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Measurement of solids circulation rate in a high-temperature dual fluidized bed pilot plant

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ABSTRACT

A number of fluidized bed reactor processes operating at high temperature require that solid particles be circulated back and forth between two reactor vessels. Since the circulation rate strongly affects mass and energy balances, and therefore greatly influences hydrodynamics and performance of the system, a reliable technique for its accurate measurement would be helpful in monitoring and modeling the process. However, there are no reported techniques suitable for measuring solid circulation rates at elevated temperatures typical of gasification systems.

A novel thermal-tracing technique was developed for measuring the solids circulation rate between two reactors. Particles at room temperatures (cold particles) are injected into a downward-moving packed bed of solids at elevated temperature (hot particles), creating reduced-temperature zones inside the moving bed. The transit time of the cold-particle-clusters between pairs of thermocouples is determined by cross correlation allowing the flux to be estimated. The technique was shown to provide sensitive and reproducible data for a cold model unit with injection of dry ice. The technique was then applied to determine the solids circulation rate between the bubbling bed gasifier and the riser combustor of a pilot scale dual fluidized bed gasification system. A number of conditions are imposed on the data to eliminate unsatisfactory data at high temperatures. Data which satisfy the discrimination criteria are shown to lead to measured solids circulation fluxes up to 133 kg/m^2-s at temperatures up to 856 °C in the gasifier test section. The technique provides high-temperature solids circulation rate information beyond the capability of other techniques.

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1. Introduction

One of the principal advantages of fluidized beds is that particles can be readily circulated between vessels, e.g. between a cracker and regenerator in the case of fluid catalytic cracking (FCC), or between a calciner and a carbonator in the case of carbon capture. Dual fluidized bed gasifiers, requiring circulation of particles between gasification and combustion reactors, are being developed in several countries as a means of efficient generation of synthesis gases from carbonaceous feedstocks. The dual fluidized bed (DFB) pilot gasifier located at the University of British Columbia is capable of producing high quality synthesis gas (syngas) from a variety of solid fuels, including different types of biomass. The syngas can be used to produce heat and electricity, liquid fuels through Fisher-Tropsch Synthesis and hydrogen, among others [1]. When biomass is used in a DFB with integrated carbon-dioxide capture option, it can even become a carbon-negative energy system [2].

The DFB physically separates endothermic gasification reactions which take place in a bubbling fluidized bed (BFB) reactor from exothermic combustion reactions occurring in a circulating fluidized bed (CFB) riser [3]. A schematic diagram of the process is given in Fig. 1. The flue gas generated in the CFB combustor is not allowed to mix with the syngas produced in the BFB gasifier, and, as a result, syngas with high energy content is obtained [4]. An inert heat carrier (e.g. sand) must be constantly circulated at high flow rates to transfer the heat generated in the CFB combustor to the BFB gasifier in order to support endothermic reactions there [5]. The inert heat carrier also acts as bed material for both reactors. Mass and energy balances of individual reactors and the overall system greatly depend on the rate of circulation of solid heat carrier. Thus the circulation rate of solid particles is one of the most important hydrodynamic parameters, with strong influence on the performance of both the CFB and BFB reactors.

The engineering design of any commercial-scale DFB gasification plant would benefit from the accurate determination of the circulation rate of solids between the reactors. If an appropriate technique is developed, it could make a substantial contribution to the development of DFB gasification technology, while also finding potential applications

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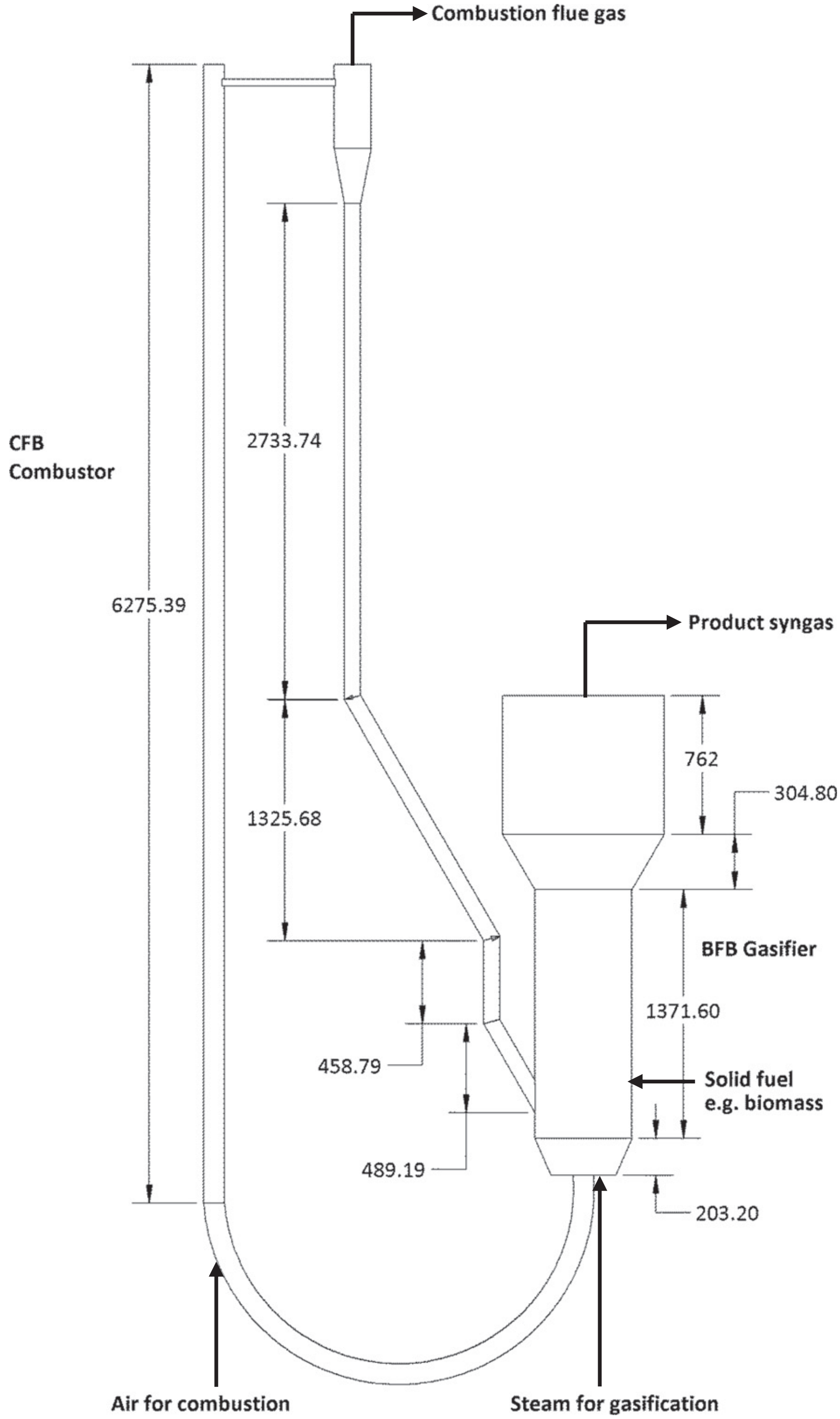

Fig. 1. Schematic of DFB pilot plant at the University of British Columbia (Dimensions are in mm).

in other circulating systems, such as fluid cokers and fluid catalytic crackers.

A number of attempts to measure solid circulation rate have been reported over several decades. Burkell et al. [6] considered five different techniques for measuring solid circulation rates: impact flowmeter, modified orifice meter, porous valve method, time of descent method and calorimetry. None of these methods is fully appropriate for a high-temperature DFB gasification system. When particles strike the pan of impact flow meter, the resulting force is mechanically transmitted by a sensitive load beam. This is too cumbersome for a high temperature equipment. Application of the flow meter was found to be limited to low solid circulation rates due to overloading of beam. A number of acrylic discs were stacked to make the modified orifice meter where differential pressures across the stack were measured to determine accumulation of solids. The pressure drops obtained at low rates of circulations were too small to be recorded, whereas they fluctuated wildly at high rates. In its closed position, the porous valve accumulated solids over periods of time. At high circulation rates, the interference caused by closing the valve could significantly upset the steady-state operation of the system. The visual determination of time for the descent of particles required that the test section be made of transparent materials was not practical for a high-temperature setup. In addition,

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