Air and oxyfuel combustion of torrefied biomass in new spiral combustion reactor

Eyersalem M. Gucho*, Eddy A. Bramer, Gerrit Brem

Department of Energy Technology,
Faculty of Engineering Technology, University of Twente,
Drienerlolaan 5, 7500 AE Enschede, The Netherlands

A new spiral reactor was designed to study visually the combustion characteristics of solid fuel. The ignition and combustion time of torrefied biomass was investigated under different temperature in O₂/N₂ and O₂/CO₂ atmosphere. High speed camera was used to determine the ignition and combustion time of the fuel. The ignition and combustion time decreases as the reactor temperature increases. Statistically describing, ignition time has lower standard deviation than combustion time as the former is mainly depend on the gas temperature and the availability of oxygen around. At lower temperatures between 500-600 °C sudden decrease in ignition time was shown, which was the lowest temperature where ignition commences. Finally, changing the gas composition from O₂/N₂ and O₂/CO₂ (both 21% O₂) showed increase in ignition time as the CO₂ has high heat capacity which lowers the temperature round the particle.

Keywords: biomass, torrefaction, ignition, oxyfuel

1. Introduction

Increasing CO₂ emission and the dwindling of fossil fuel reserve brings more attention to utilization of biomass energy in different energy producing sectors like in coal fired power plants. The combination of biomass co-firing and oxyfuel combustion has double effect in reducing the CO₂ emission from coal fired power plants. However, the combustion of biomass in enriched oxygen atmosphere has not yet demonstrated in large scale. Furthermore, some of the properties of the biomass hampers its utilization at high cofiring rate. Torrefaction, which is a thermal pre-treatment of a biomass helps to produce a material more similar to coal.

Several experimental techniques have been used to study the combustion characteristics of solid fuels like biomass or coal. Thermogravimetric analyser (TGA) , which is commonly used technique to study the reactivity, kinetics of the fuel using mass change as indicator. However, the heating rate is quite low to compare to actual boiler conditions. In contrast, drop tube furnace (DTF) with high heating rate close to actual boiler condition is used to study the ignition and burnout characteristics of solid fuel. However in DTF, it is difficult to measure the residence time of the particle experimentally. Most of the time CFD modelling are used to determine the residence time of the particle or assuming as the gas residence time, which leads to some errors. These days some optical access on the DTF are used to visualize the particles. However, this optical access location are fixed to one place.

* Corresponding author. Tel.: +31 489 3564; fax: +31 489 3663.
E-mail address: e.m.gucho@utwente.nl.
not the whole reactor makes difficult to follow the particle for the whole journey during its decomposition. Here we designed a new spiral reactor which takes the pluses from both TGA and DTF setup.

This paper will discuss the combustion characteristics of torrefied biomass at different reactor temperatures and gas compositions in new spiral reactor designed in our Thermal Engineering laboratory in University of Twente.

2. Experimental section

2.1. Material properties

For this investigation severe torrefied beech wood at torrefaction temperature 350 °C (STBW) and residence time of 10 min was used.

2.2. Experimental setup

A new spiral combustion reactor was developed to study visually the volatile and char ignition, and burnout behaviour of solid fuels. The reactor is made from quartz glass that facilitates the visual combustion study. The spiral shape makes the setup compact and easy to access during maintenance. The spiral reactor has a total length of 3.5 m in which the first 1.5 m from the outside diameter used as the gas preheater. The gas flow can be adjusted in different range depending on the requirement of the study. As it is shown in Fig.2 the setup consists of different parts, fuel injection with pressurised gas that is activated by electric signal from the computer. For visual observation, high speed camera with specification frame rate of up to 1000 frame/sec and with image quality of 460 x 460 pixel is used. The heating rate of the particle is ~1000 °C/s.

A single-particle experiment of (STBW) with particle diameter of 500-600 µm was carried out in temperature range of 500-950 °C. The experiment helps us to determine the effect of temperature on the ignition and combustion time. The ignition time is the time between the time at which the particle mixed with the hot gas till flash of the particle happens. The ignition time is the parameter which describes the reactivity of the fuel. The ignition time of the fuel depends on many process parameter like process temperature, initial volatile matter and gas composition. On other hand, the combustion time is the time between the flash occurred and till the flash disappears. In case of lower temperature the combustion time could not been seen as the residence time was not enough to be fully converted. The longer the combustion time, the char burnout efficiency in actual case will be low and vice versa for short combustion time.

3. Result and discussion

The statistical distribution is formulated from 50 test at each temperature. As it is shown in Fig2.(a) as expected the ignition delay moves towards to shorter time as the gas temperature increases to 950 °C. For temperatures between 500 to 600 °C the ignition time distribution decreases sharply and becomes narrow, which is the boundary temperature region for the ignition to commence. The ignition time also has shown small standard deviation compared to combustion time as ignition mainly depends on the availability of oxygen and the gas temperature around.
Fig. 2 Influence of reactor temperature on the ignition delay (a) and combustion time (b) for severely torrefied beech wood samples (STBW) in air atmosphere $d_p$ (500-600 µm).

Fig. 3 Influence of gas composition on the ignition delay for severely torrefied beech wood samples (STBW) $d_p$ (500-600 µm).

On the other hand, as shown in fig. 2 (b) the combustion time still shows decreasing trend as the temperature increases though the standard deviation slightly higher the ignition delay time. Finally, as shown in fig. 3, changing the gas composition from $O_2/N_2$ and $O_2/CO_2$ (both 21% $O_2$) showed increase in ignition time as the $CO_2$ has high heat capacity which lowers the temperature round the particle.

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