This highlight refers to the PhD Thesis by Evan Milacic (2021)

Liquid injection in fluidized beds

Evan Milacic, Maike Baltussen and Hans Kuipers

Fluidized bed reactors are gas-solid contactors which are often used in industry due to their uniform temperature profile throughout the reactor and the high solids mobility. In many industrially operated fluidized bed reactors, liquid is injected to act as reactant, as a carrier for the deposition of materials or as a cooling agent. Although the liquid has an essential role in the operation of this reactor, it also increases the complexity of the reactor drastically. The injected liquid affects the motion of the solids and thereby the bed uniformity. In addition, the liquid also increases the adhesion of the solids leading to the formation of clusters of particles and liquid, which are called wet agglomerates. The effect of the liquid injection on the temperature distribution and the hydrodynamics inside a fluidized bed were studied.

The effect of liquid injection on the bulk behaviour of the fluidized bed was studied using a combination of Particle Image Velocimetry (PIV) and Infra-Red Thermography (IRT) on a pseudo-2D bed. PIV was used to study the solids motion in the bed, while the temperature field was obtained using IRT. The pictures are taken simultaneously to enable calculation of the local solids heat flux. Figure 1 shows the local solids fraction (left) and the temperature profile (right). The probability density function of the particle temperature was determined to study the effect of the liquid injection in the bed. The experiments showed that the temperature was less uniform when small droplets were injected compared to the injection of large particles (Milacic et al., 2022a,b).

Although there is a clear correlation between the two images in Figure 1, the right image shows some low temperature spots throughout the reactor, which are the created agglomerates. The agglomeration behaviour is more pronounced when the droplets used for injecting the liquid are larger. In addition, a decrease in the solids motion, e.g., a decrease in the gas velocity, will also promote the formation of agglomerates. Although the agglomerates are very clearly visible in the IRT images, their formation is not visible in the probability density function of the particle temperature (Milacic et al., 2022a,b).

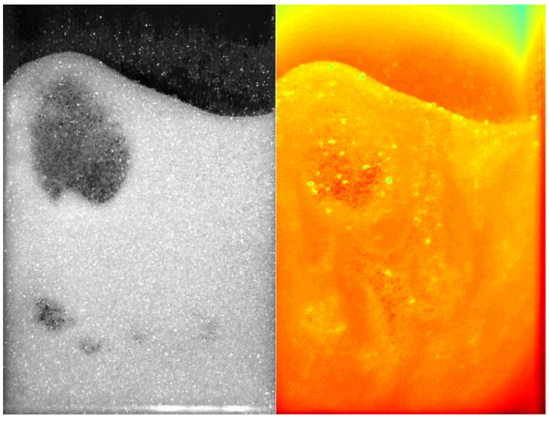

Figure 1: Fluidized bed with liquid injection from a nozzle located at the centre of the inlet plane. The left image is taken by the visual camera and the right image by the infra-red camera. The right image clearly shows the agglomerates in the bed as cold spots, which are not visible in the other image. The particles are glass Geldart B particles.

In the previous experiments, glass particles have been used to study the effect of liquid injection. However, the particles in most industrial applications are porous. Therefore, we have studied the effect of the porosity and the specific surface area of the particle on the particle temperature distribution. The results showed that the distribution of the particle temperature is mainly influenced by the specific surface area (Milacic et al., 2022c).

Besides the effect on the temperature distribution, the introduction of liquid in a fluidized bed of porous particles will also lead to the imbibition of liquid in the particles. Therefore, density driven segregation is more pronounced in the case of porous particles. The main factors that increase the density driven segregation of the particles are the porosity of the particles and a decreased solid agitation. The density segregation leads to the formation of large clusters at the bottom of the bed, which lead to defluidization of (a part of) the bed (Milacic et al., 2022c).

To obtain a better understanding on the formation of the phenomena found in the larger scale experiments, Direct Numerical Simulations are used to determine the lifetime of these agglomerates based on the evaporation of the liquid. For this specific study, the Volume of Fluid method was used to represent the gas-liquid interface, which was coupled to a second-order implicit Immersed Boundary Method of Deen et al. (2012) to represent the gas-solid interface using a static contact angle boundary conditions at the gas-liquid-solid contact line (Milacic et al., 2019).

After validation, the combined Volume of Fluid / Immersed Boundary Method was first used to study the spreading of a viscous droplet on a single particle. Compared to spreading on a flat plate, the droplet spreads less on a curved surface. The main factor determining the coverage of the solid surface by the liquid is the volume ratio of the droplet and the particle. In addition, a dimensionless droplet spreading time was determined that allows for comparison to other relevant time scales in a fluidized bed. For example, the dimensionless spreading time is generally larger than the time between collisions of particles, i.e. particles collide before the liquid of a droplet is completely spread over a surface (Milacic et al., 2019).

This study on single particles was extended to a cluster of particles to better predict the agglomerate lifetime. This lifetime is partly governed by the evaporation rate from the available gas-liquid interface in an agglomerate. Therefore, the available gas-liquid interface was studied as shown in Figure 2. In the study, it was determined that the available area largely depends on the ratio of the liquid and particle volume and the static contact angle near the interface (Milacic et al., 2020).

Figure 2 shows two identical cases from this study. Although the main physical properties are the same in these simulations, the available gas-liquid area for evaporation is much larger for the agglomerate in the left graph compared to the right graph. This difference is caused by the different random positions of the particles. Due to the effect of the particle configurations, several realization of comparable agglomerates should be investigated to enable the development of a predictive correlation of the available gas-liquid interface area in an agglomerate (Milacic et al., 2020).

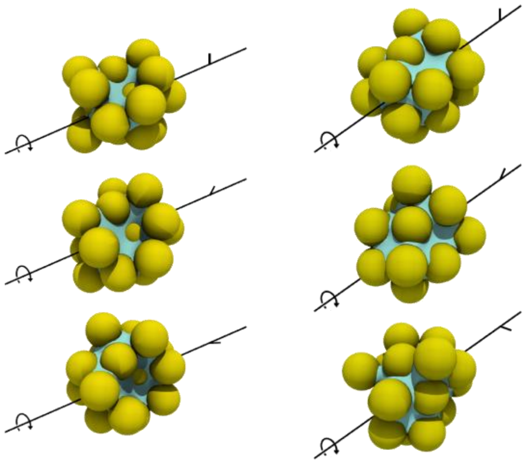

Figure 2: The distribution of the liquid droplet in an agglomerate of 19 particles, with a solids volume fraction of 55% and a static liquid contact angle of 30^o (Milacic et al., 2020).

References

Deen, N.G., Kriebitzsch, S.H.L., van der Hoef, M.A., Kuipers, J.A.M., 2012. Direct numerical simulation of flow and heat transfer in dense fluid–particle systems. Chem. Eng. Sci. 81, 329–344.

Milacic, E., 2021. Studying liquid injection in fluidised beds through simulations and experiments, PhD Thesis, Eindhoven University of Technology.

Milacic, E., Baltussen, M.W., Kuipers, J.A.M., 2020. Direct Numerical Study on the free liquid area in liquid-particle agglomerates., in: Proceedings from the 14th International Conference on CFD in Oil & Gas, Metallurgical and Process Industries. 72–76.

Milacic, E., Baltussen, M.W., Kuipers, J.A.M., 2019. Direct numerical simulation study of droplet spreading on spherical particles. Powder Technol. 354, 11-18.

Milacic, E., Nunez Manzano, M., Madanikashani, S., Heynderickx, G.J., Van Geem, K.M., Baltussen, M.W., Kuipers, J.A.M., 2022a. Liquid injection in a fluidised bed: Temperature uniformity. Chem. Eng. Sci. 256, 117622.

Milacic, E., Nunez Manzano, M., Madanikashani, S., Heynderickx, G.J., van Geem, K.M., van de Greef, A.A.M., Richter, A., Kriebitzsch, S.H.L., Buist, K.A., Baltussen, M.W., Kuipers, J.A.M., 2022b. Experimental study on the temperature distribution in fluidised beds. Chem. Eng. Sci. 248, 117062.

Milacic, E., Rangtong, D.R., Kuipers, J.A.M., Baltussen, M.W., 2022c. Temperature distribution in fluidized beds of porous particles with liquid injection. Chemie Ing. Tech. under review.