air flow, respectively. The authors also analyzed the elemental composition of the solid residue in order to determine the effects of different oxygen concentration on the pyrolysis of rice husk. They found that C, H and O were still the major constituents of pyrolysis residues. The C/H ratios of final residual masses were about 32.03, 27.66, and 38.75% for the pyrolysis reactions in N_2, 10% O_2, and air flow, respectively. For pyrolysis in N_2, the total combustibles (C, H, N, O, and S) in residues reduced only by 6.08% (from 38.39–32.31%). However, with pyrolysis in 10% O_2 and air, the char yield reduced by 14.68% (39.22–24.54%) and 13.46% (37.44–23.98%), respectively. The decrease in C/H ratio in different oxygen environment was contributed mainly by the mass changes of C, H, and O, especially for O. From the results of their experiment, the char yield significantly decreased in higher oxygen environment and deduced that the reaction of oxygen with the pyrolysis products of intermediates resulted in the C–C, C–O, and C–H bond ruptures of intermediates at a higher temperature ranges.

Effect of Air Contact Time on Char Yield

The effect of air contact time on char yield was investigated for a wide range of air contact time. The result of the experiment is presented in Fig. 3.5. As can be shown in the figure the char yield were decreased from 27.73 to 25.43% and 32.25 to 28.75 % by weight when the air contact time was increased from 40 to 60 min for constant air flow rate of 0.0005

m^3/s and particle size of 2.18 and 2.58 mm respectively.



▲U_a= 0.0005 m^3/s, d_{p1} = 2.18 mm; ■U_a= 0.0004 m^3/s, d_{p1} = 2.18 mm;◆U_a= 0.0005 m^3/s, d_{p2}= 2.58 mm and●U_a= 0.0004 m^3/s, d_{p2}= 2.58 mm

Fig. 3.5: Effect of Air Contact Time on Yield

Generally from the result it was observed that higher air contact time resulted in a lower char yield. This is probably because of the release of additional volatiles and tars in to gaseous and liquid products that are left the particle at higher air contact time.

N. Yub Harun, M.T. Afzal and M.T. Azizan [13] conducted TGA analysis of 250 and 500µm particle size of rubber reed kernel for 1.5 and 3 hours heating time in order to study the possibility of converting biomass wastes into solid fuels through torefaction. The authors reported that longer reaction time can result in lower production of solid product. This may be due to more biomass is converted to gaseous and liquid products and the change is more significant for a longer heating time as a result of a change in composition.

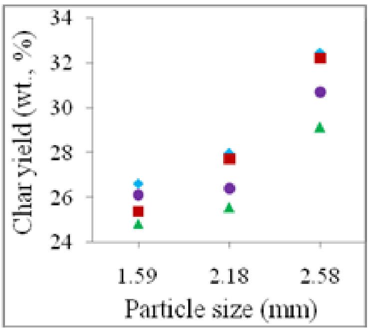
Effect of Particle Size on Char Yield

The effect of particle size on char yield was investigated in pilot scale carbonizing kiln for a wide range of particle size from 1.59 to 2.58 mm. The result is presented in Fig. 3.6. As can be seen in the figure, the carbonaceous char yield were increased from 25.39 to 32.25% and 24.87 to 29.16% by weight when the particle size of rice husk were increased from 1.59 to 2.58 mm for air flow rate of 0.0005 m^3/s and air contact time of 40 and 50 min respectively. Similarly, the char yield was also found to increase from 26.63 to 32.49% and 26.13 to 30.74 by weight when the particle size of the husk were increased from 1.59 to 2.58 mm for air flow rate of 0.0004 m^3/s and air contact time of 40 and 50 min respectively.

This is because particle size affects both the heat flux and heating rates. In smaller particles, the heat flux and heating rates are higher due to its greater surface area. Consequently, the higher heating rate and higher heat flux in smaller particle size enhance the combustion rate thereby decreases the final carbonaceous char yield. Increasing the heating rate also breaks the mass and heat transfer resistance inside the particle favoring in increased liquid and gaseous yield and decreased char formation.

In addition, smaller particle size also favors the cracking of hydrocarbons in to gaseous products due to increased heating rate. In smaller particle size the produced volatile matter and gases left the particles faster than large particles, resulting shortening of its residence time inside the particle and preventing to undergo secondary cracking to augment the char yield within the particle rather it favors cracking of the produced hydrocarbons and tars in to gaseous products.

Increasing particle size also delays the escape of volatiles. Thus, it gives additional opportunities for residual tarry vapors to undergo secondary reactions with the solid and increases the yield. For example, the American Chemical Society [4] reported an increase in solid residual yield during carbonization of macshell charcoal from 20 to 29% as the particle size increased from <120 µm to a single 2-mm particle.



▲U_a= 0.0005m^3/s, A_{ct} = 50min;●U_a= 0.0004 m^3/s, A_{ct} = 50 min; ■U_a= 0.0005 m^3/s, A_{ct}= 40 min and ◆U_a = 0.0004 m^3/s, A_{ct} = 40 min

Fig. 3.6: Effects of Particle Size on Char Yield

The results obtained in this work are in good agreement with the result obtained by Natarajan. E. and Ganapathy Sundaram, E. [14]. The authors studied pyrolysis of rice husk in a fixed bed and found that the char yield decreased from 36.37 to 34.17% when the particle size is decreased from 1.8 to less than 0.15 mm. The decrease in the solid yield with decreasing particle size could be due to greater temperature gradient inside the particles. The authors also reported that particle size has a significant effect on char, oil and gas yield in the pyrolysis of olive bagasse, pine sawdust and wood birch.

Proximate analysis of rice husk and its carbonaceous char

From the results of the *analysis*, it was observed that moisture content of rice husk varies from 5.99 to 6.46% while moisture content of the produced solid char varies from 2.60 to 3.38%. For rice husk the volatile matter observed in the range of 63.58 to 63.94% while the carbonaceous char residue varies from 5.50 to 13.29%. It was also observed that rice husk has fixed carbon content in the range of 11.89 to 12.61% while its char varies from 43.45 to 51.70%. The ash content of rice husk was also observed less than its char residue and varies in the range of 23.58 to 24.17% and 38.08 to 48.23% respectively.

The result obtained was in good agreement with the values reported by International Rice Research Institute [15]. According to the report, rice husk has volatile matter of 64.7%, fixed carbon content of 15.7% and ash content of 19.6% respectively all expressed in dry basis. According to Zakaria et.al. [16], rice husk has a fixed carbon content of 17%, volatile matter of 68% and ash content of 15% where as its char has a fixed carbon content of 51.30%, volatile matter of 9.90% and ash content of 38.80% by weight on dry basis. The increased in fixed carbon content of the char is due to the release of volatile matter during pyrolysis.

CONCLUSION

It was observed that fluidization system provides a suitable means to carbonize such low bulk density biomass materials compared to manually operated system. The system has greatly reduced the carbonization time to the range of 2 to 3 hours as compared to 96 to 144 hours using manually operated vertical cylindrical metal kiln. It was also observed that all the parameters considered do affect not only the char yield and its quality but also it affects both the carbonization time and temperature distribution of the pilot kiln. Further experimentation and modelling is required to explain the complex interplay of hydrodynamics, mass and transfer mechanism of the fluidization system.

Aknowledments

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REFERENCES

1. Wan-Fu Chiang; Hung-Yuan Fang; Chao-Hsiung Wu; Ching-Yuan Chang;Yu-Min Chang; and Je-Lueng Shie, "*Pyrolysis Kinetics of Rice Husk in Different Oxygen Concentrations", Jour. of Environmental Engineering,* Vol. 134, No. 4, pp. 316 – 325, April 2008.
2. Daniel M. Kammen and Debra J. Lew, "*Renewable and Appropriate Energy Laboratory Report*" - Review of Technologies for the Production and Use of Charcoal, Energy and Resources Group and Goldman School of Public Policy, University of California, Berkeley, CA 94720-3050, March 1, 2005.
3. UNDP, "*Harnessing Carbon Finance to Promote Sustainable Forestry, Agro-Forestry and Bio-Energy*", USA - New York, 2009.
4. American Chemical Society, "*The Art, Science, and Technology of Charcoal Production*", Ind. Eng. Chem. Res., Vol. 42, pp 1619 – 1640, 2003.
5. Mari Rautiainen, MikkoHavimo and KristapsGruduls, "*Biocoal Production, Properties and Uses*", University of Helsinki, Department of Forest Sciences, 2012.
6. FAO, "*Industrial Charcoal Production*", Croatia, 2008.
7. CRC, "*Household Energies Atlas of Equipments using Biomass in Sahelian Countries*", Regional Program for the Promotion of Household and Alternative Energies in the Sahel, Burkina Faso, 2009.

8. Sanger S.H., Mohod A.G., Khandetode Y.P., Shrirame H.Y. and Deshmukh A.S., "*Study of Carbonization for Cashew Nut Shell*", Research Journal of Chemical Sciences Vol. 1(2), pp. 43-55,May 2011.
9. K. G. Mansaray and A. E. Ghaly (1997), "*Physical and Thermo-Chemical Properties of Rice Husk*", Energy Sources, 19:9, pp. 989-1004.
10. Wayne E. Moore and Edward Beglinger, "*A Method of Charcoal Analysis*", Forest Products Journal, January 1961, pp. 17-18.
11. Rosa Miranda, César Sosa, Diana Bustos, Eileen Carrillo and María Rodríguez - Cantú, "*Characterization of Pyrolysis Products Obtained During the Preparation of Bio-oil and Activated Carbon*", México.
12. N.YubHarun, M.T. Afzal and M.T. Azizan, "*TGA Analysis of Rubber Seed Kernel*", International Journal of Engineering Volume (3): Issue (6), pp. 639 – 652.
13. Natarajan. E. and Ganapathy Sundaram. E.,"*Pyrolysis of Rice Husk in a Fixed Bed Reactor*", World Academy of Science, Engineering and Technology 56, pp. 504 – 508, 2009.
14. International Rice Research Institute, "*Properties of Rice Husk and Rice Straw*", 2009.
15. Z. Zakaria, M. A. MohdIshak, M. F. Abdullah and K. Ismail, "*Thermal Decomposition Study of Coals, Rice Husk, Rice Husk Char and their Blends During Pyrolysis and Combustion via Thermo-gravimetric Analysis*", International Journal of Chemical Technology, 2(3): Malaysia, pp. 78 -87, 2010.