

Effect of Oven Drying and Reactor Temperature on Rice Husk Pyrolysis in a Fixed Bed Reactor

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Abstract – This work investigated the effect of different oven drying and furnace temperatures on product yield distribution of rice husk pyrolysis. Rice husk was procured from a rice milling plant in Ogbomosho, South-Western Nigeria and was sundried for 3 days, and then oven dried at different temperatures (60, 75, 90, 105 and 120 °C) for 30 minutes in Chemical Engineering Laboratory, Ladoke Akintola University of Technology, Ogbomosho, Nigeria. The samples were then pyrolysed at different reactor temperatures (400, 500, 600 and 700 °C) with a residence time of 25 minutes. The retort was inserted into the furnace after being fed with the sample. For each run, the reactor temperature was set to be 100 °C higher than the desired temperature in order to compensate for heat loss during retort insertion. Moisture loss was in the range 5.58% (at 60 °C drying temperature) to 9.03% (at 120 °C drying temperature). The yields of tar, gas and char were then obtained after pyrolysis and expressed in percentage of the weight of the initial sample. Tar (liquid), char and gas yields were in the range of 8-12%, 30-50% and 18-58%, respectively at different oven drying and reactor temperatures. Findings showed that char yield was largely influenced by oven drying temperatures at reactor temperature of 700 °C. Results also showed that the yield of liquid can be optimized at reactor temperature of 500 °C while that of gas at 700 °C. Oven drying and reactor temperature conditions strongly influenced the yield of bio-fuels from rice husk pyrolysis.

Keywords – Rice Husk, Microwave Oven Drying, Biomass, Pyrolysis, Fixed Bed Reactor.

I. INTRODUCTION

Demands for energy generation that will not endanger human health are at the heart of research globally [1]. Renewable resources find their way in generating such sustainable energy ([2], [3]). Biomass is among the renewable sources of energy that have been accepted the world over. Research shows that different types of biomass used in generation of energy depend on their abundant availability and ease of conversion processes ([4], [5]). Of the entire agricultural residues, rice husk finds its way because it is produced in large quantity alongside with rice seed [6]. Rice is one of the most consumable cereals in the world with about 89% of the World rice production come from Asian countries [7]. Demand for increase in its production still continues to grow in developing nations like Nigeria [8]. Hence, the

amount of rice husk produced alongside with rice seed is so much that if not properly managed can cause nuisance to the environment (land pollution). Like most other biomass materials, rice husk contains high amount of organic volatiles (71-89 wt%) and 11-29 wt% of inorganic materials [9]. Various methods have been devised for rice husk utilization through biochemical and thermochemical conversion routes to avoid setting it on fire, which will not only cause air pollution but also greenhouse effect ([5], [9], [10], [11]). Amongst these methods are conversion of rice husk to produce silicon and silicon carbide, gasification of rice husk to produce gaseous fuel, slow pyrolysis of rice husk to produce char used in maintaining alkalinity of the soil, fast pyrolysis of rice husk to produce biooil and production of additives used in concrete materials ([1], [12], [13], [14], [15], [16]). Other applications of rice husk have been reported

by [17]. The cost of gasification plant is very exorbitant, the processes involved in the conversion of rice husk into silicon, silicon carbide and additive in concrete materials have not been effectively put into practice due to their complexity. Fast pyrolysis and gasification of rice husk to produce bio oil and fuel gas, which are supposed to be the possible solutions, have not been practised effectively due to oil-water phase of the bio-oil and the protective layer of rice husk at high temperatures, thereby hindering its usefulness in internal combustion engines [18]. This work is therefore aimed at determining the effect of various degrees of oven drying and reactor temperatures on rice husk pyrolysis.

II. SAMPLE PROCUREMENT AND PROCESSING

Rice husk was procured from a rice milling plant in Ogbomoso, Oyo State, South-Western Nigeria. The husk was ground, sun dried for 3 days, and then dried in a laboratory oven in Chemical Engineering Laboratory of Ladoké Akintola University of Technology, Ogbomoso, Nigeria. The heating chamber is 420 × 350 × 300 mm with a fixed laminated tray to carry the samples to be dried. Samples of ground rice husk (50 g each) were placed in the oven, one at a time, and were oven dried at five different temperatures (60, 75, 90, 105, and 120 °C) for 30 min. The dried samples were allowed to cool down and then reweighed to account for moisture loss using a digital weighing scale of sensitivity ±0.001 g. Moisture loss in the sample at various drying temperatures was calculated using equation 1.

$$\% \text{ moisture loss} = \frac{\text{initial weight of sample} - \text{weight of sample after drying}}{\text{initial weight of sample}} \quad 1$$

III. EXPERIMENTAL SETUP AND PROCEDURE

Figure 1 shows the exploded view of the fixed bed reactor used for the pyrolysis experiment. The reactor comprises of a cylindrical retort with a bottle neck to enhance a firm closure of the lid, a volatile conduit, tar collectors and a pyrogas receiver. The carrier gas (Nitrogen) was used to purge the reactor and sweep the volatiles from the reactor. The conduit channeled the volatile stream into the tar collectors which were immersed in ice-bath (tar trapper) for condensation of condensable gases and non-condensable gases were passed on to the gas collector. Samples of 50 g each, dried at different temperatures, were pyrolysed at different reactor temperatures (400, 500, 600, and 700 °C) for 25 min at atmospheric pressure. The reactor pyrometer (sensitivity ±20 °C) is preset to be 100 °C higher than the desired temperature in order to compensate for the heat loss during insertion of the preloaded retort and then reset to the required temperature after inserting the retort. The retort lid was firmly secured in place by using the hold down bolts and nuts with gasket as a packing material to prevent product leakage. Products collectors were weighed to ascertain their initial weight. Residence time of 25 minutes count down was achieved by means of a stop watch. The collected tar was weighed on the weighing balance and its yield was determined by subtracting the initial weight of both collectors from their final weight after the experiment. The retort was removed from the reactor immediately after 25 minutes, allowed to cool for 10 minutes, the bolt and nut loosed and the char was let out from the retort. The char and tar were

weighed using a digital weighing balance of sensitivity ±1g. Weight of pyrogas was obtained by subtracting the weight of tar and char from the initial weight of the sample (mass balance). Products yields were expressed as percentage of initial weight of the sample.

IV. RESULTS AND DISCUSSION

4.1 Effect of oven drying on sample moisture loss.

Effect of oven drying on moisture loss of the sample is presented in Figure 2. From the figure, percentage loss in moisture increased with drying temperature. This increase in moisture loss with drying temperature was accompanied with decrease in sample weight. Furthermore, there is tendency of partial pyrolysis at high drying temperatures since biomass sample temperature would have increased after enormous loss of moisture in the sample [19].

4.2 Effect of drying and reactor temperatures on tar yield

Figure 3 shows tar yield profiles at different reactor temperatures (400, 500, 600 and 700 °C) and drying temperatures (60, 75, 90, 105 and 120 °C). From the figure, tar yield attained maximum values at 500 °C for all the drying temperatures with the peak at a drying temperature of 90°C. At 400 °C, the lower the drying temperature the higher the yield of tar and vice-versa except at 120 °C where there was a slight rise in tar yield. This is due to the presence of moisture at lower drying temperature. Tar yield profile at 600°C follows the pattern at 400 °C except that it started

rising from 105 to 120 °C drying temperature. This may be due to the drying effect that might have broken down some intra-particle bonds during drying at this temperature range, which favours pyrolysis [20]. At 700 °C, tar yield was so small compared to those at other pyrolysis temperatures. This

may be due to tar cracking at this temperature, yielding pyrogas and char ([6], [21]).

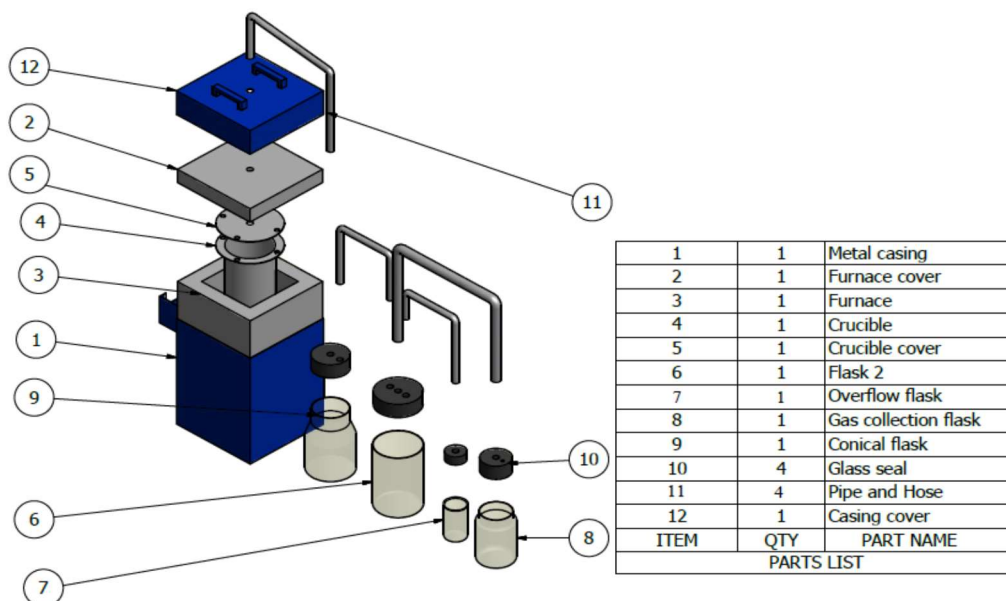


Figure 1: Exploded view of the pyrolysis unit

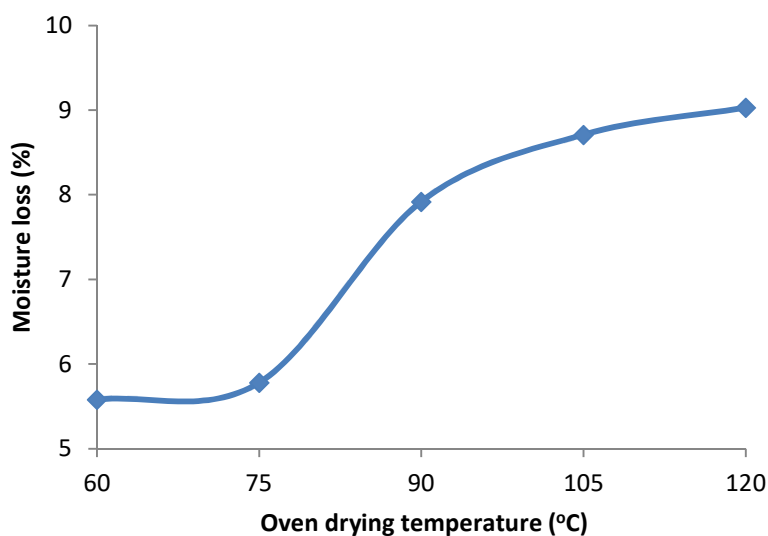


Figure 2: Moisture loss at different drying temperatures

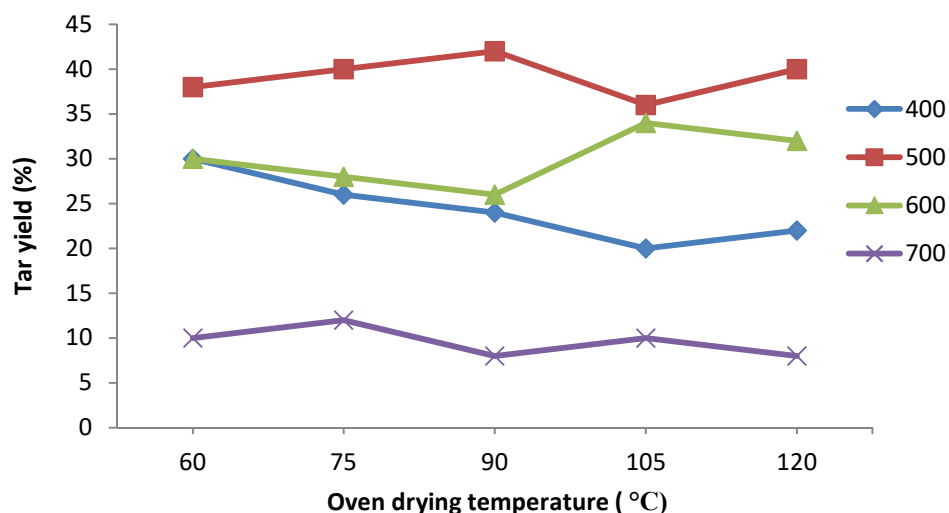


Figure 3: Tar yield at different drying and reactor temperatures

4.3 Effect of drying and reactor temperature on char yield

Figure 4 shows char yield profiles at different reactor temperatures (400, 500, 600 and 700 °C) and drying temperatures (60, 75, 90, 105 and 120 °C). At 700 °C, there was an irregular pattern in char yield, having the maximum value at 90 °C drying temperature. This may be due to repolymerization of decomposed tar to form char and pyrogas ([22], [23]). A further fall in char yield with the drying

temperature increase from 90 to 105 °C at this pyrolysis temperature may be due to partial decomposition of the sample, which might have taken place during drying since virtually all moisture in the sample would have evaporated at 90 °C and further increase in drying temperature would cause slow pyrolysis to occur [19]. Char yield at 400, 500, and 600 °C follow almost the same pattern but the maximum yield was obtained at 400 °C for all drying temperatures. This should be expected as slow pyrolysis at lower temperatures favours the yield of char ([24], [25]).

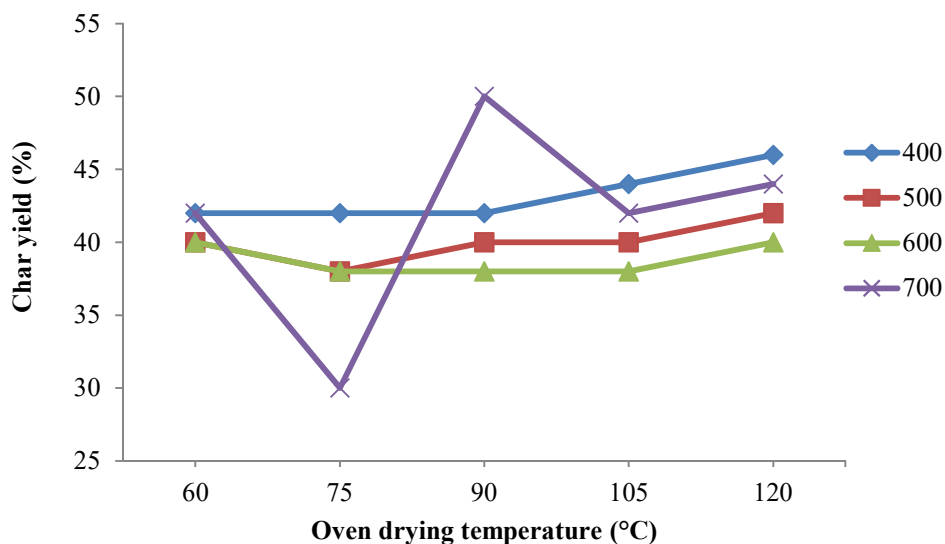


Figure 4: Char yield at different drying and reactor temperatures

4.4 Effect of drying and reactor temperature on pyrogas yield

Figure 5 shows pyrogas yield at different reactor temperatures (400, 500, 600 and 700 °C) and drying temperatures (60, 75, 90, 105 and 120 °C). It was observed that maximum yield of pyrogas was obtained at 700 °C (75 °C drying temperature). Increase in reactor temperature aided pyrogas yield due to high decomposition of lignin and increase in tar cracking at this temperature [21]. At 400 °C and barely at 500 °C, pyrogas yield increased with drying temperature (between 60 and 105 °C) then followed by a

slight reduction in yield (between 105 and 120 °C). This reduction in pyrogas yield may be as a result of the mild pyrolysis likely to have occurred at 105 and 120 °C drying temperature. At 600 °C, pyrogas yield increased with drying temperature until 90 °C, when the yield suffered some decline. This decline may also be due to the occurrence of mild pyrolysis during oven drying above 90 °C. Minimum yield of pyrogas was obtained at 500 °C for all drying temperature. This was due to high yield of tar and char at this temperature. At higher temperatures, due to predominance of lignin devolatilization, chemical kinetics favoured gas formation.

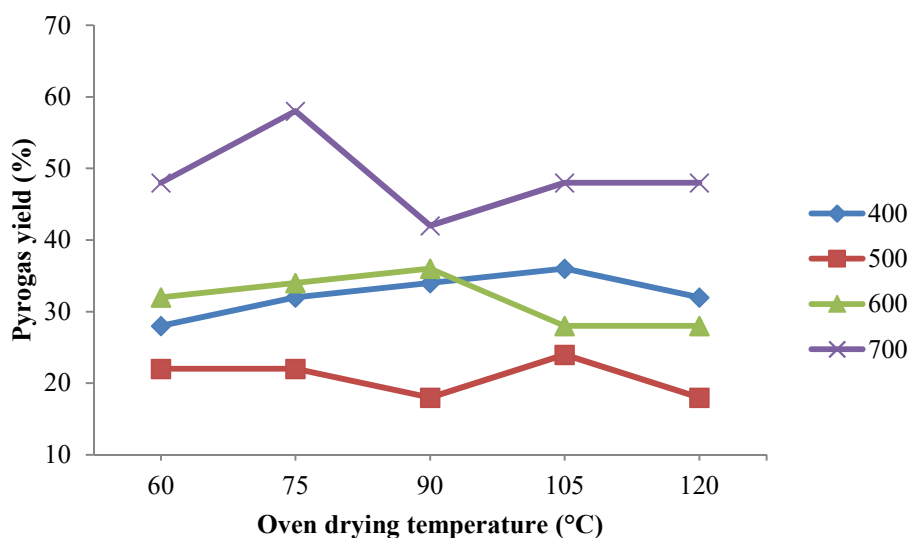


Figure 5: Pyrogas yield at different drying and reactor temperatures.

V. CONCLUSIONS

Effect of oven drying and reactor temperature on rice husk pyrolysis in a fixed bed reactor has been studied. Oven drying was in the range of 60 – 120 °C while pyrolysis temperature varied between 400 and 700 °C. The highest yields of tar (liquid) were obtained at 500 °C, attaining a peak value of 40% (at drying temperature of 90 °C). Gas yields were highest at 700 °C, with the optimum value of 58.2% (at drying temperature of 75 °C). Char yield has both the lowest (29.5% at 75 °C drying temperature) and the highest (50.2% at 90 °C drying temperature) yields at 700 °C. At 700 °C reactor temperature, char yield did not follow any definite pattern, suggesting a strong influence of secondary reactions at this temperature. However, the char yield can be optimized at 400 °C reactor temperature. Changes in both oven drying and reactor temperatures have significant effect on rice husk pyrolysis. The liquid product obtained has low water content

and therefore can serve as a good fuel or chemical feedstock for chemical industries.

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