Experimental characterization of the operating limits of a rotating packed bed equipped with twin gas inlets

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Context

Process intensification methods and equipment are vital in meeting the challenges posed by the increasing global population, demand for energy, and contamination of the environment. A rotating packed bed (RPB), or HIGEE (High gravity) equipment, is a compressed process intensification equipment in which gravitational force is superimposed several folds by centrifugal force. RPBs have the potential to enhance chemical processes by accelerating the recovery of resources via safe, cost-effective, and sustainable means. RPBs also ensure reduced production time and complexity; reduced operator-dependent risks, and the ease of modifying a single piece of equipment for various processes. Several studies have been conducted to study the hydrodynamic behaviour of RPBs (Groß et al., 2018; The work of (Hendry et al., 2020) detailed the contributions of different zones of the RPB to its overall pressure drop obtained by profiling each zone's internal radial pressure drop. Three major operating parameters: rotation speed, gas, and liquid flow rates, significantly influence the hydrodynamics of RPBs. Gas flow rate has the highest influence on the hydrodynamic characteristics of RPBs. In the literature, commonly reported Conventional, single-block RPBs operated counter currently has a single gas inlet (Im et al., 2020; Neumann et al., 2017; Rao et al., 2004) as shown in Figure 1(a) as opposed to the twin gas inlet shown in Figure 1(b).

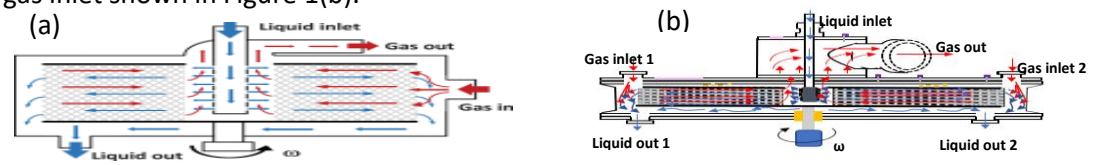

Figure 1: Schematic diagrams of RPB with (a) single gas inlet (Im et al., 2020)and, (b) twin gas inlets

In this study, the operating limits of a pilot-scale rotating packed bed equipped with twin gas inlets are characterized. The characteristics investigated were the dry and wet pressure drops and the operating limit (flooding point). A sensitivity analysis of the single-phase, two-phase pressure drops, and flooding points on three operating parameters—the rotation speed, gas flow rate, and the liquid flow rate was also conducted. The aim was to study the influence of the additional gas inlet and the degree of sensitivity of the investigated operating parameters on the explored operating parameters.

Keywords: characterization, operating limits, rotating packed bed, dry pressure drop, wet pressure drop

Materials and methods

A pilot-scale, single-stage, vertical rotor type RPB with a casing diameter of 676mm, an inner rotor diameter of 160mm, and an outer rotor diameter of 500mm was used. The RPB was equipped with two gas inlets at the top of the casing. Gas was supplied from a central laboratory supply. The packing was stainless steel wire mesh with an axial height of 40mm, a specific surface of 2400m^{-1}, and a porosity of 0.86. Pressure drop was measured in real-time by interfacing a pressure sensor (Rosemount 3051 Pressure Transmitter) to a computer using DASYLab (V9.00.02) data acquisition system. Operating limit (flooding point) was based on visual observation and spike in pressure drop. The operating parameters were: a gas flow rate of 0-400Nm^3/h, a liquid flow rate of 0-0.75m^3/h, and a rotation speed of 0-1500 rpm.

Results and Discussion

Figure 2 shows the effect of the gas flow rate, V_G on the stationary rotor in the unirrigated RPB. As V_G gas flow rate. This is largely caused by the effects of gas inertia and friction.

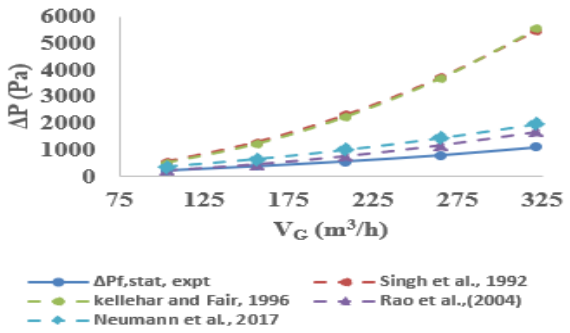

Figure 2: Comparison of effect of gas flowrate on dry pressure drop with literature

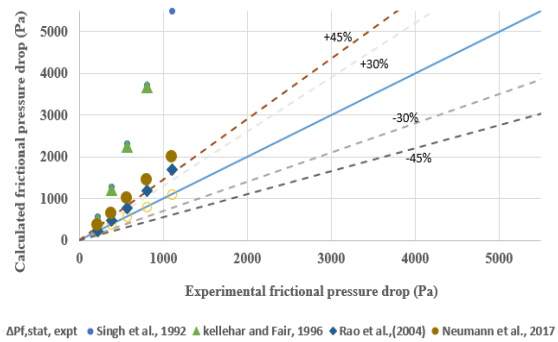

Figure 3: Parity plot for effect of rotation speed on pressure drop with literature

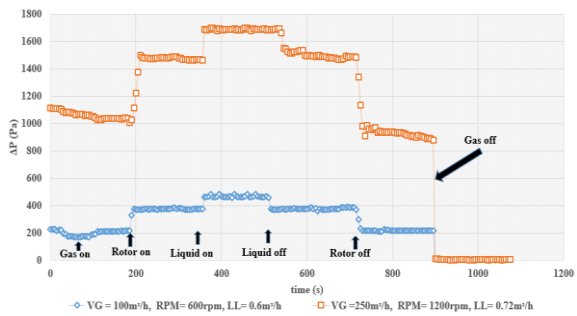

Figure 4:Effect of operating parameters on pressure drop across the RPB

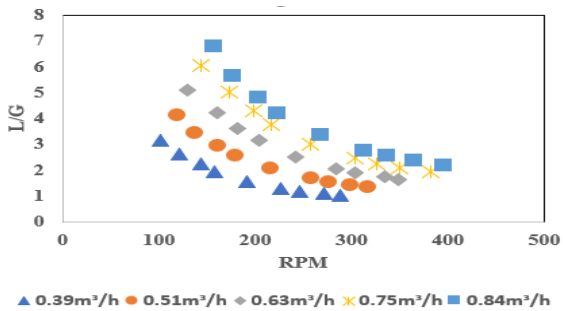

Figure 5: Effect of rotation speed on L/G ratio at flooding points

A comparison of the experimental results with previous studies obtained using single-inlet RPBs by various researchers (Figures 2 and 3) shows that the twin gas inlet RPB produced lower frictional pressure drops within limits investigated. The effect of the operating parameters on the pressure drop across the RPB shows a consistently higher pressure drop for the wet RPB bed than the dry bed, as shown in Figure 4. the trend is in line with conventional packed beds and contrary to the unusual findings reported by some previous researchers that that used single gas inlet RPBs such as (Keyvani & Gardner, 1989; Zheng et al., 2000). Figure 5 shows the effect of rotation speed on the liquid-to-gas ratio at the flooding point, where constant liquid flow rate and increased rotation speed results in a decreased L/G ratio. Thus, a higher capacity of the RPB can be achieved by simply increasing the gas flow rate at a given liquid flow rate.

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