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Full Length Article

An approach to model the thermal conversion and flight behaviour of Refuse Derived Fuel

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HIGHLIGHTS

- Numerical models for combustion and flight behavior of RDF are presented.
- An extensive fraction based fuel analysis was carried out.
- Drag and lift coefficients were derived by drop-shaft measurements.
- Characteristic combustion phases and times were determined with a single particle reactor.
- The numerical models were applied to a full scale industrial boiler simulation.

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ABSTRACT

The current paper presents a simplified approach which allows the CFD simulation of Refuse Derived Fuel (RDF) combustion. The starting point is the subdivision of a real RDF into characteristic fuel fractions by sorting. Each of the fractions was analyzed concerning elemental composition, heating value, proximate analysis as well as size and shape. The flight behavior of the RDF fractions has been characterized in a drop-shaft. A stereoscopic camera system was used to derive drag and lift coefficients. In addition, a single particle combustion reactor has been used to measure the duration of the relevant combustion phases like volatile combustion or char burn-out.

A model calculating the particle trajectories based on the measured drag and lift frequency distributions has been developed. For combustion modelling the RDF has been subdivided into devolatilizing and char forming fractions and into fractions which are converting through a melting and decomposition process. For both types of materials combustion models have been formulated. Intra particle temperature gradients are accounted for. A change of particle shape during combustion is considered using sphericity as a model parameter. The models have finally been introduced into FLUENT by user defined functions.

Comparison with drop-shaft measurements and a single particle combustion reactor show that the models formulated can statistically describe the motion and conversion behaviour of RDF with sufficient accuracy. As an example of application, the models were finally used for the CFD simulation of the furnaces of a 612 MW(e) RDF co-fired coal power plant. The results indicate an overall slower reaction rate of RDF compared to coal, resulting in a total conversion of RDF of 83%.

1. Introduction

Compared to coal, the conventional primary fuel for boilers or cement plants with particle sizes below 200 μm, RDF contains a large amount of irregular shaped particles with edge lengths exceeding 1 cm. Together with the strong chemical and physical inhomogeneities this hinders easy substitution of fossil fuels [1].

Commercial CFD codes do not contain appropriate models to describe the complex RDF flight and combustion behavior. In recent work, these tools were already adapted to the simulation of alternative fuels and used for the investigation of co-firing biomass in pilot scale reactors [2,3] and in full scale power plant boilers [4–6]. Numerical simulations of co-combustion of RDF in industrial furnaces such as calciners [7–9] or rotary kilns [10] for the cement manufacturing process or power plant boilers [11,12]

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often rely on simplified models in terms of combustion and motion of the geometrically complex particles. Giddings et al. [7] published a simulation of car-tyre chips, fired as secondary fuel, in a pre-calciner. They considered these complex particle shapes as spheres and did not calculate a temperature gradient within the relatively large particles. Kurniawan [8] extended this simulation procedure using shape factors. Deeg et al. [11] developed a model for RDF co-firing using conversion models specific for biomass and plastic constituents and applied it in the CFD simulation of a 600 MW(e) pulverized coal utility boiler. However, both authors assumed homogenous particle temperatures, and there is no information given how the non-spherical shape of RDF particles influences their trajectories. Agraniotis et al. [12] used a similar model for the simulation of a RDF co-fired utility boiler. They investigated different operating conditions and varied RDF feeding locations. Unfortunately, there are no details of the aerodynamic models presented. Yin et al. [13] coupled a biomass specific combustion model with the complex motion behavior of cylindrically shaped particles. Their model considers drag- and lift- forces, as well as resulting torques due to the particle orientation and also calculates the actual surface area for the reaction model. However, the heterogeneity and unknown shape of the RDF particles need an expanded simulation approach. To categorize the individual aerodynamic behavior of RDF components, Dunnu et al. [14–16] worked on RDF classification in terms of fuel composition, particle sizes as well as measuring individual drag coefficients. They concluded that reliable drag and lift coefficients are essential to a more accurate calculation of particle trajectories in numerical simulations.

In the present paper, a new method is presented to model combustion and flight behaviour of RDF using the Euler-Lagrange approach. Our method is based on an advanced fuel characterization, subdividing the RDF into several material fractions. The fuel characterization includes the statistical spread of fuel composition and particle shape, reflecting the associated influence on conversion times and particle tracks.

We coupled our models to the Discrete Phase Model (DPM) in Ansys FLUENT. This method has been applied to simulate a large scale pulverized coal boiler.

2. Experimental

2.1. Sorting analysis

The initial step of fuel characterization is a sorting based on a representative [17,18] RDF ensemble, in which the different fuel components are divided into pre-defined groups. In this work, we define 5 different fractions which are illustrated in Fig. 1. The group of 2D Foils consists mostly of soft and thin polyethylene foils (with a typical thickness in the order of 50 μm). The fraction 3D Plastics contains polymers such as pieces from plastic cups or solid packing materials with a three dimensional appearance (minimum thickness >0.5 mm). All paper materials as newspapers, advertising brochures but also paper- and cardboard are assigned to the fraction of Paper & Cardboard (P&C). The fraction Textiles contains all textile fabrics and fringes. The remaining small and not assignable fibres and particles are grouped into the fraction of Fines. RDF also contains a fraction of non-combustible, inert material which basically forms a sixth fraction. In the current work we excluded it from CFD combustion simulations, because small amounts of inert materials only marginally contribute to the heat balance.

The sorting is carried out manually, where visual and tactile characteristics as well as the particle size and geometry are used as classification criteria. The advantage of this method lies in the good portability to other RDF. Unlike the characteristics of a total fuel, the differences in the fraction-specific properties for different RDF samples are considerably smaller, which allows to refer to earlier tests on the properties of RDF fractions (condensed in our RDF fraction data base [19]). The fuel properties of the new unknown RDF sample can thus be estimated, with a reasonable uncertainty, by just a new sorting analysis.

2.2. Fuel analysis

The fuel analysis comprises proximate [20–22] and ultimate analysis [23], as well as the calorific value [24] of each fraction. A typical analysis of a RDF sample can be taken from the three charts, illustrated in Figs. 2 and 3. Fig. 2 shows the calorific values and Fig. 3 the ultimate and the proximate analysis of the fractions. In

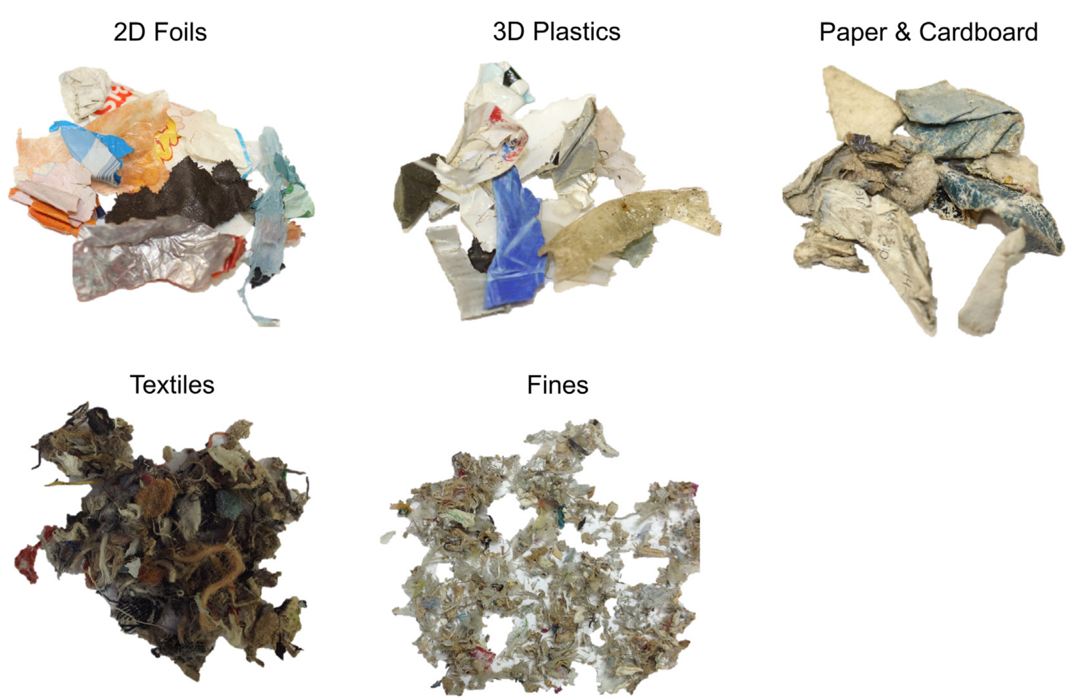

Fig. 1. RDF fractions considered in this work.