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Co-firing of pressed sugar beet pulp with coal in a laboratory-scale fluidised bed combustor

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HIGHLIGHTS

- Pressed pulp (71% moisture) has been successfully co-fired with coal.
- Maximum pulp proportion in the blend for successful operation was 50%.
- Effect of moisture can increase throughput of fluidised bed.
- No agglomeration observed during extended co-firing tests.
- NO_x emissions were observed to be reduced during co-firing.

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ABSTRACT

Relatively cheap, poor quality, unprepared biomass materials can be difficult to burn efficiently on a large commercial scale because of their variable composition, relatively low calorific values and high moisture contents. Consequently it is often necessary to co-fire these materials with a hydrocarbon support fuel to ensure stable and efficient combustion. Fluidised bed combustion (FBC) is a promising method for burning mixtures of fuels with widely differing individual characteristics although there is a need for further information on the "optimum" conditions for efficient operation as well as on the proportions of support fuel which should be used in particular applications. This paper is therefore concerned with co-firing of coal with pressed sugar beet pulp, (a solid biomass with an average moisture content of 71%), in a lab scale (<25 kW net thermal input) fluidised bed combustor.

The project was undertaken in collaboration with British Sugar plc. who operate a large coal-fired fluidised bed, with a nominal thermal rating of 40 MW, to generate hot combustion gases for use in subsequent drying applications. The combustion characteristics of different coal and pressed pulp mixtures were investigated over a wide range of operating conditions. For stable combustion the maximum proportion of pulp by mass in the blended fuel was limited to 50%. However under these co-firing conditions a fixed bed temperature can be achieved with 20% lower fluidising air (when compared with coal alone) since evaporation of the moisture in the pressed pulp provides additional cooling of the bed. This reduction in excess air will be beneficial for the output of the full scale plant at British Sugar since at present the flow rate of the fluidising air and hence the amount of coal which can be burnt is limited by high pressure drops in the bed air distributor system. The pressed pulp has relatively low nitrogen levels and hence a further benefit of co-firing is that NO_x emissions are reduced by about 25%.

Agglomeration of the bed can be a problem when co-firing biomass because of the formation of "sticky" low melting point alkali metal silicate eutectics which result in subsequent adhesion of the ash and sand particles. Consequently, longer term co-firing tests were undertaken with a 50/50 blended fuel by mass. Problems of bed agglomeration were not observed over the duration of these tests and moreover, scanning electron microscopy (SEM) studies indicated that the levels of alkali metals in the ash were relatively low.

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1. Introduction

As a result of the need to reduce carbon dioxide emissions from combustion processes there is currently widespread interest in the use of biomass materials in commercial and industrial heat generation processes. The technology can also often result in reduced emissions of NO_x and SO_x and a further environmental benefit can often be a reduction in the amount of waste which has to be sent to landfill. However the more widespread use of these "carbon neutral" fuels is restricted by the difficulty of burning relatively cheap, poor quality, unprepared biomass materials. These can vary from "batch to batch" in composition and fuel properties and often have high moisture contents and hence relatively low calorific values so that the stability and efficiency of the combustion process can be adversely affected.

Combustion of high moisture content biomass is a particular challenge and co-firing with a hydrocarbon support fuel is usually necessary. Consequently different systems have been investigated for efficient and reliable combustion of such mixtures of fuels with very different individual characteristics. The most widely employed method for commercial or general industrial applications (i.e. excluding large utility power generation) is the use of fluidised bed combustion (FBC) and this has been shown to satisfactorily burn a variety of alternative fuels [1].

Biomass has been successfully co-fired with coal on industrial scale but share of biomass in the combined fuel is very low. Co-combustion of biomass with coal has been studied in the past and few articles are available in open literature. Co-combustion of coal with switch grass [2], cattle feedlot [3], hardwood and softwood [4], forest residue (Pine bark) [5], meat and bone meal [6–9], poultry litter [10–12], municipal solid waste [13–16], wood chips [17], olive oil waste [16,18,19], rice husk [20], spent mushroom compost [21], wheat straw [22] and sewage sludge [23] among others have been reported. Although considerable effort has been made, there are still technical barriers to the large scale application of biomass as a fuel either alone or in combination with other fuels. Nevertheless further research is still needed to define the "optimum" conditions for co-firing of coal/high moisture biomass as well as on the proportions of support fuel which should be used in particular applications. Moreover, co-combustion of high moisture biomass particularly pressed sugar beet pulp, the subject of this study, has not gained much attention either by academic or industrial researchers.

Pressed Sugar Beet Pulp is a very high moisture content solid fibrous residue left after the raw sugar juice is extracted from sugar beet. Even after further mechanical de-watering this residue (so-called pressed sugar beet pulp) can typically contain about 71% moisture. This pressed pulp can then be sold as cattle feed following further drying and subsequent pelletisation.

However, depending upon the prices of cattle feed, need sometimes arises for alternative uses of this valuable biomass material. Few efforts have been made to produce biogas by anaerobic treatment of sugar beet pulp e.g. Stoppock and Buchholz [24], Hutnan et al. [25] and Brooks et al. [26]. Devrim [27] investigated the pyrolysis kinetics of the Yeni Çeltek lignite and sugar beet pulp blends prepared at different ratios (100:0, 80:20, 60:40, 40:60, 20:80, and 0:100) by thermogravimetric analysis (TGA) in nitrogen atmosphere. Yilgin et al. [28] studied co-pyrolysis of 50/50 (wt/wt%) pellets of Soma Lignite and sugar beet pulp (from a sugar plant in Elazig, Turkey) at 600 °C. However, combustion of sugar beet pulp has received very little attention. Jevic et al. [29] performed basic assessment of thermal efficiency and emissions parameters by combusting 65 mm briquettes of blend of wheat straw and 15% sugar beet pulp (wt/wt) in a 8 kW nominal heat output prototype of combustion accumulation stove SK-2 with upper after burning. Hrdlicka and Dlouhy [30] co-fired lignite and sugar beet pulp having 79.7% moisture, 1.21% ash and with energy value of 1.45 MJ/kg. Combustion of pulp alone was possible when moisture content of the pulp was reduced to 45% and its energy value increased to 8.5 MJ/kg. They co-fired lignite and pulp blends in 2 MW fluidised bed boiler with lignite to pulp ratios of 3:1 and 1:1.

Apart from Jevic et al. [29] described above, there is no authentic open literature on the combustion of pressed pulp primarily due to the reason that so far the pulp has been used as a feedstock for animals. However, an alternative use for the mechanically de-watered pressed pulp is to co-fire it in coal-fired fluidised bed combustor. Therefore the current project has been concerned with the fluidised bed combustion of blends of coal with solid pressed sugar beet pulp.

The main aim of the work was to determine the combustion characteristics and performance of different coal/biomass blends over a range of operating conditions such as fluidising velocity, bed temperature, fuel input and excess air levels. However, bed agglomeration and subsequent defluidisation can be a major problem due to the relatively high alkali metal content of some biomass materials [31]. Consequently, the potential likelihood of this problem arising with the present co-firing blends was investigated by observing the performance of the combustor over a longer timescale of about 56 h. In addition, scanning electron microscopy (SEM) was employed to determine the "pick up" of the alkali metals in the ash deposited on the bed sand particles.

2. Experimental details

2.1. The laboratory fluidised bed combustion test facility

The laboratory scale fluidised bed combustion test facility used in the project, see Fig. 1, has a maximum thermal input of approximately 25 kW when fired with coal. The fluidising gases (air under normal operation or combustion products from a gas burner during start up) are fed into the bed through four standpipes which are mounted in a water-cooled distributor plate. The bed of graded sand is 168 mm in diameter and the nominal bed height above the stand pipes was 200 mm. The fluidising velocity at normal operating temperatures can be varied over a range of approximately 1–4 m/s. The hot combustion gases are removed through a 2 m high over-bed (or freeboard) section before finally exiting through an extraction system fitted with an induced draft fan. The fluidised bed is insulated with fibre insulation to reduce heat losses to the surroundings. The combustor can readily be taken apart for the purposes of bed inspection, removal and replacement.

The test facility is extensively instrumented so that the flow rates of both the fuel and combustion (fluidising) air can be monitored. In-bed and over-bed temperatures at heights of 0.24 and

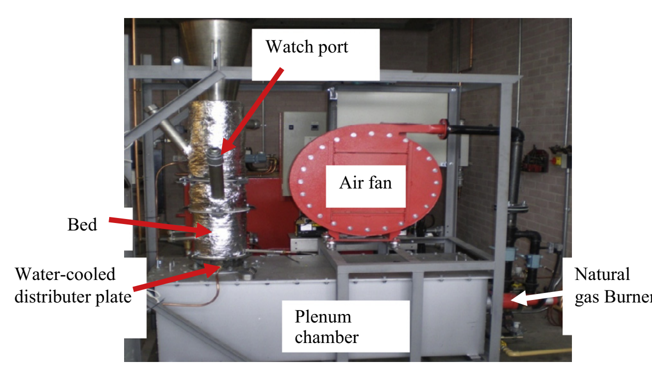

Fig. 1. The laboratory scale fluidised bed combustor.