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Review

Biomass as an energy source in coal co-firing and its feasibility enhancement via pre-treatment techniques

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ABSTRACT

Biomass co-firing is recognised as a crucial technology to aid in curbing the use of fossil fuels, particularly due to its relative ease of implementation. This article provides an introduction to biomass and its use as a fuel – as with any fuel, this includes its characterisation and energy conversion. Key fuel properties, both chemical and thermochemical, are described. Combustion is the energy conversion technique that is focused on; the implications of biomass co-firing are discussed along with an overview of current co-firing technology. Biomass pre-treatment techniques are identified as a means of alleviating some of the drawbacks of co-firing, and this is the chief focus of this paper. A comprehensive review is carried out on torrefaction and leaching, which aim to enhance the physical/thermochemical and chemical properties of the biomass, respectively. Milling and pelletising are also looked at. Additionally, the practical aspects of implementing biomass pre-treatment are explored, and areas where further research work is needed are identified. The final section of the review is concerned with CO_2 avoidance, which is one of the key drivers behind adopting biomass co-firing.

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1. Introduction

The dual issue of greenhouse gas emissions and finite reserves has been driving a move away from the use of fossil fuels for energy. Combustion of fossil fuels is a major contributor to carbon dioxide (CO_2) emissions which has been linked to global warming and the ensuing climate change. The non-renewable nature of these fuels means that their reserves would be diminished in the foreseeable future; by some projections, coal would run out within a century [1,2]. Biomass is becoming an increasingly important contributor to the global energy mix, in light of it being both relatively carbon-neutral over its life cycle and renewable if grown sustainably. Biomass co-firing with coal is being recognised as a particularly attractive proposition for electricity generation since it provides an immediate and practical means of mitigating coal usage; existing coal power plants of several hundred MW can be used as opposed to the <100 MW capacity of contemporary biomass-only plants [3,4].

This paper aims to review biomass as an energy source in coal co-firing and its feasibility enhancement via pre-treatment techniques. The first two sections of the paper provide a comprehensive introduction to biomass and its physicochemical characterisation as a fuel. Following this is a review on current biomass co-firing technology and the difficulties encountered – biomass co-firing is not without its own set of drawbacks. These issues are primarily caused by the difference in properties between coal and biomass. To minimise the implications thereof, various biomass pre-treatment techniques have been investigated and implemented with success. Although there are a considerable number of studies on individual pre-treatment techniques such as torrefaction and leaching, there is a dearth of reviews carried out on the overall state of the art of biomass pre-treatment as a precursor to combustion or co-firing. Among the few existing reviews are those by Kargbo et al. and Tumuluru et al. [5,6]. The former was specific to rice straw, while the latter covered a wider scope encompassing emissions and policy matters as well. The major part of this paper is devoted to a more up-to-date, detailed review on pre-treatment techniques which are applicable to a wide range of biomass feedstock. Compared to that by Tumuluru et al., the present review aims to place a particular emphasis on torrefaction and leaching which are potentially two of the most important strategies to improve the fuel properties of biomass, and explores these two techniques in greater detail. The final section of this paper briefly explores the viability of co-firing as a strategy to reduce CO_2 emissions, which is a key driver in favouring biomass over coal.

2. Biomass

The term "biomass" refers to a solid product which is a combination of organic and inorganic matter. Its distinguishing characteristics are that it is formed by life processes (biogenic) and is contemporaneous (as opposed to fossil fuels such as coal) [7,8]. The most crucial biological process involved in the natural production of biomass is photosynthesis. Photosynthesis is the process by which the chlorophyll pigment in plant matter uses sunlight to convert atmospheric CO_2 and water (H_2O) to produce carbohydrates. What is essentially being carried out is that the energy in sunlight is being stored within chemical bonds in the carbohydrates formed. This energy can be recovered for human consumption by carrying out an appropriate process on the biomass, for example combustion. The cycle completes, and CO_2 and H_2O are once again produced, while the energy stored in the bonds is extracted.

As Pérez et al. describes, these carbohydrates are the basis of the biomass matter, and can be classified into three main groups – cellulose, hemicellulose and lignin (collectively termed lignocellulose) [9]. Hemicellulose consists of several sugars linked to form polymer chains. Cellulose is also a polymer, but consists primarily of glucose, and has a higher average molecular weight than hemicellulose. Lignin has the highest average molecular weight and consist of interlinked carbon chains and rings; it is also the most difficult to decompose into its constituents. These three classes of carbohydrates have different physical and thermochemical behaviours. Hence, depending on the relative proportions of each class present, different biomass varieties can have a wide range of characteristics.

Biomass can be classified into several different categories, but a typical breakdown would be:

- Woody biomass
- Herbaceous biomass
- Aquatic biomass
- Wastes – includes manure, sewage, refuse containing biological matter, etc.

The method of utilising a particular type of biomass typically depends on which of the above categories it falls into. An overview of biomass energy conversion options by McKendry explains the correlation between the type of biomass and the conversion method [10,11]. The moisture content is a primary deciding factor in choosing which energy conversion process to use, and the moisture present varies greatly from category to category. The latter two generally have the highest moisture content, and is more suited to biochemical methods (which do not require a dry substrate). Such methods include fermentation and anaerobic digestion. Anaerobic digestion is typically used for biomass with moisture content ranging from 80% to 90% [11]. Woody biomass has the lowest moisture levels, while herbaceous biomass has an intermediate range. Most industrial applications have been centred about thermochemical processes which utilise woody biomass and low-moisture varieties of herbaceous biomass. These processes include combustion, gasification and pyrolysis.

Combustion entails burning the biomass in the presence of oxygen (O_2), whereby the energy stored in the chemical bonds within the carbohydrate molecules is converted into heat and mechanical energy. Temperatures exceeding 800 °C can be reached. Gasification involves applying high temperatures (800–900 °C) in order to cause partial oxidation of the biomass. This results in the evolution of a gas which can be combusted as a fuel, or used to manufacture other chemicals such as methanol. Pyrolysis is a non-oxidative process, where the biomass is heated in an inert atmosphere to approximately 500 °C. The subsequent thermochemical decomposition results in the production of solid,