Numerical analysis on gas-solid mixing in ceramic dry granulation room with baffles

D H Liao, Q Zheng, Z Y Zhao and N X Wu
Jingdezhen Ceramic Institute, Jingdezhen, Jiangxi, 333403

Abstract. In order to investigate the influence of baffles on the mixing effect of particles during ceramic dry granulation process. Air-particles interaction was analyzed by euler gas-solid two phases flow model, the granulation area was simplified. The three dimensional physical model of particles mixing process was constructed, granulation room rotary motion was simulated by sliding grid method and multiple reference frame method, turbulent motion was analyzed by modified RNG discrete model. The influence of different baffles on particles mixing was investigated according to the volume fraction distribution and velocity field, changed the position of the baffle can increase the blending effect by about 22%. The results showed: when there were no baffles, wall baffles and middle baffles in the granulation room, the average volume fraction of powder was about 0.22, 0.18 and 0.26 respectively. The average speed of powder was about 0.6m/s, 0.9m/s and 0.4m/s respectively. The wall baffle made the powder have significant axial movement, the experimental data showed: when granulation room had wall baffles, the content of active particles accounted for about 73%. It is helpful to improve the understanding of gas-solid two phase flow field in ceramic drying granulation room and provide some theoretical guidance for the design and optimization of the baffle.

1. Introduction

Ceramic dry granulation technology has the advantages of low emission and high efficiency, it has gradually replaced the wet granulation technology with high energy consumption and low production value [1-2]. However, the particles were made by dry granulation have many defects. Such as uneven composition, serious accumulation and single diameter gradation [3-4]. In the rotary flow field, the baffle could prevent the phenomenon well of particles were easy to form solid rotary area [5]. It makes the particles mix evenly, improves the dispersibility of particles and the diversity of particles size [6].

The baffle was arranged outside the wall of the granulation mechanism, the stirring main shaft and the granulation room. Many scholars have extensively studied the stirred room with baffle. Congcong Guo et al. analyzed the flow field of different baffle coefficients by numerical simulation, when the baffle coefficients increase to 0.35, the stirring power will no longer increase. Tiancheng Zhong and others studied the solid and liquid mixing process in the propellant agitator, the bottom baffle can reduce the accumulation and promote particles suspension. Cuixun Z and others analyzed and compared power consumption with their counterparts in the standard stirred tank, the results showed that semicircular canal baffles could enhance the uniformity of fluid velocity distribution and reduced the power consumption for about 5%.

Based on the research of the flow field in the stirred room with baffles, the three-dimensional model and mesh of granulation room with different baffles was created by GAMBIT. Particles mixing process was analyzed by constructing euler air-particles two phase flow model, the relationship
between the flow field and the baffle in the granulation room was researched. The correlation between particles mixing performance and baffle position was discussed according to the volume fraction of particles and velocity field of particles, the correctness of numerical analysis was verified by experimental data. The method and conclusion have some theoretical guiding significance for the optimization of ceramic dry granulation particles mixing performance and the improvement of baffle.

2. Finite element model

2.1. Geometric model of granulation room and baffles
SolidWorks 2014 was used to establish the model of granulation column and crushing reamer. The length of granulation baffles was 20mm, the diameter of granulation baffles was 8mm. The diameter of reamer was 90mm, the thickness of reamer was 8m. The diameter of addendum circle was 128mm, the diameter of root circle was 90mm. The granulation room wall, mixing spindle and baffle were modeled by brick, cylinder, split and other commands of gambit. The internal region of granulation room was simplified as shown in Figure 1, each particles component was mixed by combined action of crushing reamer, granulation column and granulation room wall. The diameter, high, baffle width of granulation room was 235mm, 300mm, 20mm respectively. The sketch map was shown in Figure 1.

![Figure 1](image.png)

**Figure 1.** Sketch map of granulation room with rectangular wall baffle.

The section view of three granulation room model was shown in Figure 2:

![Section View](image.png)

(a) No baffle  (b) Middle baffle  (c) Wall baffle

**Figure 2.** Section view of granulation room structure.

2.2. Boundary condition
The room was divided into dynamic calculation area and static calculation area. The dynamic calculation area was the adjacent area of reamer and granulation column, the rest area was the static calculation. The sliding mesh was adopted in the dynamic calculation area, and the static calculation area was set to the multiple reference coordinate system. The dynamic and static calculation area was connected by the interface so that the flow field data in the two regions can be freely communicated. The granulation room wall, mixing spindle, baffles, reamers and granulation columns were all set up...
as walls. The influence of other factors on the mixing process could be neglected, the specific setting was shown in the following Figure 3:

![Figure 3. Boundary condition of granulation room.](image)

2.3. Grid independence verification and grid partition
Based on the average volume fraction of particles, when the total number of meshes in wall baffle granulation room was 132434, 171365, 207364 respectively, the volume fraction of particles was 0.29, 0.20 and 0.20 respectively. Therefore, it can be seen that when the total number of meshes was 171365 and 207364, the volume fraction of particles was no longer changed. So the number of grids was divided into 171365 to save the calculation time.

Because the structure of the reamer area was complex, it was difficult to use the hexahedral structural grid to divide. The complete tetrahedron mesh was used to divide it, the number of grid units was 72851. The static calculation area was simple, so the hexahedron mesh was mainly used to divide it, the number of grid units was 98514. Grid partition schematic diagram was shown in the Figure 4.

![Figure 4. Sketch map of mesh generation.](image)

2.4. Solution method
The boundary conditions were defined and the euler-euler two fluid model was modified to better match this model. The implicit solution algorithm was used to solve the unsteady flow field. The flow field distribution was simulated by the modified euler-euler two fluid model. k-ԑ rmg discrete model was chosen for turbulence model, time dependent solution was solved by unsteady state model, pressure velocity coupling phase was adopted phase coupled simple algorithm. The convergent residual values of all variables were less than 1×10^{-4}. The rotary speed of reamer and mixing spindle were 1200r/min, the rotary speed of the granulation room was 40r/min.

3. The control of two-phase equations
① Continuity conservation equation
Continuity equation of air phase:

\[ \frac{\partial}{\partial t}(\varepsilon_g \rho_g) + \frac{\partial}{\partial x_j}(\varepsilon_g \rho_g v_j) = 0 \]  

(1)
\[
\frac{\partial n_p}{\partial t} + \frac{\partial}{\partial x_j} (n_p v_{pj}) = -\frac{\partial}{\partial x_j} (n_p y_{pj}) \\
\frac{\partial \rho_p}{\partial t} + \frac{\partial}{\partial x_j} (\rho_p v_{pj}) = -\frac{\partial}{\partial x_j} (\rho_p y_{pj})
\] (2)

\(t\) was time, \(\epsilon_s\) was turbulence energy dissipation rate of air phase, \(\rho_a\) was density of air phase, \(V_j\) was axial velocity of air phase, \(V_{pj}\) was axial velocity of power phase, \(n_p, \rho_p\) were density of additives and materials respectively.

(2) Momentum conservation equation
Momentum equation of air phase:
\[
\frac{\partial}{\partial t} (\epsilon_s \rho_a v_i) + \frac{\partial}{\partial x_j} (\epsilon_s \rho_a v_i v_j) = -\epsilon_s \frac{\partial \rho_a}{\partial x_i} + \mu \frac{\partial^2 v_i}{\partial x_j^2} + \frac{\partial v_i}{\partial x_j} + \epsilon_s \rho_a g_i + \frac{\rho_a}{\tau_{rp}} (v_{pi} - v_i) - \frac{\partial}{\partial x_i} (\epsilon_s \rho_a v_i v_j)
\] (3)

Momentum equation of particles phase:
\[
\frac{\partial}{\partial t} (\rho_p v_{pj}) + \frac{\partial}{\partial x_j} (\rho_p v_{pj} v_j) = -\epsilon_p \frac{\partial \rho_p}{\partial x_j} + \frac{\partial}{\partial x_j} (\tau_{ij}) + \rho_p g_i + \frac{\rho_p}{\tau_{rp}} (v_{pj} - v_{pi}) - \frac{\partial}{\partial x_j} (\rho_p v_{pj} v_j) + v_{pi} \rho_p v_{pj} + v_{pj} \rho_p v_{pj}
\] (4)

\(\rho_p y_{pj}, \rho_p v_{pj}, v_{pj}, \rho_p y_{pj}, \rho_p v_{pj}, \rho_p v_{pj}\) were unknown and therefore closed in the fluent euler two-phase flow model. \(V_i\) was radial velocity of air phase, \(V_{pi}\) was radial velocity of power phase, \(\rho\) was static pressure, \(\mu\) was coefficient of kinetic viscosity, \(g\) was gravity, \(\tau_{rp}\) was movement relaxation time of power phase, \(\epsilon_p\) was turbulence energy dissipation rate of power phase, \(\tau_{ij}\) was shear of particles phase.

4. The results and discussion of numerical analysis

4.1. Axial image of particles volume distribution
The axial plane of the granulation room was adopted to analyze the volume fraction of particles, shown in Figure 5. The results were shown: when there was no baffle in granulation room, particles movement area accounts for about 70% of granulation volume, the average volume fraction was 0.22, the area that particles volume fraction below 0.12 accounts for about 20% of the motion area. These particles mainly exist in the adjacent region of the stirring shaft. The area that particles volume fraction exceed 0.24 accounts for about 40% of the motion area, these particles mainly exist in the adjacency of walls. When there had wall baffle in granulation room, particles movement area accounts for about 85% of granulation volume, the average volume fraction was 0.18, the area that particles volume fraction below 0.12 accounts for about 8% of the motion area, the movement of these particles mainly on the top. The area that particles volume fraction exceed 0.24 accounts for about 7% of the motion area, these particles only exist adjacent to baffles and reamer.
4.2. Radial image of particles volume distribution
The plane above the reamer was shown in Figure 6, when there was no baffle in granulation room, average volume fraction of particles was 0.22, the area that particles volume fraction exceed 0.22 accounts for about 53% of the plane, the area that particles volume fraction below 0.12 accounts for about 14% of the plane. When there was wall baffle in granulation room, average volume fraction of particles was 0.20, the area that particles volume fraction exceed 0.22 accounts for about 5%, these particles aggregated at the side of baffle. When there was middle baffle in granulation room, average volume fraction of particles was 0.26, the area that particles volume fraction exceed 0.24 accounts for about 78%, these particles aggregated at the cylinder wall, the accumulation of particles was serious.

4.3. Axial image of particles speed distribution
The axial plane of the granulation room was shown in Figure 7, when there was no baffle in granulation room, the average speed of particles was 0.6m/s, the max speed area was at granulation column and reamer. When there had wall baffle in granulation room, the average speed of particles was 0.9m/s, the maximum velocity area was at the bottom, the particles moved upwards first and then to the granulation mechanism, there had obvious axial motion. When there had middle baffle in granulation room, the average speed of particles was 0.4m/s, the max speed area was under the reamer.
4.4. Radial image of particles speed distribution
Vector diagram of particle radial velocity was shown in Figure 8. When there was no baffle in granulation room, the average speed was 0.9m/s, the maximum velocity was 2m/s at the edge of the reamer, the track of particles was very regular, there had a serious rotary area. When there was wall baffle in granulation room, the average speed was 0.5m/s, the maximum velocity was 2m/s, but the particles outside the range of reamer had dispersion velocity. When there was middle baffle in granulation room, average volume fraction of particles was 0.26, the area that particles volume fraction exceed 0.24 accounts for about 78%, these particles aggregated at the cylinder wall and baffle.

5. Experimental analysis
5.1. Particle dispersion
The particle diameter was measured in the three kinds of structure granulation. The fluxing material required for the experiment contained: potassium feldspar, albite, calcium feldspar, talc, limestone, marble, dolomite. The plastic material contained: clay, montmorillonite, kaolin, bentonite. The poor plastic ceramic materials: quartz and quartz sand. The raw materials was proportionated according to the quality and mix them into the granulation room. The powder particles are fully mixed and the particles were discharged from the granulation room after granulating. The 20 mesh, 40 mesh, 60 mesh and 80 mesh standard screen plugging were used to screen out the particles of different particle sizes, the 20-80 mesh particles were considered as effective particles. Figure 9 was the particle size distribution diagram of three different baffles. When there had no baffle, the effective particle was about 51%, when there had wall baffle, the effective particle was about 75%, when there had middle baffle, the effective particle was about 54%. The experimental results showed that when the granulation room contains wall baffle, the effective particle ratio is the largest and the granulation effect was the best.

![Figure 8. Vector diagram of particle radial velocity.](image)

![Figure 9. Particle size percentage.](image)
6. Conclusions

(1) The baffle could change the movement state of the powder, obstructed the appearance of the powder whirlpool, and reduced the accumulation, but the baffle could also reduce the movement speed of the powder. The method and conclusion can provide some theoretical guidance for the movement state of the powder in the granulation room.

(2) The numerical results showed that the axial movement of powder was the most significant when the wall baffle adopted in the granulation room. The experimental results showed that the particle had the highest efficiency. It has a certain theoretical reference value for the baffle optimization of ceramic dry granulation room.

References

[1] Shu Z, Zhou J, Wang Y, et al. 2010 A novel approach of preparing press-powders for cleaner production of ceramic tiles Journal of Cleaner Production 18(10-11): 1045-1051

[2] Tao C, Yutao L, Yongbin H, et al. 2016 Analysis of tilting rate of building ceramics dry powder making granulation room based on CFD Journal of Ceramics 37(6): 724-728

[3] Tamburini, A. Cipollina, G. Micale, A. Brucato, M. Ciofalo 2013 CFD simulations of dense solid-liquid suspensions in baffled stirred tanks: Prediction of solid particle distribution Chemical Engineering Journal 24(07): 223-226

[4] Dongling Y, Yongbin H, Nanxing W, et al. 2017 Effect of Blank Particles Forming and Speed of Granulating on Dry Granulation Process of Ceramic Wall and Floor Tiles Bulletin of The Chinese Ceramic Society 36(10): 3353-3360

[5] Chaoyu Y, Chunxi L, Dewu W, Yansheng L, Rui C 2010 Numerical simulation of transient hydrodynamics in gas-solid airlift loop reactor Journal of chemical industry 61(09):2225-2234

[6] Shabani M O, Mazahery A, Alizadeh M, et al. 2012 Computational fluid dynamics(CFD) simulation of effect of baffles on separation in mixer settler International Journal of Mining Science and Technology 22(5): 703-706

[7] Congcong G, Wenheng Z, Zhuo X, Chao Z 2011 Numerical simulation of baffle mixing effect in stirred tank Water and wastewater engineering 47(S1): 199-202

[8] Tiancheng Z, Wencheng T, Bixi L 2016 CFD simulation of solid-liquid mixing in stirred vessel by propeller agitator Journal of Southeast University(JSEU_EE) 46(4): 713-719

[9] Cuixun Z, Fengling Y, Jiyong L 2015 Turbulent flow in a stirred tank equipped with half-circle-tube baffles Journal of Shandong University (Engineering Science) 45(01): 76-81