Motion Characteristics of Shaped Grains in Gas-solid Two-phase Flow

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Abstract: In order to simplify the calculation and analysis process, the the difference of shape and size of cereal grain shaped particles was converted to projected diameter. Using the theory of multiphase flow, resistance coefficient, fluid drag force and relaxation time of entrance flow on single grain particle and grain particles of dilute phase and dense phase flow conveying were researched. The results showed that the different kind of grain particle can be characterized as volume shape factor and projected diameter. The fluid drag force of single grain particles or particles in different regions with different Reynolds number have different variation. The same type of particles is also affected by projection diameter, suspension speed and other parameters. The inlet relaxation time of the dense phase transport particle group is higher than that of dilute phase transport, and the single particle fluidization relaxation time is one order of magnitude. Different kinds of raw material grains flow of the relaxation time is different, so the energy consumption to achieve the suspended feed status is also different.

1 INTRODUCTION

Pipeline pneumatic conveying is characterized by high speed and large quantity of conveying by conveying the scattered material through the pipeline using the flowing air. With the development of industry and the progress of science and technology, the pneumatic conveying technology is widely used in many fields, such as port loading and unloading, mining, coal, chemical, building materials, pharmaceutical, casting and textile[1-3]. The application and research of the pipeline pneumatic conveying in the grain industry is mainly embodied in two aspects, one is the pipeline pneumatic conveying part on the single machine equipment, such as the pipe conveying system, which is widely used in the grain absorbing equipment of the station, the port and the warehouse, and the transportation distance varies from several tens to hundreds of meters[4]. On the other hand, it is the pneumatic conveying in the factory, including the component of the pneumatic conveying of the distribution of the bulk material, or the pipe connection between the different equipment in the plant. The transmission distance is usually about hundreds of meters, and the longest distance is up to 1000 meters[5].

The flow field of grain pipeline conveying is a gas solid multiphase flow field with air medium as a continuous phase, raw grain particles with different shapes and sizes and the impurities mixed in them as discrete phases. The multiphase flow can be divided into thin phase suspension transport and dense phase suspension transport according to the transport concentration of central grain particles, but the thin phase suspension transportation has high transport wind speed, large power consumption, easy wear of the pipe wall and high crushing rate of conveying material[6].

In order to increase the flow rate and flow of the fluid in order to increase the transport capacity, it will not only produce large energy loss, but also consume a large amount of fluid medium, which makes the transportation benefit low and the economy is poor. The concentrated phase suspension transport can effectively utilize the energy of the airflow, for example, Tong Deng[7] and so on, a fluid model which considers the particle size distribution effect in the dense phase pneumatic conveying of particle flow is proposed, and the size distribution of the material particle size of the plugging pipe is calculated.

In relation to the calculation of the drag force of the fluid, the modified drag force model for dense gas solid two phase flow is proposed by Wang Xueyao[8] and so on, and a three-dimensional flow model based on the multi scale is established in combination with the theory of particle dynamics. In the study of particle flow characteristics in multiphase flow field, PIV two phase simultaneous measurement method was used, SuJing, Jiang Guifeng, Liu Zhaohui[9] and so on to study the particle motion characteristics in high Reynolds number of gas solid two nozzles against impinging jet.

In this paper, in view of the motion characteristics of the grain original grain in the pipeline pneumatic conveying flow field, the multi phase flow theory is applied to the non spherical grain grain projecting. The results of the study of the dilute phase flow field and the relaxation time of the fluid drag force and the entrance fluidization in the concentrated phase flow field are calculated. It provides theoretical support for the design of pneumatic conveying system for grain raw grain and optimization of the structural parameters of conveying equipment.

2 SIZE CHARACTERISTICS OF HETEROMORPHIC GRAINS IN CEREAL

In the process of pipeline pneumatic conveying, different kinds of grain produce different hydrodynamic characteristics in the gas solid multiphase suspension because of the difference in the shape and size of the particles, which leads to the different stress conditions in the multiphase flow field.

In order to study the motion characteristics of the grain original grain in the gas solid two phase flow field, and to determine the fluid force of the continuous phase air flow to the non spherical discrete grain grain particles, the characteristic parameters of different heteromorphic particles should be determined.

Based on the analysis method proposed by Heywood[10] to indicate the size of non spherical irregular shape particles with the projection diameter, the projection diameter dp and other characteristic parameters of several typical grain raw grains are calculated.

In the typical cereal grains, soybean particles can be considered as spherical particles, while wheat, rice and corn grains are typical non spherical and heteromorphic particles. In order to simplify calculation and convenient analysis, the particle size distribution function is calculated according to the average size of particle size. The system is simplified as a gas solid two phase flow system with monodisperse particle size, and the characteristic parameters of several representative grain grain heteromorphic particles are shown in table 1.

Table 1: Characteristic parameter values of several representative cereal grains based on Heywood analysis method.

type	Ratio of Width to thickness （m）	Ratio of length to width （n）	Volume shape coefficient （Z）	Particle volume/mm^3 (V_p)	Projection diameter/mm （d_p）
soybean	-	-	0.5236	87.07	5.5
wheat (common)	3.2/2.9	6.2/3.2	0.3226	28.78	4.47
Rice	3.4/2.3	7.4/3.4	0.2293	20.88	4.50
Corn	8.5/5	10/8.5	0.2712	291.67	10.25

It is known from table 1 that the irregular shape of grain original grain is characterized by the parameter of volume shape coefficient *Z*, according to its shape and size. The *Z* value of the soybean particle near the spherical shape can be directly taken as $\pi/6$, the volume shape number and the diameter of the projection of the other three raw grains can be based on the width to thickness ratio and the ratio of length to width. By comparing the volume shape coefficient, it is found that except for soybean granules, the grain shape of rice grains is close to the lowest sphere, and the wheat grain is nearly spherical. Although the volume of wheat grain is larger than that of paddy grain, the volume shape coefficient is different, which makes the two kinds of particles basically close to the projected diameter. Because of the large volume of corn granules, the projection diameter is also large.

3 DRAG COEFFICIENT AND FLUID DRAG FORCE

In the flow field of pipeline pneumatic conveying of grain, the grain particles are moving along the direction of flow under the action of flow force. Only considering the movement of a single grain in the fluid, the drag force of the fluid can be calculated by formula (1).

$$F_D = \frac{1}{8} C_D \pi d_p^2 \rho_f u_p^2 \tag{1}$$

In the formula, C_d is the drag coefficient, which varies with the Reynolds number R_e, and the parameter d_p is the projection diameter of the grain grain, which is used to replace the spherical particle diameter in the stationary viscous fluid, and the ρ_f f is the fluid density (the air density is about 1.29Kg/m³), and the u_p is the velocity of the grain particles in the stationary fluid.

At low Reynolds number (Re≦1), Cd increases linearly with decreasing Re, and the corresponding formula for calculating fluid drag is obtained by using Stokes's formula (2).

$$F_D = \frac{3}{R_e} \pi d_p^2 \rho_f u_p^2 \tag{2}$$

When the Reynolds number is 1≦Re≦700, the parameter Cd decreases with the increase of Re, and the effect of friction resistance becomes smaller. The inertia force will gradually increase with the increase of Reynolds number. According to the formula of Rowe, the formula of the calculation of the drag force can be obtained, such as formula (3).

$$F_D = \frac{3}{R_e}(1+0.15R_e^{0.687}) \pi d_p^2 \rho_f u_p^2 \tag{3}$$

When the Reynolds number is 700≦Re≦2×105, the friction resistance effect can be ignored at this time and the inertia force is dominant, and the resistance coefficient Cd is approximately constant, and the corresponding calculation formula of the fluid drag force can be obtained (4).

$$F_D = 0.055 \pi d_p^2 \rho_f u_p^2 \tag{4}$$

When the Reynolds number exceeds the critical Reynolds number of 2×105, the drag coefficient will suddenly decrease, because the viscous fluid layer on the particle surface will change to a turbulent state.

According to the formula (2), (3) and (4), the relation curve of the fluid drag-force Fd of several typical single grain particle with the change of Reynolds number Re is obtained, as shown in Figure 1.

Among them, up is assumed to be the suspension velocity of grain grains, and the suspension velocity of soybean, common wheat, rice and corn grains are 10m/s, 8.4m/s, 7.5m/s and 13.5m/s respectively[11].

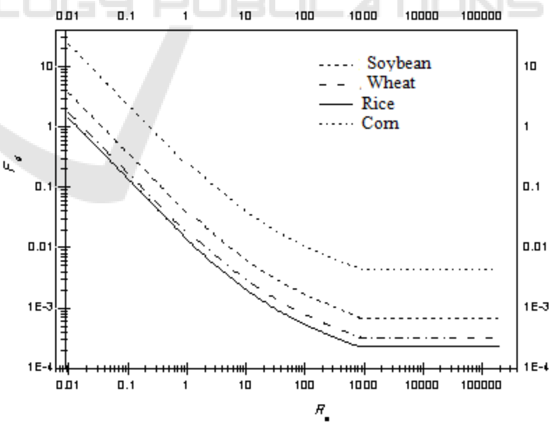


Figure 1: relationship between the drag force and the Reynolds number of a single grain particle.

For the gas solid two phase flow of cereal grain particles, when the porosity ε is large enough (ε>0.92), the interaction between the particles can be ignored. The calculation of the resistance coefficient Cd can further calculate the force of the single grain grain in the continuous phase fluid. According to the variation of Reynolds number Re, the variation of fluid drag force produced by air flow on the grain in the dilute phase system can be obtained.

From Fig. 1, it can be see that the variation of Fd of different single grain in different regions is basically the same as that of Reynolds number Re. Because the soybean particles are close to the spherical particles, the average diameter of the particles is calculated for the diameter of the ball according to the particle size distribution, and the other three kinds of cereal grains are converted to the projection diameter dp.

Although the projection diameter of wheat grains is slightly smaller than the projection diameter of rice grains, the suspension velocity is higher than that of rice grains, making the difference in the drag force of the fluid under the same Reynolds number. The projective diameter of the corn grains is larger and the suspension speed is higher, so the fluid drag force of the particles under the same Reynolds number is also larger, which means that more energy is consumed during the pipeline transportation.

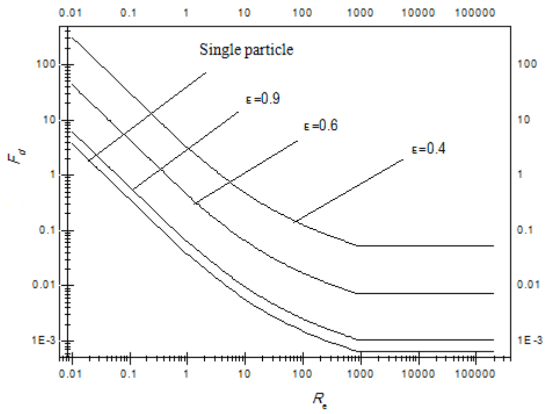
With the increase of grain transport concentration, the concentration of discrete phase in the gas-solid two-phase flow system increases. At this time, the system is gradually transformed from dilute phase system to concentrated phase system. The above calculation is no longer applicable, but it should be considered according to the movement law of grain group. According to the expression of the air clearance degree ε of the gas solid suspension system determined by Wen, the void function φ(ε) is considered in the calculation of the resistance coefficient. The drag force of the grain group fluid suitable for the dense phase conveying system can be given by the by the following formulas.

$$F_D = \frac{3}{R_e}\pi d_p^2 \rho_f u_p^2 \varepsilon^{-4.85} \qquad (R_e \leqq 1) \qquad (5)$$

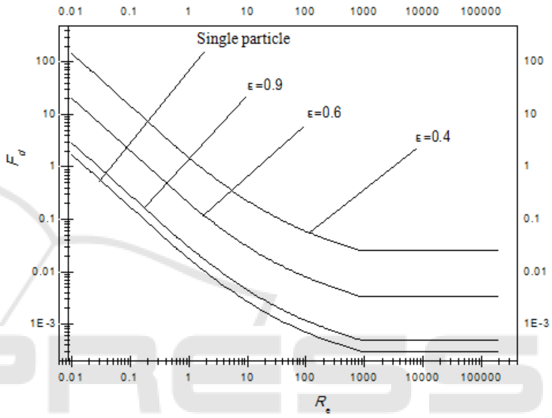
$$F_D = \frac{3}{R_e}(1+0.15R_e^{0.687})\pi d_p^2 \rho_f u_p^2 \varepsilon^{-4.7} \quad (1< R_e \leqq 700) \qquad (6)$$

$$F_D = 0.055\pi d_p^2 \rho_f u_p^2 \varepsilon^{-4.78} \qquad (700< \mathrm{Re} \leqq 2\times 10^5) \qquad (7)$$

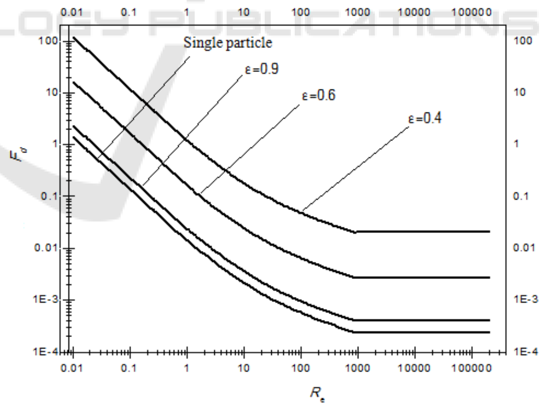
The formula (5), (6) and (7) can be used to determine the relationship between the fluid drag force F_d of the bulk grain and the change of the Reynolds number R_e in the different flow areas, as shown in Figure 2.



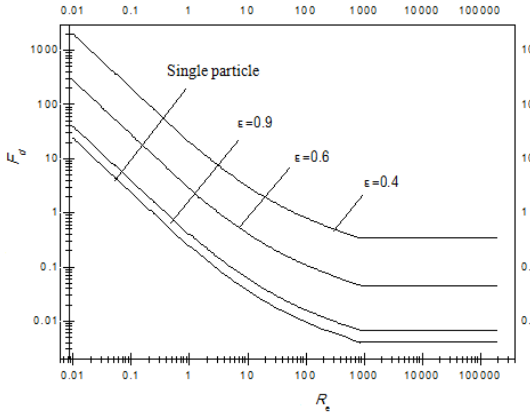
（a）Soybean granules（dp=5.5mm，up=10m/s）



（b）Wheat grain（dp=4.47mm，up=8.4m/s）



（c）Rice grain（dp=4.5mm，up=7.5m/s）



（d）Corn grain（dp=10.25mm，up=13.5m/s）

Figure 2: relationship between the drag force and the Reynolds number of grains in the grain stock group.

As shown in Fig. 2, when the porosity parameter ε is close to 0.9, the fluid drag force of different types of grain grains is close to that of a single particle. However, with the reduction of the porosity parameter ε (the volume fraction of the particle phase increases) and the same Reynolds number R_e, the numerical value of the drag force increases significantly if the different types of particles are to reach the corresponding suspension velocity.

In addition, the larger the projective diameter of a single particle and the higher the suspension velocity, the greater the fluid drag force of the particle group. The projection diameter and the suspension speed of the corn grains are higher than other grains of raw grain, so the drag force of the particle group is much larger than that of the other grains.

4 RELAXATION TIME OF ENTRANCE FLUIDIZATION

Before the normal grain delivery is realized, the grain supply must be fluidization through the feeder at the entrance of the pipe, and the material particles and the air flow are fully mixed, so that the particle phase is accelerated by the continuous phase flow and transported under the action of the flow force.

If the conveying air velocity is u, when the raw grain particles enter at zero speed, the particles will be accelerated at the condition that the gravity effect is ignored. The particle velocity u_p increases from 0 to the levitation speed and is evaluated with the time required for the movement of the air. Under the initial conditions t=0 and up=0, the law of individual particle velocity varying with time t is shown in formula 8.

$$u_p = u(1 - e^{-\frac{18\mu}{d_p^2 \rho_p} t}) \tag{8}$$

According to the above formula, the relationship curves of single grain velocity up and time t are obtained, as shown in Figure 2.

In the formula, ρp is the grain density of raw grain, the average density of soybean is 1200Kg/m3, and the density of medium wheat is 760Kg/m3. The average density of paddy in China is1195Kg/m3, the density of corn kernel is about 1150Kg/m3, and that of μ is aerodynamic viscosity coefficient, which is 1.83×10-5Pa·s.

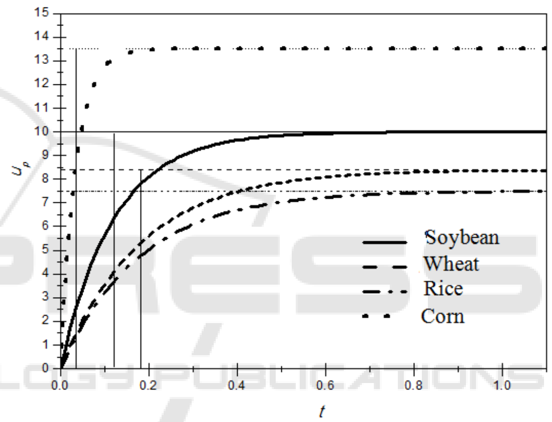
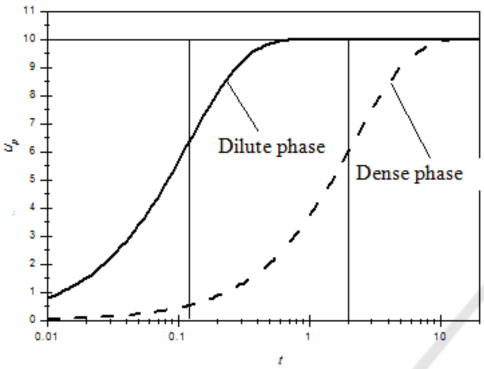


Figure 3: Relationship between grain velocity and grain time in cereal grain.

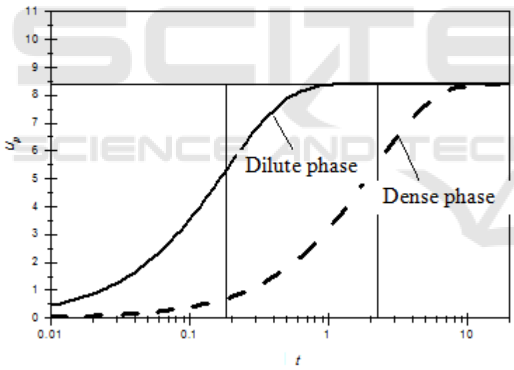
Figure 3 is the relation curve of speed changing with time when the grain is accelerated. It is shown from the diagram that the time of the grain grain with different shapes and sizes to reach their respective floating speed after entering the air flow is different. The relaxation time is related to the projection diameter and the suspension speed of grain particles, and the relaxation time of the particles with larger projection diameter is significantly reduced. This is because the higher the velocity of the suspended velocity is, the higher the flow velocity is, and the relaxation time of the particles with similar projection diameter is also basically the same. In addition, the relaxation time of grain particles with higher suspension speed will also decrease, which means that the particle acceleration time of the grain in the initial stage of air flow will be reduced.

For the dense phase conveying system with the void fraction ε increasing , the interaction and influence between particles should be considered. The voidage function of the grain group is determined in advance. When the relaxation time τ is replaced by the formula (8), the relation expression of the particle swarm velocity up with time t can be obtained as shown in the formula (9).

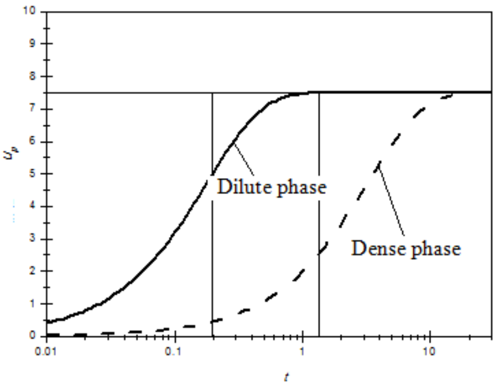
$$u_p = u(1 - e^{-(\frac{\mu}{d_p^2 \rho_p} + 1.75\frac{\mu}{\varepsilon d_p \rho_p} u_f)t}) \qquad (9)$$



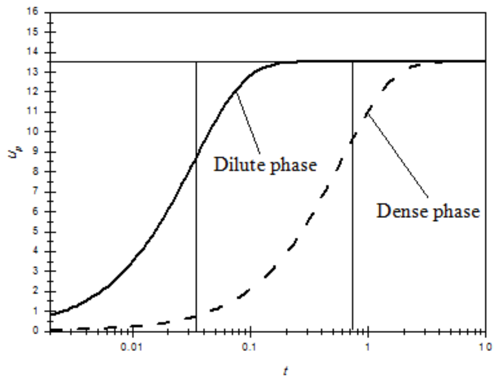
(a) soybean particle swarm



(b) grain group of Wheat



(c) rice grain group



(d) corn grain group

Figure 4: relaxation time of the fluidization of grain group.

Figure 4 compares the velocity changes of grain groups of different kinds of raw grain. It can be seen from the diagram that the acceleration process of the grain group in the concentrated phase system is more than one order of magnitude compared with the dilute phase system. This shows that the starting and accelerating process of the grain group with a certain volume rate at a lower initial speed or near the velocity of zero speed will take longer to reach the complete suspension state. Because the interaction time between the air flow and the grain grain is longer, the loss of the energy is greater.

It can be seen from the diagram that the relaxation time of the grain group of different kinds of grain is mainly related to the suspension speed. The higher the suspension speed, the shorter the time for the grain group to accelerate to the required speed, the higher the flow velocity and pressure will be needed. If the inlet air velocity is increased, although the relaxation time can be reduced, the pressure loss of the pipeline will also increase, and the energy loss will be increased. The relaxation time of the particle group in the dense phase system is related to the shape and size of the different shaped particles and the air gap of the particle group, as well as the inlet air velocity.

5 CONCLUSIONS

The motion characteristics of the special-shaped grain particles in the gas-solid two-phase flow are studied in the process of grain pipeline pneumatic conveying. The heterogeneous grains of non spherical raw grain are converted into volume shape coefficient and projection diameter use the multiphase flow theory to adapt to the calculation and the analysis of gas solid multiphase flow of grains with different shapes and feet.

Through the calculation and analysis of the resistance coefficient, the fluid drag force and the entrance fluidization relaxation time of the particle and particle swarm in the gas solid two phase flow system, the particle movement law in the raw grain pneumatic conveying flow field is found, which provides theoretical support about grain pneumatic conveying system design and the application of the pneumatic conveying engineering.

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