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Research paper

Numerical and experimental analysis of municipal solid wastes gasification process

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HIGHLIGHTS

- A multiphase 2-D model coupled with chemical reaction for MSW gasification.
- The numerical model is developed under the CFD Fluent framework.
- SYNGAS generation from biomass residues gasification is studied.
- Numerical and experimental (semi-industrial BFB gasifier) data are compared.

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ABSTRACT

As the quantity of municipal solid waste (MSW) increases with economic growth, problems arise in regard to sustainable management solutions. Thermal treatment presents a valid option for reducing the amounts of post-recycling waste to be landfilled. Incineration technology, besides reducing the total volume of waste and making use of the chemical energy in MSW for power generation, has negative environmental impact from high emission of pollutants. Recent policy to tackle climate change and resources conservation stimulated the development of renewable energy and landfill diversion technology, thereby giving gasification technology development renewed importance. In this work a two-dimensional CFD model for MSW gasification was developed and an Eulerian–Eulerian approach was used to describe the transport of mass, momentum and energy for the solid and gas phases. This model is validated using experimental data from the literature. The numerical results obtained are in good agreement with the reported experimental results.

1. Introduction

The amounts of municipal solid waste (MSW) produced increase with economic growth in both industrialised and developed countries, raising the issue of sustainable management solutions [1].

MSW management activities contribute to the generation of greenhouse gas and consequently to the climate change problem. Landfill waste decomposition contributes greatly to the formation of these gases [2–5]. Another environmental problem associated with MSW management systems is the potential generation of dioxins and furans associated to complete combustion of wastes [2].

Thermal treatments are a valid option for reducing the amounts of post-recycling waste to be landfilled, which is considered to be one of the most sanitary disposal methods [3].

It should be noted that biogas production is not an alternative to thermal treatments like incineration or gasification because biogas

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is produced from the organic fraction of MSW and thermal treatment is applied to the non-organic, non-recyclable fraction [4].

In theory, gasification is a more suitable technology even where the market for thermal product is difficult, however the constraint with gasification of MSW is the technology which is not yet proven at commercial scale [4].

Raw MSW contains a large amount of non-combustible material, and therefore requires pre-processing before sending it to a gasifier. The pre-processing must be able to meet the requirements of the gasifier and be flexible enough to handle MSW variability. This flexibility must be in terms of the type of material handled and its frequency of delivery. The pre-processing area is assumed to be similar to a Refuse Derived Fuel (RDF) facility. Some recyclables and non-combustibles are removed from the MSW to make a higher heating value product that is sized appropriately for gasification [5]. Therefore, incineration continues to be the most common method of thermal treatment for waste-to-energy facilities. However, with the enhancement of environmental restrictions and the development of gasification technology, gasification presents an increasingly efficient and viable alternative to incineration. Gasification is a waste-to-energy conversion scheme that offers a most attractive solution to both waste disposal and energy problems. However, gasification still has some economic and technical challenges, concerning the nature of the solid waste residues and its heterogeneity [4–6]. The greatest strength of gasification is the environmental performance, since emission tests indicate that gasification meets the existing limits and it can also have an important role in the reduction of landfill disposal [3].

Incineration reduces the initial volume of the waste by as much as 85% and offers solutions for problems such as waste odour and leachate. The incineration process creates a large amount of solid residues which are divided into bottom ash and fly ash. Bottom ash represents 85–90% of the total ash produced and is collected at the base of the combustion chamber. This type of ash consists primarily of coarse non-combustible material, unburned organic matter and grate siftings [7]. These are disposed of in sanitary landfills. Fly ash are finely divided particles of ash which are normally entrained in the combustion gases. Fly ash is recovered from the gas stream by a combination of precipitators and cyclones. Incineration technology was developed to reduce the total volume of waste and make use of the chemical energy of MSW for energy generation. However, the incineration process also creates high emissions of pollutant species such as NOx, SOx, HCl, as well as harmful organic compounds and heavy metals. Another problem with MSW incineration is corrosion of the incineration system by alkali metals in solid residues and fly ash [8].

Recent policies to tackle climate change and resource conservation such as the Kyoto Protocol, the deliberations at Copenhagen in 2009 and the Landfill Directive of the European Union have stimulated the development of renewable energy and landfill diversion technology, thereby giving the development gasification technology renewed importance [9].

Gasification is a thermochemical process that involves the oxidation of matter using a fraction of oxidizing agent in low quantities, inferior to the stoichiometric need. Gasification is considered an efficient and environmentally friendly way of extracting energy from different sources of organic materials [10]. Various studies [4,5,11–13] pointed out that gasification is an emerging but promising technology, especially when compared with commercially-available technologies, such as direct combustion. For instance, Murphy and McKeogh [4], Jones et al. [5] and Lymberopoulos [11], suggested that gasification has better performance, e.g. higher electrical and overall efficiency, lower emissions and lower investment costs than direct combustion. Boustouler and Reynolds [12] corroborates with Lymberopoulos [11] in this regard but also claimed that reduced slagging problems is another advantage of gasification. Roos [13] discussed in more details environmental benefits of biomass gasification, including (i) reduced carbon emissions as a result of improvement in energy efficiency and char addition to soils, (ii) reduced use of fertilizers and runoff of nutrients from soils amended with char-containing ash, and (iii) reduced NOx emissions due to better control of the combustion process.

The environmental performance is one of the greatest strengths of gasification technology, which is often considered a comprehensive response to the increasingly restrictive regulations applied around the world [4,9]. Independently-verified emissions tests indicate that gasification is able to meet existing emissions limits and can have a great effect on the reduction of landfill disposal option. Economic aspects are probably the crucial factor for a relevant market penetration, since gasification-based plants tends to have ranges of operating and capital costs about 10% higher than those of conventional combustion-based plants [9]. This is mainly a consequence of the ash melting system and the added complexity of the technology.

The technical challenges to overcome for a wider market penetration of commercial advanced gasification technologies can be investigated with the development of numerical simulation methods validated with experimental results of MSW gasification.

Gasification involves a set of fairly complex phenomena such as heat and mass transfer, fluid dynamics, and different chemical reactions. Numerous approaches to modelling gasification in CFD [14–19] and non-CFD [20–24] have been made. Currently there are three numerical techniques used for the studying gasification in fluidized beds in literature and these are Eulerian–Lagrangian with single particle or a particle parcel and a group of particles, Eulerian–Eulerian Two Fluid Model and Discrete Element Method within Eulerian–Lagrangian concept [14]. Literature concerning the numerical modelling of fluidized bed gasifier could be divided into three parts based on the geometric regions of fluidized bed furnace. It is dense bed, splash zone and freeboard/riser of fluidized bed units. Regarding dense bed most of studies are done with Eulerian–Eulerian Two Fluid Model approach [19]. Most of the literature in fluidized bed gasification is overlooking three-dimensional behaviours [14].

Cornejo and Farías [15] developed three-dimensional numerical model that describes the process of coal gasification in fluidized-bed reactors using an Eulerian–Eulerian approach. The main contribution of this work was implementing some sub-models within the FLUENT code in order to handle reactive fluidized-beds in complex geometries.

Xie et al. [16] developed a three-dimensional numerical model to simulate forestry residues gasification in a fluidized bed reactor using an Eulerian–Lagrangian approach. The model predicts product gas composition and carbon conversion efficiency in good agreement with experimental data.

Baliban et al. [17] proposed an approach for modelling of a biomass gasifier which is validated for lignocellulosic type of biomass with experimental data.

Onel et al. [18] presents a generic gasifier model towards the production of liquid fuels using municipal solid wastes. Using a nonlinear parameter estimation approach, the unknown gasification parameters are obtained to match the experimental gasification results. The results suggest that a generic MSW gasifier mathematical model can be obtained in which the average error is 8.75%.

Silva et al. [19] developed a two-dimensional Fluent based model to simulate the gasification of agro-industrial residues. The numerical simulation results were compared and validated versus a set of runs using three kind of biomass residues that were gasified