Fast Pyrolysis of Turkish Hazelnut Shell by Using Novel Wire Mesh Reactor

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Abstract— The present paper studies fast pyrolysis of Turkish hazelnut shell under various conditions in a novel wire mesh reactor (WMR). Particular emphasis was given to understand volatile yield at high heating rates at elevated temperatures. Volatile yields from fast pyrolysis (~3000 ºC/s) showed higher values from both as received (80 wt.%) and dried fuels (85 wt.%) than proximate analysis (PA) (75 wt. %) done at low heating rates (20 ºC/min). Brunauer–Emmitt–Teller (BET) surface analysis was carried out to determine surface areas from the chars obtained from WMR tests.

Keywords— hazelnut shell, fast pyrolysis, volatile yield, BET analysis, wire mesh reactor

I. INTRODUCTION

Turkey has a wide variety of biomass sources, including olive residue, almond shell, hazelnut shell. Therefore, over recent decades governmental projects are more prone to be focused on biomass technology. Based on the data provided by Turkish Grain Broad [1], from 2012 to 2016, the average annual production rate of hazelnut in Turkey was 537,400 metric tons, which also comprises 67% of the global average annual hazelnut production. Therefore, in Turkey, hazelnut shell can be used as a biomass source to obtain a clean energy. Hazelnut has a high heating value of approximately 19,300 kJ/kg found by the experiments and also calculated by equation (1) as presented by Demirbaş [2]. Hence, this work is focused on characterization of hazelnut shell at high heating rate pyrolysis.

$$HHV = \{33.5[C] + 142.3[H] - 15.4[O] - 14.5[N] * 10^{-2} \quad (1)$$

In recent years, wire mesh reactor became a widely used approach in pyrolysis experiments. Motivation of using it in the present work, is easiness of obtaining high heating rates, which resembles a real-life power plant environment. Rapid pyrolysis at elevated temperatures plays a key role as it happens during the first stages of combustion and gasification processes. Therefore, pyrolysis conditions significantly influence char yield and their reactivity [3]. Present study aims to report volatile yields from hazelnut shell and BET surface area of obtained chars upon pyrolysis.

II. MATERIALS AND METHODOLOGY

A. Biomass Sample Preparation

In this study hazelnut shell obtained from Trabzon province of Turkey was characterized as a biomass source in pyrolysis experiments. Fuels were chopped with kitchen chopper and ASTM standard sieves were used to get the size range of 106-125 µm. Due to the small particle sizes, particles' temperature assumed to be uniform throughout the experiments. BET (Brunauer–Emmitt–Teller) analysis was performed to get the surface area of obtained chars and parent fuel. Ultimate and proximate analyses were carried out at METU Central Laboratory based on standard procedure and are shown in Table I.

TABLE I
ELEMENTAL ANALYSIS OF HAZELNUT SHELL

Proximate Analysis (as received, wt.%)	
Moisture	5.5
Volatile matter	75.1
Fixed Carbon*	18.5
Ash	0.9
Ultimate Analysis (dry basis, wt.%)	
C	48.0
H	6.3
N	0.4
S	0.0
O*	45.4

* Calculated by difference

B. Experimental Approach

Wire mesh reactor (WMR) shown schematically in Figure 1, was used under different conditions to carry out pyrolysis of hazelnut shell to obtain the char. During experiments, stainless steel (SS316) and high purity (>99.99%) molybdenum wire meshes were used. Wire meshes have an aperture size of 40 µm which prevents loss of particles in the range of 106-125 µm. Two different mesh types were used due to their durability at different maximum temperatures, 1200 ^{0}C and 1600 ^{0}C. Wire meshes, were cut into sizes with an area of 75x40 mm in order to collect sample of char.

Parts of the reactor are; 1- two wire meshes placed on top of each other to hold the sample in between and heat the sample, 2- R type thermocouple with 125 µm wire diameter was welded to the bottom mesh in order to measure the temperature, 3- electrodes which were made of copper to conduct current to the mesh, 4- a chamber that was made of glass to create a desired inert atmosphere for the pyrolysis, and 5- a vacuum pump in order to create vacuum inside the chamber which will then be filled with desired inert (N_2) atmosphere see Figure 1.

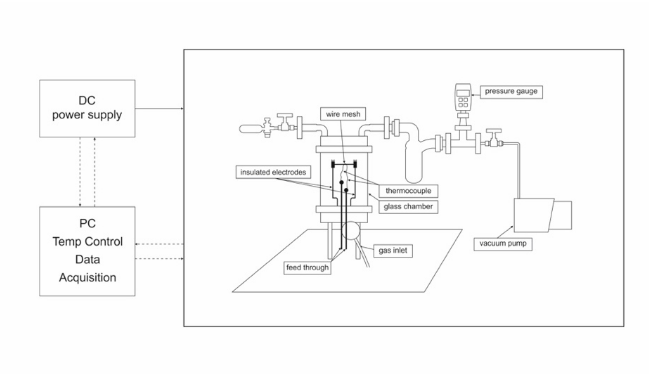

Fig. 1 Schematic overview of wire mesh reactor (WMR) with control system

Electrodes transmit high current from a DC power source to the mesh. Since atmosphere inside the glass chamber is controlled, vacuum tight connection elements were used for the thermocouple and electrodes. Temperature values measured by the thermocouple were recorded using LabVIEW software.

Hazelnut shell pyrolysis experiments were conducted in a wire mesh reactor (WMR) with low residence time, 5 seconds, at high temperature and high heating rate conditions. To decide on minimum residence time for complete pyrolysis of 106-125 µm particle range, preliminary analyses were performed at different holding times 3, 5 and 10 seconds. Volatile yield content almost stayed at a constant value for residence times above 5 seconds as depicted in Fig. 2. Therefore, pyrolysis experiments in the current study were conducted for 5 seconds.

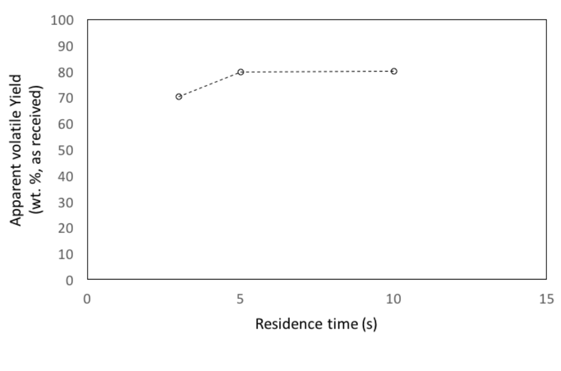

Fig. 2 Influence of residence time on volatile yield of hazelnut shell pyrolyzed in WMR

III. Results and Discussion

C. *Apparent Volatile Yield*

Several pyrolysis experiments were carried out under two different temperature (1270 ºC, 1550 ºC) conditions with the particle size range of 106-125 µm by using wire mesh reactor (WMR). Heating rate was around 3000 ºC/s for the experiments. In order to understand effect of moisture content over the chars, both dried and as received fuels were used in the experiments. Equation (2) was used to calculate volatile yield from pyrolysis. Moisture content of as received hazelnut shell was 5.5%, obtained from proximate analysis. To calculate the volatile yield of a dried fuel pyrolysis, moisture content in the equation was neglected.

$$Volatile\ Yield\ [wt\%] = [1 - char_{wt.\%} - moisture_{wt.\%}] * 100 \quad (2)$$

Apparent volatile yields from high heating rate WMR pyrolysis and low heating rate (20 ºC/min) proximate analysis (PA) were presented in Fig. 3. To study the influence of a heating rate on volatile yield, results from WMR were compared with proximate analysis (PA). As seen from Fig. 3, WMR results showed higher yield values which are 85 wt. % from dried fuel and 80 wt.% from as received than proximate analysis (75 wt. %). Similar trend was also observed in a work from Trubetskaya et al. [4] and the reason was explained that at high heating rates and elevated temperatures, enhanced devolatilization may cause high volatile yields in WMR. Moreover, as clarified by Trubetskaya et al. [5], pyrolysis in proximate analysis takes place at a low heating rate with a temperature of 950 ºC, which may reduce volatile yield by implementing secondary reactions of tar. Based on a study carried out by Laurendeau [6], high volatile yield may also be due to the gasification of char-CO_2, since in the reactor CO_2 together with pyrolysis gases present at high temperatures (1270 ºC, 1550 ºC) which is higher than minimum required temperature of char-CO_2 gasification. Similarly, in the study of Gil et al. [7, 8] char-CO_2 gasification was the reason of getting high volatile yields from different biomass chars.

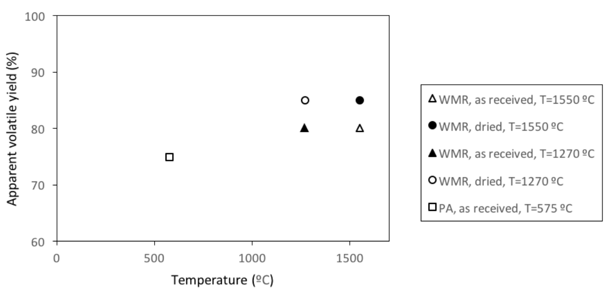

Fig. 3 Volatile yield with respect to temperature for hazelnut shell pyrolysis at 5 seconds

D. *BET Surface Analysis*

Using Brunauer–Emmitt–Teller (BET) analysis through nitrogen adsorption, surface areas of each char samples obtained from as received and dried fuels pyrolyzed at 1270 ºC and 1550 ºC were measured. Results are tabulated below in Table II.

TABLE II
BET SURFACE AREAS OF PARENT FUEL AND CHARS

Chars and parent fuel	BET Surface area (m^2/g)
Parent fuel, AR	3.0
WMR, AR, T=1270ºC	15.0
WMR, Dried, T=1270ºC	23.0
WMR, AR, T=1550ºC	15.0
WMR, Dried, T=1550ºC	7.8

In accordance to literature [9-13], BET surface areas of biomass chars obtained at high heating rates, presented high values (95-275 m^2/g). However, in the present work, low char surface areas were observed from BET analysis. As concluded by Zhai et al. [14], during high heating rate pyrolysis fast release of large amount of volatiles causes creation of macropores which results in crash of micropores. As a consequence, char surface areas may reduce. Similarly, in the present study, low surface areas and no micropores were observed in the chars obtained at high heating rates (~3000 ºC/s).

Furthermore, from Table II it can be deduced that, BET surface areas of as received (AR) hazelnut shell chars were the same (15 m^2/g) at two different pyrolysis temperatures (1270ºC, 1550ºC) since they also present same char and volatile yields similarly concluded in the study done by Trubetskaya et al. [15]. However, surface areas of the chars obtained from dried fuels seems to be affected by different pyrolysis temperatures. While the surface area of the char obtained from T=1270ºC condition increased to 23 m^2/g with decreasing moisture content, a decrease to 7.8 m^2/g with decreasing moisture content was recorded in surface area of the char pyrolysed at T=1550 ºC.

Considering effect of moisture content, based on results obtained by Burhenne et al. [16], char surface area increased with increasing moisture content, where the same trend (increase from 7.8 m^2/g to 15.0 m^2/g) was observed in the current study between dried and as received chars obtained at pyrolysis temperature of 1550ºC. However, comparing char surface areas of dried and as received fuels obtained at T=1270ºC; reverse trend, increase in surface area with a decrease in water content was observed.

IV. CONCLUSION

Fast pyrolysis of Turkish hazelnut shell in wire mesh reactor (WMR) under different conditions were studied in this work. In preliminary experiments 5 seconds were determined to be sufficient for a complete pyrolysis of hazelnut shell of 106-125 µm particle size range. Volatile yield content was determined for as received and dried fuels and compared with proximate analysis (PA) result. Both volatile yields from as received and dried fuels were higher than PA which was due to high devolatilization rates at fast pyrolysis conditions in WMR. BET analysis was performed to obtain char surface areas. Effect of high heating rate conditions result in low surface area char yields.

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