Renewable and Sustainable Energy Reviews 40 (2014) 153–160

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

A review on torrefied biomass pellets as a sustainable alternative to coal in power generation

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ARTICLE INFO

Article history:
Received 10 June 2013
Received in revised form
26 April 2014
Accepted 17 July 2014
Available online 12 August 2014

Keywords:
Biomass pellets
Torrefaction
Sustainability
Co-firing
Power generation

ABSTRACT

The torrefaction of biomass is a thermochemical process based on the de composition of hemicellulose, which is the dominant reaction, while the cellulose and lignin fractions remain almost unaffected. Torrefaction of biomass improves its physical properties like grindability, particle shape, size, and distribution, pelletability, and composition properties like moisture, carbon and hydrogen contents, and calorific value. The already higher energy density can be increased further by a pelletizing step after torrefaction. These improved properties make torrefied biomass particularly suitable for co-firing in power plants. Co-firing biomass with fossil fuels is one of the solutions to reduce the greenhouse gas emissions of existing power plants. Several studies on torrefaction of biomass for heat and power applications have been documented in the literature, which need to be reviewed and analyzed for further actions in the field, because significant gaps remain in the understanding of the biomass torrefaction process, which necessitate further study, mainly concerning the characterization of the torrefaction chemical reactions, investigation of equipment performance and design, and elucidation of supply chain impacts. This is the main objective of the present review study, which consists in three parts. The first part focuses on the mechanism of biomass torrefaction. It is followed by a review of biomass co-firing with coal. Finally, market opportunities for the process are discussed.

Contents

1. Introduction

Biomass as a sustainable energy resource has recently attracted more interest from both political and scientific perspectives. However, these biomass energy resources need special attention and more expensive solutions in terms of storage, handling,

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http://dx.doi.org/10.1016/j.rser.2014.07.181
1364-0321/

milling, and feeding compared to existing systems used for coal [1]. Especially in pulverized firing systems, size reduction of biomass material is much more demanding than for coal due to its fibrous and more tenacious structure. Other challenges with biomass include low energy density and great inhomogeneity of biomass fuels [2]. Torrefaction, also known and described as mild pyrolysis in many recent research studies [3–12], is a thermal conversion technique that allows to improve the energy density of biomass, consisting basically in the heating of biomass to moderate temperatures in the absence of oxygen and under atmospheric pressure. During the treatment, biomass starts to decompose and releases combustible volatile matter, mainly composed by organic compounds, together with moisture. Thereby, the energy density of the torrefied biomass is increased. Moreover, during torrefaction the structure of the biomass is changed, becoming powdery and thus much easier to grind [13]. This effect would lower the energy demand during size reduction of the biomass prior to combustion or pelletizing. Furthermore, if torrefaction is combined with pelletizing, the energy density of biomass fuels increases significantly and thus energy and emission savings could be made in the transport of fuel [14].

Torrefaction is a thermochemical treatment process that involves heating biomass at temperatures of 200–300 °C in the absence of oxygen, during which the biomass partly decomposes, releasing different types of volatiles [15]. The final product of the process is the remaining solid, which is referred to as torrefied biomass if it is produced from woody biomass [16]. Considerable energy densification can be achieved by torrefaction, as the remaining solid typically contains up to 90% of the initial energy content but only 70% of the initial weight of the biomass feedstock [17–19].

Biomass is completely dried during torrefaction and its hygroscopic nature changes to hydrophobic [20]. Uptake of moisture after torrefaction is very limited. This implies that biological degradation does not occur anymore. Torrefaction also improves the grindability characteristics of biomass, which can be a great advantage when co-firing with coal in existing coal-fired power stations [21–23]. Indeed, due to the increased calorific value, hydrophobic nature, and better grindability, the properties of torrefied biomass approach those of coal [24].

Torrefied biomass, usually in the form of woodchips, presents a low volumetric density, so densification is usually required to improve transport and storage conditions. Densification is also desirable because it reduces dust formation and increases the mechanical strength of the product [25,26]. Densification of torrefied biomass may be done through pelletizing [27,28].

The combination of both torrefaction and pelletizing stages results in the torrefied biomass pellets (TBP's), an energy dense biomass solid fuel with many similar properties to coal, such as high bulk and energy density, high calorific value, hydrophobic nature, and improved grindability compared to untreated biomass. These properties make TBP's an attractive fuel especially for co-firing in coal-fired power stations [29]. Because of these advantages, TBP's are attracting increasing interest.

The review of recent literature about new developments of biomass converting processes suggests that torrefaction is a promising technique to improve the performance of biomass for energy utilization [30–34]. Despite a number of important studies implemented as described above, there still remains a lot of torrefaction information that is not recognized in sufficient detail concerning economic issues of torrefied biomass [35–39]. Several studies have been documented and substantial amounts of data are available in the literature and need to be reviewed for further actions in this field, being this the main objective of the present study, which aims to significantly contribute by analyzing and gathering some of the most recent studies of biomass torrefaction, with emphasis on the mechanism of biomass torrefaction process applied to the particular case of co-firing with coal, and also about market opportunities and developments.

2. Torrefaction process

2.1. Raw materials

In theory and as stated in the studies previously referred, all lignocellulose biomass can be torrefied. In recent years, torrefaction of lignocellulose biomass has attracted more interest in research resulting from its potential applications. In order to recognize the role played by torrefaction in improving the properties of biomass, a number of studies have been implemented [40–41]. However, there are technological limitations on the allowable variation in feedstock properties. This implies that if a torrefaction plant is based on only one type of feedstock, its design can be specific. The type of biomass used has an impact on the mass and energy yield of torrefaction [42].

Woodchips are currently used in energy production, but through torrefaction and pelletizing, the properties of the fuel can be enhanced and a significant energy densification is achieved [43,44]. The main source of forest woodchips used in energy production is currently forestry waste [45–47] produced by chipping or crushing of woody material. The particle size of chips varies between 3 and 50 mm, depending on the raw material and the chipper [48].

The moisture content of woodchips is between 30% and 60%. The moisture content depends on the source of the woodchips and especially on the length of time for which the biomass has been left to dry on the harvesting site before chipping [49].

The energy content of woodchips depends on the moisture content: the higher the moisture content, the lower the lower heating value (LHV) which indicates how much energy can be obtained from the fuel upon combustion [50]. The bulk density of woodchips also depends on their moisture content: the higher the moisture content, the higher the bulk density [51]. Typical ranges for the moisture content, energy content, bulk density, and energy density of woodchips are presented in Table 1.

Although the potential of wood energy harvested is rather high, not all of this biomass energy is available at reasonable costs [52]. The greater the demand for woodchips, the higher the production costs tend to become, because the location of wood harvesting has to be extended further from the end user and to less favorable places [53].

2.2. Torrefaction and pelletizing

Torrefaction is a thermal pre-treatment method that improves the fuel properties of biomass and makes it more suitable for co-firing with coal. When combined with pelletizing, torrefaction results in energy-dense pellets with a high calorific value and other properties such as a hydrophobic nature and improved grindability characteristics compared to untreated biomass [54]. The torrefaction and pelletizing process consists of five steps:

Table 1
Properties of woodchips [19].

	Moisture content (%) wt	Mass density (kg/m^3)	LHV (MJ/kg)	Calorific value (MWh/t)	Energy density (MWh/m^3)
Woodchips	30–60	250–400	6–13	1.7–3.6	0.7–0.9