

# Gas-solid hydrodynamic study in a rotor-stator vortex chamber reactor

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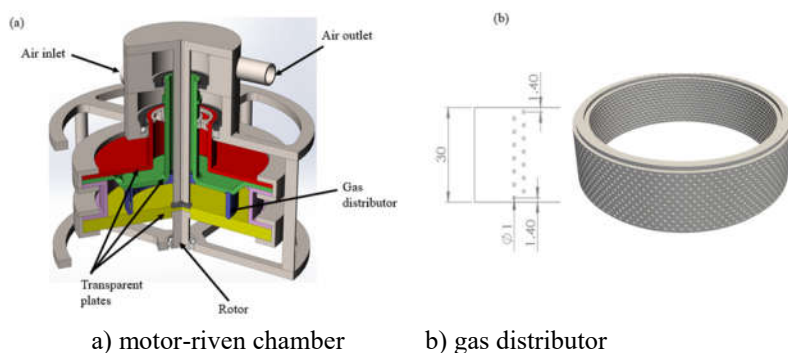
## Introduction

The gas-solid vortex reactor (GSVR) shows great potential in process intensification that has been demonstrated by both numerical and experimental studies. Limitations for the applications of GSVR are particle entrainment caused by gas jets [1], high gas-solid mass ratio [2], and low azimuthal velocity due to strong particle-wall friction [3]. A promising rotor-stator vortex chamber design has been developed and patented by LCT [4], in which a rotating chamber is driven by the impact of the gas on the blades, aiming to remove the limitations abovementioned. The optimization to achieve more favorable fluidization characteristics (e.g. radial solid movement) is essentially a search of optimal rotating speed vs. air flowrate. This brings a big challenge since the two factors are coupled. To gain understanding it would be better to decouple the two factors. One option is to introduce a motor to drive the chamber. Once the influence of each factor on the hydrodynamics has been investigated, the optimal combinations of rotating speed vs. air flowrate can be determined. Eventually, these combinations can guide the optimization. By using monosized aluminum balls (diameter 0.5 mm, density 2700 kg/m<sup>3</sup>) as the bed material and air as the fluidizing agent, the gas-solid hydrodynamics in the motor-driven chamber have been studied. The flow behavior is observed via a CCD camera. The bed thickness from both the top view and bottom view as well as the bed pressure drop are measured against the air flowrate. Moreover, particle image velocimetry (PIV) measurements are employed to further analyze the fluidization behaviors of particles.

## Methodology

The motor-driven vortex chamber as the core piece of the experimental setup is shown in Figure 1. A gas distributor with 1400 inclined holes is inserted between two endplates. Air (0 - 90 m<sup>3</sup>/h) supplied by a compressor flows through the inlet to the reactor (annular space between the red and green part), then contact with solids after distribution by

the distributor. Solids loading is in the range of 100 – 200 g and rotating speed can be varied from 0 to 800 RPM. A CCD camera is set below or above the reactor to record images that are used to determine the particle velocity as well as bed thickness. The pressure drop across the solids bed is obtained by two differential pressure sensors which measure the pressure drops from the air inlet to the gas distributor and the center of the reactor respectively.



a) motor-driven chamber      b) gas distributor  
Figure 1. Three-dimensional view of the chamber and gas distributor

## Results and Discussion

The first objective is to construct a map of the fluidization behavior in the unit. For a rotating bed, fluidization is a result of the balance of centrifugal force and drag force. One of the biggest advantages of having a motor is that we can decouple the centrifugal force and the drag force by controlling the air flow rate and rotation speed individually. Figure 2 shows the influence of the rotating speed and air flowrate on particle flow behaviors. At low rotating speed (e.g. 100 RPM), aluminum balls are easily entrained by the air and cannot form a stable bed. On the other hand, when the rotating speed is very high, e.g. 500 RPM, the bed is so densely packed that it cannot be fluidized even at the maximum air flowrate. In the range of 200 - 400 RPM, the transition between a packed bed and a fluidized bed is observed when air flowrate increases gradually. Moreover, with a higher rotating speed, a larger flowrate is required to

fluidize particles. It is worth mentioning that the flow behavior of particles from the top view and bottom view at the same operating conditions is different due to the gravity effect. This can also be demonstrated by PIV results that the velocity of particles at the topmost layer is slightly higher than that for the bottommost layer. In addition, particles at different radial positions have different velocities, as illustrated in Figure 3.

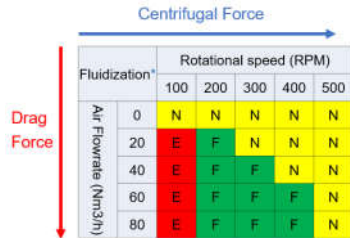


Figure 2. Fluidization map for aluminum balls at different combinations of air flowrate and rotating speed (E – entrainment, F – fluidization, N - no fluidization).

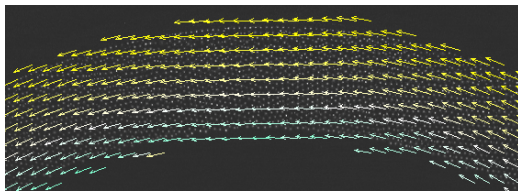


Figure 3. Velocity vector fields obtained from bottom view with a 2D PIV (rotating speed: 300 RPM, solids loading: 100 g).

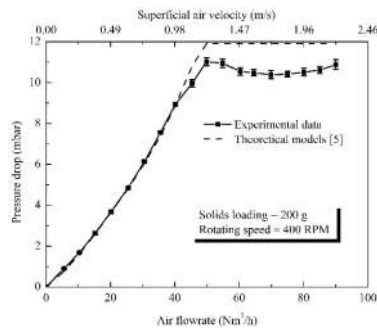


Figure 4. Comparison of experimental and calculated pressure drop.

As mentioned above, gravity plays a significant role in solids distribution in the chamber of the reactor. As solids tend to deposit on the bottom plate. The bottom bed thickness is always larger than its top counterpart. When the air flowrate increases, particles slowly move upwards, as a result, top bed thickness increases and bottom bed thickness decreases. At the maximum air flowrate, the top bed thickness is very close to the bottom thickness.

On the other hand, the rotating speed also influences the top-bottom bed thickness gap. The higher the rotating speed is, the smaller the gap is.

Overall, both rotating speeds and flowrates can shape the structure of the solids bed. With the motor-driven unit, we can manipulate the bed shape by adjusting the rotating speed or air flowrate independently.

The profile of the pressure drop across the rotating bed displays a high resemblance to that for conventional fluidized beds. As the gas flowrate increases gradually, the pressure drop increases almost linearly and then levels off after incipient fluidization despite some fluctuations. We can also determine the minimum fluidization velocity from the pressure drop vs. air flowrate curves. The pressure drop can also be calculated based on mathematical models available in the literature [5]. The theoretical pressure drop shows good agreement with experimental data, although the models tend to overpredict the pressure drop in the fluidized bed regime (an example shown in Figure 4).

## Conclusion

By introducing a motor to drive a vortex chamber, the rotating speed and gas flowrate are decoupled and the influence of each on gas-solid hydrodynamics has been independently investigated. The results reveal that both high rotating speeds and large air flowrates are favorable to obtain good uniformity of bed. Theoretical models developed to predicate the bed pressure drop shows good agreement with experimental data. Ultimately, the insights obtained in the motor-driven unit will be used to optimally design a blade-driven chamber, i.e., without motor.

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## Keywords

Vortex reactor; gas-solid fluidization; bed thickness; pressure drop;