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Numerical investigation of the hydrodynamic of a sand fluidized bed designed for heat storage

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ABSTRACT

The purpose of the present work is to study the capability of a sand fluidized bed system to perform as a heat storage. The focus is put on the numerical investigation of the main design criteria of the sand fluidized bed behavior, and the hydrodynamic aspect of the problem has been studied using a commercial CFD code. At first, the fluidized bed head losses which is a relevant design criterion is studied. The findings are compared with experimental data collected in the literature to approve the simulation. When the solid phase properties are set, the head loss depends on the on the fluid mean velocity and on the bed's height. The numerical tests were performed for fluid's mean velocities that are higher than the minimum fluidization velocity, and it comes that the simulated and the experimental data are similar.

INTRODUCTION

There is an increase in the necessity of energy storage technology (TES) due to the interest of energy production, especially renewable energy. It is well known that this type of production is intermittent and the peak of production usually differs from the peak of consumption. To increase the efficiency, the energy storage technologies are used to answer this problematic.

An example of energy storage technology is the synthetic oil used in the concentrated solar plant as heat storage fluid [11]. The first issue of causes by using this type energy storage is the cost which increases a lot the price of the power plant A second issue is the environmental aspect. The oil used is synthetic and not

natural. Numerable way to use other media which are less expensive and eco-friendlier are in development [6-9]. Some solution found are base on the sand as heat storage media as a packed bed [10]. The sand is very accessible for country where concentrated solar plants are built. Moreover, his thermal properties allow it to be efficient [10]. The purpose of this project is to explore the possibility for sand fluidized bed to be a good heat storage technology or not. An experimental device is being built and comparisons will be done with simulation. The first step for the simulation is to approve the computation method and here are the first results based on the pressure in fluidized bed.

NOMENCLATURE

C_D	[-]	Drag coefficient for single particle
H_0	[m]	Initial bed height
u	[m/s]	Velocity
p	[Pa]	Pressure
g	[m ² /s]	Gravity
V_r	[-]	Reynolds number ratio
Re_t	[-]	Reynolds number for single particle
A	[-]	Constant in eq (7)
B	[-]	Constant in eq (7)

Special characters

α	[-]	Volume Fraction
β	[-]	Inter Phase coefficient
ρ	[kg/m ³]	Density
τ	[Pa]	Stress tensor

Subscripts

c	continuous phase
d	dispersed phase
k	continuous or dispersed phase
s	Related to a cluster of particles

PROCEDURE AND MODELING

The sand considered in the present study for the fluidized bed is of a mean diameter 165 μm and a density of 2650 kg.m^{-3} . The sand is encompassed in a cylindrical tank with a diameter of 230mm and a total height of 800 mm [2]. The initial height of the packed bed is H_0 . Four configurations of this initial height are explored that are 20, 30, 40 and 50 cm.

The couple Air/Sand used here for fluidization is classed in the B group of the Geldart classification [3]. Regarding this classification, the expected air-sand diphasic flow is a phase dense type that may be computed using a two-fluid model with a laminar flow. [4]

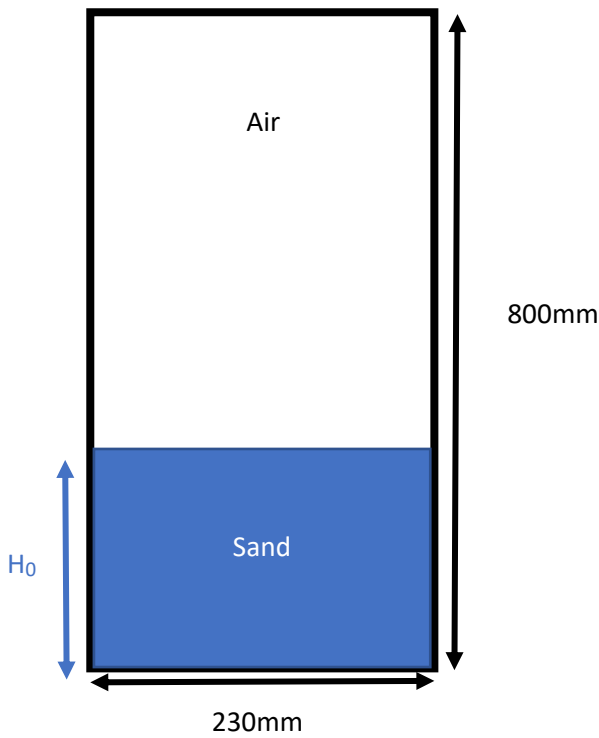


Figure 1 – Computation domain

For the CFD purpose, the computation domain is shown in Figure 1. It is represented by a 2D vertical planar with a width of 230 mm and a height of 800mm.

An eulerian-eulerian model is adopted for the laminar two fluid flow. The governing equations are as follow [1,4] :

Mass conservation for the phase k (where $k = c$ for continuous phase, here the air, and $k = d$ for dispersed phase, here the sand) :

$$\frac{\partial}{\partial t}(\alpha_k \rho_k) + \nabla \cdot (\alpha_k \rho_k \mathbf{u}_k) = 0 \quad (1)$$

With :

$$\alpha_c + \alpha_d = 1 \quad (2)$$

Where α, ρ and \mathbf{u} are respectively the volume fraction, the density and the velocity of the phase k .

Momentum conservation for the continuous phase is:

$$\frac{\partial}{\partial t}(\alpha_c \rho_c \mathbf{u}_c) + \nabla \cdot (\alpha_c \rho_c \mathbf{u}_c \otimes \mathbf{u}_c) = -\alpha_c \nabla p + \nabla \cdot \bar{\bar{\tau}}_c + \alpha_c \rho_c \mathbf{g} - \beta(\mathbf{u}_c - \mathbf{u}_d) \quad (3)$$

Momentum conservation for the dispersed phase is:

$$\frac{\partial}{\partial t}(\alpha_d \rho_d \mathbf{u}_d) + \nabla \cdot (\alpha_d \rho_d \mathbf{u}_d \otimes \mathbf{u}_d) = -\alpha_d \nabla p - \nabla p_d + \nabla \cdot \bar{\bar{\tau}}_d + \alpha_d \rho_d \mathbf{g} - \beta(\mathbf{u}_d - \mathbf{u}_c) \quad (4)$$

Where p is the pressure, $\bar{\bar{\tau}}$ is the stress tensor, \mathbf{g} the gravity, β the inter-phase momentum exchange coefficient, and p_d the interfacial pressure. This pressure is linked to the local difference of pressure on the surface of the sand particle due to his motion in the air flow. This is also linked to the drag force.

As seen in equation (4), in this study, following Mahfoudi et al. [1] the drag force is the sole force considered as acting on the dispersed phase particles. The Syamlal-Obrien model is used to evaluate the drag force of a cluster of particles based on the drag force on a single particle [5].:

$$C_D = \frac{C_{Ds}}{V_r^2} \quad (5)$$

where C_D is the drag force coefficient acting on a for single particle, C_{Ds} is the drag force coefficient for cluster of particles and V_r is the ratio between particular Reynolds number of a single particle Re_t and the particular Reynolds number of a cluster of particles Re_{ts} expressed as follow :

$$V_r = \frac{Re_t}{Re_{ts}} \quad (6)$$

The used Syamlal-Obrien states that V_r depends on the particular Reynolds number of a single particle Re_t as follow :

$$V_r = 0.5 \left[A - 0.06 Re_t + \sqrt{0.0036 Re_t^2 + 0.12 Re_t (2B - A) + A^2} \right] \quad (7)$$

Where

$$A = \alpha_d^{4.14} \quad (8)$$

And

$$B = \begin{cases} C_2 \alpha_d^{1.28} & \alpha_d \leq 0.85 \\ \alpha_d^{C_1} & \alpha_d > 0.85 \end{cases} \quad (9)$$

C_1 and C_2 are constants and their respective values are by default 2.65 and 0.8.

The inlet condition are on the air. His velocity is imposed and correspond to the fluidization velocity. The outlet is on the mixture and concern the pressure supposed to be the atmosphere, that mean a null gauge pressure. The simulations were performed with a commercial code Ansys Fluent 18 with a pressure-based solver. That means the algorithm is the following. First, the properties of fluid are updated with the present velocity and pressure fields. Then momentum equations are solved followed by pressure correction with the new velocity and mass flux fields to ensure the continuity. After this, mass fluxes, pressure and velocity fields are finally re-updated before the all properties of the fluid and the convergence is checked.

The mesh is optimized before all computation to be independent from velocity and pressure. The dimensions of the mesh are 72*225 with orthogonal quality. For this type of simulation, the time step is 1ms to insure the convergence and there are 15000 time steps to reach the 15 s of simulation, time required for the bed to be stable and with a CPU time around 240 s. The simulation was performed with a Intel® Core™ i5-8500 processor and 6 processes. After some tries, the residual criteria chosen are 0.001 on continuity, x-velocity and y-velocity of each phase to have a good convergence with an implicit scheme. For each initial bed height, six fluidization velocity has been simulated from 2.5 cm/s to 10 cm/s.

RESULTS

Figure 2 presents the evolution of the total pressure drop in the bed depending on the fluidization velocity for different initial height H_0 . For any given initial height, the pressure drop is almost constant when the fluidization velocity is increased in the consider range as it was expected among the experimental data of K. D N'Diri [2] shown on Figure 2 too. There is an increase when the initial bed height increases and the value of each step is equivalent to the measurements, that is to say a pressure drop of 2700Pa for a initial bed height of 20 cm, 4000Pa for 30cm, 5500Pa for 40cm and 7900Pa for 50cm.

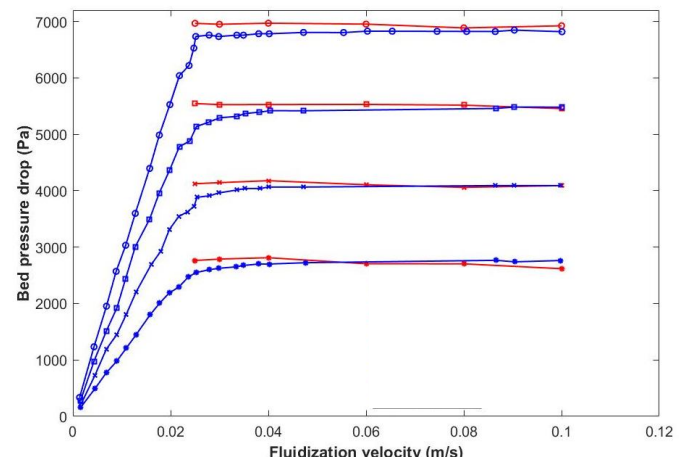


Figure 2 – Bed total Pressure drop versus fluidization velocity

The evolution of the pressure drop related to the bed height at minimum fluidization velocity is represented in Figure 3. The present model and computation results are in very good accordance with the measurement. The measurement confirms the simulation results on the fact that the pressure drop remains constant for each initial bed height. The finding shows that there is a ratio of pressure/minimum fluidization bed height of 12500Pa/m. This value is lightly underestimated compared to the 14000Pas/m measured in the experimentation (Figure3). The difference may be due to the pressure drop measurement procedure, or to the fact that some acting forces on the solid particle have been neglected in EQ (6) as above mentioned. It is noticed that the considered fluidization velocities stand between the minimum fluidization velocity the induces bubbling fluidized bed state for lesser or higher velocities, the total pressure drop versus the fluidization velocity is expected to show different trend than the one found here.

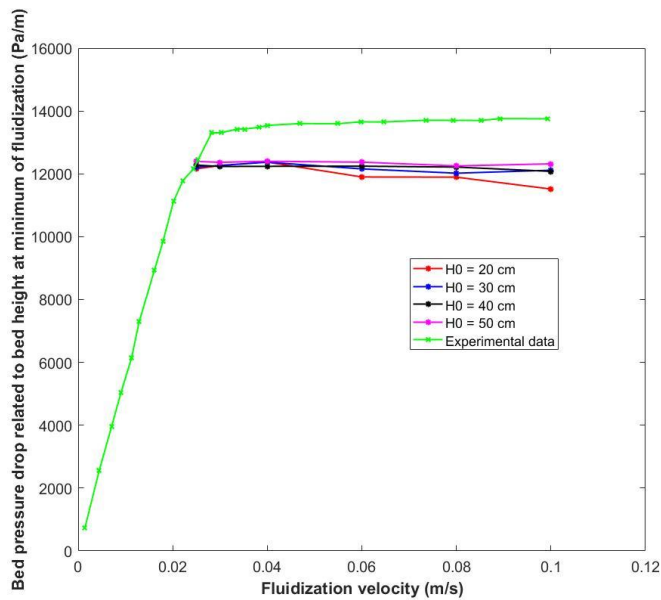


Figure 3 – Bed total Pressure drop/Minimum fluidization height versus the fluidization velocity

Furthermore, the findings show that the growth of the bed height is regular and it reaches a maximum after 12.5s (figure 4) and a final height of 63cm. In further research investigation these values must be validated using experimental work.

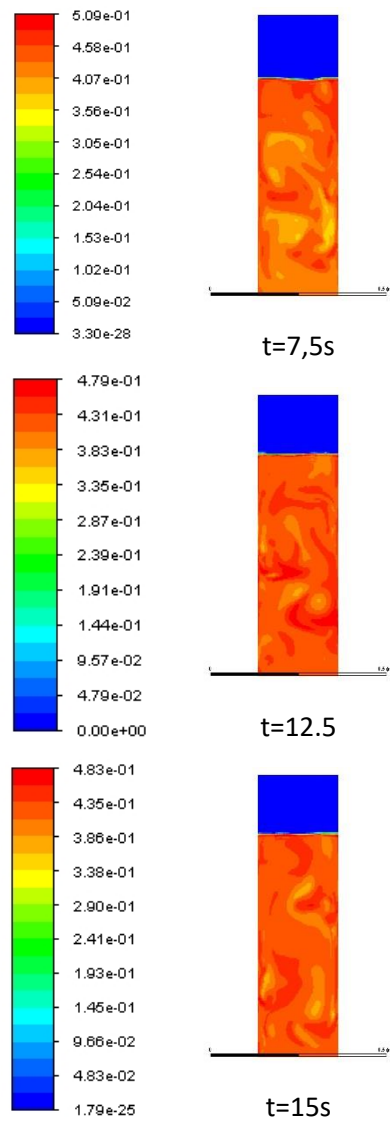
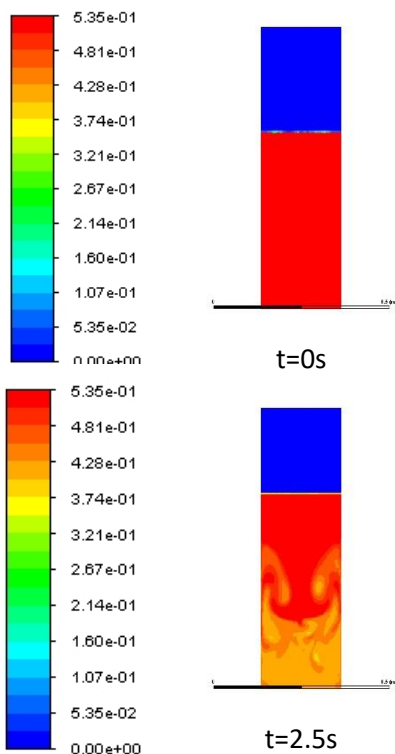


Figure 4 – Evolution of the volume fraction for a 4cm.s^{-1} - fluidization velocity and 50cm-initial bed height

CONCLUSION

A two fluids model with eulerian-eulerian schema have been used to solved with a CFD commercial code to study the hydrodynamic of a sand fluidized bed for heat storage purposes. The focus has been put on bed total pressure drop dependence on the fluidization fluid velocity. The explored fluid velocity values have been limited to range the lets studied system under the limit of bubbling fluidized bed state. The numerical results are validated against experimental published measurements and good compliances are found. There are further findings of the present study in term of the void volume fraction, of the fluidized bed final height and to the times that fluidized bed takes to reaches this a near steady high after fluidization starting. These last finding haven't been validated due to the lack of published experimental results. The next step of the

present project is to set up an experimental mockup for both hydrodynamical and heat transfer studies in an air sand fluidized bed. The developed model and numerical resolution scheme will be extended to consider the heat and mass transfer studies.

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