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Flow pattern evaluation of the internal circulation gasifying principle

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HIGHLIGHTS

- Recirculation zone is present in the INCI test-scale reactor.
- Flow pattern calculated by CFD coincide with PIV measurements.
- CFD modeling parameters are adequate.
- PIV measurement setup is reliable.

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ABSTRACT

Gasification is a key process for the thermochemical conversion of coal for both energetic utilization and its application as a chemical feedstock. In this regard low grade coal with high-ash content gains in importance. Because of its high availability, production share is increasing. Therefore, adapted gasifiers of novel design are required to meet the demands associated with converting high-ash coals. The internal circulation (INCI) principle is a multi-stage gasification system with the ability to efficiently convert high-ash feedstock.

The present paper introduces the test-scale COORVED reactor, which was designed according to the INCI principle. Particle image velocimetry (PIV) and computational fluid dynamics (CFD) simulations are conducted for ambient conditions in a cold-flow test facility to demonstrate the flow pattern according to the INCI principle. The evidence of a recirculation cell is provided by PIV experiments. CFD simulations show similar results in terms of overall flow pattern and size of the recirculation cell. After the intensive investigations of the flow pattern in the cold-flow test facility, first PIV results were obtained in the COORVED reactor. The complex accessibility of the reactor raised the necessity of the validation of the elaborate measurement setup. The reliability of the measurement results is proven by generating a laminar velocity profile at ambient conditions, whose results are comparable to analytical solutions.

1. Introduction

The utilization of high-ash coals by means of coal gasification gains emerging importance. Countries with high amounts of low-grade coal, like India, China or South Africa, are forcing this development [1–3]. The conventional approach is the gasification of high-ash coals in plant units. Here, most gasification systems show disadvantages in dealing with high-ash contents, especially regarding syngas yield and cold gas efficiency [3]. To enhance the cold gas efficiency, it is necessary to avoid slagging as a heat consuming step. On the other hand, the gasification temperature should exceed a minimum temperature for high carbon conversion. Thermodynamic evaluations of high-ash coal gasification reveal that operation temperatures below the ash fluid point are required to maximize the operation performance [3]. Thus dry ash processes are preferred for high-ash coal conversion. The dry bottom fixed-bed gasifier type was successfully applied for high-ash coal conversion, but is not capable of gasifying coal fines [4]. Fluidized bed gasifiers seem promising as they operate under dry ash conditions and have the potential to process coal fines. However, the main drawback of fluidized bed gasifiers is the incomplete carbon conversion (<97%) for coals [4] reducing with increasing coal rank. This incomplete carbon conversion and the associated necessity to post-treat the discharged bottom ash is the main reason why fluidized bed gasifiers have achieved only very limited commercial application regarding high-ash coal gasification. One emerging, alternative technique is underground coal gasification (UCG) where the coal is converted into syngas in situ underground [5,6]. However, this method is subject to both environmental

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concerns and public acceptance [7,8]. As a wide industrial application of UCG cannot be foreseen, it is necessary to improve conventional gasifiers to make them feasible for low-grade, high-ash coals.

However, today there is no technically and economically feasible utilization of high-ash coal fines. The internal circulation (INCI) principle, which was developed and patented by the TU Bergakademie Freiberg, is expected to be superior in terms of cold gas efficiencies, regarding high-ash coals [10–12]. A scheme of an INCI-based gasifier is shown in Fig. 1. Its main benefits are the prevention of heat losses by slagging, high carbon conversion and a thermodynamically optimal temperature range of the raw gas. According to the principle, a cylindrical reaction space is applied, that confines multiple flow patterns inside: a dry fixed bed at the bottom, followed by a dry turbulent fluidized bed, an agglomerating jetting fluidized bed and an agglomerating fast fluidized bed.

The fine-grained (<500 μm), fresh coal is fed into the reactor via gravity pipes and is fluidized by means of gas leaving the moving bed at its top. At the same level, the primary gasification agent is introduced through nozzles at high velocities. The resulting jets conjoin into an upflowing gas jet. Consequently, a free jet evolves, resulting in a recirculation cell. This recirculation cell is required to raise the particle residence time inside the main reaction zone, which is composed of the jetting fluidized bed and the fast fluidized bed above. The mean temperature in this reaction zone is set to 1000–1100 °C depending on coal ash properties. At these temperatures, elevated residence times (compared to entrained flow gasifiers) are required to achieve high conversion rates. The temperatures in the oxygen-rich jet will be much higher than the ash melting temperature but the particle residence time in this hot area will be very short. The particles in the recirculation cell, that surrounds the hot jet, protect the reactor wall from these temperatures. Particles that have reached a certain carbon conversion will start to partially melt at the surface. Consequently, several particles will stick together and form agglomerates. These agglomerates are heavier than the fresh coal particles and will no longer be fluidized. They fall down onto the moving bed at the bottom and will be post gasified here. The dry moving bed consists mainly of ash agglomerates with residual carbon, which is gasified by a secondary gasification agent. Thus, the post-gasified bottom product contains less than 5 wt.% carbon. The secondary gasification agent has only small fractions of oxygen (<10 vol.%) and is mixed with steam or carbon dioxide to avoid local hot spots in the moving bed. The gas leaving the moving bed at its top, serves as fluidization agent for the zones above.

The evaluation of the INCI principle will be done within the frame of the 'CO_2-reduction by innovative gasifier design' (COORVED) project at the TU Bergakademie, Freiberg. As one part of the project a model flame for partial oxidation was developed to investigate the gas phase reactions [13]. Its use is the interpretation of chemico-physical effects in partial oxidation flames and will be the basis for CFD simulations. Another main part of the project is the construction of the COORVED reactor. It is a coal gasification test plant applying the INCI principle. The test plant gives the opportunity to intensively validate the INCI principle with its different flow patterns.

The objective of the present work is the evaluation of the flow pattern of the jetting fluidized bed in the COORVED reactor and its validation by measurements. Early simulations of a pressurized industrial size gasifier which applies the INCI principle already showed the expected recirculation cell of the jetting fluidized bed [14]. The evidence of the recirculation cell in the COORVED reactor is the main focus of this work. The first evaluation results of flow pattern measurements were obtained by particle image velocimetry (PIV) and computational fluid dynamics (CFD) simulations at ambient conditions.

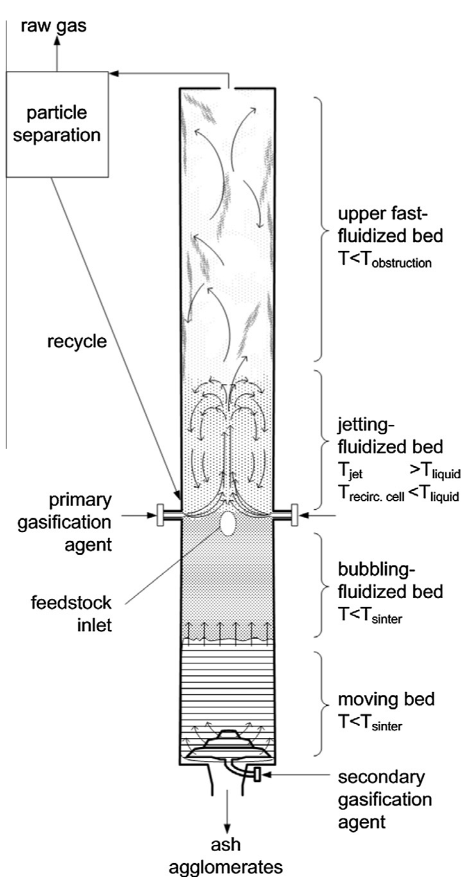

Fig. 1. Scheme of an INCI-based gasifier [9].

2. The COORVED reactor

2.1. Reactor design

The COORVED reactor is a test-scale gasifier. Compared to an industrial size gasifier based on the INCI principle it is technically slightly modified, arising from the necessity of downscaling and the planned experimental operation. Main differences from an industrial unit are:

- reduced thermal capacity,
- atmospheric pressure instead of pressures up to 30 bar,
- single nozzle for primary gasification agent located at the center, rather than distributing several nozzles in boxer arrangement around the circumference.

Its operational parameters are:

- electrically heated, up to a temperature of 900 °C,
- pressure of 100 mbar gauge,
- thermal input of 60–125 kW, which is equal to 10–15 kg/h coal, with particle sizes below 500 μm,
- primary gasification agent of max. 8 m^3(STP)/h,
- secondary gasification agent of max. 20 m^3(STP)/h,
- adjustable compositions of oxygen, steam, carbon dioxide, nitrogen and argon for the gasification agents.

Furthermore, different volume flow rates of the gases CH_4, CO and H_2 can be added to the secondary gasification agent, for the investigation of inhibition effects on gasification reactions.