Intensified carbon capture using swirling fluidized beds: hydrodynamics investigation and sorbent screening

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Fluidized beds provide a degree of process intensification compared to fixed (packed) beds because the movement of the particles facilitates improved heat and mass transfer. Additionally, conditions within fluidized beds are uniform, meaning there are no gradient effects such as those found within packed beds. For this reason, it has been proposed that fluidized beds can be used for the small-scale screening of solid adsorbents because the results can be more easily scaled up without having to account for these gradient/dynamic effects.

A further approach for intensifying gas-solid fluidization is to use a swirling gas stream to suspend the particle bed. Here, angled blade distributors are used to impart tangential momentum to a gas stream before it contacts the particle bed. The vertical velocity component of the gas provides fluidization, whilst the horizontal velocity component provides swirling motion around an annular 'race track'. Particle entrainment is minimised because the majority of the gas stream's momentum is dissipated at the base of the bed in the radial and tangential directions. Consequently, substantially higher gas velocities can be used compared to 'conventional' fluidized beds, which provides a significant improvement of the external heat and mass transfer rates to the particles because the boundary layers are significantly stripped away. Further, finer particles can be fluidized in these swirling gas streams compared to 'conventional' fluidized beds, and the gas-solid contact times are slightly increased because the gas moves helically through the particle bed instead of axially.

The leading industrial supplier of this technology is Torftech, who market this technology under the name of 'Toroidal Fluidized Bed', or 'Torbed'. Here, Torftech supply two industrial variants of the Torbed: the 'Compact Bed Reactor (CBR)' and 'Expanded Bed Reactor (EBR)', which have been established in a variety of different industrial sectors/processes. Although this technology is already available commercially, academic research (under the name 'Swirling Fluidized Bed (SFB)') is more limited. Some studies have investigated the hydrodynamics of various simple blade geometries and a small number of applications have been trialled, but crucially there is no open-source design information available. Further, the majority of the literature reporting data on the SFB is valid for bed diameters around 300–500 mm and greater.

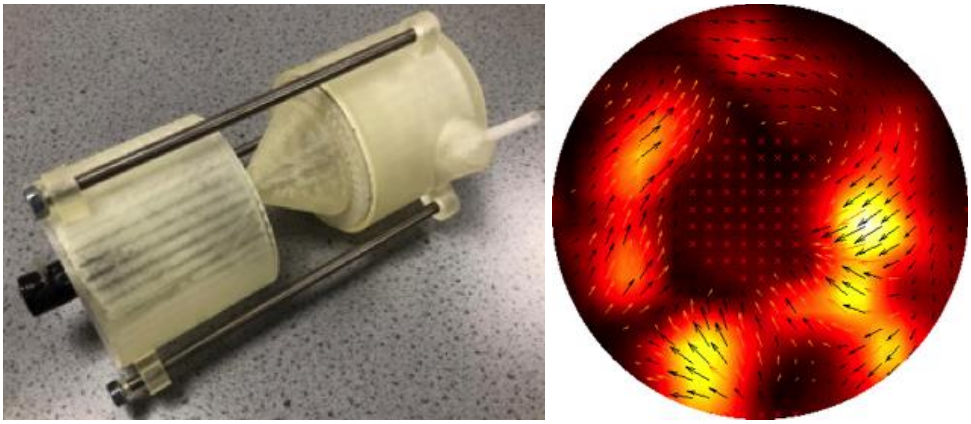

Figure 1: (L) 3D-printed miniature Torbed, (R) preliminary velocity field obtained via experimental particle image velocimetry

Minimization of the SFB geometry to scales more attributable with mini- and micro-fluidized beds (order of 10’s of mm) would enable sorbent screening experiments to be conducted with substantially less material. This is especially desirable for screening operations where only small amounts of the solid sorbent are available, or where the sorbents are expensive. The further improved heat and mass transfer rates compared to the ‘conventional’ fluidized bed might also further improve the scalability of the results by ensuring the rate-limiting step for adsorption is internal diffusion within the sorbent, which will be the same as larger scale operations.

In the present study, collaborating with Torftech, additive manufacturing has been used to construct the first small-scale swirling fluidized bed for sorbent screening applications. Here, an angled blade geometry provided by Torftech has been miniaturized and printed at the smallest possible scale using a desktop stereolithographic 3D printer (Form2). Successful swirling fluidization has been demonstrated in 50 mm and 75 mm diameter configurations. Here, high speed imaging has been used to study the particle dynamics in the swirling regime using a variety of particle types: silica particles (ρ_p = 2.65 g/cm^3, D_p = 93 ± 10 μm, Geldart A), a commercial pharmaceutical powder (ρ_p = 1.3 g/cm^3, D_p = 10 ± 2 μm, Geldart C) and hydrotalcite sorbents for CO_2 capture (ρ_p = 1–2 g/cm^3, D_p = 25 μm, Geldart C).

The present experimental focus is two-fold. To firstly perform top-down high speed camera imaging of the swirling particle bed to identifying suitable operating regimes. Then, in further collaboration with Heriot-Watt and Sheffield Universities, to screen novel hydrotalcite sorbents for CO_2 capture from an artificial flue gas stream to inform the design of a carbon capture process for processes in the industrial sector (such as cement and iron/steel production). These experiments are also being performed at varying temperatures (20–200 °C) and in the presence and absence of humid air (controlled using a membrane contactor).