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Jet flames of a refuse derived fuel

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This paper is concerned with combustion of a refuse derived fuel in a small-scale flame. The objective is to provide a direct comparison of the RDF flame properties with properties of pulverized coal flames fired under similar boundary conditions. Measurements of temperature, gas composition (O_2, CO_2, CO, NO) and burnout have demonstrated fundamental differences between the coal flames and the RDF flames. The pulverized coals ignite in the close vicinity of the burner and most of the combustion is completed within the first 300 ms. Despite the high volatile content of the RDF, its combustion extends far into the furnace and after 1.8 s residence time only a 94% burnout has been achieved. This effect has been attributed not only to the larger particle size of fluffy RDF particles but also to differences in RDF volatiles if compared to coal volatiles. Substantial amounts of oily tars have been observed in the RDF flames even though the flame temperatures exceeded 1300 °C. The presence of these tars has enhanced the slagging propensity of RDF flames and rapidly growing deposits of high carbon content have been observed.

1. Introduction

Fossil fuels are still the main source of energy conversion for the power industry and they are likely to be dominant for decades to come. Co-firing of fuels which are regarded as neutral for emissions of carbon dioxide may be one of a few low-cost options to achieve reductions in carbon dioxide emissions. The currently occurring increase of the fuel and energy prices has resulted in increased interest in secondary/alternative fuels to the extent that has never been observed before. Both co-firing and complete fuel substitution belong to the most relevant issues in industrial combustion. In Germany sewage-sludge, saw-dust, agriculture wastes and in particular refuse derived fuels (RDF) have been combusted with coals in cement-making plants on a regular basis. In the power industry the substitution levels are restricted at present to about 5% or less.

In Germany, the new legislative regulations, introduced in 2005, allow for waste disposal through landfill for biologically neutral wastes only. Thus the municipal solid wastes, commercial and bulky wastes have to be processed either in mechanical–biological or mechanical–physical waste treatment plants. Refuse derived fuels produced as pellets or fluff are the principal products of these waste treatment processes. Co-firing of RDFs with fossil fuels has become not only an industrial necessity but it also opens up options for decreasing overall fuel costs since plant/boiler operators are remunerated for the RDF usage. In short, RDFs have become very important secondary fuels of Europe.

There exist several reviews on co-firing of coal with biomass fuel blends as exemplified by Refs. [1,2]. However there are perhaps only a few publications directly related to the burner design. Abbas et al. [3] used a 0.5 MW thermal input down-fired furnace to examine the influence of the fuel injection mode on coal–biomass flames. Pine saw-dust and dry pulverized sewage-sludge were combusted with bituminous coal. Both secondary fuels were supplied to the burner through separate channels and two burner configurations were examined. In the first configuration, named as annular primary fuel (APF), a central secondary fuel jet was surrounded by an annular orifice that supplied the pulverized coal. In the second configuration named as central primary fuel (CPF), the central jet of pulverized coal was surrounded by an annular biomass stream. Gerhardt et al. [4] also studied the combined combustion of municipal sewage-sludge in coal dust furnace with emphasis on fuel handling, combustion characteristics and NOx emissions. In their trials the sludge provided up to 80% of the 500 kW total thermal input. Van de Kamp and Morgan [5] carried out trials at 2 MW thermal input and burned straw, waste paper and municipal sewage-sludge with two bituminous coals. The co-firing ratio varied from zero to 100% for both the straw and the sludge. The paper [5] focused on establishing the effect of co-firing on NOx, SOx emissions and char burnout in Type I and Type II (IFRF classification [6]) flames.

We are aware of only two publications where RDF was co-fired with pulverized coal. Wolski et al. [7] examined the effect of RDF share on partitioning of trace metals while Kupka et al. [8] investigated slagging propensity of a 5% RDF/95% coal blend. Some preliminary experiments on RDF–coal firing in a cyclone combustor were also carried out within the scope of the EEC PowerFlame2

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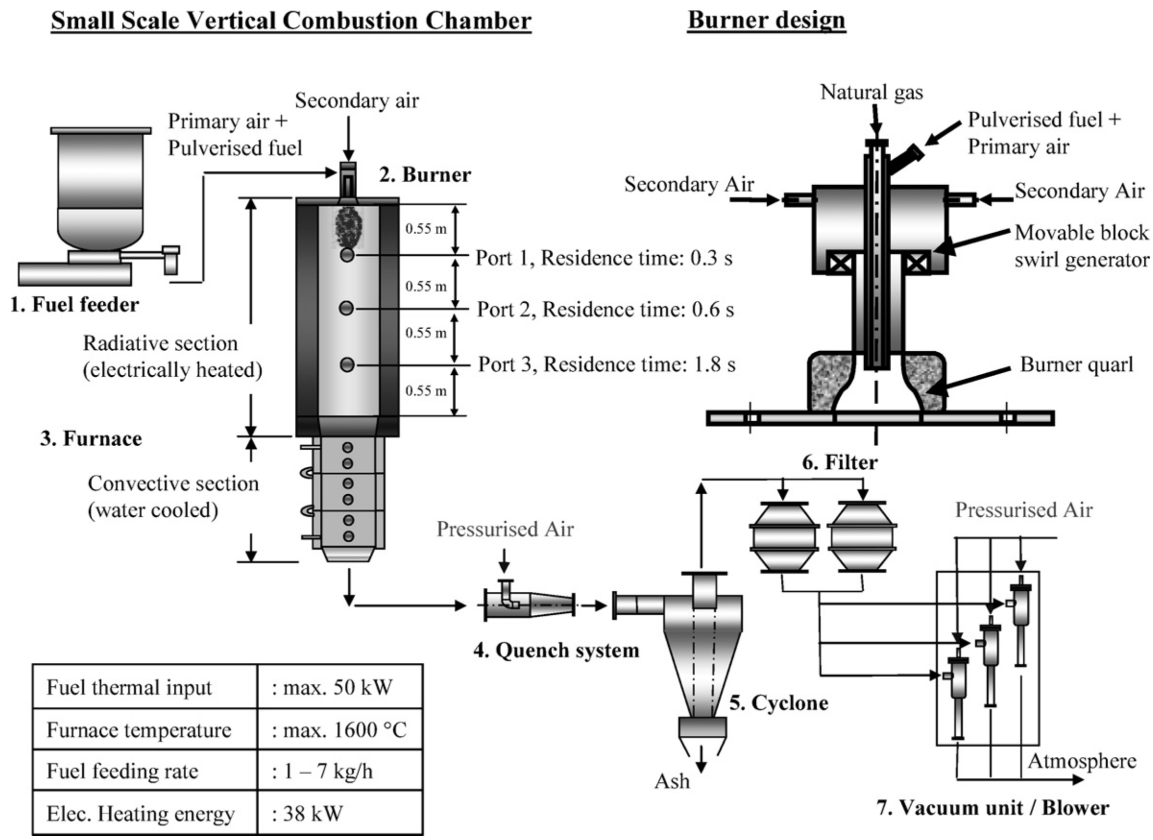

Fuel thermal input	: max. 50 kW
Furnace temperature	: max. 1600 °C
Fuel feeding rate	: 1 – 7 kg/h
Elec. Heating energy	: 38 kW

Fig. 1. A schematic diagram of the experimental rig.

project [9]. There exist several publications on chemical characterization of ashes produced during co-firing RDFs with coals as exemplified by the work of Norton et al. [10]. However, the literature on RDF firing is indeed scarce.

2. Objectives

Our paper is concerned with combustion of a refuse derived fuel in a small-scale flame. To the best of authors' knowledge this is the first time a RDF flame is created to establish its basic characteristics. Furthermore, we wish to provide a direct comparison of the RDF flame properties with properties of pulverized coal flames fired under similar boundary conditions. Such an approach facilitates a RDF characterization technique applicable to co-firing of pulverized fuels. There is an urgent demand for such a technique since the conventional fuel characterization methods based on TGA [11,12] are of a limited applicability to pulverized fuel firing. Similarly, the RDF combustion characterization in fixed beds [13–15] although informative and useful for grate fired stockers, is practically of no help for pulverized fuel firing.

3. Experimental

The essential parts of the rig (see Fig. 1) are: the fuel feeding system, the burner, the vertical furnace and the ash collecting facility. The pulverized fuel K-Tron feeder is used to provide a constant fuel flow rate to the reactor system. A screw feeder at the bottom of the hopper gently moves the bulk material to the large throat and then into the discharge screws. A twin screw system is used since it is particularly useful for handling difficult and hardly flowing fuels. The pulverized fuel is transported pneumatically to the burner (2) in an air stream coming from an air injector.

The furnace (3) consists of a vertical cylindrical combustion chamber that is fired from the top. It is divided in a high-temperature, 2.2 m-long radiative section of 0.3 m diameter made of a refractory material and a low-temperature, 1.8 m-long convective section of 0.25 m diameter which is made of a carbon steel. The radiative section is equipped with four heating elements to compensate for heat losses. The elements allow for setting up a required temperature profile along the radiative section. The heating elements have a thermal input of 8.8 kW each and withstand temperatures up to 1600 °C. The convective 1.8 m-long section is water-cooled using three independent jackets, which allow for co-current, counter-current and cross-flow cooling installations. The convective section's main purpose is to cool down the offgas to temperatures below 1000 °C. A direct quench system (4) is also installed to cool down the offgas to about 180 °C by means of pressurized air. The cooling is necessary to avoid exceeding operating temperatures of downstream equipment. Fly ash is collected in the offgas system consisting of a cyclone (5) and a filter (6) located just downstream the cyclone, to remove fine particles. As all above units cause pressure drops in the offgas system, a vacuum unit (7) is required to drive the flow through all reactor parts.

The properties of the RDF and the two coals fired are given in Table 1. One interesting facet is the relatively low fuel-nitrogen content (0.76%) and low sulfur content (0.04%) of the RDF. The particle size distribution of a South African bituminous Middleburg coal (Fig. 2) corresponds to a typical milling for such coals (75% < 75 μm). A German sub-bituminous Hambach coal is typically milled to coarser fractions (75% < 150 μm), as shown in Fig. 2. For our experiments the RDF has been shredded and milled to provide two size classes: particles smaller than 0.5 mm and not larger than 1 mm, as shown in Fig. 2, to facilitate the feeding through the burner. The RDF fired in our experiments is identical to the one used by Kupka et al. [8] and Morris et al. [9].

The burner is operated at a constant 15 kW fuel input. Fig. 3 shows the burner for the RDF flame (configuration B-1) and for pulverized coal flames (configuration B-2). In configuration B-2,