Effect of Reactor Temperature on Pyrolysis of Lignocellulosic Medical Waste in a Fixed Bed Reactor

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Abstract

The lethargic modes of medical waste disposal in many developing countries have been a cause of concern to many regulatory agencies. In this study, effect of reactor temperature on pyrolysis of lignocellulosic medical waste in a fixed bed reactor was investigated. Gauze bandage was procured from AKOL Pharmacy, Ogbomoso, South-Western Nigeria. Samples of the gauze bandage, 40 g each at a time, were fed into a retort and the retort inserted into a developed fixed bed reactor for pyrolysis at different temperatures (300, 400, 500 and 600 ^{o}C) with a residence time of 15 minutes. Tar, gas and char yields were weighed using an electronic balance (WT20002T, RS232C) and were further expressed in percentage of the initial weight of the sample. Results showed that tar and gas yields increased with increasing reactor temperature while char yield decreased with it. Both intra- and extra-particle secondary reactions were insignificant and therefore could not influence the yield spectra of products. The highest yield of tar, gas and char were 52.08, 28.42 and 52.7%, respectively while the lowest yield were respectively 30.50, 16.80 and 19.50%. Lignocellulosic medical waste can be a viable source of biofuels and raw materials respectively for sustainable development and for chemical industries.

Keywords: Pyrolysis, medical wastes, biofuels, fixed bed reactor

Introduction

In recent times, agitations abound over the poor handling of medical wastes in Nigeria. Various agencies have raised concerns regarding inappropriate modes of medical wastes disposal. The phenomenal increase in the volume of medical waste is premised on increment in the usage of disposables as precautionary measures against infectious diseases such as HIV/AIDS on one hand and increase in the number of facilities where critically ill or injured patients are treated on the other hand. These wastes, if not properly disposed, would produce incalculable harm to both the human populace and environment (Cesaro and Belgiovini, 2015).

Medical waste is a mixture of infusion tubes (plastics), surgical gloves (rubber), cotton wool or gauze (biomass class), and sharps (metallic objects). Various methods are being used for handling these categories of medical waste, including incineration, autoclaving, chemical disinfection, microwave heating, irradiation, gas sterilization and open pit burning (Klangsin and Harding, 1998). More often than not, when some of these methods are used for Lignocellulosic medical waste and plastics, solid residues are disposed in landfills, constituting nuisance to the environment. Therefore, there is need to devise a method of handling medical wastes that are biomass in nature so as to convert them to value added products with no environmental nuisance.

Pyrolysis, a thermochemical process is an already established procedure that has been used immensely for both agricultural residues and municipal wastes. Several researchers have worked on biomass pyrolysis (Horne and Williams, 1996; Di Blasi et al., 2001; Lu et al., 2010; Okekunle et al., 2011; Piskorz et al., 1998; Park et al., 2010). Present sources of energy are not sufficient to meet the increasing needs. The major energy demand is fulfilled from the conventional energy resources like coal, petroleum and natural gas. Pyrolysis products can be used as fuels, with or without prior upgrading, or they can be utilized as feedstock for chemical or material industries.

Previous research efforts have shown that the percentage of pyrolysis products yields varies based on the type of biomass feedstock used and other process parameters (Di Blasi, 2008). When these materials are heated during pyrolysis, as a clean fuel, the oil so produced has a number of practical advantages; it is renewable and locally produced from organic waste, it can be stored and transported similar to petroleum-based products, it is greenhouse gas neutral and can generate carbon dioxide credits, and lower NOx emissions than light fuel oil in gas turbines and diesel fuel oil in stationary diesel engines. Damberger (1991) reported that a landfill could be transformed with plasma pyrolysis for its rich source of carbon monoxide and hydrogen and that pyrolysis results in a reduction of over 90 percent in the volume of material. Some researchers have also attempted to adopt pyrolysis for handling biodegradable medical wastes (Zhu et al., 2008; Yan et al., 2009; Nema and Ganeshprasad, 2002). However, data on medical waste pyrolysis are scarce and this method has not been utilized in Nigeria. Therefore, this research is aimed at studying the effect of reactor temperature on biofuel yields from pyrolysis of medical waste in a fixed bed reactor.

Material and Method

Sample Procurement

Gauze bandage, made from cotton fibre, was chosen as the sample for this study. This is because gauze bandage is a good representation of lignocellulosic medical waste usually disposed from hospitals. The sample was obtained from AKOL Pharmacy, Ogbomoso, South-Western Nigeria.

Experimental Setup and Procedure

The exploded view of the fixed bed reactor used for the pyrolysis process is shown in Figure 1. The reactor comprises of a cylindrical retort with a bottle neck to enhance a firm closure of the lid, products collector pipe, tar collectors and a pyro-gas receiver. Carrier gas (nitrogen) was used to purge the reactor and sweep the volatiles from the reactor. The collector pipe channeled the volatiles stream into the tar collectors which were immersed in an ice- bath (tar trapper) for condensation of condensable gases and non-condensable gases passed on to the gas collector. The details of the setup have been reported in Okekunle et al. (2019).

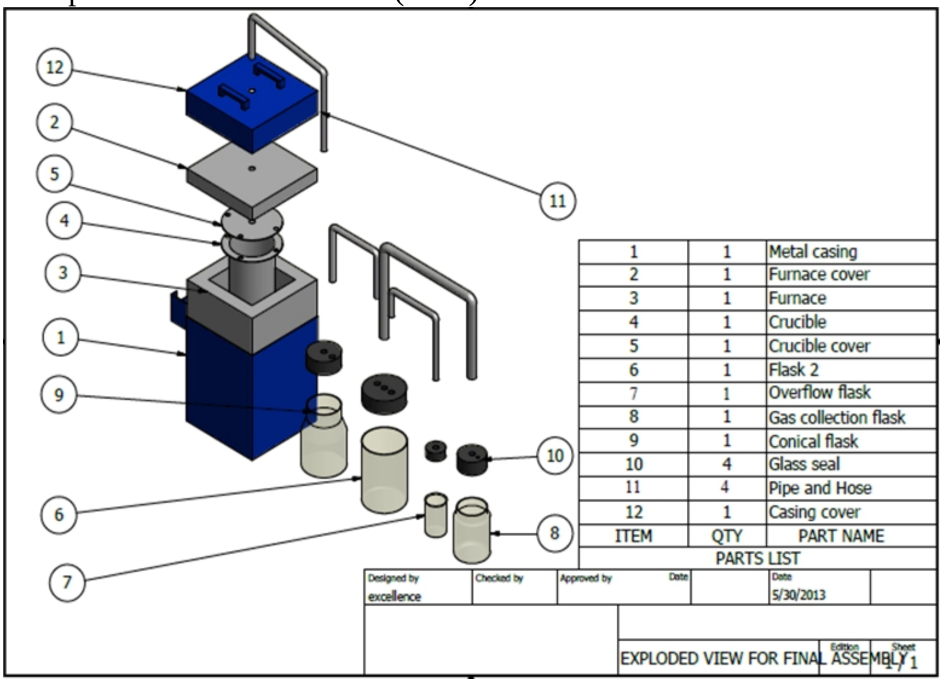

Figure 1: Exploded view of the pyrolysis unit

In each experimental run, 40 g of gauze bandage was introduced into the crucible, fastened with bolts and nuts. The furnace was heated 80°C higher than the desired temperature in order to compensate for the heat loss during retort (crucible) insertion. The preloaded crucible was then inserted into the furnace and the furnace was firmly closed and was then set at the desired temperature. Samples were pyrolysed at furnace temperatures of 300, 400, 500 and 600°C for 15 minutes. The yield of char and tar (pyro-oil) were measured using an electronic balance (WT20002T ,RS232C) and were expressed as percentage of the initial weight of the sample according to equations 1 and 2, respectively. The yield of gas was obtained by conservation of mass according to equation 3.

$$Y_{char} = \frac{W_{char}}{W_{is}} \times 100\% \quad (1)$$

$$Y_{tar} = \frac{W_{tar}}{W_{is}} \times 100\% \quad (2)$$

$$Y_{gas} = (100 - Y_{char} - Y_{tar})\% \quad (3)$$

where Y_{char}, Y_{tar} and Y_{gas} are char, tar and gas yield, respectively. W_{char}, W_{tar} and W_{is} are the weight of char, tar and initial sample, respectively.

Results and Discussion

Tar yield

Figure 2 shows the percentage yield of tar from pyrolysis of medical waste at different reactor temperatures. As shown in the figure, tar yield increased with increasing reactor temperature. Except at 300°C, the yield of tar was high and represented a larger percentage of the products obtained from the pyrolysis process at different temperatures. This result can be justified from the standpoint of cellulose pyrolysis because cellulose is the major constituent of gauze bandage. Liao et al. (2004) have reported that increase in temperature causes active cellulose to undergo two competitive reactions; cracking of glycosidic bond to produce levoglucosan and its isomeric anhydrosugar, and opening of acetal structural ring and cracking of internal C-C bond in pyranoid ring to form hydroxyl-acetaldehyde (HAA), acetol and furfural. All these contribute to increase in tar formation with increasing reactor temperature. This result also shows that, tar secondary reactions were not favoured, given the size of the sample and stream of inert gas used for conveying the volatile product stream from the reactor to the tar traps.

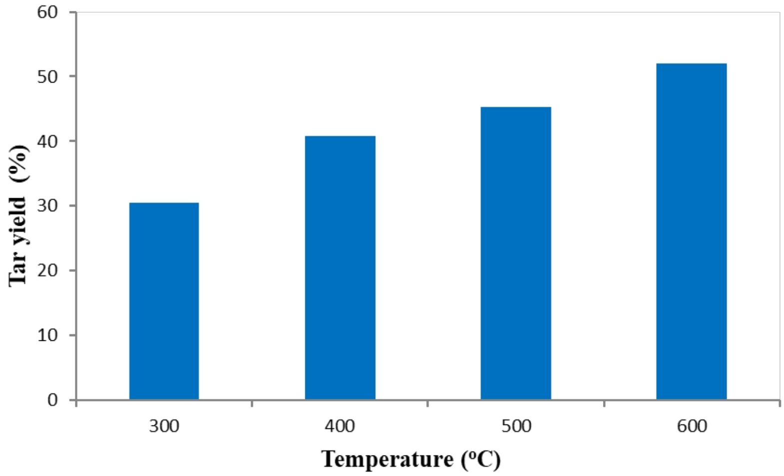

Figure 2: Tar yield at different pyrolysis temperatures

Gas yield

Figure 3 shows the percentage yield of gas at different temperatures. From the figure, it can be seen that gas yield increased with increasing temperature. This result follows a common trend in biomass pyrolysis. Increase in temperature will enhance the speed and quantity of the gas produced. From chemical kinetics, increase in temperature favours the rate of chemical reactions, which in this case, implies a higher conversion of the sample to volatiles. Several researchers have reported similar observations (Blondeau and Jeanmart, 2012; Sundaram and Natarajan, 2009; Di Blasi et al., 1999). Gas yield ranged between 16.80 and 28.42%.

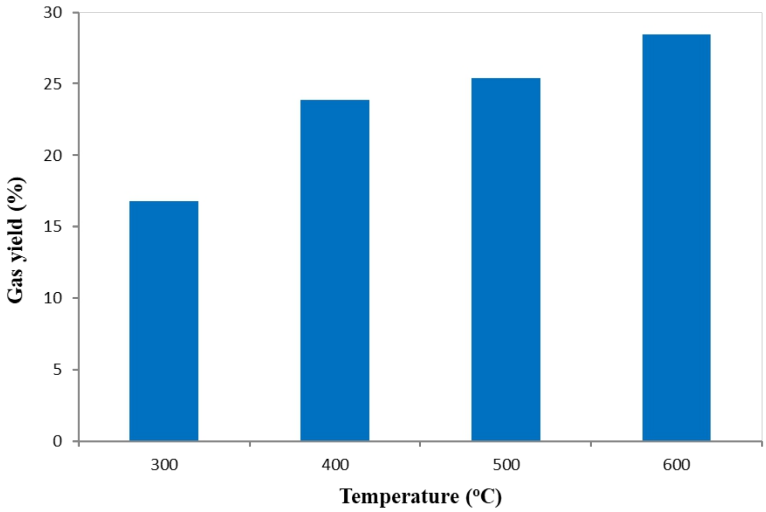

Figure 3: Gas yield at different pyrolysis temperatures

Char yield

Figure 4 shows char yield at different pyrolysis temperatures. From the figure, it is seen that char yield decreased with increase in pyrolysis temperature. The maximum yield of char was 52.7% at 300°C while the minimum was 19.5% at 600°C. The decrease in char yield with increasing temperature is due to a greater degree of primary decomposition of the sample at higher temperature. This is in agreement with pyrolysis convention and several other researchers have reported the same trend (Sundaram and Natarajan, 2009). The main source of char formation during pyrolysis has been identified to be thermal decomposition of lignin (Yang et al., 2006; Yang et al., 2007). The high yield of char (52.7%) suggests gauze bandage has appreciable lignin content.

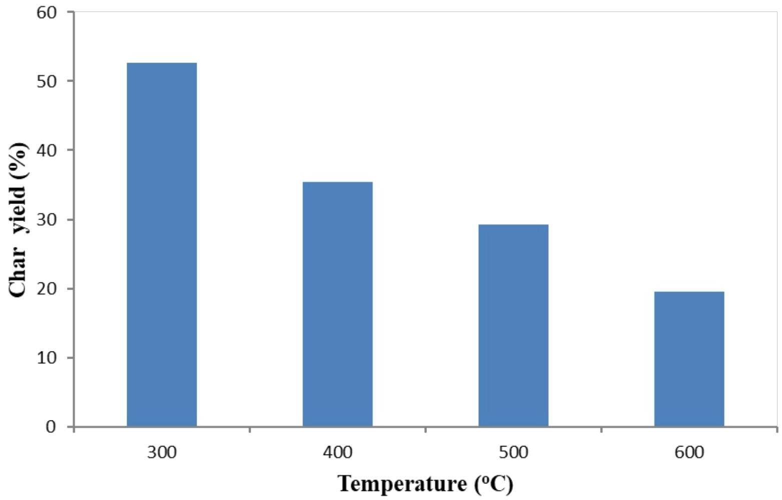

Figure 4: Char yield at different pyrolysis temperatures

Conclusion

Effect of temperature on the yield of tar, gas and char during pyrolysis of gauze bandage has been studied in a fixed bed reactor. Pyrolysis temperature varied between 300 and 600°C. Tar, gas and char yields were in the range 30.5 – 52.08%, 16.80 – 28.42% and 19.5 – 52.7%, respectively. Findings revealed that cellulose, being the major constituent of gauze bandage, was responsible for the high yield of tar. Secondary reactions did not change the products spectra even at 600°C because of the size of the sample on one hand and the fact that the volatiles stream was conveyed by the carrier gas as soon as the volatiles were released from the decomposing sample on the other hand, thereby giving no ample time for extra-particle secondary reactions to take place in the reactor. Hospital wastes that are biomass in nature can be a good source of biofuels through thermochemical processes.

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