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# Combustion of solid fuel in a hybrid porous reactor

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**Abstract**

One of the most significant human-made methane emission sources is the municipal solid waste (MSW), deposited on sanitary landfills and open dumps [1,2].Within this work, an alternative MSW treatment concept is presented, which could provide a relatively clean waste/biomass-to-energy transformation. The proposed procedure comprises of a combustionand agasification (or pyrolysis) step, which are consecutively taking placein atwo-stage hybrid porous reactor system. The core of the system are two packed bed reactors, in which solid fuel (waste or biomass) is mixed with inert ceramic particles of similar size.
This paper overviews the initial experimental investigation of the combustion stepof a hybrid mixture, composed of wood pellets (fuel) and alumina balls (inert ceramic particles) in a 250 mm-high batch reactor. The temperature profile along the reactor, the concentration of CO and the flame front propagation velocity were measured as a function of the ceramic particlesize (11 and 20 mm), the inert-to-fuel mass ratio (0:1, 2:1, 3:1) and the airflow rate (30, 42, 60 l/min).
Experiments indicate that an increase of the mass ratio of inert-to-fuel material and a decrease of the inert ceramic particles size lead to a decrease of the maximum temperatureof the packed hybrid bed. Measured CO concentrations showed strong dependence on the inert ceramic particle size, i.e. the particle size reduction from 20 to 11 mm resulted in a significant reduction of CO-emission peaks. The maximum flame front propagation velocityof 0.2 mm/sec was detected for the airflow of 42 l/min, the particle size of 20 mm and the mass ratio of 3:1.


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## 1. Introduction

A growth of world population leads to an increased amount of produced waste in general, and of municipal solid waste (MSW) per day in particular. According to the World Bank [1], from the total amount of globally produced MSW, currently estimated to 1.3 billion tons per year, almost 80% end on the sanitary landfills (47.4%) and open

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dumps (32.4%). This form of MSW is a significant emitter of landfill gases, which is one of the major human-made methane sources [1,2]. The rest of MSW is recycled (6.8%), incinerated (4.6%), openly burned (5.4%) or disposed in other ways (3.4%).

Since MSW is a global issue, its treatment and utilization is widelyinvestigated [3,4]. A conventional approach to waste-to-energy treatment is direct combustion of waste (incineration), which has the goal to recover the energetic value of wastes. Other thermochemical treatment methods, i.e. pyrolysis and gasification,may additionally be used for recovering the chemical value of wastes, i.e. for production of chemicalsor secondary fuels [5].

The main advantage of gasification over direct combustion of solid wastes is related to the production of syngas, which is suited for use in different applications [6].Gasifiers can be classified based on the contact between the fuel and the oxidizing agenttofluidized bed gasifiers[7], packed bed gasifiers [8,9] and plasma gasifiers [10]. Gasification processes can be autothermal, where the heat for the endothermic gasification reaction is produced by combustion of part of the fuel inside the reactor, andallothermal (indirect) gasification, where the heat is being supplied from the external source [11].The gasification of biomass is still a challenging issue due to the production of tar [12].

While incineration is mainly performed on a moving grate, gasification and pyrolysis can be conducted in a classical packed bed reactor [5,6]. The advantages of the packed bed treatment are low investment costs (limited to low capacities), high carbon conversion and high flexibility in terms of fuels[6,13,14]. On the other hand poor mixing and inhomogeneous combustion conditions within the bed [14] limit the application of this reactor type.

If packed bed is made of inert material through which gaseous fuel flows, a specific form of combustion occurs, i.e. porous media- or filtration combustion [15,16]. The presence of solid matrix in the combustion zone provides efficient heat transfer between gas and solid, while the dispersion of the gas flowing through a porous media increases effective diffusion and heat transfer in the gas phase [16]. A heat released in the reaction zone is being transferred to the solid matrix immediately above and below the combustion zone, which provides stability of the combustion process in a wide range of gas velocities, equivalence ratios, and power loads [16,17]. If part of the inert solid particles are exchanged with uniformly distributed solid fuel particles [17], a hybrid filtration combustion reactor is formed, where solid and gaseous fuels can be treated simultaneously [18, 19].

### *1.1. Motivation and goal*

The motivation of the presented work was to investigate an alternative two-stage waste/biomass-to-energy treatment concept, which would consists of a combustionstep and a consecutive gasification (or pyrolysis) step in two hybridpackedbed reactors. The scheme of the proposed process is shown in Fig. 1.

The main part of the proposed concept are two hybrid, packed bed reactors, where solid fuel (waste or biomass) is mixed with inert ceramic particlesof similar size. The inert particles are heated up during the combustion phase within the first reactor, and are pushed to the second reactor, where e.g. allothermal gasification in the presence of steam can take place. The role of the inert particles is to provide the spatially uniform temperature profile of the desired level within the second reactor. Due to the combustion process, the temperature of the inert particles is expected to reach temperatures as high as 900-1000°C, which is enough to disintegrate the tar product of gasification, thus increasing the heating value of the obtained fuel. The proposed process would ensure high temperature conditions at the atmospheric pressure, necessary for the production of a high value syngas (composing of $H_2$, CO, $CH_4$, etc.).

For the successfulness of the gasification (or pyrolysis) step in the second reactor, it is necessary to characterize the operational conditions within the first reactor, especially to determine under which conditions the highest temperature level of inert particlescan be reached. According to literature [6,9], the temperature level required for gasification is between 500°C and 1600°C, and for pyrolysis between 500°C and 800°C.

The presented study was focused on the combustion process in the first hybrid reactor. The goal was to investigate the influence of the inert particles size, the inert-to-fuel mass ratio and the airflow rate on output parameters, i.e. the temperature distribution along the reactor, the temperature of exhaust gases and the CO-concentration.