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Combustion behavior of different kinds of torrefied biomass and their blends with lignite

Asli Toptas, Yeliz Yildirim, Gozde Duman, Jale Yanik *

Faculty of Science, Department of Chemistry, Ege University, 35100 Bornova, Izmir, Turkey

HIGHLIGHTS

- Torrefaction process improved the reactivity of char combustion step of biomasses.
- No interaction between lignite and torrefied biomass at initial step of co-combustion.
- Poultry litters can be used as a solid fuel by mixture with lignocellulosic biomass.

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ABSTRACT

In this study, the combustion behavior of different kinds of torrefied biomass (lignocellulosic and animal wastes) and their blends with lignite was investigated via non-isothermal thermogravimetric method under air atmosphere. For comparison, combustion characteristics of raw biomasses were also determined. Torrefaction process improved the reactivity of char combustion step of biomasses. Characteristic combustion parameters for blends showed non-additivity behavior. It was found that the mixture of torrefied biomasses and lignite at a ratio of 1:1 had a lower ignition and burnout temperature than the coal-only sample. Although no interactions were observed between the lignite and torrefied biomass at initial step of combustion, a certain degree of interaction between the components occurred at char combustion step. Kinetic parameters of combustion were calculated by using the Coats Redfern model. Overall, this study showed that poultry litters can be used as a substitute fuel in coal/biomass co-firing systems by blending with lignocellulosic biomass.

1. Introduction

Turkey's domestic resource potential is 15.4 billion tons of coal and of this total 14.1 billion tons is lignite. And in energy consumption, coal has a share of 31.3% of energy consumption (http://www.enerji.gov.tr/). However, by 2023, government wants domestic resources to make up the main share rather than imported natural gas. Because of this, coal is now referred to as the energy source of the future in Turkey. But it is well known that combustion of brown coal causes significant greenhouse gas emissions. On the other hand, co-combustion of biomass with coal provides the reducing net CO_2 emissions from coal-based power plants besides it provides the most efficient and inexpensive uses of biomass. Because of the high content of volatiles and low sulfur in biomass, the combustion of biomass with coal also provides in reduction of NO_x and SO_2 emissions (Munir et al., 2010a,b). In addition, co-combustion is a very effective way to dispose of waste materials. Much work on co-combustion of coal with various lignocellulosic biomasses has been reported in literature, such as cotton stalk (Munir et al., 2010b), forest residues, olive kernel, and wood (Kastanaki and Vamvuka, 2006), fir wood (Taş and Yürüm, 2012), wastes from palm oil production (Idris et al., 2012), olive tree pruning (Vamvuka et al., 2014), pine sawdust and oat straw (Kubacki et al., 2012). There are technical challenges in co-combustion of biomass with coal in existing coalfired power plants. The most common challenges include: (1) poor grindability resulting in higher grinding energy requirements, (2) low energy density causing flame instabilities in the combustion chambers, (3) low biomass flowability and fluidization properties leading to difficulties in feeding biomass into combustors (Sarvaramini et al., 2014). All these downsides cause the difficulty of utilization of biomass. In order to eliminate these downsides, the quality of biomass can be improved by a pre-treatment process, such as torrefaction. Torrefaction is a slow pyrolysis process carried out at low temperatures, within a temperature range of 200–300 °C. Torrefaction

* Corresponding author. Tel./fax: +90 232 3888264.
E-mail address: jale.yanik@ege.edu.tr (J. Yanik).

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produces charry material which has lower moisture content and higher calorific value compared to the raw biomass. The low moisture increases the storage duration of the torrefied product. Furthermore, torrefaction greatly enhance the grindability of the treated biomass. It should be also noted torrefaction may led to release of a significant amount of chlorine in biomass as HCl. As known, biomass may have a high content of chlorine which is very undesirable in power plant fuels. It leads to formation alkali chlorides leading to corrosion during combustion. The studies related to pyrolysis of different types of biomass showed that between 20% and 60% of the chlorine was released at moderate temperature pyrolysis (Björkman and Strömberg, 1997; Jensen et al., 2001) as HCl.

It is clear that the use of torrefied biomass instead of raw biomass may be a preferred option in co-combustion with coal. The combustion behavior of blends of torrefied biomass and coal has not been studied so much (Sarkar et al., 2014a,b; Li et al., 2012; Goldfarb and Liu, 2013; Kastanaki and Vamvuka, 2006; Park et al., 2012; Farrow et al., 2013). More recently, Sarkar et al. reported that the use of rice husk char and sawdust char with lignite provides synergistic effect in burning performance (Sarkar et al., 2014a,b). They observed the lowering of activation energy and improvement of reactivity in major combustion zone for the co-combustion of blends an Indian coal with saw dust and rice husk. A case-study boiler showed that boiler can be operated with the blends containing high ratio of torrefied biomass without decreasing of energy efficiency and fluctuation of boiler load (Li et al., 2012). In the study on the oxidation kinetics of coal–torrefied biomass blends, it was observed that the activation energy for the initiation of thermal decomposition decreased sharply as the percent of torrefied biomass increased (Goldfarb and Liu, 2013). Park et al. (2012) reported that burnout time for the coal–torrefied biomass blend increased and ignition temperature decreased as the torrefied biomass ratio was increased.

Turkey is one of the biggest grape and olive producer countries in the world. So, huge amount of pruning residues (stem) from olive tree and vine may become an important energy resource in Turkey. Corncob also is the widely planted in Turkey.

These wastes are disposed as burning on the field. Besides these plants, poultry production is an important and diverse component of Turkey agriculture as world agriculture. Today, most of the production of poultry is carried out by a large number of farmers. The intensification and concentration of poultry operations pose major pollution problems at regional and global scales. The waste produced by farmer raises serious concerns about treatment and disposal. Traditionally, farmers have managed manure by spreading it on fields. But the intensive poultry production is resulted in more manure than agriculture can use. Poultry manure is produced during the normal operation of hatcheries, broiler production and egg laying production. There is a difference in the set-up of layer and broiler operations which leads to a difference in the type of litter produced. The manure from chicken broiler (broiler litter) is a mix of poultry excreta, spilled feed, feathers, and bedding materials (straw, sawdust, etc.), while the other (laying hens litter) contains only poultry excreta. Laying hens litter is relatively dry as it falls through layer cages into a concrete storage area. A growing legal restrictions for poultry manure are inducing the search for appropriate methods of disposal. The previous study dealing with co-firing of broiler litter and coal in a circulating fluidized bed combustor (CFBC) showed that co-firing in an existing CFBC boiler firing coal is a good way to utilize litter (Jia and Anthony, 2011). Co-combustion of all these wastes with lignite is an effective alternative to decrease both the dependence on oil and environmental pollution.

Thermal gravimetric analysis (TGA) is effective way to analyze combustion behavior of different kinds of fuels. In this study, we used thermogravimetric analysis to investigate the combustion characteristics of both raw- and torrefied-biomasses and their blends with coal. Different types of biomass were investigated. The main objective of this paper is the study of agricultural and animal wastes as potential substitute fuels for co-combustion with coal. To the best of our knowledge, there has been no study on the combustion and co-combustion behavior of torrefied-biomasses used in this study.

2. Methods

2.1. Materials

The solid fuels used in this study included a Turkish lignite (from the Soma basin), vine pruning (VP) and olive tree pruning (OP), corn stalk (CS), poultry litters (broiler litter – BL and laying hens litter – LL). Poultry litters were kindly provided by CP Group, Izmir, Turkey. Agricultural wastes were collected from the agricultural fields of Izmir, Turkey.

Prior to experiments, the coal and biomasses were previously dried at room temperature and ground to <2 mm, then in a drying oven at 105 °C overnight. Dry samples were further ground to <250 μm, and then they were stored in sealed containers until use. The characteristics of biomasses and lignite are given in Table 1.

2.2. Characterization of materials

Proximate analysis of samples was made according to standard analysis methods; thus ASTM D3174-04 for ash analysis and ASTM D3175-89 for volatile matter. The gross calorific values of samples was determined using an IKA C-2000 basic model calorimeter according to ASTM D240-02. The elemental analysis was carried out by a LECO CHNS 932 elemental analyzer according to ASTMD 5291-96. The ash content was analyzed by Atomic Absorption Spectrometry (A.A.S.) following acid digestion. Component analysis (extractives, lignin, hemicellulose, and cellulose) was carried out according to TAPPI standards.

2.3. Torrefaction

Torrefaction experiments were carried out in a stainless steel 1 L vertical reactor which was a fixed bed design at 300 °C with a reaction time of 30 min. In a typical run, 50 g of biomass was placed into the reactor and then the system was heated to 300 °C under N_2 atmosphere at a heating rate of 5 °C min^{-1}, and held at this temperature for 30 min. After then, reactor was cooled down under nitrogen gas stream. The amount of resulting char product (torrefied biomass) were determined by weighting and then were ground to <250 μm and stored in sealed containers until further analysis. For torrefaction, the temperature of 300 °C was selected, taking into account the mass yield and energy yield which is defined as fuel value of solid product (biochar) as a fraction of fuel value of raw biomass. The mass yield and energy yield of the torrefied-biomass are defined as follows:

$$\text{Mass yield, \%} = (\text{mass of biochar}/\text{mass of biomass}) \times 100 \qquad (1)$$

$$\text{Energy yield} = \text{mass yield of biochar} \times \left(\frac{\text{energy content of the biochar}}{\text{energy content of the biomass}}\right) \qquad (2)$$

2.4. Thermogravimetric analysis

Combustion characteristics of biomasses and their blends with lignite were determined by a thermo gravimetric analyser (Perkin