



Full Length Article

Gasification of powdered coal in filtration regime with a fuel continuous injection



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ABSTRACT

A new method for gasification of a powdered fuel in filtration regime with continuous injection of fine dust is proposed and tested. The fuel is supplied suspended with the flow of oxidant gas, whereas the gas flow filters through a porous bed of large inert particles making a heat recovery medium. The experiment showed a possibility to enhance efficiency of gasification of solid fuels in filtration regime. The efficiency is enhanced by means of improved throughput of a reactor and production of the gas without a noticeable concentration of pyrolysis tars, which gas, upon cleansing of fly ash is suitable to feed a gas motor.

1. Introduction

Filtration combustion (FC) arranged with a heating wave propagating in the same direction with the direction of gas flow (in case of countercurrent flows of gas and the porous medium in the reference frame associated with the reaction zone) is very interesting from both scientific and practical viewpoints [1–4]. A number of studies on non-isothermal self-sustaining processes in the counterflow regime are aimed to optimizing various processes, such as in-situ coal gasification [5], self-propagating high-temperature synthesis [6], power and syngas production [7–11], hydrogen production [12], etc. Owing to the heat exchange between countercurrent solid and gas flows part of the heat is recuperated and transferred from the products to the reaction zone. The heat accumulation in a relatively narrow combustion zone can result in the temperature within the combustion front substantially higher than the adiabatic temperature calculated for the initial temperature of the reactants being that ambient and the heat of the reaction is evenly distributed over the products [13,14]. The concentration of heat in the counterflow filtration is due to the inert components in the reaction system make efficient heat carriers, which secure both a fuel and an oxidant being highly preheated prior to entering the chemical reaction zone. The superadiabatic combustion of solid fuels provides, compared to known technologies, a higher energy efficiency, which provides a possibility to process lean fuels with mere 5% combustibles, low formation of pollutants in gaseous combustion products, a possibility to efficiently process various wastes [15–21]. A most interesting feature of such autowave processes is a nonlinear dependence of the combustion temperature on the reaction heat. In the regime of filtration combustion with counterflow of reactants the reaction temperature is high and the

reaction rate might be not kinetically controlled but limited by the reactants supply to the reaction zone (filtration flow) [22–24].

An important drawback of the FC with counterflow of reactants when performed in a vertical shaft kiln reactor is the hydrodynamic instability of the combustion front due to low permeability of the fuel bed [25]. One cause for an instability is the loss of uniform filtration of the oxidant gas due to initial nonuniformity of the porous bed and later nonuniform burnout of the fuel. Ultimately FC front instability results in fingering [26].

Another drawback of packed bed gasifiers is their relatively low throughput. To enhance throughput one must raise the flowrate of the oxidant gas and simultaneously increase the reactive surface of the solid fuel, i.e. reduce the size of the fuel particles, as a decrease in the particles size results in shorter burnout time. However an increase in the gas flowrate has its limit associated with fluidization of a packed bed [27]. Gasification of a fine-grained fuel in a packed bed gasifier is hardly feasible due to a high pressure drop on such bed for a filtering gas, one cannot blow the oxidant through [28]. A solution for this contradiction can be gasification of a fine fuel dust with a flow of gaseous oxidant filtering through an inert porous matrix; i.e. similar to FC of gases [29]. In this case the fine fuel is only a chemical reactant, whereas the porous matrix secures heat recuperation from the reaction products to the fresh oxidant gas. The hot reaction products leaving the reaction zone lends part of the heat to the porous matrix, which further descends below the combustion zone. The incoming gas, which has an ambient temperature, is heated from the hot porous matrix prior to entering the reaction zone.

The FC of gases is known to manifest higher stability of the combustion front especially when a gas mixture permeates a uniform

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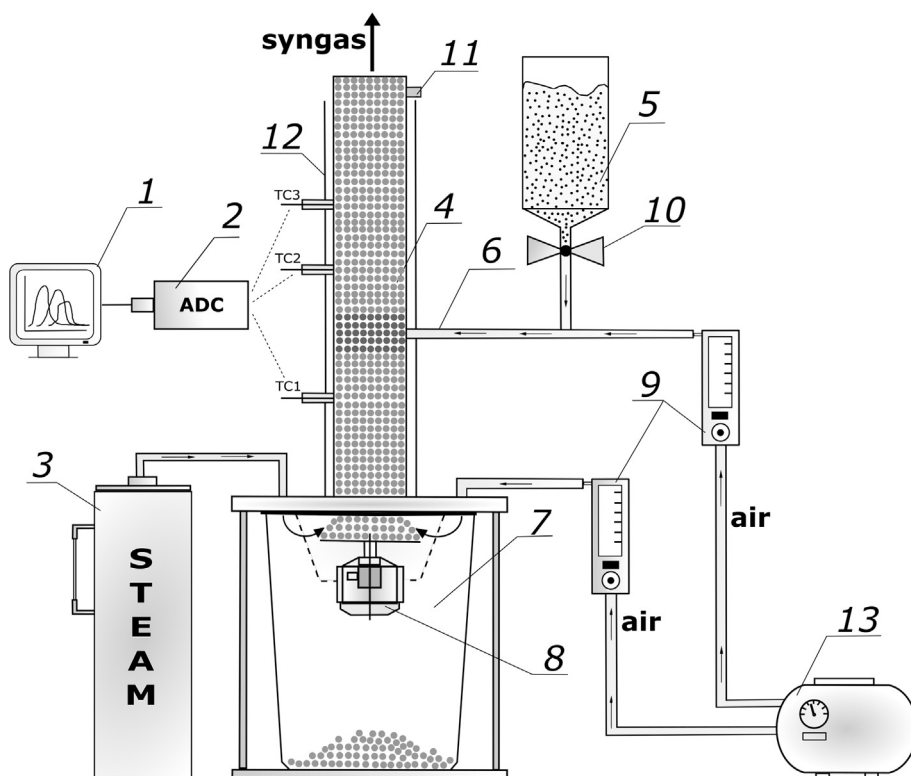


Fig. 1. Schematic of the experimental reactor. 1 - data acquisition, 2 - ADC, 3 - steam generator, 4 - quartz reactor, 5 - fuel bin, 6 - fuel supply line, 7 - collection bin for inert solid, 8 - rotating grate, 9 - flowmeters, 10 - fuel dosing valve, 11 - sampling probe, 12 - mirror screen, 13 - air compressor.

porous matrix, which stabilizes the flame [30–32]. Thus an objective of this study was a development of the method for gasification of a solid fuel in a flow of fine particles entrained by oxidant gas through an inert porous medium. This approach is a novel one [33,34] and promises a possibility to combine the merits of superadiabatic gasification by means of FC with a high throughput of a reactor inherent in gas combustion.

2. Experimental

The laboratory studies were performed on a vertical shaft kiln reactor (4) made of quartz schematically shown in Fig. 1. The reactor length comprised 400 mm, inner diameter 66 mm, walls thickness 3 mm. In order to reduce the lateral heat loss from the reactor it was covered with a mirror screen (12) made of aluminum foil reflecting the IR radiation. The bulk of the reactor was filled with a granular inert solid, 5×10 mm porcelain Raschig rings. The average porosity of the granular bed was 0.6. The melting temperature of the porcelain was 1400°C . The fuels used for gasification were commercial birch char and a bituminous coal. The former provided a model ash-free fuel yielding no volatiles. The coal was representative of a low-grade fuel having a high ash content and high yield of volatiles.

The oxidant gas (air) was supplied to the reactor via two inlets of air compressor (13). Major part of the air was supplied from the reactor bottom via the bin (7). The supplementary air flow served as a carrier for the finely grinded fuel supplied to the reactor via inlet (6). The fuel supply rate was controlled by adjusting supplementary air flowrate and an opening of the fuel dosing valve (10) at the bottom of the fuel bin (5). The fuel dosing valve was a tube with changing internal cross section. The fuel supply rate was measured as average for the consumption over the experimental span; the relative accuracy of fuel supply rate measurement was not worse than 15%.

The temperature in the reactor was measured using three Type K (chromel–alumel) thermocouples. The first thermocouple TC1 was mounted 100 mm up from the reactor bottom. The fuel inlet (6) was 65 mm above the first thermocouple. Further 65 mm up was mounted

the second thermocouple TC2 and 65 mm over the second, the third TC3. The junctions of the thermocouples were positioned at the inner wall of the quartz reactor. This position of thermocouples and fuel inlet (6) secured sufficient time to control discharge of the inert solid without an overheating of the grate (8). The readings of the thermocouples through ADC (2) were transferred to a data-acquisition computer (1) in real time; this provided us data for control of the inert solid discharge to maintain the position of the high-temperature combustion zone at a prescribed elevation. The scatter of the combustion temperature $\pm 50^\circ\text{C}$ was determined by reproducing 3–5 experiments under similar conditions. The product gas was sampled each 2–3 min to a glass flask with a probe (11) from the upper part of the reactor. The composition of the gaseous products was analyzed using a GC-CRYSTAL 5000 chromatograph, which provided a possibility to measure the concentration of substances that are gases at normal conditions. The concentration of C2–C5 hydrocarbons can be detected with an accuracy of 0.01% vol.

The fuels used for gasification were commercial birch char Type A and a bituminous coal. The proximate analyses of the birch char performed in the IPCP Analytical Center showed the following composition (% dry mass.): C – 84.0, O – 12.5, H – 2.7, N – 0.3, ash – 0.5. The birch char humidity measured by the ultimate mass loss in the muffle furnace at 105°C was 4%. The lower heating value of the birch char calculated for this composition using the Mendeleev formula is found to be 28.6 MJ/kg. The composition of coal was (% dry mass.): C – 64.1, O – 9.7, H – 3.4, N – 1.4, S – 0.4, ash – 21.0. The coal humidity is found to be 15%. The lower heating value of the coal is found to be 20.2 MJ/kg. The yield of volatiles in coal pyrolysis comprised 25–30%. The ash melting temperature exceeded 1200°C . The experiments were performed with 63–100 μm fuel dust. The fuel supply was varied from 0.31 to 0.38 g/s for the birch char and from 0.41 to 0.5 g/s for coal. These supply rates were chosen during preliminary experiments in a way to provide a stoichiometry of fuel oxidation with predominant formation of carbon monoxide. The total flowrate of air (sum of major supply and supplementary used for fuel transport) was measured with “Mass-view” (Bronkhorst High-Tech) electronic flow meters (9) and maintained at

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