Energy 165 (2018) 303–313

Contents lists available at ScienceDirect

Energy

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

Oxidative torrefaction of briquetted birch shavings in the bentonite

Alexandr Leontiev [a], Boris Kichatov [a, b, *], Alexey Korshunov [a, b], Alexey Kiverin [a], Natalia Medvetskaya [a], Ksenia Melnikova [a]

[a] Joint Institute for High Temperatures, Russian Academy of Sciences, 125412 Moscow, Russia
[b] Moscow Institute of Physics and Technology (State University), 141701, Russia

ARTICLE INFO

Article history:
Received 22 June 2018
Received in revised form
18 August 2018
Accepted 15 September 2018

Keywords:
Biomass
Briquettes
Oxidative torrefaction
Energy yield
Biofuel
Bentonite

ABSTRACT

Oxidative torrefaction of briquetted birch shavings inside the quiescent layer of bentonite clay was investigated in a muffle furnace. In the considered process the briquettes are buried under the layer of bentonite clay and the reactor is heated at atmospheric conditions without the use of inert gas. The main role of the bentonite clay is to limit the oxygen access to the torrified biomass from the environment. The paper considers the effects of briquette thickness, bentonite layer height, temperature and torrefaction duration on the mass yield and energy yield of the biomass. It is shown that to increase the enhancement factor of HHV of the biomass it is necessary to reduce both the height of bentonite clay and the briquette thickness. As well the torrefaction temperature and duration should be increased. It is also established that the height of bentonite layer affects negligibly on the energy yield.

1. Introduction

The problem of climate changes related to the carbon dioxide emissions induces a certain interest to the issues of fossil fuels replacement with clean energy sources. Among all the renewable energies such as solar, hydro, wave and wind, biomass occupies an important place. Biomass is a renewable and carbon neutral energy resource which has high potential for replacing fossil fuels. Biomass is made up of organic matters in which energy is stored in form of chemical bonds through the photosynthesis process [1]. Biomass can be used in cofiring coal fired power plants to reduce carbon dioxide emissions and may even reduce fuel cost in some cases. However, direct utilization of biomass as a fuel is limited that is due to heterogeneity, hygroscopic behavior, low energy density, and fibrous nature of biomass [2]. Torrefaction is a thermochemical treatment process which allows one to overcome these shortcomings in raw biomass [3]. During torrefaction, hemicelluloses in biomass are decomposed into volatiles, whereas cellulose and lignin are dehydrated and partly decomposed [4]. Decomposition of hemicellulose helps in destroying tenacious and fibrous nature of biomass. Dispersed torrefied biomass can be utilized for suspension fuel formation on the water base [5]. In turn, harmful emissions formation can be significantly reduced when burning such suspension fuels [6–9].

Usually torrefaction process is carried out in a non-oxidative environment at temperatures of 200–300 °*C* [10,11]. However, as well the torrefaction can be carried out at limited content of oxygen in the gaseous phase (oxidative torrefaction) [12–18]. Herewith, a reduction in cost could potentially be achieved due to exothermic reactions of biomass oxidation.

As a rule, the reactors with indirect heating [18] or convective reactors [19,20] are used for torrefaction process. In the reactor with indirect heating, heat is transferred through the outer wall and/or through the pipes system set up inside the reactor. Inside the convective reactor, heat to the biomass is transferred from heated gas filtered through the biomass. Among disadvantages of this technique is the necessity to heat a significant amount of inert gas. As a result, gaseous products of pyrolysis inevitably occur to be diluted with an inert gas that makes it difficult to utilize them in future. Note that it is possible to realize oxidative torrefaction when using both types of reactors [18,19]. For example, Nhuchlen and Basu [18] studied the torrefaction of poplar wood in a batch reactor. To limit oxygen access to the torrefied biomass reactor was sealed. Heating of biomass inside the reactor was carried out in presence of air. Such a technique can be economically justified since one should

* Corresponding author. Joint Institute for High Temperatures, Russian Academy of Sciences, 125412 Moscow, Russia.
E-mail address: b9682563@yandex.ru (B. Kichatov).

https://doi.org/10.1016/j.energy.2018.09.103
0360-5442/

not heat the inert gas. The disadvantage of this process is the inevitable emergence of excess pressure inside the sealed reactor that is due to heating of moist biomass. When constructing the industrial reactors this demands significant expenses for equipment able to operate under excess pressure.

Properties of torrefied products depend on several factors such as biomass type, reactor type, torrefaction temperature, working environment, and residence time. Despite nowadays there are a lot of various techniques of torrefaction [20], commercial utilization of biomass torrefaction technology is limited and sometimes is not economically justified [21]. This is partly due to the fact that optimal process conditions have not been well established for the various concepts and feedstocks. In addition, there are significant environmental issues related to the problem of utilization of gaseous pyrolysis products.

One of the possible approaches aimed to solve problems mentioned above is to utilize the technique of biomass torrefaction inside quiescent layer of bentonite clay. Within the framework of this technique, biomass inside the reactor is buried under the layer of bentonite clay with the characteristic particles size of 10 … 50 μm. In the process of torrefaction, the reactor is not sealed. Reactor heating is carried out through the outer wall and/or via a system of pipes inside the reactor (Fig. 1).

At the stage of reactor start-up, the system of pipes inside the reactor can be used to reduce heating time and to achieve more uniform temperature distribution. The main role of the mineral filler concerns two basic functions. On the one hand, bentonite favors more uniform temperature distribution inside the reactor that is due to the high heat conductivity of bentonite. Besides, clay microparticles limit the diffusion flux of oxygen towards biomass from the environment. Therefore, torrefaction can be carried out without the use of inert gas as well as without reactor sealing. It is important to note that in the considered process gaseous products of pyrolysis are not diluted with a large amount of inert gas. As a result, one can easily utilize them via afterburning or condensation. Gaseous products contain valuable chemical components – alcohols, aromatic compounds and carbon acids [22].

The technology of biomass torrefaction inside the layer of bentonite clay consists of several basic steps (Fig. 1). At the first step, wooden shavings are briquetted. Prepared briquettes are loaded into the reactor where they are covered by a layer of bentonite clay. After this, the reactor is heated up to the given temperature. To heat the industrial reactor it is necessary to use not only the outer shell but also the pipes system inside the reactor that would provide more uniform temperature field in the reactor. After torrefaction briquettes and bentonite are separated. For example, clay can be removed out from the reactor with use of pneumatic conveying. It should be noted that the necessity to utilize briquettes as an initial biomass for considered technology is determined as well by simplicity of the mineral filler and biomass separation. Torrefied briquettes are fragmented before burning inside the furnace.

The aim of this work is to study experimentally the process of torrefaction of briquetted birch shavings in the bentonite. Here we analyze the effects of briquette thickness, temperature and duration of torrefaction and height of bentonite layer on the mass yield and energy yield of the biomass. Main attention in the work is paid to the technology of briquettes torrefaction that is due to the set of reasons. Although torrefaction leads to a higher calorific value on a mass basis, it does not increase the volumetric energy density of the biomass much. Briquetting allows significantly increase the volumetric energy density, to facilitate easy storage and handling, to reduce the transportation cost [23–28]. Densification is also desirable because it reduces dust formation and increases mechanical strength of the product [29,30].

2. Experimental section

2.1. Biomass sample

As an initial raw material for torrefaction briquetted birch shavings were used. Briquette thickness was changed in the range from 3 to 6 cm. Before torrefaction briquettes were dried for two hours at the temperature of 105 °*C* and were kept in a plastic bag to avoid change in initial moisture content of raw biomass.

2.2. Procedures

Fig. 2 shows a schematic of the experimental setup used. For biomass torrefaction the muffle furnace (*SNOL* 6/11-B, Russia) was

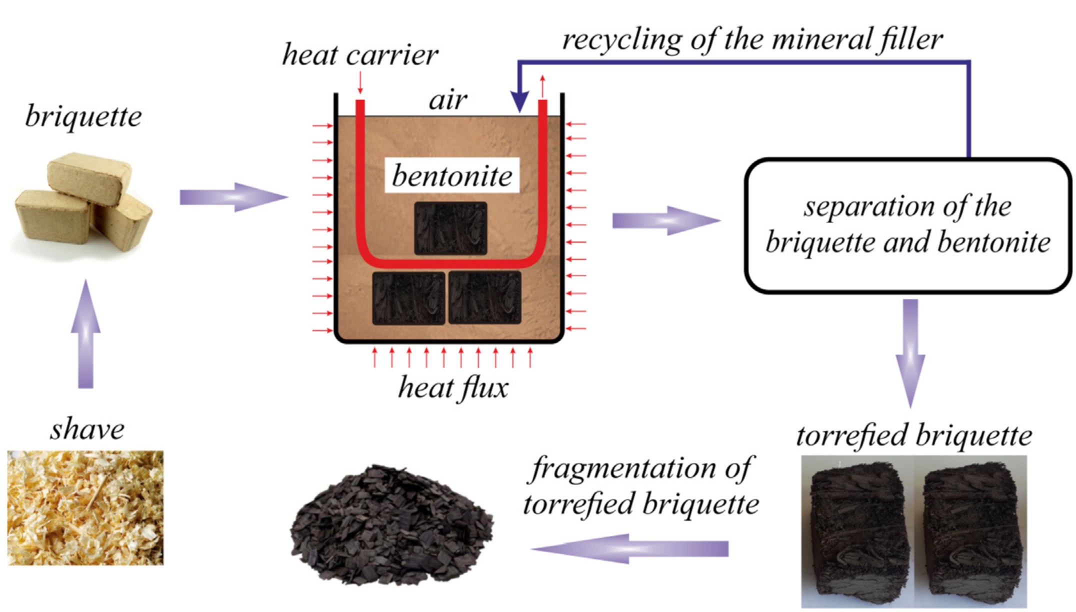

Fig. 1. Technological process of torrefaction of briquetted wooden shavings.