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Short communication

Bio-coal, torrefied lignocellulosic resources – Key properties for its use in co-firing with fossil coal – Their status

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ARTICLE INFO

Article history:
Received 29 March 2012
Received in revised form
6 April 2012
Accepted 11 May 2012
Available online 7 June 2012

Keywords:
Bio-coal
Torrefaction
Co-firing
Co-combustion
Grindability
Equilibrium moisture content

ABSTRACT

Bio-coal has received generous amounts of media attention because it potentially allows greater biomass co-firing rates and net CO_2 emission reductions in pulverised-coal power plants. However, little scientific research has been published on the feasibility of full-scale commercial production of bio-coal. Despite this, several companies and research organisations worldwide have been developing patented bio-coal technologies. Are the expectations of bio-coal realistic and are they based on accepted scientific data? This paper examines strictly peer-reviewed scientific publications in order to find an answer. The findings to date on three key properties of torrefied biomass are presented and reviewed. These properties are: the mass and energy balance of torrefaction, the friability of the product and the equilibrium moisture content of torrefied biomass. It is these properties that will have a major influence on the feasibility of bio-coal production regardless of reactor technology employed in production. The presented results will be of use in modelling commercial production of bio-coal in terms of economics and green-house gas emission balance.

1. Introduction

In recent years so-called *bio-coal* (or *green coal*) has received at lot of attention in the energy sector. To be clear bio-coal, as the name implies, is a fossil coal substitute which is produced from renewable biomass resources. It is considered a coal substitute because it can be handled and combusted in the same way as fossil coal in pulverised-fuel power plants without the need of additional infrastructure. Coal-like physical properties would permit much greater co-firing rates in these plants enabling substantial net carbon dioxide emissions. Additionally, bio-coal is assumed to be in pellet or briquette form in order to achieve greater bulk energy density (closer to that of lesser coal) for transport purposes. Herein when using the term *bio-coal*, it is this which is meant.

Serious investigation into bio-coal production began at the Energy Centre of the Netherlands (ECN) and resulted in an extensive ECN report on the topic in 2005 which is well-circulated and frequently cited [1]. The report focuses on the process at the heart of bio-coal production, torrefaction, which was demonstrated in France in the 1980s as a method of upgrading green wood as a fuel and reducing agent without the energy losses associated with traditional wood charcoal production [2].

Since ECN's activities began, which includes investing in their own bio-coal production process (the TOP process [3])

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0961-9534/$ – see front matter
doi:10.1016/j.biombioe.2012.05.004

Nomenclature

T	Torrefaction temperature (°C)
t	Torrefaction time (min.)
Δq	Relative heating value increase (%)
LHV	Lower heating value (MJ kg^{-1})
HHV	Higher heating value (MJ kg^{-1})
daf	Dry ash free
d_{50}	The particle diameters obtained from the cumulative distribution data at 50%
E_g	Specific energy consumption for grinding untreated material (kWh t^{-1})
E_g'	Specific energy consumption for grinding torrefied material (kWh t^{-1})
ΔE_g	Change in specific energy consumption for grinding (%)
HGI	Hardgrove grindability index (unitless)
m_{H_2O}	Mass of water content in fuel (kg)
m_{fuel}	Mass of dry matter in fuel (kg)
EMC	Equilibrium moisture content, m_{H2O} $[(m_{H2O} + m_{fuel})]^{-1}$
RH	Relative humidity (%)

several companies and other research organisations worldwide have been developing their own patented technologies. Proponents of renewable energy would like to know if the expectations of bio-coal are realistic.

This paper looks at some key findings. Recent peer-reviewed scientific publications are examined in order to review the experimental data on three key properties of torrefied biomass which are often touted by those promoting the technology. These properties will have a major influence on the feasibility of bio-coal production regardless of reactor technology employed in production. Herein some familiarity with torrefaction and proposed bio-coal production is assumed. The purpose is to answer the question: How well do recent experimental findings support some of the more popular claims made of bio-coal? The results presented here will be of use to those wishing to realistically assess commercial production of bio-coal, with regards to economics and green-house gas emission balance.

2. Materials and methods

Torrefaction is the thermal process, similar to coffee roasting, used to pre-treat biomass in bio-coal production. It has also been called incomplete pyrolysis but to be clear, torrefied biomass is not charcoal. Torrefaction is a distinct thermal regime using temperatures of 220–300 °C and, as in charcoal production, a low-oxygen atmosphere so that combustion reactions are suppressed. The result is literally a toasted product containing most of the initial volatile matter content, not carbonised char. A more extensive description of the process can be found elsewhere [1,4]. Typically the biomass is pelletised (or briquetted) after roasting to achieve a higher bulk energy density.

It is natural to compare bio-coal production with conventional wood pellet production so as to recognise the potential added value of torrefaction and determine feasibility. Bergman has done this using one possible economic production scenario [3]. Based on such comparisons, the expected benefits of torrefaction technology have been summarised qualitatively [5]. Some of these will depend strongly on process technology, location and feedstock making them a challenge to quantify without the hindsight of experience with demonstration plants. Nonetheless, physical properties which lead to three specific benefits can be evaluated quantitatively from recent scientific literature. The properties and their expected benefits are summarised in Table 1. These properties are the heating value increase (mass-energy balance), grindability and water-uptake ability (hydrophobicity) of torrefied biomass.

2.1. *Mass and energy balance (heating value increase)*

The mass and energy balance of torrefaction is important because it determines the heating value of the solid product and the required volumes of raw materials. The rationale of torrefaction is that the energy yield is greater than the mass yield; thereby resulting in an increase in the material's heating value. It has been shown that the mass yield is less because the most volatile compounds (which are the first to undergo thermal degradation) have relatively low energy content. These stem mainly from hemicellulose [6]. The gaseous products in torrefaction, so-called *torgas*, contain the energy extricated from the solid. Utilising the low heating value of these gases in the process is seen as a major aim in most bio-coal production schemes. Bergman has defined *autothermal operation* as the point where the energy needs for drying and torrefaction are met by the heating energy of the torgas [1]. This is assumed to be optimal operation for a given feedstock. Too little energy in the torgas necessitates an auxiliary fuel and too much means a loss of product. A commonly seen value of mass and energy yield (for woody biomass) is 70 and 90% respectively.

2.2. *Grindability of torrefied biomass*

The grindability of torrefied biomass is an important benefit for two reasons. Firstly, during the production of pellets made

Table 1 – The expected benefits of three key properties of torrefied biomass, modified from [5].

Key property	Expected benefit
Mass and energy balance	+ Improved heating value
Improved grindability	+ Reduced electricity use for size reduction + Enables displacement of fossil coal use
Lower equilibrium moisture content (EMC)	+ Reduced storage infrastructure investment + Higher received heating value