Fuel 142 (2015) 145–151

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Experimental investigation of wood pellet swelling and shrinking during pyrolysis

Rolandas Paulauskas *, Algis Džiugys, Nerijus Striūgas

Laboratory of Combustion Processes, Lithuanian Energy Institute, Breslaujos Str. 3, LT-44403 Kaunas, Lithuania

HIGHLIGHTS

- The wood pellet changes in the radial direction during pyrolysis was captured with the digital camera.
- The swelling phenomenon of wood pellet was observed during pyrolysis.
- Heating temperature of pyrolysis influenced the radial swelling and shrinking of wood pellet.
- The estimated peaks of the heating rates indicate the chemical processes and their intensity inside the wood pellet.
- A discussion was given for the mechanism of the wood pellet swelling phenomenon during pyrolysis.

ARTICLE INFO

Article history:
Received 9 July 2014
Received in revised form 30 September 2014
Accepted 5 November 2014
Available online 17 November 2014

Keywords:
Wood pellets
Pyrolysis
The center temperature
Swelling
Shrinking

ABSTRACT

Gasification of wood pellets in downdraft gasifier is confronted with the problem of granulated fuel agglomeration. It occurs when the wood pellets are moving from the pyrolysis zone to the oxidation zone and pellets stick together in lumps, which disrupts the movement of fuel and stops further process. In order to investigate the cause and regularities of fuel agglomeration, experimental studies of wood pellets thermal deformations during pyrolysis were carried out. Experimental studies were performed in an electrically heated horizontal tubular furnace from 300 °C to 1000 °C temperature in an inert atmosphere capturing wood pellet thermal deformations by a digital camera. During investigation the center temperature of the pellet was also measured. Analyzed results showed that wood pellet final diameter decreased when the heating temperature increased. It was also established that the pellet expanded from 400 °C to 900 °C heating temperature at the beginning of pyrolysis process. The maximum swelling effect was reached at 550 °C temperature and after it swelling intensity was decreasing till 900 °C temperature. Over 900 °C heating temperature, the expansion phenomenon was no longer visible. The tendency of wood pellet size alteration (swelling and shrinking) depends on heating temperature.

The obtained results explain the reason for adhesion of wood pellets in the gasifier and reveal regularity of wood pellet size changes with increasing heating temperature.

1. Introduction

Renewable fuel resources are widely used to produce electricity and heat. The growing demand for these stocks and their price results in searching for ways how to use low-quality biofuels. One of the ways is gasification [1]. During this process, the solid fuel is gasified and turned into higher quality gas, which is used to generate heat or electricity. However, use of granulated biofuel for the gasification results in fuel agglomeration that stops the entire process. More often agglomeration problem occurs in hoppers [2] when the particulate solid fuel forms a stable structure interfering the movement of the fuel. The blockage of fuel movement is caused by different size and shape of particles, moisture content and incorrect designed transport system. The problem is avoided by improving the fuel transport system in several ways [3]: use of nitrogen flow to flush the fuel or brake the fuel blockage, or the fuel vibration powered by an eccentric motor. Many publications have also reported that the agglomeration phenomenon occurs in the oxidation zone due to the use of fuel of high ash and moisture content [4,5]. When the temperature is too high, the fused ashes form slag, which grows and thus stops the gasification process. In order to avoid slag formation, the temperature of oxidation zone is decreased by a large quantity of steam or an additional system of ash removal is installed to the gasifier [6–8].

* Corresponding author. Tel.: +370 37 401875; fax: +370 37 351271.
E-mail address: paulauskas.r@mail.lei.lt (R. Paulauskas).

http://dx.doi.org/10.1016/j.fuel.2014.11.023

However, the wood pellet gasification tests showed that wood pellets stick together moving from the pyrolysis zone to the oxidation zone due to the initial expansion of pellets and stop the further gasification. This fuel agglomeration problem is commonly encountered in the gasification of pellets made from recycled waste [9]. However, much more studies of wood or straw pellets size changes due to high temperature are published. Several researchers investigated thermal deformations of wood particles during pyrolysis at 700 °C temperature [10]. The cylindrical particles with a diameter of 25 mm, length of 300 mm, were prepared from 150 mm diameter birch trunk. The prepared sample was inserted in an electrically heated vertical furnace with an inner diameter of 150 mm and a height of 1100 mm, where was created an inert environment. The temperature was measured by five thermocouples installed at the sample surface and by one seated in the center of the sample. The results showed that wood particle heated up to 700 °C during 800 s and shrank till 20 mm in the radial direction. Longitudinal shrinkage was not observed. Davidsson and Pettersson [11] performed a more detailed study of the shrinkage of cubic wood particle during pyrolysis from 350 to 900 °C temperature. The wood particle ($\sim$5 mm) was inserted into the stationary temperature vertical pyrolysis reactor on alumina plates, which was connected to the scales. Particle size changes were captured through the window by the digital camera installed in the reactor. According to the obtained data, the authors [11] found that the wood particle lost from 45% to 70% of its initial volume, and established the shrinkage of the particle in three directions: longitudinal shrinkage varies from 5% to 25%, tangential – from 25% to 40% and radial – from 15% to 40%. The most intensive shrinkage of particle in the radial direction was measured in 500–700 °C temperature range. Authors Kumar et al. [12] researched changes of wood particle size during combustion process at 650 °C, 750 °C and 850 °C temperature. The wood particles of shapes like cylinder ($l/d \sim 1$), disk ($l/d = 0.2$–0.67) and rod ($l/d = 2$–10) were used for investigation. The particle was weighed and its size was measured before the experimental test. The particle dimensions varied from 5 to 100 mm. The prepared sample was inserted into a special basket made from 1 mm wire in the combustion reactor where the required temperature and air content were maintained. The view of particle ignition moment and combustion process was monitored from a mirror system. After extinction of the volatiles flame, the basket with the particle was removed from the reactor and the residual size of the particle was measured. The experiment results showed that the particle shrinkage in longitudinal direction depended on the particle length: the longitudinal shrinkage varied from 17% to 11% due to the variation of length from 8 mm to 20 mm. The radial shrinkage varied from 14% to 28.6% with the increase of the particle's length and diameter ratio. Wood particle lost from 38% to 58% of its initial volume irrespective of its length and diameter ratio during the combustion process. Scientist group from Sweden [13] presented the recovered solid waste pellets with 8 mm diameter swelling and shrinking investigation during pyrolysis in 500–900 °C temperature range. The sample was placed on a holder in the horizontal pyrolysis reactor, where the constant temperature and nitrogen flow were maintained. The holder was connected to the digital scales for pellet mass change recording and the pellet surface and center temperature was measured by K-type thermocouples during the pyrolysis process. The change in the size of the pellet was captured by the CCD camera and the collected data analyzed using the ImageJ software. Obtained results showed that the recovered solid waste pellets expanded to 54% of the initial volume per 70 s at 550 °C heating temperature and after that the particle shrank to the initial volume value per 80 s. The swelling of the pellet reached 58% of the initial volume per 40 s at higher heating temperature (660 °C). For comparison purposes, the authors repeated the experimental investigation with the straw pellets. The tendency of the straw pellet swelling and shrinking was different: the pellet expanded to 18% of the initial volume at 660 °C heating temperature and after that began to shrink till 44% of the initial volume [13].

The reviewed works mostly analyze the changes in size of wood particles [10–12], straw and recycled solid waste pellets [13] at high temperatures. In order to determine the origin of the adhesion of wood pellets due the expansion and find possible solutions to decrease the risk of the bridging, it is necessary to investigate size changes of wood pellets at high temperatures. According to this, experimental investigations were performed in the electrically heated horizontal furnace from 300 °C to 1000 °C temperature at an inert ambient. The wood pellet with 6 mm diameter was captured by the digital camera during the pyrolysis process and the obtained results are presented in this paper.

2. Experimental methodology

2.1. Sample characterization

The tested material for research was pellets made from softwood sawdust. The diameter of samples varied from 6.1 to 6.4 mm, length from 15 to 17 mm. The material analyzes were performed using an IKA C5000 calorimeter, a Flash 2000 CHNS analyzer and a NETZSCH STA 449 F3 Jupiter thermogravimeter (TG, DTG,) coupled Fourier-transform infrared (FTIR) spectrometer Bruker Tensor 27 with external TGA-IR module (Gran Schmidt) in accordance with: LST EN 14774-1 (moisture content), LST EN 14918 (HHV), LST EN 14775 (ash content), LST EN 15148 (volatile content) and LST EN 15104 (CHNS content) and obtained characteristics are presented in Table 1.

2.2. Research methodology

Investigation of pelletized wood fuel swelling and shrinking was carried out using the electrically heated horizontal tubular furnace Nabertherm RS 80/500/13 with a temperature control unit (measurement accuracy ±3 °C). A scheme of this experimental rig is shown in Fig. 1.

A working sillimantin tube (2) with outer diameter of 80 mm and length of 850 mm was mounted inside the furnace (1) with heating zone length of 500 mm; the tube was heated on both sides. One end of the working tube was supplied by a nitrogen flow, whose temperature with 2.2 °C accuracy was measured by an installed K-type thermocouple. The other end of the tube was left open for placement of a special pad with wood pellet and for capturing the sample size changes. The nitrogen flow of 7 l/min

Table 1
Characteristics of wood pellets in experimental investigation.

Parameter	Softwood wood pellets
Proximate analysis wt.%	
Moisture	5.2
Volatiles	79.2
Fixed carbon	15.2
Ash	0.4
HHV (MJ/kg)	19.0
Ultimate analysis wt.% (dry basis)	
Carbon	49.20
Hydrogen	6.20
Oxygen (diff.)	44.06
Nitrogen	0.08
Sulphur	0.06
Ash softening	
Temperature (°C)	1315