19th Brazilian Congress of Thermal Sciences and Engineering
November 6th–10th, 2022, Bento Gonçalves - RS - Brazil

ENC-2022-0058
CRYSTALLIZATION IN BIDISPERSED BEDS

Vinícius Pereira da S. Oliveira
Willian Righi Assis
Erick de Moraes Franklin
State University of Campinas, R. Mendeleyev, 200 - Cidade Universitária, Campinas - SP, 13083-860
v265311@dac.unicamp.br

Abstract. *Fluidized beds are described as suspensions of solid particles (grains) in a vertical duct by an upward flow of fluid forced against a porous plate. When the aspect ratio (relation between the diameters of the tube and the grain) is equal to or less than ten, the fluidized bed is said to be a very narrow fluidized bed. The bed behavior is influenced by the interstitial fluid. For example, if it is a liquid in a low grain concentration, fluid interactions are dominant, such as drag interactions, buoyancy and virtual mass; on the other hand, if it is a gas, particle interactions such as shocks and solid friction are more prominent. Narrow fluidized beds have very rich dynamics at both the bed (macroscopic scales) and grain (microscopic scales), with phenomena such as crystallization, blockages and plug formation occurring at the bed scale while shocks, sliding and vortex shedding occur at the grain scale. The addition of a different particle species causes other phenomena to appear, such as mixing and layer inversion, in addition to modifications in bed crystallization. This work investigates the crystallization in bidisperse beds. We present, among other results, the mean temporal evolution of the granular temperature, crystallization time, and intensities for bidisperse and monodisperse beds.*

Keywords: *crystalization, narrow beds, fluidized beds.*

1. INTRODUCTION

Solid-liquid fluidized beds present an intricate dynamics, involving fluidization and sedimentation. The solid mass is suspended in a vertical duct by an ascendant fluid flow forced against a porous plate, in which the flow rate is sufficient to generate enough drag to balance or surpass the weight of the particles (Guazzelli, 2004). Its dynamics comprehends particle-particle, particle-fluid and particle-wall interactions. The interstitial fluid also influences the bed regime, where liquids make the fluid interactions dominant, such as drag, buoyancy and virtual mass. On the other hand, with gases, shocks and solid friction are predominant (Cúñez and Franklin, 2020; Cúñez *et al.*, 2021).

Any of the above-mentioned configurations provide high heat and mass transfers and are often employed in industrial processes such as, combustion or gasification of coal and biomass, drying, cooling, and coating of solids (Cúñez and Franklin, 2019). Several of these problems involve a good mixing between both phases, with blocking and arching being an obstacle to the satisfactory performance of such processes. Sedimentation and fluidization are physical phenomena that have been studied for a long time. Stokes was the first to formalize analytical expressions for a sphere settling with rest at infinite, simply by balancing weight (minus the buoyancy) and drag (Elizabeth, 2006). Although taking account only one particle, Stokes provided analytical expressions for the perturbation caused by a sphere in its surroundings.

Richardson and Zaki (1997) performed a range of experiments to study the sedimentation of particles, obtaining a relationship between the void fraction and the velocity of a particle fluidized on a bed. Although it is an empirical equation, the Richardson-Zaki equation provides a good estimate of the velocity of a particle in an ensemble of others in a bed. They also documented the formation of a hollow structure composed of organized particles near the wall in a fluidized bed of iron cubes (an example of crystallization). In addition to sedimentation and fluidization, mechanical phenomena in the solid phase such as collisions between particles, friction and formation of particle clusters (causing blockages and macroscopic structures such as crystals and arches) can occur in systems with a high concentration of particles. Goldman and Swinney (2006) expose this problem and make an analogy with the formation of glass, bringing a new look to this type of problem.

The complete understanding of the dynamics of an ensemble of particles remains open, especially at high concentrations. Despite being apparently simple and even adopting several simplifications, such a system has a very high complexity when composed of more than one particle. In addition, considering the perturbations that several particles suffer due to interactions with others, the mechanical characteristics of the shocks may present different sources. The aim of this work is to investigate, experimentally, granular temperatures and crystallization behavior for a bidisperse fluidized bed (two species of particle).

2. METHODOLOGY

The experiment was conducted using a set of airsoft pellets with two different weights (0.2 g and 0.3 g) that compose the granular medium and a flow of water imposed by a pump to establish the uniform flow. The particle set consists of airsoft pellets with a standard size of 5.95 ± 0.05 mm. The bed is composed of 200 for each test run. The data for each particle is in Tab. 1. The interstitial fluid (water, $\mu = 0.00102$ Pa.s and $\rho = 1000$ kg/m^3) is displaced by a centrifugal pump and homogenized by a column of alumina particles to ensure a constant and uniform flow of water in a circular duct with 25.4 mm ID.

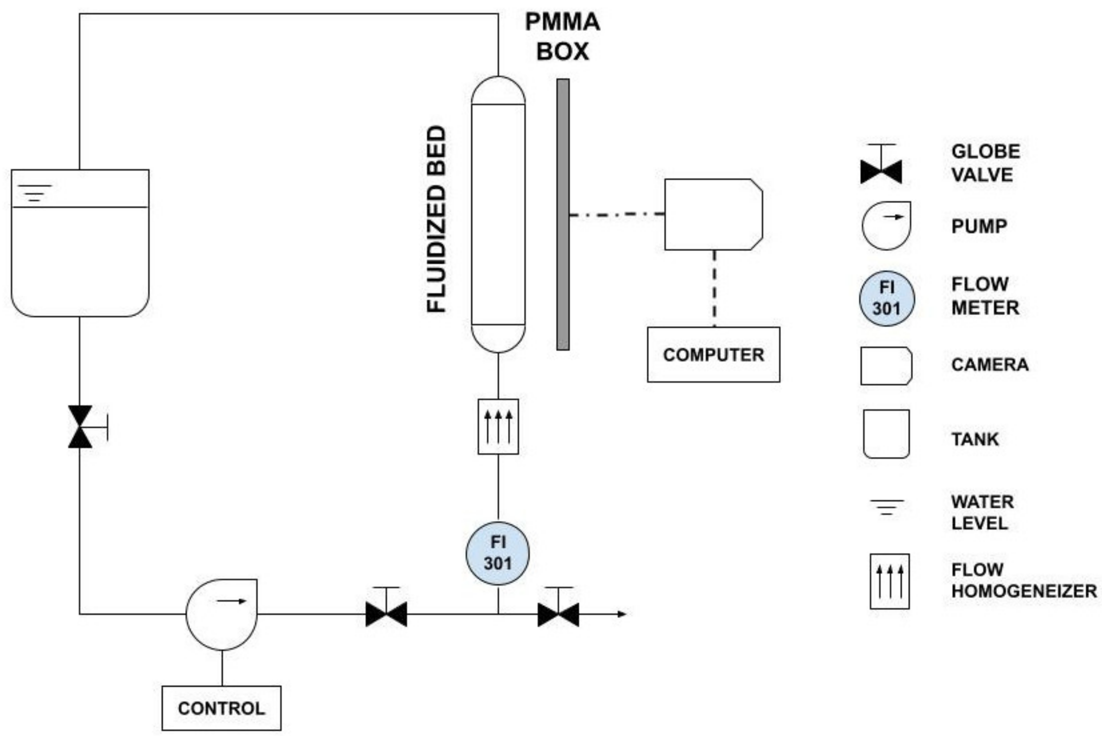

Figure 1. Experimental setup.

Data is acquired from a Nikon 5600 complementary-metal-oxide-semiconductor type which was placed in front of the experimental setup. The bed is indirectly illuminated by two 100 W LED reflectors and is viewed through a rectangular acrylic (polymethylmetacrylate - PMMA) box in order to reduce distortions. Parchment paper is also used to disperse the light from the LEDs and reduce possible reflections on the particles. The background used is black in contrast with white particles to improve post-processing. The method of reading the flow is analog, and the specific command in the inverter depends on the previous reading of the flow in the flow meter. The complete setup is shown in Fig. 1. A summary of parameters can be seen in Tab. 1.

Table 1. Data set of experiments.

Parameters	
Weight (g)	0.2, 0.3
Superficial velocities U_0 (m/s)	0.0822, 0.110, 0.137, 0.131
Diameter ratio	4.27
Test duration (s)	300
Size of the bed N (particles)	200

3. RESULTS

For the tested beds, The particle's kinematics were computed. The mean agitation of the particles was measured by the granular temperature. In addition, crystallization times were also measured from the observation of the granular temperature. An example of the average instantaneous granular temperature for a particle can be observed in Fig. 2. The data for crystallization times from the beds is can be found in Tab. 2. It is expected that heavier particles present a greater incipient fluidization velocity. We can observe that with superficial velocities closer to the minimum fluidization, the phenomenon tends to occur in shorter time than greater ones. It suggests the existence of a minimum time of crystallization.

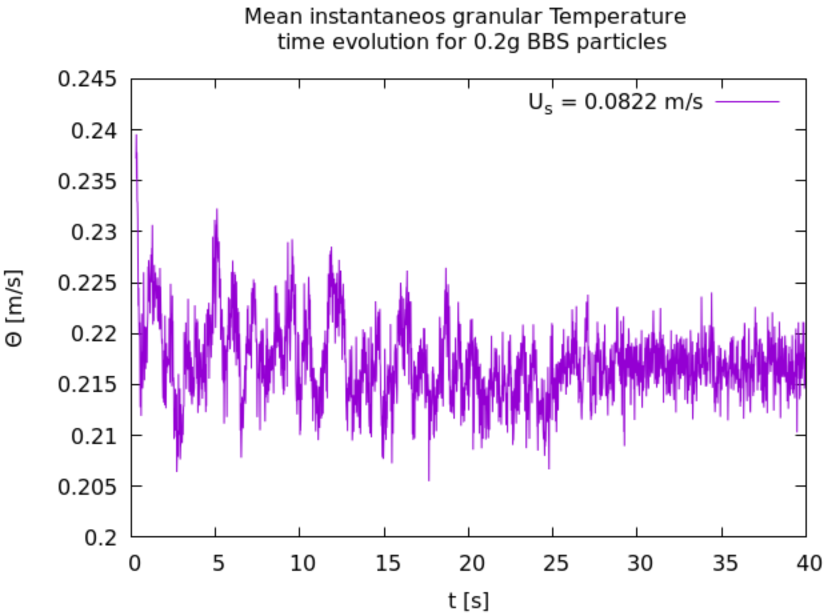

Figure 2. Time evolution of mean granular instantaneous temperature.

Table 2. Crystallization
times for different experiments.

Particles	U_0 (m/s)	t (s)
BBS 0.2 g	0.082	25
BBS 0.2 g	0.110	-
BBS 0.2 g	0.137	-
BBS 0.3 g	0.110	10
BBS 0.3 g	0.131	300
BBS 0.3 g	0.147	-

4. CONCLUSIONS

Crystallization is a not completely understood phenomenom. The investigation of this phenomenon can be advantageous for a wide range of sectors of the economy. There are hypotheses for the phenomenon, but no plausible conclusions about its real nature. To explore it, we propose to test (so far) bidisperse beds composed of BBS polymer particles and observe the temporal development of the bed and the mobility of the particles through of the granular temperature. In this first moment, we could observe that crystallization time depends on incipient fluidization.

5. ACKNOWLEDGEMENTS

The authors are grateful to FAPESP (Grants numbers 2018/14981-7, 2019/10239-7 and 2020/00211-0).

6. REFERENCES

Cúñez, F.D. and Franklin, E.M., 2019. "Plug regime in water fluidized beds in very narrow tubes". *Powder Technology*, Vol. 345, pp. 234–246.

Cúñez, F.D. and Franklin, E.M., 2020. “Crystallization and jamming in narrow fluidized beds”. *Physics of Fluids*, Vol. 32, p. 083303.

Cúñez, F.D., Lima, N.C. and Franklin, E.M., 2021. “Motion and clustering of bonded particles in narrow solid-liquid fluidized beds”. *Physics of Fluids*, Vol. 33, p. 023303.

Goldman, D.I. and Swinney, H.L., 2006. “Signatures of glass formation in a fluidized bed of hard spheres”. *Physical Review Letters*, Vol. 96, No. 145702.

Guazzelli, E., 2004. *Fluidized Beds: From Waves to Bubbles*. The Physics of Granular Media. Wiley-VCH Verlag GmbH & Co. KGaA.

Richardson, J.F. and Zaki, W.N., 1997. “Sedimentation and fluidisation: Part i”. *Trans IChernE*, Vol. 75, No. S82-S100.

7. RESPONSIBILITY NOTICE

The authors are solely responsible for the printed material included in this paper.