

Research Article

Effect of Parameters of Guide Vanes on Separation Characteristics in a Turbo Air Classifier

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Abstract

In this paper, the influence of angle and number of guide vanes on the classification performance in a turbo air classifier is investigated. In this paper, a two-fluid model coupled with a population balance equation was used to consider the classification characteristics. This model is superior to the DPM (Discrete Phase Model) method because the distribution of volume fraction and velocity vector along the grain size of each particle can be considered from the Eulerian point of view. First, the validation of the computational model was verified by comparing the calculation results with the experimental data of the previous study. Next, the classification characteristics with the change of the guide vane parameters in a turbo air classifier were investigated. The calculations were performed for the cases that the coarse particle exit was open and blocked. The number and angle of guide vanes had a significant effect on the classification efficiency when the coarse particle exit was blocked. For the guide vanes angle of 36°, the cut size (d_{50}) decreases with the increase of the number of guide vanes. For 54°, cut size decreases with the increase of the number of guide vanes to 24, but it does not change for more than 24 and for 72°, the cut size shows a rather increasing trend when the number of guide vanes increases above 24. Also, in the case of the coarse particle exit opening, the number of guide vanes does not significantly affect the classification performance, in which case the fine particles are mixed with the gas and discharged to the coarse particle exit by 40%. The parameters of the guide vanes generally do not have a large influence on the classification sharpness index, but the classification sharpness index decreases when the angle of the guide vanes is 72° and the number of guide vanes is more than 36.

Keywords

Turbo Air Classifier, Multiphase Flow, Reynolds Stress Model, Classification Efficiency, Computational Fluid Dynamics

1. Introduction

Air classification according to the particle size of the powders or air separation of fine particles is one of the processes widely used in various fields of industry including the separation of pulverized coal in power plants, the separation of cement powder in cement industry and the removal of fine dust in various industrial furnaces. Therefore, the study of air

separators used in such processes has been widely conducted since long ago. Especially, with the increasing demand for ultrafine powders, there is a growing interest in turbo air classifiers with low energy consumption and good classification sharpness index [1]. Many researchers have analyzed in detail the effect of inlet condition and rotor speed on classi-

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fication efficiency and sharpness through the analysis of the flow field of fluid inside the turbo air classifier and the motion of the fine particles to be classified. So far, the research on turbo air classifier has shown that the rotational speed of the rotor and the inlet velocity of the air are the main factors affecting the classification sharpness and efficiency of the classification process [2, 3], and therefore, a lot of research has been done on it. Yun Zeng et al. analyzed the classification characteristics of a turbo air classifier with rotor rotational speed and inlet air speed using ANSYS Fluent and obtained the optimal process parameters [2]. Zhanpeng Sun et al. analyzed the flow field in a horizontal turbo air separator and showed that the rotational direction of the rotor and the position of the air inlet has a great effect on the flow field distribution, and accordingly, the classification accuracy can be increased from 7.5 to 10.3% [4]. Wenjing Ren et al. made an analysis of the influence of rotor blade profile and installing angle on the flow field in a turbo air classifier and gave a method to design a rotor blade with a non-radial arc blade [5]. They found that the air streamlines could be aligned with the non-radial circular arc blade profile to eliminate the air vortex in the passage of the rotor chamber and hence increase the classification accuracy from 10.6 to 40.8%.

Y. Yu et al. performed simulations of the flow field in the annular region of a turbo air classifier and proposed a method to determine the cut size [6]. To verify the accuracy of the simulation, the experimental and calculated values of d_{50} with inlet air velocity and rotational speed of the rotor were compared, and then the deviations ranged from 0.8 to 22.8%.

Appadurai A. et al. performed numerical studies by the Lagrangian-Eulerian model on particle separation in a dynamic separator and found that the particle separation trend obtained in numerical calculations is in agreement with experiment only when particle collisions are considered [7]. They emphasized that particle collisions play an important role in the separation process, in addition to centrifugal, drag and gravity forces. Titov D. A. et al. performed simulation calculations for an industrial dynamic separator used in coal separation of a power plant and compared the separation characteristics with experiments [8].

Mohamed A. et al. also evaluated the cut size and the classification slope with air flow rate and rotational speed in a turbo air classifier by CFD method and experiment, and showed that the calculation results agree well with experiment, and reported that the vortex formation between the blades affects the cut size and the classification sharpness [3].

Yuan Y. et al. proposed a method to design the profile of the spiral section to guide the inlet air flow in a turbo air separator as a logarithmic spiral shape, and found that the flow in the annular rotating region can be uniform and the classification characteristics was improved when designed as such [9].

Yun Zeng et al. found that the circumferential velocity of

the flow is proportional to the rotational velocity of the blade, the radial velocity is related to the flow rate, and the classification sharpness decreases with increasing rotational velocity [2]. In addition, Shubo W. et al. simulated using discrete phase model in ANSYS Fluent and showed that when using double layer spread plate, the dispersion of material was improved and the probability of impaction and the aggregation of grains were reduced, resulting in a smaller cut size diameter and a large increase in the classification sharpness than when using single layer spread plate [10]. In addition to the above mentioned studies, there are many examples of studies on different types of turbo air classifier [12-15].

In summary, the research on turbo air classifier is mainly concerned with the influence of the inlet air volume and the rotor rotational speed on the classification performance, and the influence of the number and angle of guide vanes on the classification performance is less discussed.

In this paper, we will investigate the influence of parameters of the guide vane on the classification characteristics of a turbo air classifier.

2. Modeling of Flow and Polydispersed Particle Motion in Turbo Air Classifier

The model and dimensions of the considered turbo air classifier are shown in Figure 1. From the annular inlet at the bottom of the classifier, air with a mixture of powder material is introduced and enters the classification zone between the rotor and the guide vanes through the guide vanes.

Here, due to the rotation of the rotor, the coarse particles do not pass through the rotor region due to centrifugal force, fall down and exit the coarse particles outlet. And the fine particles are entrained by the air stream and pass through the rotor region to the upper outlet. So far, the discrete phase model (DPM model) has been widely used as a model to consider the motion of air and particles in such turbo air classifier [2-4, 14]. In the discrete phase model, the Eulerian model is used for the air as the primary phase and the motion of the particles is considered in a Lagrangian way. Here, for the motion of particles we use the two-fluid model coupled with the population balance equation [15], an Eulerian model rather than discrete phase model.

This method has the advantage that, unlike the DPM method, the velocities and concentrations of particles of different sizes can be considered separately. Also, in the DPM model, the presence of a region of concentration of particles makes the calculation unstable, whereas in the two-fluid model coupled with PBE the calculation is stable even in the same case. In addition, the velocity and concentration distributions of particles of different sizes can be directly seen, so that the behavior of the particles with size can be studied intuitively.

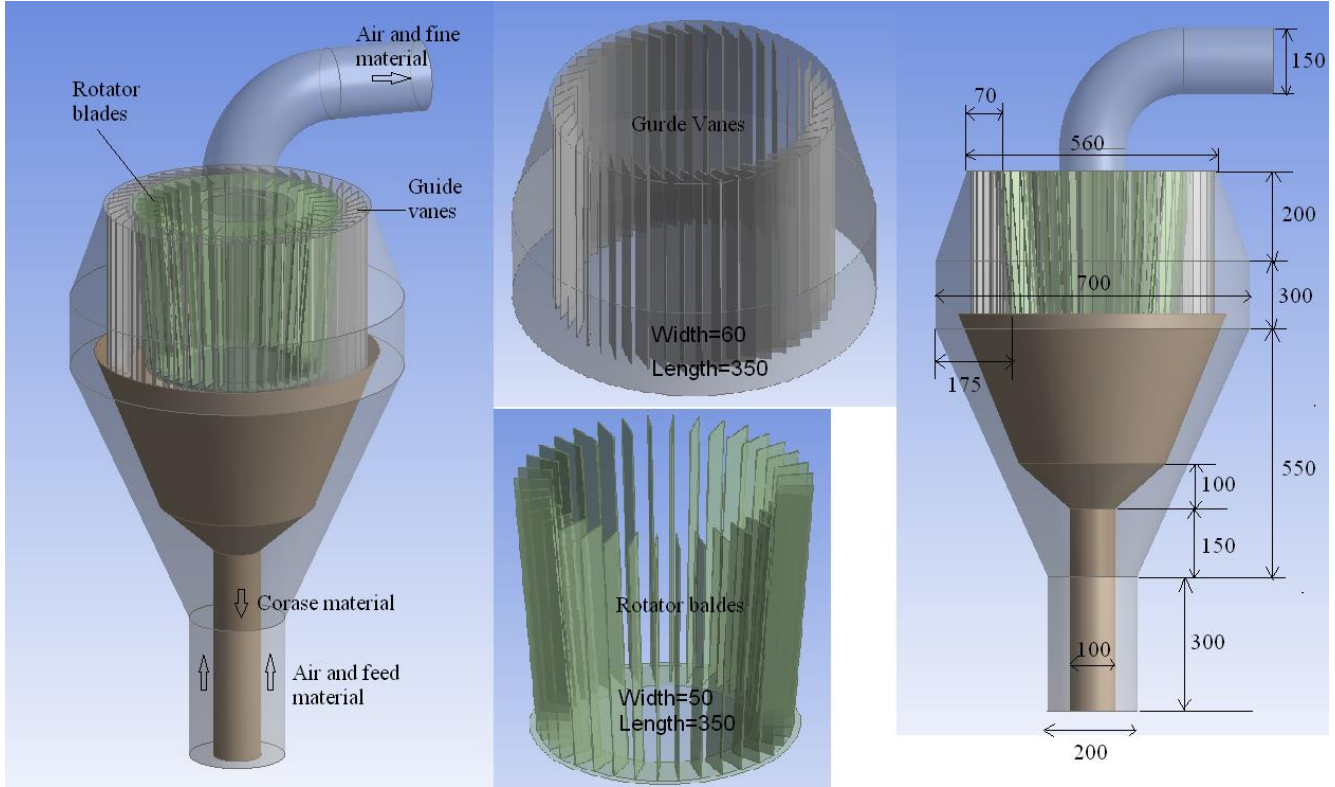


Figure 1. Geometry and dimensions of the turbo air classifier.

The equations of continuity and momentum for the gas and particle phase are the same as in the conventional two-fluid model.

The basic equations of two-fluid model coupled with PBE (Population Balance Equation) can be written as follows:

Continuity equation for the gas phase:

$$\rho_g \frac{\partial \alpha_g}{\partial t} + \rho_g \nabla \cdot (\alpha_g v_g) = 0, \quad (1)$$

where α_g is the volume fraction of gas phase and ρ_g is the density of gas phase. v_g is the velocity of the gas phase.

Momentum equations for the gas phase:

$$\rho_g \frac{\partial}{\partial t} (\alpha_g v_g) + \rho_g \nabla \cdot (\alpha_g v_g v_g) = -\alpha_g \nabla p + \nabla \cdot \tau_g + \alpha_g \rho_g g + R_{s,f}, \quad (2)$$

where p , τ_g are the pressure and strain tensor of the gas phase, respectively, and $R_{s,f}$ is the interaction force of the particle and gas phase, and g is the vector of gravitational acceleration.

Continuity equation for the granular phase:

$$\rho_s \frac{\partial \alpha_s}{\partial t} + \rho_s \nabla \cdot (\alpha_s v_m) = 0 \quad (3)$$

where α_s is the volume fraction of granular phase and ρ_s is the density of granular phase, and v_m is the velocity of the granular phase.

Momentum equations for the granular phase:

$$\rho_s \frac{\partial}{\partial t} (\alpha_s v_m) + \rho_s \nabla \cdot (\alpha_s v_m v_m) = -\alpha_s \nabla p - \nabla p_s + \nabla \cdot \tau_s + \alpha_s \rho_s g + R_{f,s}, \quad (4)$$

where p_s is solid pressure and τ_s is strain tensor of the gas phase.

Volume fraction equation of particles with different diameters:

$$\rho_s \frac{\partial \alpha_{si}}{\partial t} + \rho_s \nabla \cdot (\alpha_{si} v_m) = -\rho_s \nabla \cdot (\alpha_{si} v_{si,m}) \quad (5)$$

where α_{si} is the volume fraction of a particle with a diameter $d_i (i = \overline{1, N})$ when the particle is considered to be a group of N diameter particles and then $\alpha_s = \sum_{i=1}^N \alpha_{si}$ is established. Also $v_{si,m} = v_{si} - v_m$, where v_{si} is the velocity of particles with diameter d_i .

If we do not consider the birth and disappearance of the population by breakage and aggregation in the population

balance equation [16], Equation (5) is obtained.

Velocity of particles with different diameters [15]:

$$\frac{\partial}{\partial t}(\alpha_s f_i v_{si}) = f_i \frac{\partial}{\partial t}(\alpha_s v_m) + \frac{R_{f,si}}{\rho_s} - \frac{f_i R_{f,m}}{\rho_s}, \quad (6)$$

where f_i is the relative fraction of the particles with a diameter of d_i , denoted by $f_i = \alpha_{si}/\alpha_s$, and v_{si} is the velocity of the particles with a diameter of d_i . And $R_{f,si}$ is the interaction force between the fluid and the particle with a diameter of d_i , and $R_{f,m}$ is the averaged interaction force between the granular phase and the fluid.

In the population balance model of ANSYS Fluent, the phases are set to two phases consisting of gas phase and granular phase, and the basic equations (1)-(4) for the two phases are solved by the two-fluid model using the finite volume method [17] and then the population balance equation (5) with the source term is solved. From this, v_g and v_m are obtained and the velocity of polydisperse particles with different diameters can be calculated by Equation (6).

Using the Gidaspow model [18] in (6), the interaction terms can be written in the form $R_{f,si} = \rho_s \alpha_{si} k_{si}(v_g - v_{si})$ and $R_{f,m} = \rho_s \alpha_s k_m(v_g - v_m)$. Here k_{si} and k_m are the coefficients obtained from the model.

Also, the velocity v_{si} of the dispersed particles satisfies the following condition:

$$v_m = \sum_{i=1}^N f_i v_{si}. \quad (7)$$

Therefore, the velocity v_{si} obtained from (6) must be modified to ensure that the above condition holds. We give a method to modify the velocity v_{si} in the following conditional optimization method.

Let v'_{si} be the velocity modified so that (7) holds. Then, we minimize the difference between v'_{si} and the velocity v_{si} already found, i.e.

$$v'_{si} = \operatorname{argmin}(\sum_{i=1}^N (v_{si} - v'_{si})^2). \quad (8)$$

When the velocity vectors are $v_{si} = (u_{si}, v_{si}, w_{si})$, $v'_{si} = (u'_{si}, v'_{si}, w'_{si})$ and $v_m = (u_m, v_m, w_m)$, the above optimization expression can be written as follows for the u -component.

$$u'_{si} = \operatorname{argmin}(\sum_{i=1}^N (u_{si} - u'_{si})^2), u_m = \sum_{i=1}^N f_i u'_{si}. \quad (9)$$

For all three velocity components, we can write the above conditional optimization.

In this way, we can calculate the velocity of polydisperse particles without increasing the number of phases like the number of diameters, and calculate the volume fraction of particles with different diameters in space by Equation (5).

3. Selection of Turbulence Model and Validation of Computational Model

In the calculation of the turbo air classifier, several turbulence models were used for the flow of the gas, which is the primary phase.

Yun Zeng et al. and Wenjing Ren et al. used the RNG (Renormalization Group) $k - \varepsilon$ model [2, 5], Zhanpeng Sun et al. used the RSM (Reynolds Stress equation Model) model [4], and Mohamed A. et al. used the SST (Shear Stress Transport) $k - \omega$ model [3]. Guizani R. et al. used the RSM model for the calculation of turbo air classifier, which could not obtain the converged solution for steady calculation, but only by reducing the size of time step in unsteady calculation [14]. They pointed out that this model is computationally expensive and time consuming compared to other models.

Mohammad B. et al. also compared the SST $k - \omega$ model and the RSM model and indicated that the particle concentration in the classifier showed differences in the two models [11].

In summary, the results of the previous studies show that SST $k - \omega$, RNG $k - \varepsilon$ and RSM models are mainly applied in the calculation of turbo air classifier, but it is not clear which model is the most reasonable yet. Therefore, we will perform calculations for a turbo air classifier using the above three models and validate the turbulence model through comparison with experimental data [6]. The turbo air classifier used for model validation is the same as that used in the study of [6] whose geometry is shown in Figure 2.

In Figure 2, the outer diameter and inner diameter of the rotor blade are 0.106m and 0.076m, respectively, and the number of rotor blades is 24 and is evenly placed in the radial direction. The size of the air inlet is 0.095m high and 0.062m wide, with the rotor blade and the top being the same height, and the guide vanes are uniformly placed along the circumferential direction of radius 0.136 m at an angle of 15 ° with 24 blades of size 0.095m×0.03m×0.003m.

Table 1. The diameter and volume fraction for each bin in the feeding material.

Bin number	bin 0	bin 1	bin 2	bin 3	bin 4	bin 5	bin 6	bin 7
Diameter (μm)	64	48.5	36.76	27.86	21.1	16	12.1	9.19
Volume of fraction	0.015	0.018	0.02	0.025	0.0288	0.0411	0.0735	0.0771

Bin number	bin 0	bin 1	bin 2	bin 3	bin 4	bin 5	bin 6	bin 7
Bin number	bin 8	bin 9	bin 10	bin 11	bin 12	bin 13	bin 14	bin 15
Diameter (μm)	6.96	5.28	4	3.03	2.3	1.74	1.32	1
Volume of fraction	0.1485	0.1776	0.157	0.11	0.04	0.03	0.02	0.0124

In Figure 2, the feeding material is uniformly injected through the face marked as the feeding inlet, fine particles are brought out of the upper outlet with the air stream, and coarse particles are collected at the bottom and discharged periodically. The density of the material to be separated was 2700kg/m^3 , with feeding rate of 0.0183 kg/s (66 kg/h). In the calculation, we used a multi reference frame to model the rotation of the rotor, and activated the discrete model of the population balance model and set up 16 particle bins. The mesh independence test was carried out and the appropriate mesh number was set to 1,278,414, the Gidaspow model as

the interaction model, the Gidaspow model as the granular viscosity model [18], the lun-et-al model as the granular volume viscosity, and the lun-et-al model as the solid pressure model [19]. In the calculation, the particle volume fraction of the input material was given as 0.3, and the numerical differentiation was calculated after finding the integral distribution in their study to give the particle size distribution as in Y. Yu et al. (2018). The ratio factor was set to 1.2 and the minimum diameter to $1\mu\text{m}$, and the volume fraction for each bin was set as Table 1. The unsteady calculation was carried out, and the time step was 0.002 s .

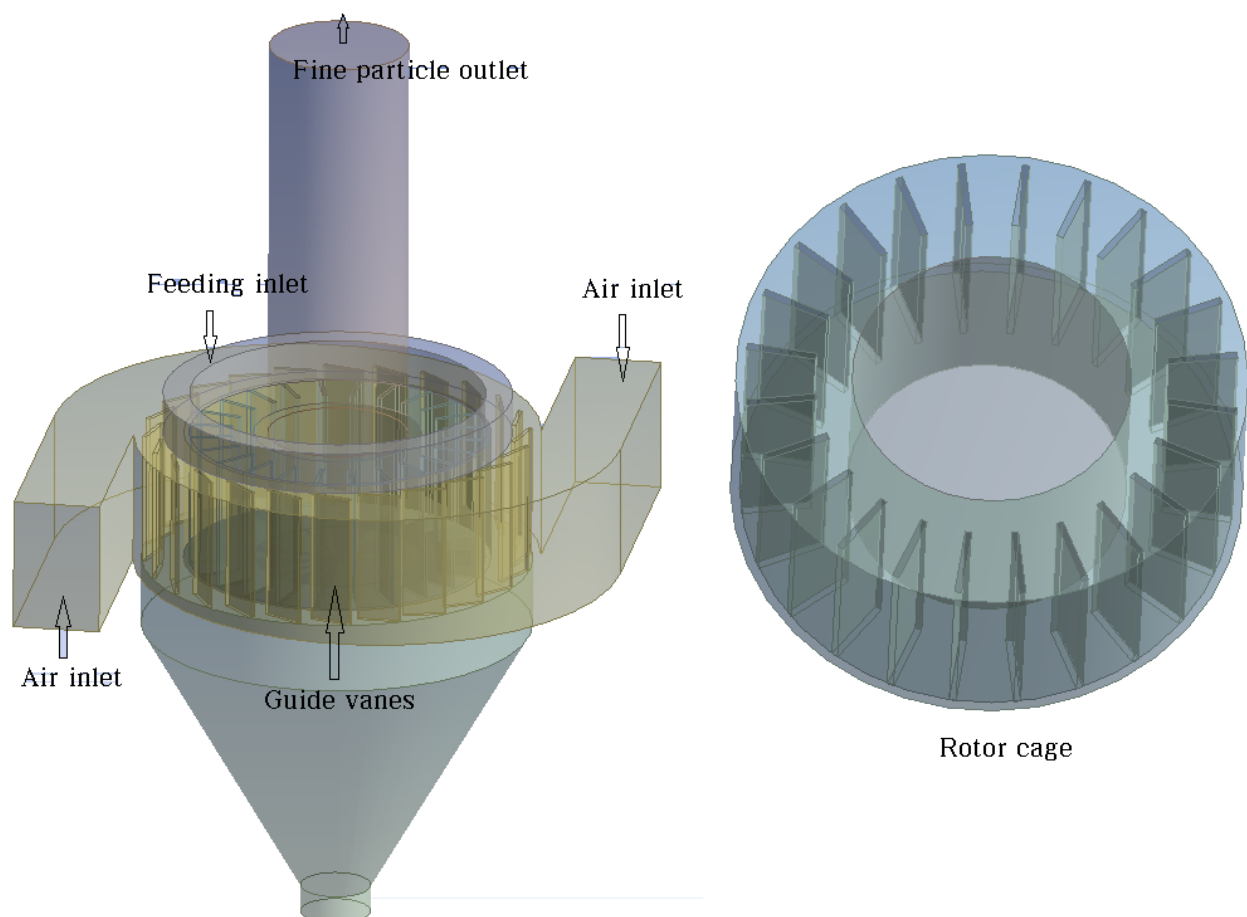


Figure 2. Geometry model of turbo air separator used for verification of computational model [6].

The calculations were performed using three turbulence models at an air inlet velocity of 11 m/s and a rotor rotational speed of 1000 rpm , and the separation characteristics along the particle size were compared with the experimental Tromp curves (Figure 3).

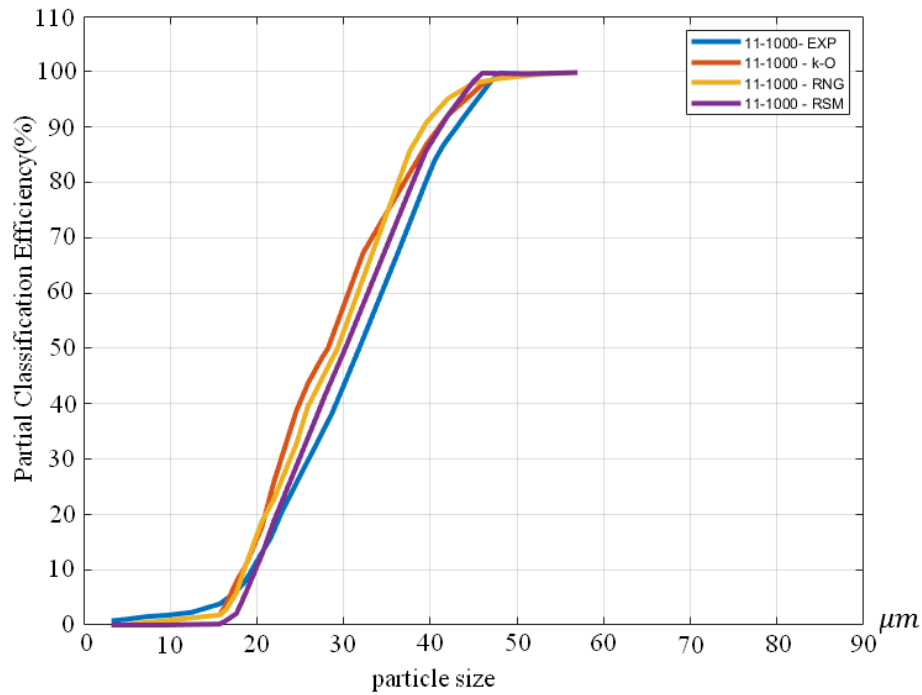


Figure 3. Comparison of partial classification efficiency curves with turbulence model.

Looking at Figure 3, it can be seen that the RSM model is the closest to the experimental curve in the partial classification efficiency curves when the three models are used. Hence, we will use the RSM model in the following.

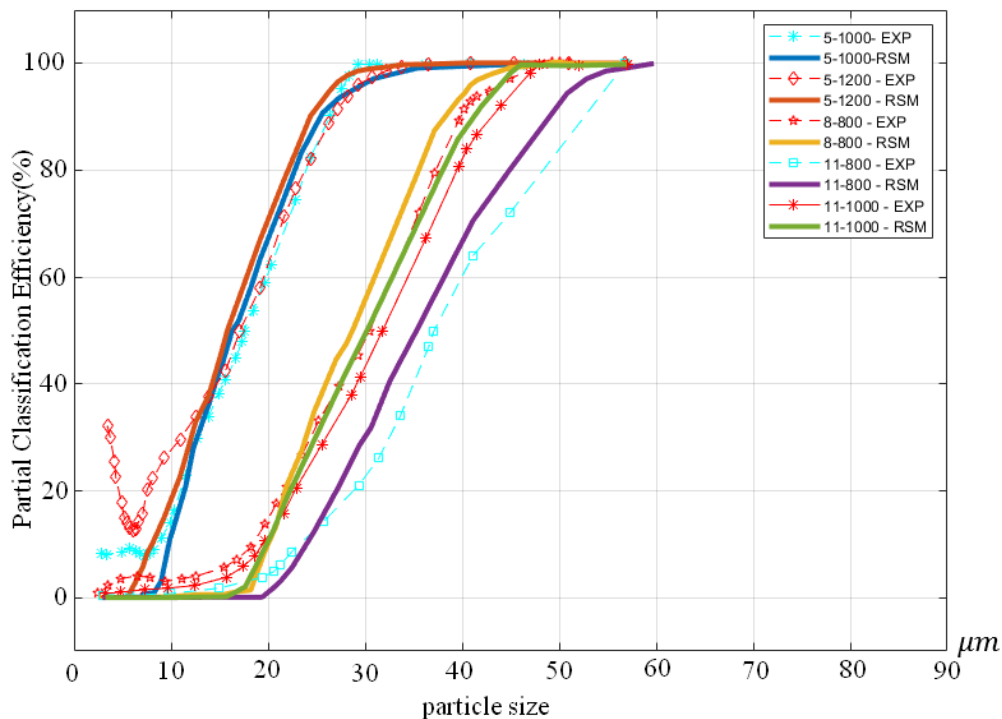


Figure 4. Partial classification efficiency curve for different inlet velocity and rotational speeds.

Figure 4 shows the partial classification efficiency curves calculated using the RSM model for different inlet velocities and rotating speeds compared with the experiment. From

Figure 4, it can be seen that our calculation results agree well with the experiment except for the vicinity of small grain size. In addition, the classification efficiency curve obtained from

the calculation is mostly left-biased compared to the experimental curve, which indicates that the classification efficiency with particle size is estimated to be higher than the actual one in the calculation. In particular, for 5-1000 (air velocity 5 m/s, rotational speed 1000 rpm) and 5-1200 (air velocity 5 m/s, rotational speed 1200 rpm), the separation efficiency obtained experimentally around small particle sizes shows an increasing trend with decreasing particle size, but the separation efficiency in the calculation drops to zero.

This phenomenon in the experimental curve is attributed to the “fishhook” effect of the partial classification efficiency curve [14], which is considered to be the difference resulting from the fact that in the real process, the aggregation of small particles is formed and separated, but in our model the particle aggregation is not considered.

Table 2 shows the d_{50} cut diameters versus operating parameters obtained from the partial classification efficiency curves compared with the experimental values.

Table 2. The cut size with the operating parameters (Exp. Y. Yu et al., 2018).

No	Air velocity (m/s)	rotational speed (rpm)	d_{50} Exp. (μm)	d_{50} Cal. (μm)	Relative error (%)
1	5	1000	17.5	16.32	6.74
2	5	1200	17.1	15.83	7.42
3	8	800	30.5	28.71	5.86
4	11	800	37.1	35.28	4.9
5	11	1000	31.8	30.17	5.12

Looking at Table 2, the calculated values are in agreement with the experimental values in a difference of less than 7.5% from the experimental cut-off diameter. From the table, it can be seen that the calculated values are generally estimated to be smaller than the experimental values.

4. Computational Results and Discussion

Here, the influence of the guide vane parameters on the classification characteristics was investigated for the turbo air classifier shown in Figure 1. In the calculations, the RSM model was used as turbulence model because it is the closest

to the experimental values, as seen in the above model validation. The air and the material to be classified are mixed and introduced through the annular channel below the classifier. Air has a density of 1.05 kg/m^3 , a velocity of 15 m/s ($1268 \text{ m}^3/\text{h}$), a density of the feed material of 2800 kg/m^3 , and a mass flow rate of 0.658 kg/s , resulting in a mass loading ratio of 2. The volume fraction at the inlet was 0.001, and a multi reference frame was used for the rotor motion. To consider only the influence of the guide vanes, the rotor blades were fixed with 36 blades in the radial direction.

Table 3. The diameter and volume fraction of material at the inlet.

Bin number	bin 0	bin 1	bin 2	bin 3	bin 4
Diameter (μm)	135	93.6	65	45	31.2
Volume of fraction	0.001	0.0018	0.0052	0.0135	0.0392
Bin number	bin 5	bin 6	bin 7	bin 8	bin 9
Diameter (μm)	21.6	15	10.4	7.2	5
Volume of fraction	0.1074	0.2397	0.366	0.2113	0.0148

In the discrete model of the population balance model, the number of bins was set to 10, the ratio factor to 1.585, and the minimum diameter to 5. Then, the maximum grain size is

$135 \mu\text{m}$, and the volume fraction according to the grain size is shown in Table 3. As above, for other granular models, we used the Gidaspow model for the interphase interaction and the

granular viscosity, and the lun-et-al model for the granular volume viscosity and solid pressure, respectively. Based on a full review of the mesh dependency, computational meshes with 900,000 to millions of polyhedra elements were used for the following cases.

4.1. Effect of the Number and Angle of Guide Vanes in the Case of Blocking of Coarse Particle Exit

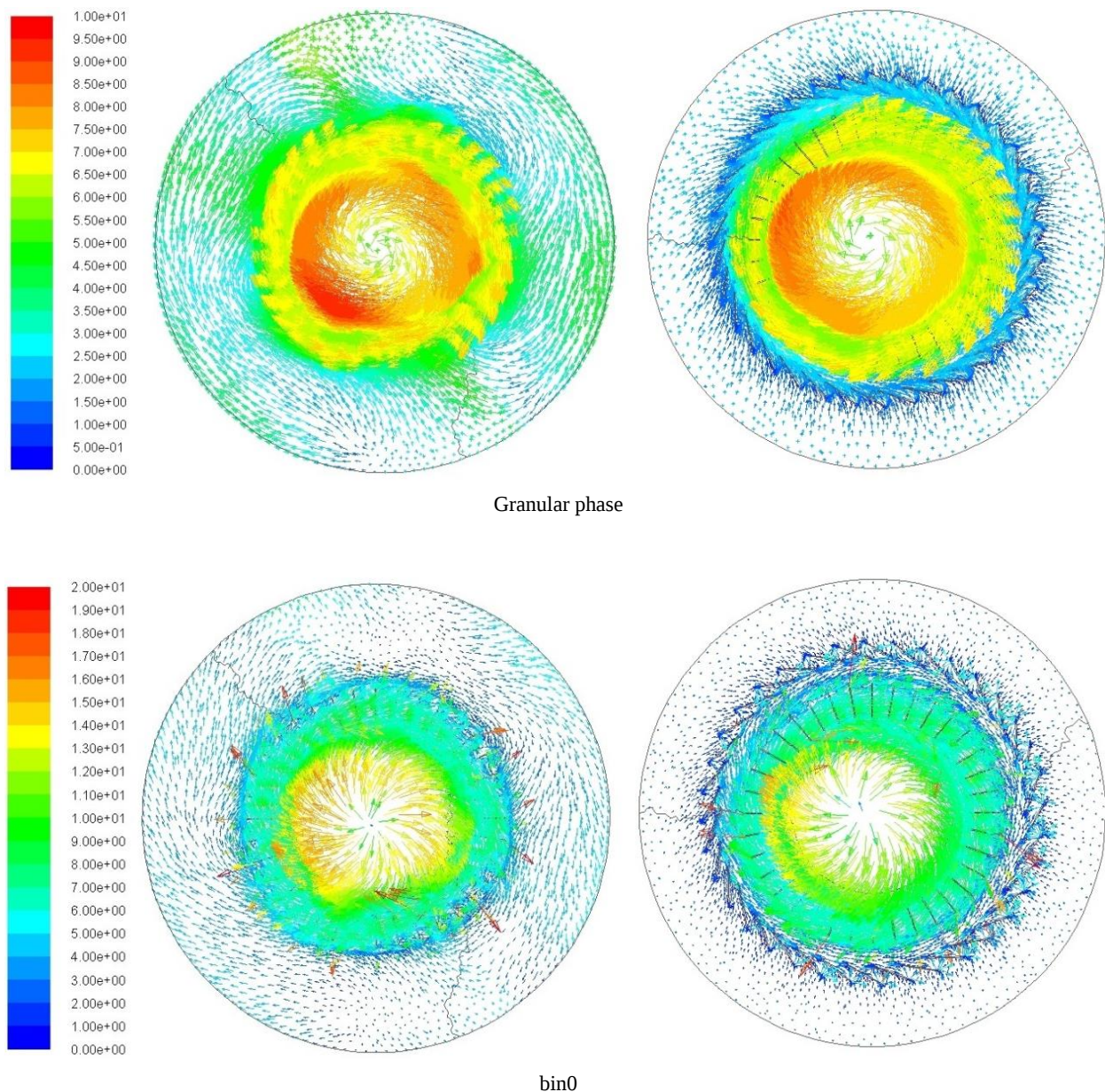
First, the calculations are performed when the coarse grain outlet, i.e., the down surface, is set as the wall in Figure 1.

Figure 5 shows the velocity distribution along the particle size for a rotational speed of 360 rpm. In the figure, the left side is the velocity distribution without guide vanes and the right side is the case with 36 guide vanes with an angle of 72° with the radial direction.

Also, Figure 6 shows the fraction of the volume for the

particle phase obtained under the same condition.

The first figure of Figure 5 shows the velocity distribution of the granular phase for both cases, and it can be seen that the flow field is not uniform in the case without guide vanes compared to the case with guide vanes. Also, with the guide vanes, the rotational flow is large inside the guide vanes, but there is little flow in the rotational direction outside the guide vanes. However, in the absence of the guide vanes, the flow in the direction of rotation is wide spread. Next, considering the velocity distribution of particles by particle size, the velocity vector in the velocity distribution of bin 0 and bin 1 is radially outward. This indicates that when the particle diameter is large, separation is achieved in the rotor region by the action of centrifugal force. However, if we look at the velocity distribution of bin 5 and bin 9, the velocity vector is in the direction of rotation, and the velocity distribution is almost identical to that of the granular phase.



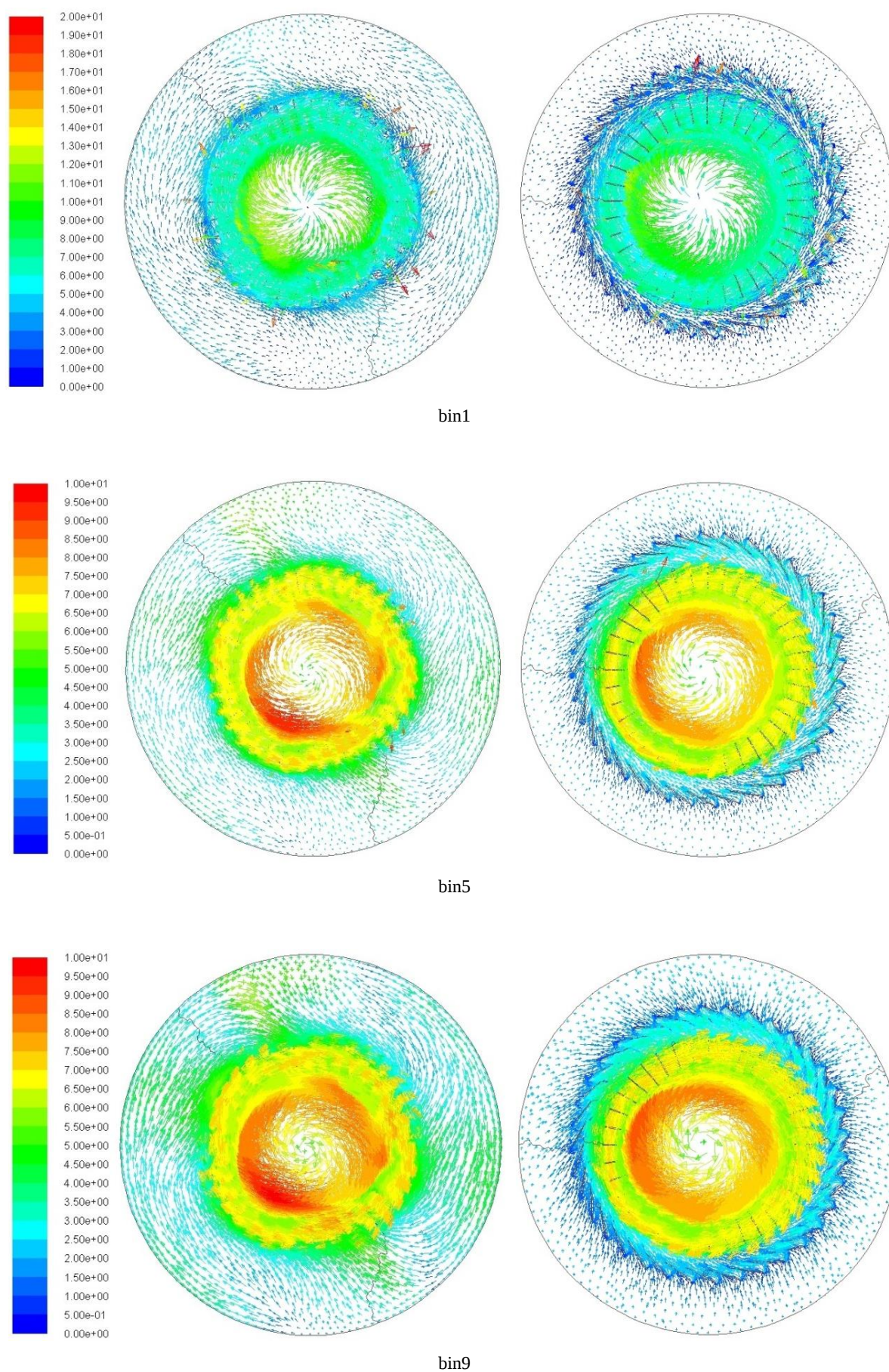
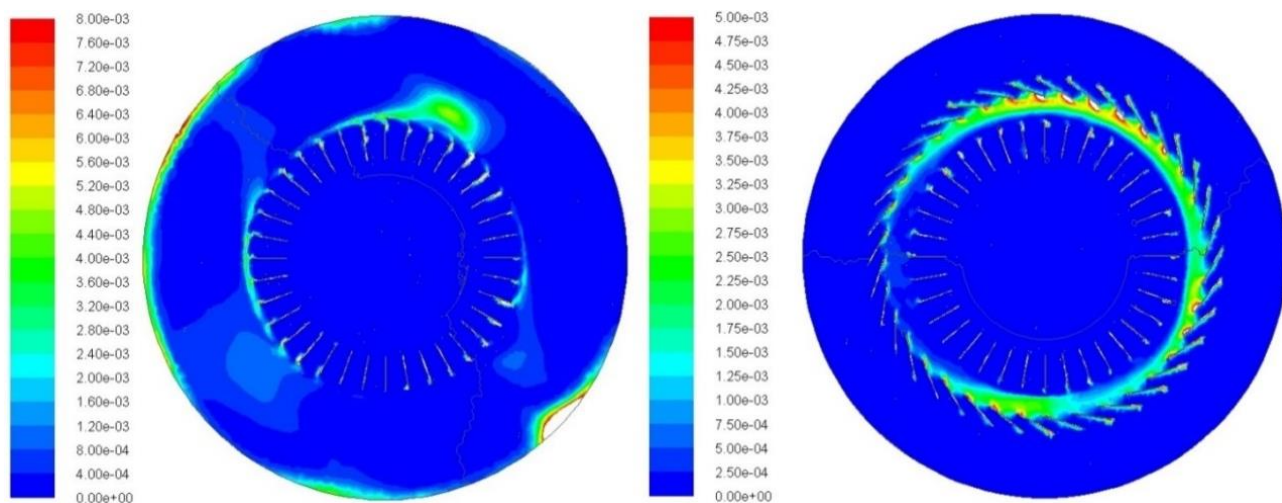
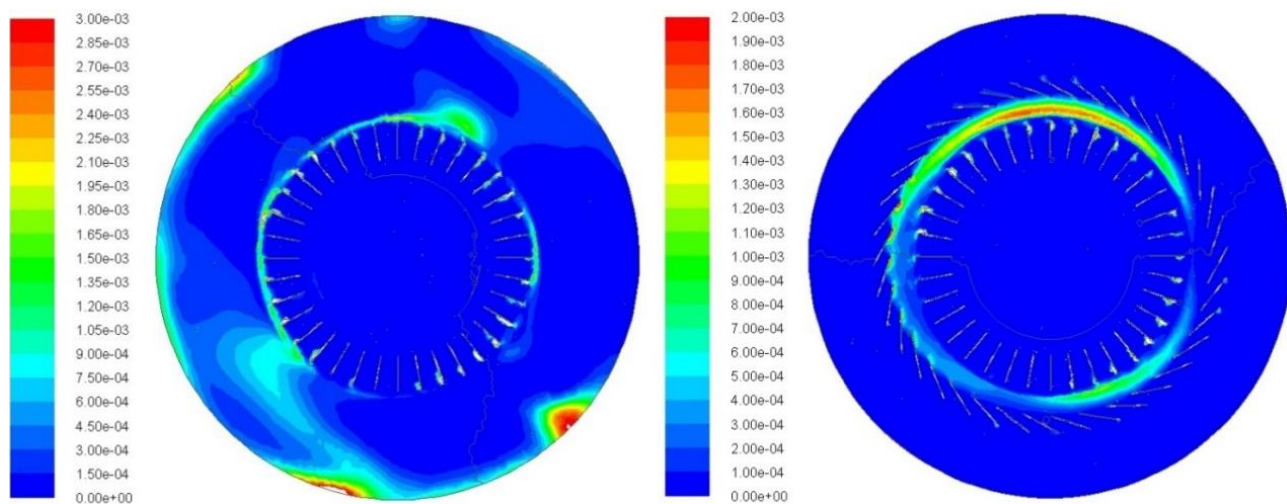


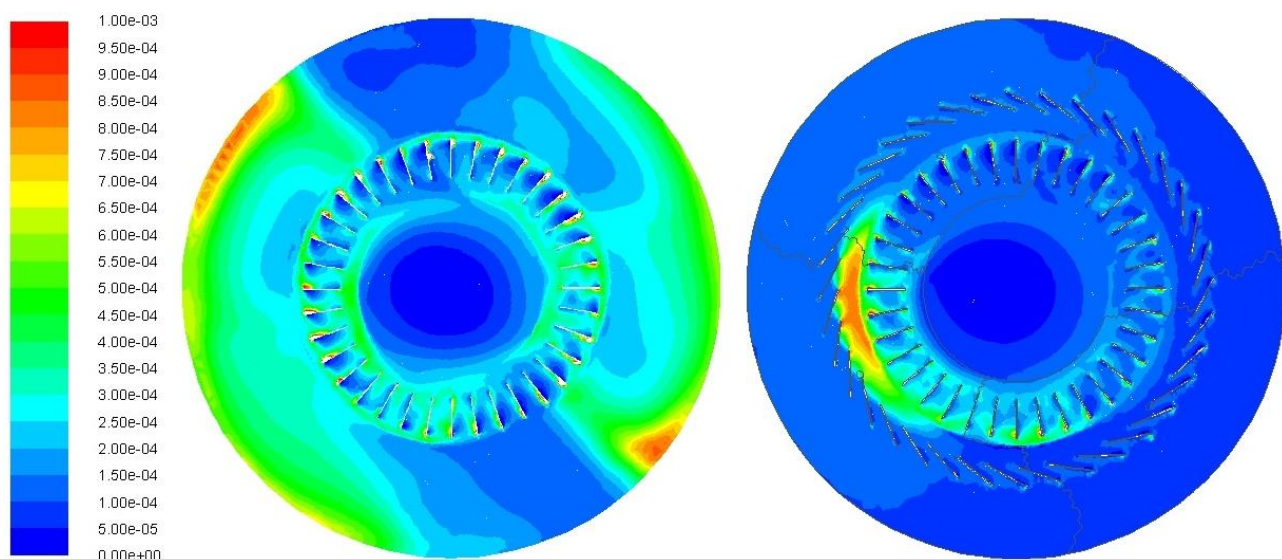
Figure 5. Velocity distribution of the granular phase and velocity distribution by particle size at the mid-section of the blade. Left: No guide vanes, right: 36 guide vanes, angle 72 °.



bin0



bin1



bin5

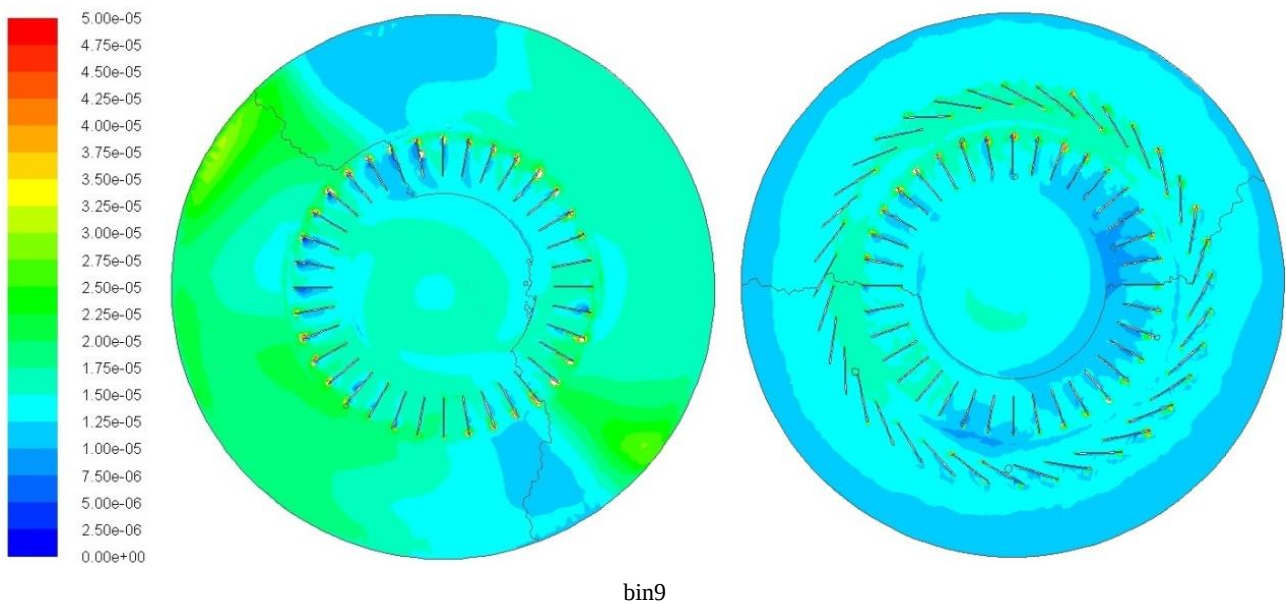
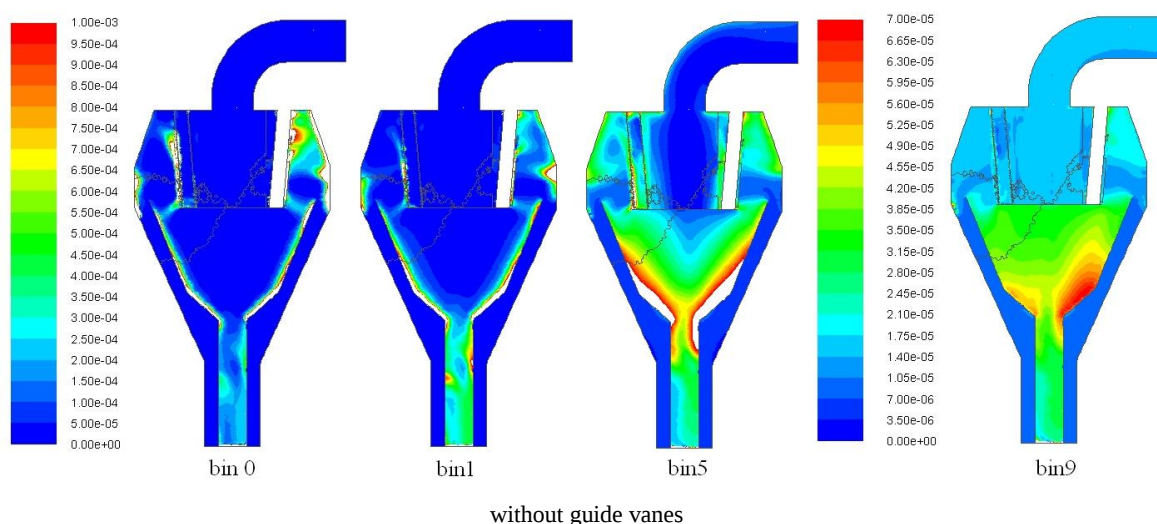


Figure 6. The volume fraction by particle size at the mid-section of the blade (A2-bin0; A3-bin1; A4-bin5; A5-bin9). Left: No guide vanes, right: 36 guide vanes, angle 72°.

Such a separation process can be seen not only through the velocity distribution but also through the volume fraction distribution along the particle size (Figure 6). The volume fraction distributions of bin0 and bin1 are almost zero in the inner region of the rotor in both cases (closed and open at the exit of coarse particles). Also, in the case with the guide vanes (right at Figure 6), the particles are distributed uniformly in the space between the rotor and the guide vanes, whereas in the case without the guide vanes, they are distributed randomly outside the rotor. During the unsteady calculation, this distribution region changes. The volume fraction distributions of bin 5 and bin 9 show that bin 5 has some grain inside the rotor, but there is little difference in the volume fraction inside or outside the rotor in figure for bin 9. That is, it can be seen that no separation is done for the small particles.

Figure 7 shows the distribution of the volume fraction by

particle size in the vertical section without and with guide vanes. In the part that is blank in the figure, the value above the maximum in the color bar is taken. In the figure, it can be seen that in bin 0 and bin 1 with large diameter, the particles descend along the cone below. However, the distribution of bin 5 shows that the volume fraction in the lower cone region is high, but it is partly out of the fine-particle outlet above. In bin 9, the volume fraction in the cone region is high and the volume fraction in the top part is small, but in the cone part it is almost stationary, so all the particles belonging to bin 9 are carried out at the fine particle outlet. Also, in comparison with the case without guide vanes (up figure) and with guide vanes (down figure), in the down figure, coarse particles are mainly concentrated in the space between guide vanes and rotor blades and are down, but coarse particles are biased towards the separator's casing.



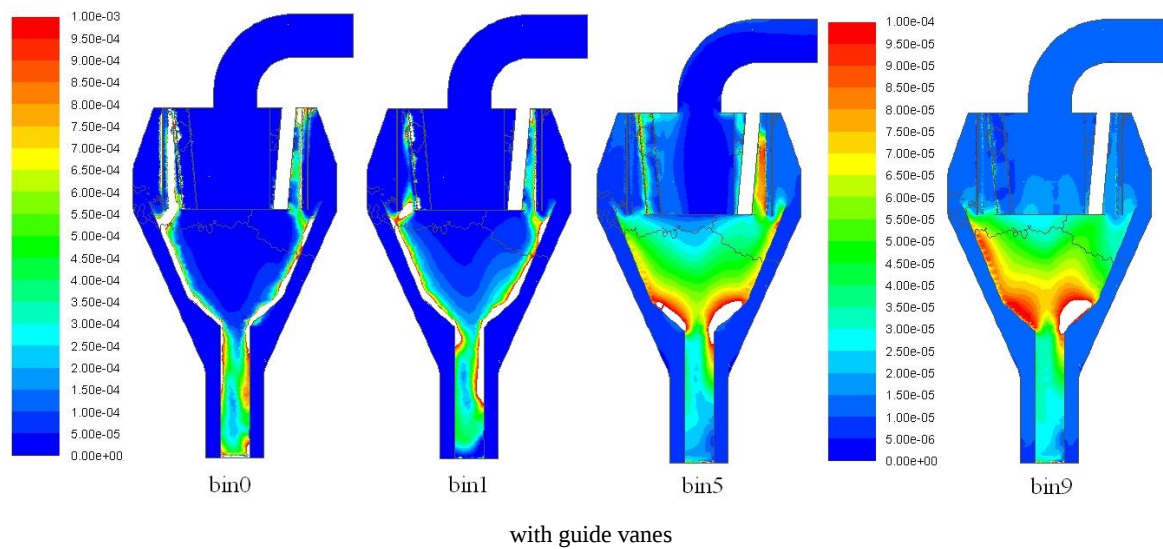


Figure 7. Volume fraction distribution by size in vertical section (In the figure, the blank area is above the maximum value of the color band.).

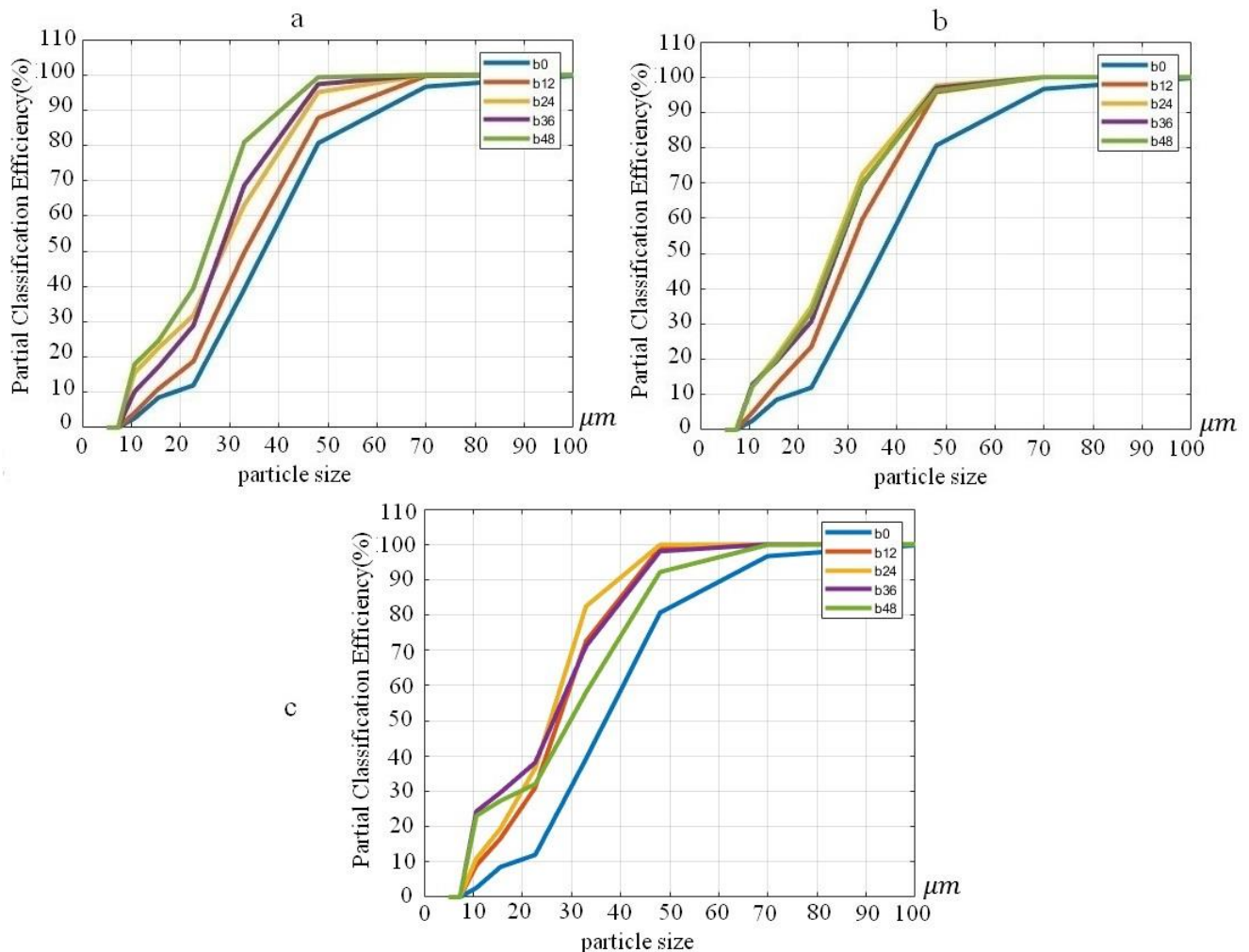


Figure 8. Partial classification efficiency according to the number of guide vanes and the angle of guide vanes (a-36°; b-54°; c-72°).

To study the effect of the parameters of the guide vanes on the classification efficiency, simulations were carried out with five changes of 0, 12, 24, 36 and 48 guide vanes and three

changes of 36°, 54° and 72° angles of guide vane and partial classification efficiency curves were obtained. Figure 8 shows the partial classification efficiency curves with the number of

blades for the guide vanes angles of 36° , 54° and 72° . First, for the case of the guide vanes angle of 36° (Figure 8a), the classification efficiency curve without guide vanes (curve b0) is the rightmost one, and the curve with 12 guide vanes (curve b12) is the right next. The curves of the cases with 24 (b24 curve) and 36 (b36 curve) guide vanes are almost similar, and the curve of the case with 48 (b48 curve) is the most left-biased. This shows that the classification curve gradually shifts to the left when the number of guide vanes increases from 0 to 48 for a guide vanes angle of 36° . Next, for the case of the guide vanes angle of 54° (Figure 8b), the classification efficiency curve also lies on the right when there are no guide vanes, and then the curve (b12) for the case with 12 guide vanes.

Then, when the number of guide vanes is 24, 36 and 48, the classification efficiency curve is almost unchanged. That is, in this case, it is shown that increasing the number of guide vanes is not effective for classification.

For the guide vanes angle of 72° (Figure 8c), the classification efficiency curve (b0) without guide vane is also the rightmost one, but this time the curve (b48) with 48 guide vanes is next. And there is no difference in the number of guide vanes 12, 24 and 36. In this figure, the classification efficiency curves are high between 10 and 20 μm for the cases of 36 (b36) and 48 (b48) guide vanes. This indicates that in this case, the fine particles are not well entrained into the fine particle exit by the path blockage of the guide vanes. That is, it is shown that the excessive number of guide vanes has a negative effect on the classification of fine particles when the guide vanes angle is large.

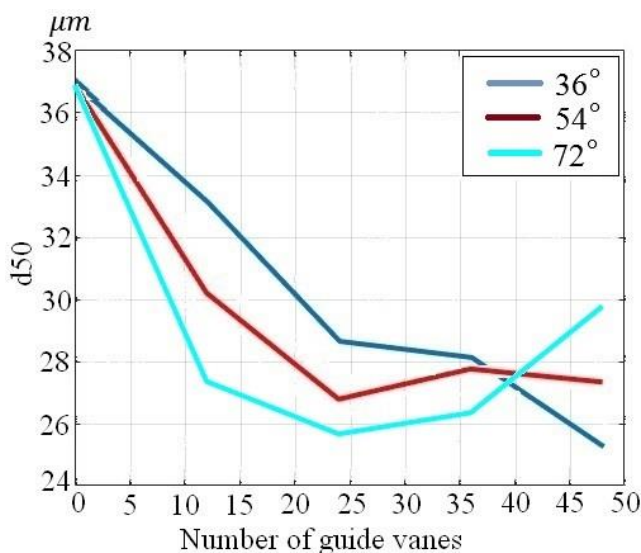


Figure 9. Cut size, d_{50} , according to the angle and the number of guide vanes.

In Figure 9, the d_{50} cut sizes obtained from the partial classification efficiency curves of Figure 8 are shown. For a guide vanes angle of 36° , the cut size diameter decreases with increasing number of guide vanes. In the case of the 54° guide

vanes, the variation in the cut size is not significant when the number of guide vanes increases to more than 24. However, for the case of the guide vanes angle of 72° , it can be seen that the cut size decreases when the number of guide vanes increases to 24 and then increases rather when the number of guide vanes increases to more than that.

Although the previous studies mainly considered the influence of rotor speed or inlet air flow rate on the classification performance, the above considerations indicate that the angle of the guide vanes and the number of guide vanes also have a significant influence on the classification performance.

So far the calculation has been done by setting the coarse grain outlet, i.e. the down-hole surface as a wall in Figure 1, but in actual practice, the coarse grains that are missing from the down-hole outlet are returned to the mill. Therefore, we next consider the classification characteristics in the case where the lower output is open.

4.2. Effect of the Number and Angle of Guide Vanes in the Case of Opening of Coarse Particle Exit

In the case of open bottom hole, the air not only exits the upper fine particle outlet, but also goes down, resulting in a change in the flow pattern, and thus the classification characteristics are also greatly changed.

Figure 10 shows the velocity distribution of the secondary phase (granular phase) with and without blocking the coarse particle exit below. As shown in the figure, when the coarse particle exit is blocked, the velocity from the lower cone to the lower passage is almost zero, but when opened, the particles are entrained with the air at a velocity of about 10 m/s. Thus, the velocity of the exit of the fine particles is about 25 m/s when the lower channel is blocked, but it decreases to about 20 m/s when opened. Hence, the classification characteristics will be significantly different if the coarse particle outlet is open.

Figure 11 shows the average particle size distribution for the open and closed coarse particle outlet cases. It can be seen that the value of the mean diameter in the coarse particle discharge tube is larger in the closed case than in the open case. At this time, there is no significant difference in the mean diameter in the fine particle discharge channel. The average diameter of the area average in the coarse particle exit section was 64.7 μm and that in the fine grain exit was 14 μm , when the bottom exit was open. However, the area average of the average diameter in the fine particle exit section was 16 μm in the case of the bottom exit closed, and the area average of the average diameter at the position 10 cm above the bottom exit closed was 117 μm . This indicates that if the lower outlet is open, more fine particles are entrained and discharged toward the lower outlet. And it can be seen that the mean diameter at the fine-grain outlet side is slightly larger in the case of the bottom outlet closed than in the open case. This is because more air flows out of the fine grain exit and therefore

more coarse grains are entrained in the fine grain exit. Figure 12 shows the volume of the fraction distribution by particle

size with and without guide vanes for the case of coarse particle exit opening.

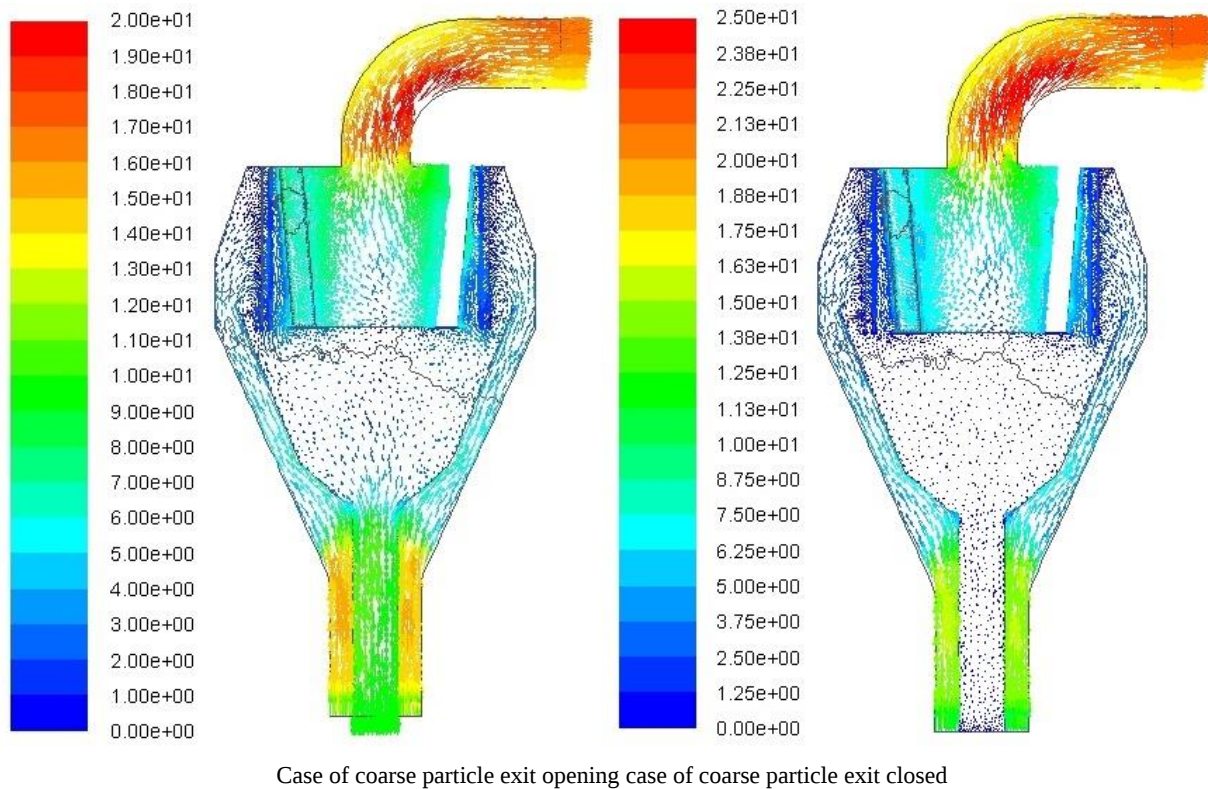


Figure 10. Velocity distribution of secondary phase (granular phase) in vertical section.

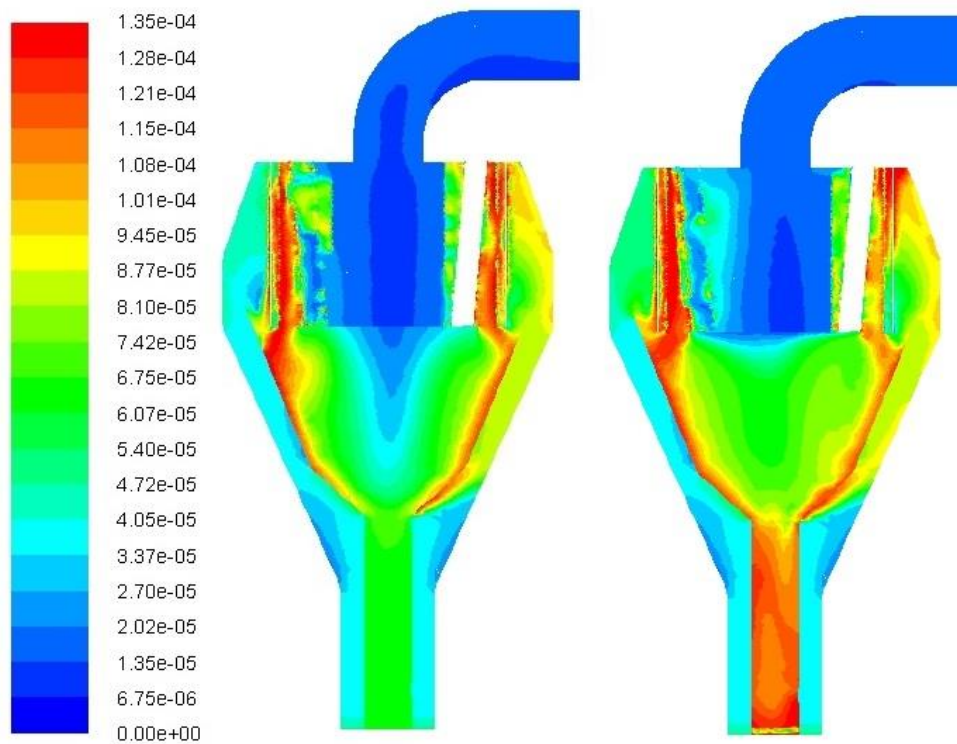


Figure 11. Distribution of average particle diameter in vertical section.

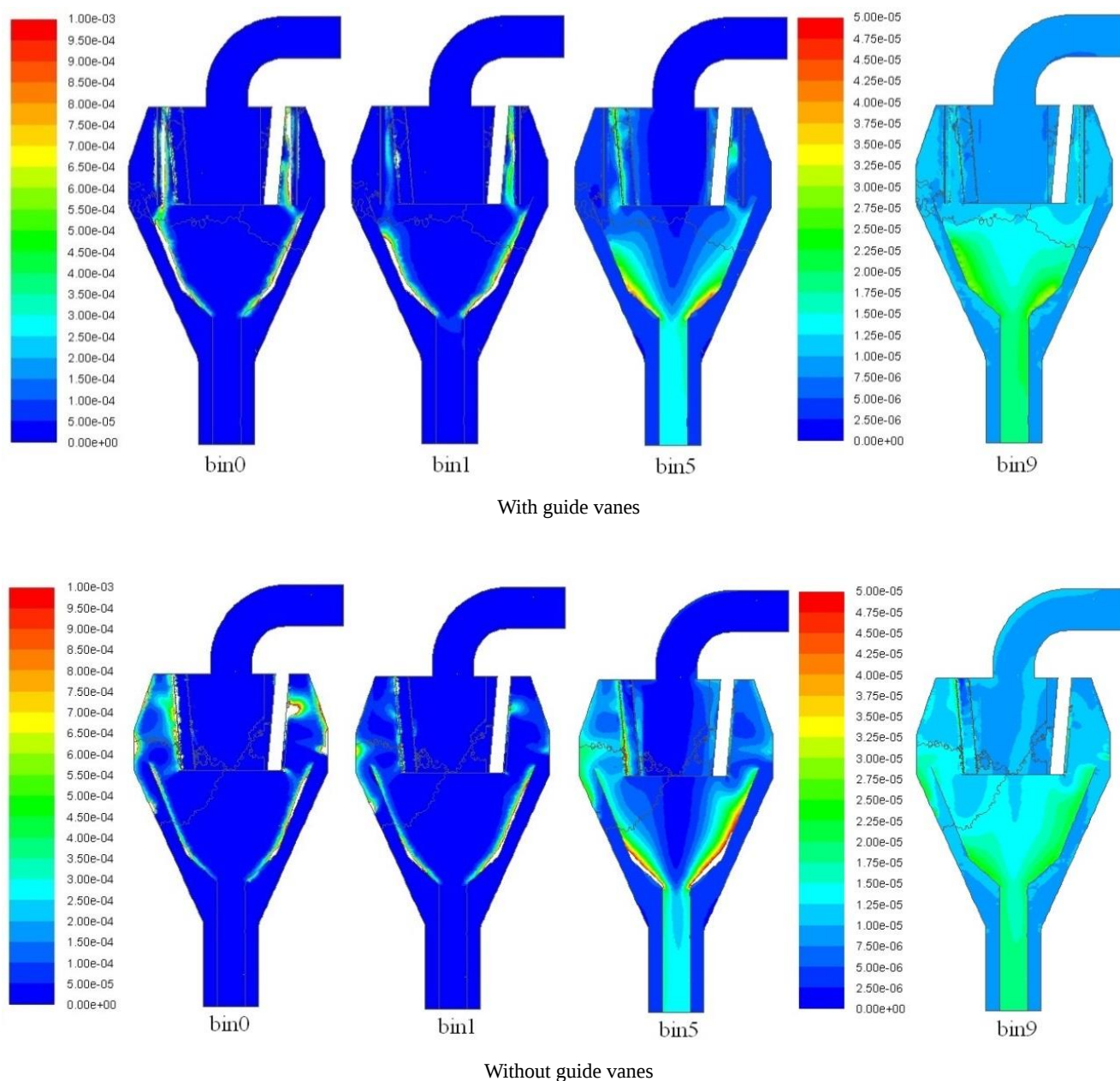


Figure 12. Volume fraction distribution along particle size in vertical section.

As shown in Figure 7, when the coarse grain outlet was closed, there was a difference in the volume fraction distribution with and without guide vanes. However, it can be seen in Figure 12 that there is little difference between the two cases for all particle sizes.

For the sake of clarity, the simulations are carried out with five changes of 0, 12, 24, 36 and 48 guide vanes and three changes of 36°, 54° and 72° in the normal angle of guide vanes and partial classification efficiency curves are shown in Figure 13. As can be seen, in this case there is little change in the classification efficiency curve in all cases. It can be seen that there is no significant difference even in the case of no guide vanes or with 48 guide vanes.

The cut diameter d_{50} obtained from the sub-sorting effi-

ciency curve in Figure 9 is shown in Table 4.

Table 4. A cut size (d_{50}) with number and angle of guide vanes (μm).

Number	Angle				
	0	12	24	36	48
36°	6.92	6.9	6.81	7.15	7.02
54°	6.92	6.96	7.09	7.18	6.81
72°	6.92	6.96	7.2	6.5	5.03

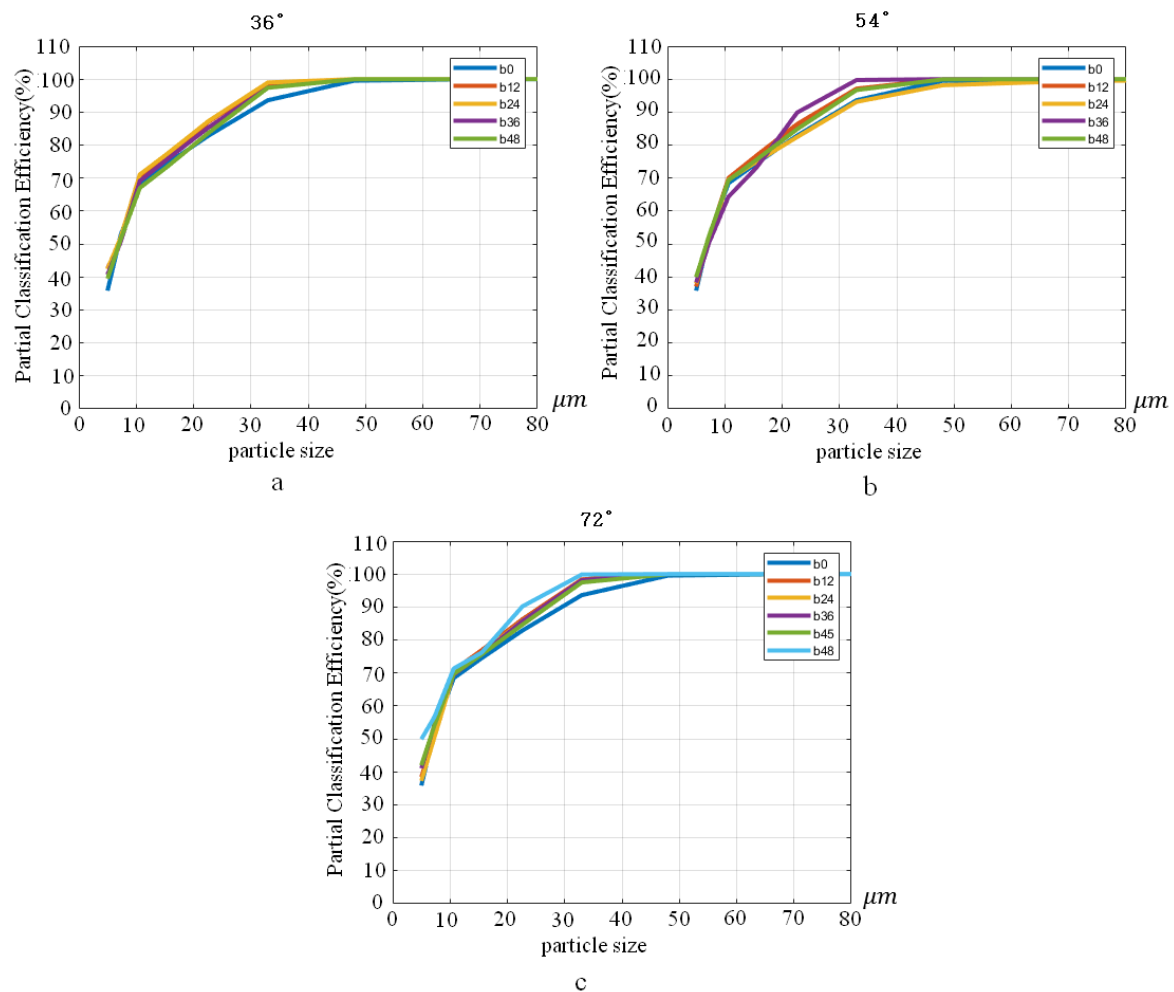


Figure 13. Partial classification efficiency with number of blades and angle of guide vane: a) 36 °, b) 54 °, c) 72 ° (The number next to b represents the number of guide vanes).

In Figure 7, the classification efficiency of particles below 7.5 μm is zero. In other words, all the fine particles appear to be going out of the fine particle exit. However, Figure 13 shows that the separation efficiency for the finest particle, 5 μm , is about 40%, indicating that about 40% of the fine particles are entrained into the gas at the coarse particle exit.

As seen from Table 4, the cut diameter varies around 7 μm and does not change significantly with the angle and the number of guide vanes. The cut diameter is small but this is not because of the increased classification efficiency, but because the fine particles are mixed into the downstream gas stream and exit the downstream outlet. In Table 4, d_{50} is smaller than the other cases when the angle of guide vane is 72 ° and the number is 48, which indicates that the fine particles do not escape into the above channel.

It can be seen that, when the angle of guide vane is large and the number of guide vanes is large, the guide vanes act as filters for fine particles as well as coarse particles and have a negative effect on the classification of fine particles. That is, the classification efficiency is low in the method of operating with the coarse particle outlet open. Thus, it is advantageous to use a method in which coarse particles are deposited and

discharged at the bottom, i.e., the method in which coarse particles are prevented from exiting and discharged after some amount of accumulation.

4.3. Effect of Parameters of Guide Vanes on the Classification Sharpness

The classification sharpness is an important factor among the characteristics of the classifier. The classification sharpness is the ratio of the diameter of the particle with separation efficiency of 25% to the diameter of the particle with separation efficiency of 75%. This shows how precisely the material to be separated is separated by a cut diameter boundary. The classification sharpness can be expressed as the following formula [3].

$$k = \frac{d_{25}}{d_{75}}$$

The classification sharpness with the number and angle of guide vanes is shown in Figure 14. This is the classification sharpness for the case where the coarse particle exit is blocked.

In the case of the coarse particle outlet opening, the classification sharpness cannot be considered because the value of d_{25} does not exist, as shown in the partial classification efficiency curve in Figure 13.

As shown in Figure 14, in general, the number of guide vanes and the guide vanes angle do not have a significant effect on the classification sharpness. However, in the case of angle of 72° , it can be seen that the classification sharpness decreases when the number of guide vanes increases above 36.

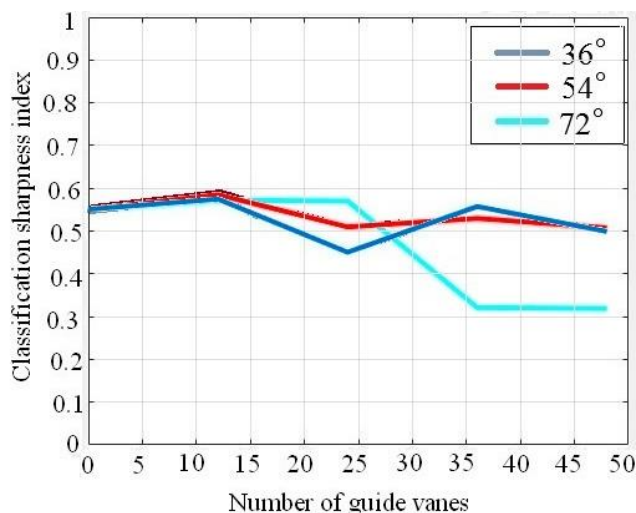


Figure 14. Classification sharpness index according to the number and the angle of guide vanes.

Thus, considering the cut size of Figure 9 and the classification sharpness of Figure 13, together, it can be seen that the cutting size is small and the classification sharpness is large when the guide vanes angle is 72° and the number of guide vanes is 24.

5. Conclusion

The effect of parameters of the guide vane on the classification performance of a turbo air classifier was investigated in this paper. The velocity and volume fraction distribution of particles with different particle sizes in a turbo air classifier were investigated using a two-fluid model coupled with a population balance equation. In the DPM model, the velocity and volume fraction distribution of particles can be considered only as the mean velocity distribution and volume fraction distribution of the secondary phase, while in the two-fluid model coupled with the population balance equations, the velocity distribution and volume fraction distribution can be considered by particle size.

First, the model was validated by comparing it with the experimental values for the turbo air classifier studied in [6]. RNG $k - \varepsilon$, RSM and SST $k - \omega$ models, which are mostly used in the study of turbo air classifier as turbulence models,

were examined and it was shown that the calculated values of the RSM model are in the best agreement with the experimental values for the partial classification efficiency curve.

Next, in a turbo air classifier the influence of the number of guide vanes and the guide vanes angle on the classification performance was investigated for the case of the coarse particle exit closed and open. In the section of the mid-plane of the blade height, the velocity distribution along particle size is radial outward, and the fine particles have a rotational velocity similar to that of the secondary phase.

Also, in the case with the guide vanes, the velocity distribution is large inside the guide vanes and there is little rotational velocity outside. In other words, as the number of guide vanes increases, the momentum of the rotor is not transferred out of the guide vanes.

The distribution of volume fraction by particle size shows that the coarse particles are distributed evenly in the space between the guide vanes and the rotor for the case with guide vanes, but the distribution is uneven for the case without guide vanes.

The number and angle of guide vanes have a significant effect on the classification performance when the coarse particle exit is closed. For the case of the guide vanes angle of 36° , the partial classification efficiency curve shifts to the left with the increase of the number of guide vanes and the cut size decreases. And for 54° , the partial classification efficiency curves are almost identical for more than 24 guide vanes and there is no change in the cut size. At 72° , the cut size shows a rather increasing trend for more than 24 guide vanes.

Also, in the case of the coarse particle outlet opening, the number of guide vanes does not significantly affect the classification performance. The partial classification efficiency curve is not different from the case without any guide vanes, even when the number of guide vanes is 48, and the cut size is also almost the same. In this case, the fine particles are mixed with the gas and discharged into the coarse particle outlet by about 40%. Also, at this time, the guide vanes do not have a significant effect on the classification sharpness, but the classification sharpness decreases when the guide vanes angle is 72° and the number of guide vanes is more than 36.

Abbreviations

DPM	Discrete Phase Model
PBE	Population Balance Equation
RNG	Renormalization Group
RSM	Reynolds Stress Equation Model
SST	Shear Stress Transport

Author Contributions

Kum-Song Ku: Conceptualization, Methodology, Writing - original draft, Software, Supervision, Project administrator.

Myong-Il Kim: Writing - review & editing, Investigation, Visualization.

Kwang-Chol Jong: Conceptualization, Writing - review & editing, Validation.

Gi-Song Hong: Writing - review & editing, Validation, Visualization.

Conflicts of Interest

The authors declare no conflicts of interest.

References

- [1] Steffen S., Current Trends in Air Classification of Powder Raw Materials for Advanced Materials, The Micromeritics, No. 64(2021) 28-34, <https://doi.org/10.24611/micromeritics.2021008>
- [2] Yun Zeng., Si Zhang, Yang Zhou, Meiqiu Li, Numerical simulation of a flow field in a turbo air classifier and optimization of the process parameters. Processes 2020, 8, 237; <https://doi.org/10.3390/pr8020237>
- [3] Mohamed A., Bernd B., Mehran J., Annett W., Alfred P. W., Limitation in the Performance of Fine Powder Separation in a Turbo Air Classifier, Processes 2023, 11, 2817, <https://doi.org/10.3390/pr11102817>
- [4] Zhanpeng Sun, Guogang Sun, Jianxin Liu, Xiaonan Yang, CFD simulation and optimization of the flow field in horizontal turbo air classifiers, Advanced Powder Technology, 4(2017).
- [5] Wenjing Ren, Jiaxiang Liu, Yuan Yu, Design of a rotor cage with non-radial arc blades for turbo air classifiers, Powder Technology 292(2016) 46-53.
- [6] Y. Yu, J. Liu. A parametric cut size prediction model for a turbo air classifier. Materialwiss. Werkstofftech. 2018, 49, 1510-1519, <https://doi.org/10.1002/mawe.201700071>
- [7] Appadurai A., Raghavan V., Numerical investigations on particle separation in dynamic separators, International Journal of Numerical Methods for Heat & Fluid Flow, 2019, <https://doi.org/10.1108/HFF-10-2018-0567>
- [8] Titov D. A., Grigor'ev K. A., Klepikov N. S., Paramonov A. P., Shtegman A. V., Numerical modeling study of the operation of a dynamic dust separator, Power Technology and Engineering, Vol. 52, No. 3, September, 2018, <https://doi.org/10.1007/s10749-018-0951-z>
- [9] Yuan Y., Wenjing R., Jiaxiang L. A new volute design method for the turbo air classifier, Powder Technology, 348(2019), 65-69.
- [10] Shubo W., Jiaxiang L., Yuan Y., Design of a new double layer spreading plate for a turbo air classifier, Powder Technology, 312(2017), 277-286.
- [11] Mohammad B., Sheldon G., Steven R., Particulate concentration distribution in centrifugal air classifiers, Minerals Engineering 126(2018) 44-51.
- [12] Zhanpeng Sun, Guogang Sun, Xiaonan Yang, Yi Yuan, Qinglian Wang, Jianxin Liu, Effects of fine particle outlet on performance and flow field of a centrifugal air classifier, Chemical Engineering Research and Design 117(2017) 139-148.
- [13] Eswaraiah C., Soni Rahul K., Sunil Kumar Tripathy, Filippov L. O., Particle Classification Optimization of a Circulating Air Classifier, Mineral Processing and Extractive Metallurgy Review, <https://doi.org/10.1080/08827508.2019.1643340>
- [14] Guizani R., Mokni I., Mhiri H., Philippe B., CFD modeling and analysis of the fish-hook effect on the rotor separator's efficiency, Powder Technology, 264(2014), 149-157.
- [15] Bokchol Song, Kumsong Ku, Myonil Kim, Kwangchol Jong, A two-fluid multiphase flow model coupled with the population balance equations for the flow of a multi-dispersed particle system, Powder Technology, V 448, 1, December 2024, 120337.
- [16] Ramakrishna D. Population Balances: Theory and Applications to Particulate Systems in Engineering, Academic Press, 2000.
- [17] Versteeg H. K., Malalasekera W., Introduction to Computational fluid dynamics, 2007, Pearson, Prentice Hall.
- [18] Gidaspow, D., Multiphase Flow and Fluidization; Continuum and kinetic theory description, 1994, Academic Press.
- [19] Lun C. K. K., Savage S. B., Jerrey D. J., Chepurnly N. (1984). Kinetic theories for granular flow: Inelastic particles in Couette flow and slightly inelastic particles in a general flow field. Journal Fluid Mechanics, 140, 223-256.