Combustion Behavior of Pyrolyzed and Original Wood Pellet in Agitated Bed

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Abstract

This paper deal with the combustion behavior of poplar wood and chars obtained from poplar wood in a laboratory-size rotating wire mesh basket. Single particles of 0.2-0.8 g average weight were loaded into a basket which was then inserted into a preheated tube furnace. The effect of agitation on combustion time of volatile matter and carbon and also carbon combustion rate was investigated and compared with those found by using a fixed basket. It was observed that burning time of volatile matter of all the chars under agitation was longer than obtained with a fixed bed and the size of the particles affected the combustion behavior in the agitated bed. The carbon combustion rate of original wood pellet was determined higher than char as expected, mainly due to the high volatile matter content.

Key words: Wood, char, combustion, agitation.

1. Introduction

Biomass is any material that is directly or indirectly derived from plant life. Typical biomass resources are wood, energy crops, farm and agricultural wastes and municipal wastes. This resource, especially wood, has traditionally been an important source of energy. The energy in biomass is the chemical energy associated with the carbon and hydrogen atoms contained in oxidizable organic molecules. Biomass energy is particularly attractive nowadays because of its inherent nature of being environmentally friendly and renewable [1-3]. An increasing use of renewable energy sources, such as wood, is an important issue in future market to solve the CO_2 problem which contributes to the greenhouse effect. Today fossil fuels are replaced by biomass because of this advantage [4].

Wood and biomass can be used to provide energy by pyrolysis. Pyrolysis is the initial stage in any gasification process because whenever a solid fuel is subjected to high devolatilization occurs. In this stage the solid fuels are converted into char as an intermediated product which subsequently or simultaneously gasified. The treatment condition in pyrolysis strongly affects the yield and reactivity of the char. Therefore the kinetic of char combustion plays a very important role since it provides valuable data for the correct dimensioning of gasifiers and burners [1,5].

Besides combustion in large heat and power plants, biomass is employed for heating and cooking, especially in scarcely populated areas and developing countries [6,7]. Fixed grates are suitable for burning wood remainder. But, when wood is burned on fixed grate the sawdust particles are usually carried out of the fuel due to the high speed of the combustion air [2]. Thus, due to this kind of certain deficiencies, such conditions should be developed to enable a process which will not only be efficient for energy conversion but also ecologically acceptable. New and upgraded biomass fuels (i.e. pellets, briquettes and powder) have become more common and especially fuel pellets are well suited for the residential market. Wood pellets have been introduced in the course of the last two decades as convenient and

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economically attractive bio fuel in forested countries [8]. Therefore, success of the residential pellet business will be dependent on preferences such as economic considerations and household attitudes. Pellets for residential heating provide possibilities of more automated and optimized systems, with higher combustion efficiencies and less product of incomplete combustion compared to traditional wood log firing and other coarse fuels such as lignite briquettes [9,10].

The objective of this work is, therefore, to evaluate wood residues for pellet and solid product (char) from wood pellet pyrolysis and research the combustion behavior of char in both fixed and agitated bed. Ash related problems have been observed in residential wood pellet burners. Despite the pellet burners, the advantage of agitated bed is its ability to remove the ash layer formed on the char surface during combustion, as a result of abrasive friction between moving pellets in the bed.

2. Material and Method

2.1. Sample preparation

Poplar wood was used as raw material in this study. The wood chips were dried at 105°C in the oven, milled and sieved, respectively. Particle size between -100+200 mesh was used to make cylindrical pellet of 6 mm height and 13 mm diameter. Single pellets of 0.8 g average masses were prepared with a laboratory press. Two kinds of pellets were prepared. One of them was untreated pellet and the other was pyrolyzed pellet.

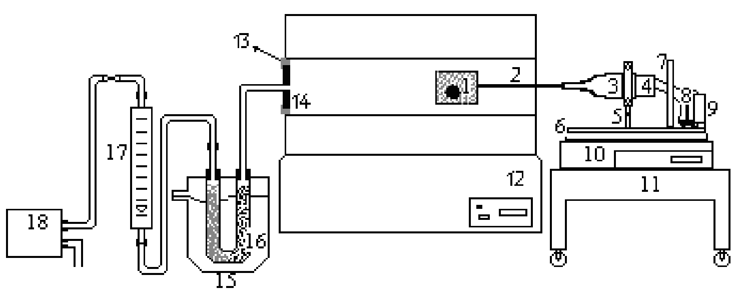

Figure 1. Experimental system: 1. basket; 2. shaft rod; 3. reduction gear; 4. DC motor; 5. clip; 6. carrier plate; 7. view mirror; 8. potentiometer; 9. battery; 10. top balance; 11. moving table; 12. tubular furnace; 13. quartz wool; 14. iron sheet lid; 15. cooling vessel; 16. U tube; 17. flow meter; 18. vacuum pump.

Pyrolysis of wood pellet was performed in the quartz tube which was placed in a vertical heating chamber. Single pellet was pyrolyzed on a wire mesh basket in a quartz tube. Pyrolysis experiments were conducted at 673, 773 and 873 K. Nitrogen was used as inert atmosphere in the experiments.

2.2. Experimental procedure

Combustion experiments of original and pyrolyzed wood pellets were performed using the system given in Fig.1, used in the previous study [11]. Wood pellets were placed in a stainless steel wire mesh basket of 60 mm height and 40 mm diameter. There was a wire mesh cap on the front face of the basket. Rear face was connected to a DC motor via a stainless steel shaft of 200 mm length and 2 mm diameter. The basket and motor system were mounted on an iron plate of 200x200x2 mm by the help of a moving clip. This assembly was placed on a top balance standing on a small table with wheeled legs. These wheels move the entire system and insert the basket into the selected region of the heated ceramic tube of a tubular furnace. Inner diameter and length of the ceramic tube were 65 and was 660 mm, respectively. The exit of the ceramic tube was closed with an iron sheet closure, on which a copper tube of 4 mm inner diameter was attached at the centre to serve flue gas outlet. The location of the basket in the ceramic tube was 250 mm a far from the open face of the tube in all the experiments.

The continuous flow of the air at a constant velocity through the ceramic tube was maintained by using a vacuum pump and measured with a flow meter. Flue gas, sucked from the ceramic tube via the copper tube attached to the back closure of the furnace, was passed through a tap water-cooled trap located on the line to free flue gas from soot and tar before discarding.

Before the experiments, the tubular furnace was set to working temperature (973 K). The lignite pellet was put in the basket and the front cap was shut. Then, by pushing the entire assembly, the basket was inserted into the predetermined section of the ceramic tube. The rotation of the basket and time measurements was started, and the first mass reading was taken. The mass recordings during volatiles and subsequent char combustion periods were made at 15 and 30s intervals, respectively. In addition, the times to cease the volatiles flame and to extinguish the glowing char after volatile combustion were recorded. Experiments were repeated by rotating basket (12 rpm)

3. Result and discussion

Table 1. Char yield of poplar wood at different temperature.

Temperature (K)	Char yield [a] (%, daf)	Char yield [b] (%, daf)
673	44.46	36.30
773	38.25	35.90
873	33.74	25.86

a: experimental yield; b: estimated yield

Table 1 shows the yield of char from pyrolysis of poplar wood at 673, 773 and 873 K the first char yield was determined from difference among the weight of pellet and char. The second char yield was calculated according to the following equation (1).

$$\text{Char yield} = (a_w/a_c - a_w/100)/(1-a_w/100) \quad (1)$$

where a_w is the weight % ash in dry wood and a_c is the weight % ash in dry char obtained from pyrolysis.

The temperatures in Table 1 are initial furnace temperature. Both of char yields decrease with increasing pyrolysis temperature. Since pyrolysis of wood gave more volatile and less char at high temperature, in previous studies, lower char yield was observed for wood [12]. Higher yield of char is dependent upon high carbon content, low oxygen content, low H/C ratio and higher content of coke forming components, such as lignin, in the fuel subject to pyrolysis [13]. In Table 1, it is seen that the yield of char obtained from experimental data are higher than the data obtained from Equation (1).

Table 2 shows the proximate analysis and the calorific value of poplar wood and chars obtained after pyrolysis in the fixed bed. Proximate analyses (to determinate volatile matter and ash) were performed according to ASTM Standards (E872, D1102) and Calorific values were determined by JULIUS PETTERS I BERLIN adiabatic calorimeter. Fixed carbon was estimated from the differences. The results of these analyses indicated that the content of fixed carbon increased while the content of volatile matter decreased with increasing pyrolysis temperature. Losses in volatile matter correspond to the separation of various volatile components within char's structure favoured by high temperature [12]. The ash content of char pyrolyzed at 873 K was 27.34 wt%. The percentage of ash and the calorific values of samples also increased with increasing pyrolysis temperature.

Both the combustion behaviour of chars and original wood pellets was investigated as combustion of volatile matter together with carbon burning. Volatile matter and carbon combustion were determined by observation of flame around the pellet and flue gas analysis (as performed in many studies [14-18]. The effects of pyrolysis temperature on the volatile matter and carbon combustion times of chars are given in Fig 2. It was seen that the volatile combustion times of chars increased with increasing pyrolysis temperature in agitated bed, but decreased in fixed bed. Also, it was found that burning time of volatile matter of all the chars under agitation were longer than those obtained from fixed bed data. In most of the experiments, char particle were fractured or broken down into smaller particles during the combustion in the rotary burner.

Table 2. The proximate analysis and heating value of the poplar wood and char obtained from pyrolysis of poplar wood.

Fuel	Fixed carbon (wt%, daf)	Volatile Matter (wt%, daf)	Ash (wt%, db)	Calorific value ($Mj.kg^{-1}$,daf)
Poplar wood	25.00	75.00	3.88	18.48
Char $_{(673K)}$	58.89	41.11	10.10	27.44
Char $_{(773K)}$	66.62	33.37	10.00	29.81
Char $_{(873K)}$	62.65	27.34	27.34	33.14

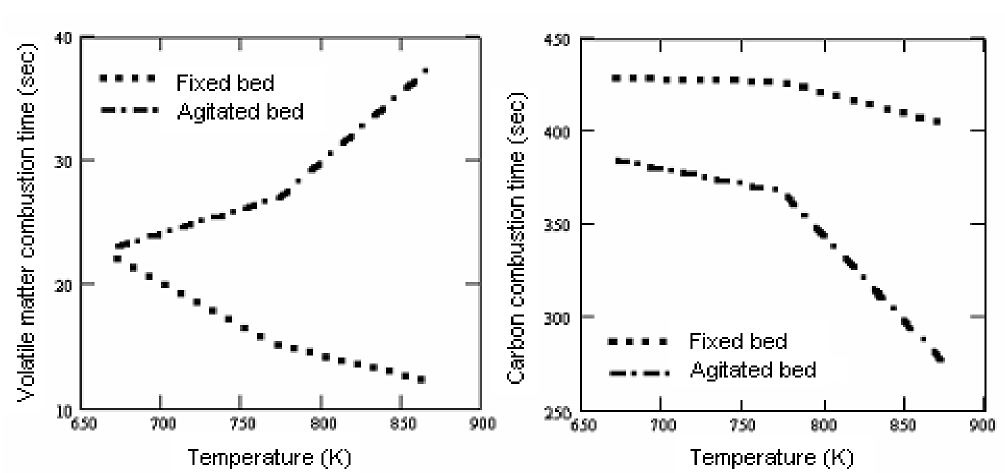

Figure 2. The relationship between the combustion times of volatile matter and carbon of chars with pyrolysis temperature.

Therefore longer volatile matter combustion time was observed. It was thought that all volatiles were removed from char. In addition, it was determined that the carbon combustion time was decreased with increasing pyrolysis temperature in both of the combustion systems. These results may be related to the quantity of volatile matter after pyrolysis.

Volatile matter and carbon combustion time of poplar wood pellet are shown in Table 3. Volatile combustion times may be taken as a measure of amount of volatile matter content. Volatile matter content of poplar wood pellet is more than of pyrolyzed chars. Thus, wood pellet has a long volatile matter combustion time in both burning systems.

The weight loss curves of the chars and original pellet shown in Fig. 3 can be easily divided into two lines of different slopes. These lines represent the volatiles and carbon combustion periods.

Table 3. The relationship between the combustion times of volatile matter and carbon of wood pellet with burning system at 973 K.

	Volatile matter combustion time (s)	Carbon combustion time (s)
Fixed bed	57	302
Agitated bed	66	291

The effect of pyrolysis temperature on the carbon combustion period of chars is given in Table 4. Carbon combustion rates were calculated by using the second part of the curves in Fig. 3. It was determined that combustion rates of low temperature chars and wood pellet under agitation were higher than fixed bed. This high combustion rate of char particle under agitation may be explained by the rotation of particle in the basket resulting in ash removal. It was seen that combustion of pyrolyzed char particle was affected considerably from agitation.

Carbon combustion rate of original wood pellet which has high volatile matter content is higher than those of chars [19-20]. This is reflected as lower carbon combustion time of wood pellet in Table 3.

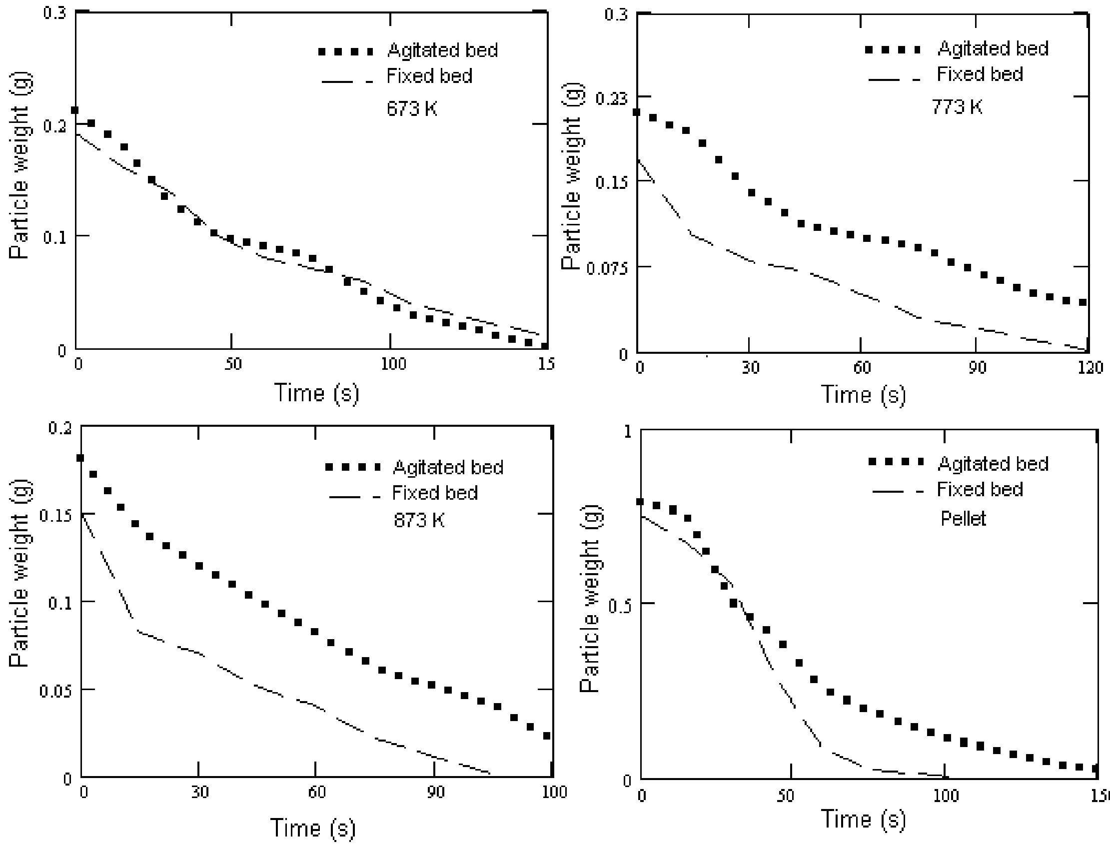

Figure 3. The changes in char weight obtained at different pyrolysis temperature with time at 973 K.

Table 4. Carbon combustion rates of original pellet and chars obtained at different pyrolysis temperature.

	Carbon combustion rate. $10^{-3}(s^{-1})$	
Temperature of pyrolysis (K)	Fixed bed	Agitated bed
673	7.5	9.3
773	7.1	8.4
873	9.2	8.2
Pellet	-	11.5

4. Conclusions

From the observations on volatiles and char combustion behaviours of the fuel pellets of poplar wood and chars obtained after pyrolysis in the fixed bed, the following conclusions may be drawn:

- The higher pyrolysis temperature has led to lower yields of char. Volatile combustion times may be taken as a measure of amount of volatile matter content. Thus, wood pellet has a long volatile matter combustion time. Burning time of volatile matter of all chars under agitation is longer than fixed bed.
- The volatile and ash contents of the particles affect the combustion behavior in agitated bed. The combustion rates of wood pellets and char particles which have low ash and high volatiles content are affected considerably by agitation.
- Since the wood pellet has more volatiles and less ash, ıt was found that carbon combustion rate of original wood is higher than of chars.

- Consequently, ıt was seen that biomass and those chars may be burned with high efficiency in the agitated bed.

5. References

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