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In-site characterization of bed fluidity in a large gas–solid fluidized bed via electric conductance method

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ABSTRACT

In various industrial applications in which a liquid is sprayed into a gas-fluidized bed such as Fluid Cokers™, fluid catalytic crackers and gas-phase polymerization reactors, parts of the bed or even the complete bed might become defluidized due to high liquid loading, agglomeration or sintering of particles. For instance, in Fluid Cokers, operating at lower temperatures increases the yield of liquid products and reduces sulphur emissions, but local defluidization may result in some bed regions with a disastrous impact on reactor operation. This loss of bed fluidity is called “bogging”.

This study examines a novel method employing electrical conductance to detect local bogging in a large scale pilot fluid bed of about 7 tonnes of silica sand. Bogging is induced by increasing the liquid load as well as by changing the atomization performance of a spray nozzle. Several other experimental methods, such as differential and static pressure measurements, image processing, and temperature measurements are evaluated.

When liquid is injected into a fluidized bed, a fraction forms liquid–solid agglomerates while the remainder forms free moisture, consisting of individual particles coated with a thin layer of liquid. Liquid present as free moisture can be beneficial as it increases the mass and heat transfer processes and increases yields of valuable products. The results indicated that conductance measurements could be used for detecting bogging phenomena online. Bogging is shown to be directly associated with the local free moisture rather than the total moisture level. Increasing the atomization gas flowrate and, consequently, the free moisture, increases the bogging risk. A measurable critical, local free moisture value above which localized bogging occurs is identified.

1. Introduction

Monitoring the fluidization quality represents an operating challenge for many processes in which a liquid is sprayed into a gas-fluidized bed, such as Fluid Coking™, fluid catalytic cracking, gas-phase polymerization, agglomeration and drying. Although the presence of liquid will generally have an adverse effect on fluidization, as it might increase the cohesivity of particles and defluidize a part or the entire bed, there are often strong incentives in operating with high liquid loadings [1]. In Fluid Cokers™, the heavy feedstock is sprayed onto hot coke particles and undergoes thermal cracking that yields lighter hydrocarbons and solid coke. The coke particles are continuously recirculated between the coker and a burner where some of the coke is combusted to reheat the particles. Excess coke is continuously removed from the system.

Operating data from the Syncrude Fluid Cokers have shown that reducing the Fluid Coker temperature provides two major benefits. Yields of valuable liquids are increased and sulphur oxide emissions are reduced by the consequent reduction in burner temperature, as sulphur is concentrated in the more refractory coke fractions that will no longer be combusted. There are, however, two major drawbacks to lower coker temperatures. First, fouling of stripper sheds increases. Second, the lower temperature reduces the reaction rate and unconverted feed may thus remain on the coke surface, making the particles sticky. This could lead to local zones of poor mixing and/or local defluidization, so called “bogging”, with detrimental effects on reactor performance and stability. The objective of this work is to develop bogging detection methods that could be applied to commercial-scale Fluid Cokers [2]. This should also be applicable to monitor equipment in which liquid is injected into a fluidized bed, such as granulation processes [3,4].

Various methods have been reported in the literature to detect fluidization quality. The apparent viscosity and fluidization quality of a fluidized bed are related [5]. Several investigators have measured the apparent viscosity of a fluidized bed with a paddle, rotating spheres, falling ball and Couette-type viscometers [5]. The results vary widely, and it is difficult to estimate apparent viscosities of such fluidized systems where the peripheral velocities of immersed objects are of the same magnitude as particle velocities in the undisturbed bed [6,7].

Several authors developed methods to detect defluidized zones between adjacent gas jets in the grid zone of a fluidized bed. Yutani et al. [8] used autocorrelation of local capacitance measurements. Industrial application of this method would be difficult as the capacitance

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probes may be too fragile for an industrial process and are typically sensitive to electrical noise.

Heat transfer measurements can also be used for the detection of defluidized zones. Ropchan [9] measured local heat transfer coefficients using a self-heated thermistor and found that defluidized zones could be detected from the fluctuations of the heat transfer coefficient. Marzocchella et al. [10] were able to identify fluidization regimes with heat transfer measurements. Karamavruc and Clark [11] found that the Hurst exponent of temperature fluctuations could detect defluidized zones around a horizontal heat transfer tube. Heat transfer measurements, however, are not suitable for the detection of other kinds of defluidized zones in beds of polymer particles: thermistors and other heat transfer probes create hot spots which may result in sintering thereby promoting the formation of defluidized zones. Such probes would also get quickly fouled by coke deposits in beds such as Fluid Cokers.

Defluidized zones were also reliably and rapidly detected by triboelectric currents generated at electrodes in the distributor zone of gas–solid fluidized beds [12]. Triboelectric currents are generated by the potential difference developed by the charging of particles by friction between two materials [13]. Accurate detection of defluidized zones required signal processing with the V-statistic, a criterion that was developed to identify cycles [14].

In addition, Tsujimoto et al. [15] tested a new non-intrusive measuring technique by applying an acoustic emission sensor to monitor the onset of unstable fluidization caused by the increase in moisture content in a fluidized bed granulator that leads to defluidization [7].

McDougall et al. [7] also developed reliable laboratory methods to quantify the eventual degradation of the bed fluidity and/or formation of agglomerates that resulted from the injection of a liquid in a fluidized bed. There is a strong need, however, for methods that are quicker and that could be used in industrial reactors. They also need to use data that can be easily and reliably collected without perturbing reactor operation [1].

Several other experimental methods have been tested to estimate the bed fluidity. For instance, pressure measurements are often used to characterize fluidized bed hydrodynamics [16], and are also a good choice for industrial monitoring purposes, since they are easy to perform, inexpensive and reliable [16]. The fluidization quality is related to the excess gas velocity, i.e. the difference between the superficial gas velocity and the minimum fluidization velocity. The fluidization quality affects the gas bubble properties and, thus, the resulting pressure fluctuations. The magnitude of the pressure fluctuations can be readily evaluated using pressure transducers. Calculation of the variance of the differential pressure fluctuations can be carried out rapidly to give a measure of the fluidization quality [17]. In addition, the analysis of wall pressure fluctuations has been used for decades for the identification of the flow regimes in bubble columns, in order to determine the transition points and also to extract regime features [18].

Furthermore, pressure measurements can be easily and reliably obtained in high-temperature industrial reactors. Several investigators analyzed pressure signal fluctuations to characterize the fluidization quality of fluidized beds [2]. Tardos et al. [19], Strusch et al. [20] and Marzocchella et al. [21] used the time-averaged bed pressure drop to investigate destabilization and defluidization of fluidized beds due to agglomeration or segregation. However, this method cannot provide early warning of poor bed fluidity.

Several studies have investigated the use of pressure fluctuations to provide early warning of poor bed fluidity. Van Ommen et al. [16] and

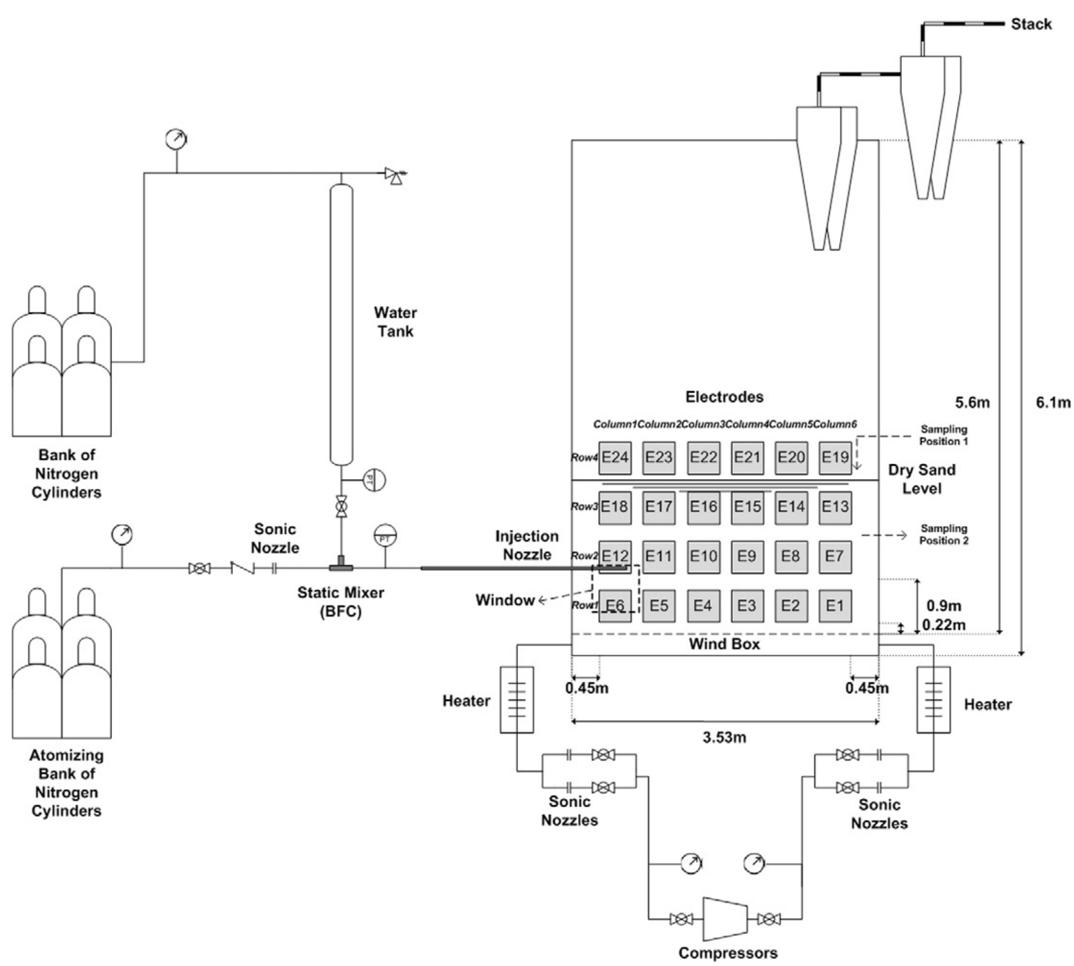

Fig. 1. Schematic diagram of the experimental set-up.