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Optimized simulation of vortex jet mill in waste rubber grinding technology by LNG

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Abstract. Frozen rubber powder has excellent qualities and application value, and it can be achieved from waste rubber after being crushed at low temperature used liquefied natural gas (LNG) as cryogen. Vortex jet mill was the key equipment to further crush the rubber particles which the pressure-air was jet into in the basic LNG technological process. After confirming the structure and size of the jet nozzle, the Height (H) between the nozzle and the bottom of the mill, the incident angle α and the initial size of the rubber particles were changed then the continuous phase and the track of single particle were optimized in order to gain more excellent crushing effect. The results showed: the jetting gas were spiral rising in the mill and the speed of it was reduced, so the particle was graded by the gas. The impact and collision could reduce the particle diameter and crush them but the result was influenced by the initial size of the particle. The size of the original rubber particles must not be more than 110μm. The simulation was helpful and leading for the experiment.

1. Introduction

The basic principle of crushing waste rubber at low temperatures was that the waste rubber blocks were quickly chilled to a temperature below its brittle cold with refrigerant and then were put into a mill. The fine rubber powder by this way maintains the material qualities and its value in use increases so this technology at low temperatures will be the direction and trend of the comprehensive utilization of waste rubber. More and more research on the method of LNG (liquefied natural gas) as the refrigerant in waste rubber crushed was carried out recent years. The research about crush waste rubber at low temperatures with LNG was still limited in conceptual stage although it was a new and promising technology for the higher requests on the equipment and operating safety. There was no completely equipment or experiment practice reported now.

2. The basic flow

The basic flow of waste rubber crushing technology at low temperature was shown in figure 1. Waste rubber blocks were chilled to -90℃ with cold energy supplied by LNG at first and then the rubber particles reached a 20-40 mesh after a simple mechanical crushing. The particles are put into a crushing equipment- vortex jet mill to be crushed further by the cold pressure air in the last step. The vortex jet mill was the key to smash of rubber particles in the whole flow. The parameter of the cold

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air and the rubber particles that entered into the mill must be controlled strictly. Size of particles entering must be between 20 and 40 mesh for too small particles would influence the classification efficiency and too large ones would result to decrease the smash efficiency. The pressure and flux of the cold air entering the mill must be controlled. The inlet pressure was about 0.4 MPa and the inlet flux was between 0.3 and 1 m^3/min adjusted by the inlet air valve [1].

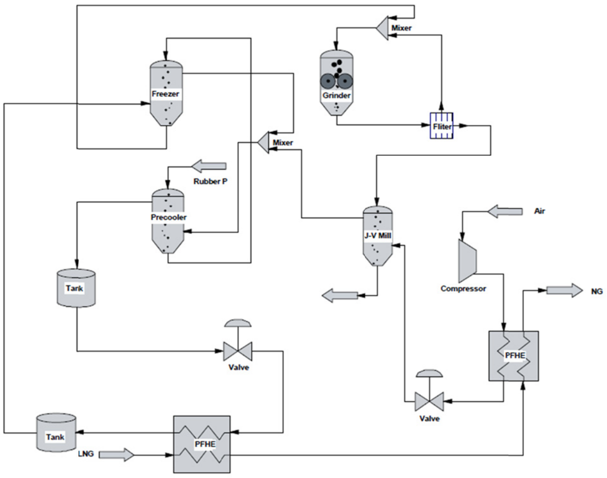

Figure 1. The basic flow by LNG.

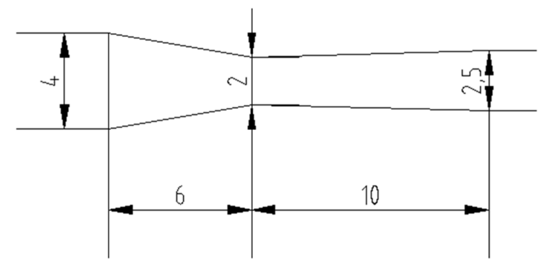

Figure 2. Structure and size of the nozzle.

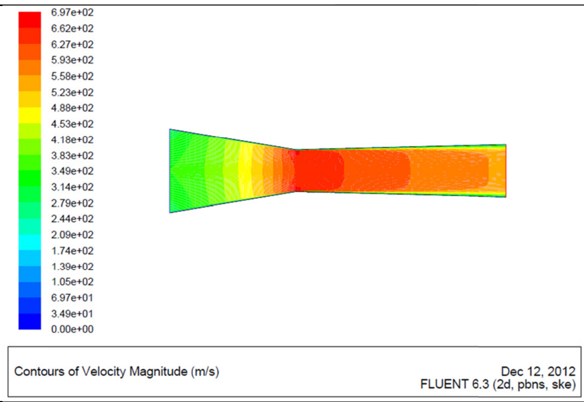

Figure 3. Velocity simulation profile in the nozzle.

3. Analog computations

3.1. *Computations of the nozzle*

In order to calculate the last speed of the cold air after going through the nozzle the cold air's motion in the nozzle was simulated. The inlet air pressure was set to 0.4 MPa and the outlet pressure was Atm. The equal diameter segments of inlet and outlet were ignored. The structure and parameters was showed on figure 2 while the computations results were shown on figure 3. The speed of cold air at the outlet was more than the speed of sound and the average speed was 550 m/s according to the results simulated by the software [2]. Then the data would be the boundary conditions in the following simulation of the grind.

Table 1. The model parameters in simulation.

No.	1	2	3	4	5	6	7	8	9
H (mm)	15	15	15	21	21	21	27	27	27
A (°)	30	35	40	30	35	40	30	35	40

3.2. Simulation of the continuous phase

The model parameters in simulation were shown in table 1 was the distance between the bottom and the nozzle and α was the angle between the nozzle line and the intersection point of tangential direction.

The Continuous phase was simulated at first without considering the rubber particles in the mill. There were 6 nozzles on the wall of the mill and the speed of the air inlet was 550 m/s while the outlet air was Atm. The 3D-model built based the data No. 4 in table 1 with software was shown in figure 3. The speed along the positive direction of Z axis and pressure inside of the grind was studied [3]. The results was shown that the maximum value of speed appeared at the wall of the mill along the positive direction of Z axis and the equal Z axis speed lines along the radial direction were in banding structure as figure 4.

Figure 4(c) was simulating results about the velocity distribution along Z axis at the longitudinal section in the mill. The velocity along the radial direction and the area near the outlet was upward while there was a small symmetrical area between the outlet and the wall in which the velocity along Z axis was down, so the air flow had a round trip between the top and bottom walls.

The air flow inside of the mill was keeping spiral upward movement and the radius became gradually smaller when the value of the speed became faster and reached to the outlet at last [4]. The results were shown on figure 4(d). The simulation result about air pressure was shown on figure 5. The pressure along the radial direction distributed in banding and there was negative pressure in the bottom centre area along Z axis. This phenomenon confirmed that the vacuum at the outlet was very necessary while the mill was working. The fastest speed of air along Z axis was 20 m/s according to the results above. Only data No. 4 was chosen to show out because the similar results were achieved under other data.

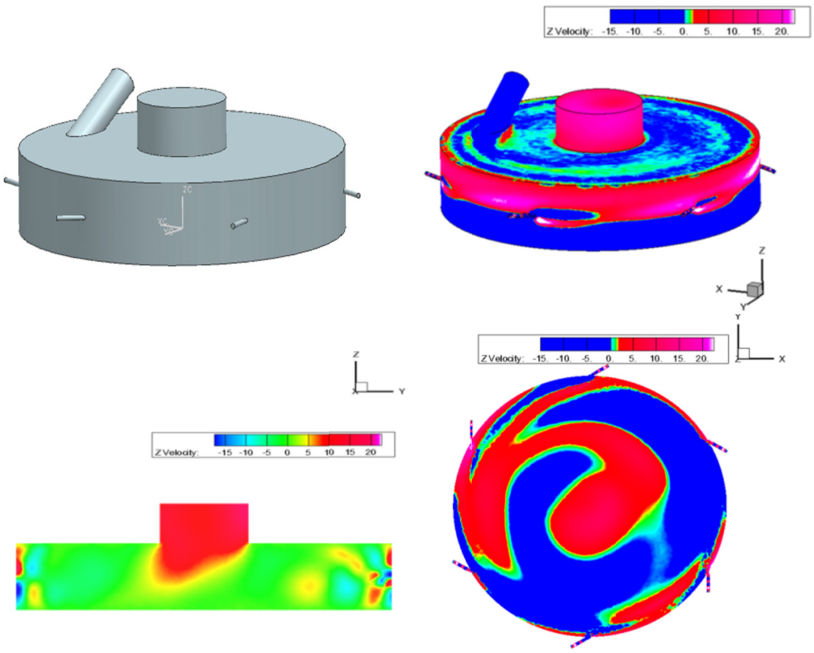

Figure 4. The simulation result of No. 3 model. a) 3D model; b) Profile of velocity along Z axis; c) along the Z-axis velocity profile at longitudinal section; d) Profile of velocity along Z axis at the nozzle level plane.

Table 2. The size of the feed rubber particles.

Size (um)	10	40	60	75	80	110	150	250	400	850
Feed rate (g/s)	1	1	1	1	1	1	1	1	1	1

3.3. *Simulation of the particles' track*

Because the particles' track can be simulated accurate only when the solid volume fraction particles was set to be 1g/s and the rate of the inlet particles to be 30 m/s. The solid volume fraction was below 10% for its density was 1000 kg/m^3. The simulation was basic on the model parameter of No. 3 with 10 nozzles. The particle phase's influence on the continuous phase was ignored and only the influence from continuous phase on the particle was considered. The size of rubber particles was shown in table 2.

Table 3. The statistics result of the rubber particles at exit.

Size(μm)	850	400	250	150	110	80	75	60	40	10
Track	216	216	216	216	216	216	216	216	216	216
flee	0	0	0	0	79	168	183	216	216	216
undone	216	216	216	216	137	48	33	0	0	0

The simulation result was shown in table 3. There were some rubber particles escaping from the exit whose size was 110 um under the model condition. All the rubber particles can escape from the exit when their size was not bigger than 60 um. The efficiency of classification of the vortex jet mill was about 50% according to the simulation. The efficiency in the actual situation would be larger than this number for the rubber particles would be smaller by the impact collision in the mill. There would be more rubber particles escaped from the exit and the efficiency of classification would be improved because of the smaller average size of the particles in the actual situation.

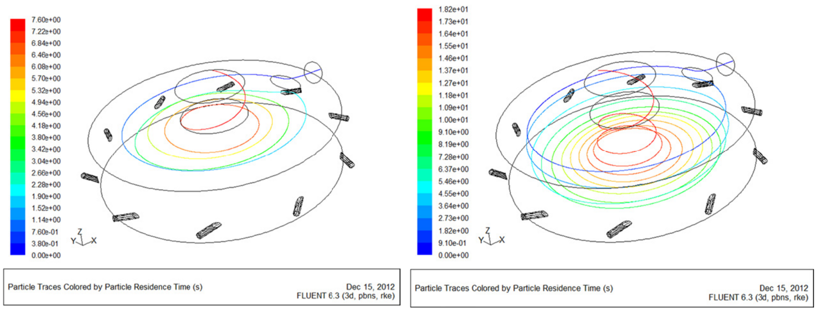

Figure 5. The trajectory figure of single particle. a) 10 um; b) 65 um.

From the trajectory figure of single particle we can see that rubber particles spiralled downward at first and became smaller and smaller simultaneously then spiralled upward to exit and escaped from it. The larger particles would spiral downward further and their radius of gyration would be larger than the small ones. Figure 5 was shown the trajectory of particle of 10 um and 65 um. From figure 5 we can see the 65 um particles spiralled downward at first and reached the bottom of mill so the larger particles had more probability to impact the bottom and the wall of the mill [6]. The gather of particles larger than 110 um near the bottom and circumferential wall increased the probability of collision and improved the crushing effect.

4. Conclusion

The simulation was carried out with different H (the distance between nozzles and the grind bottom, angle of incidence α and the size of inlet particle after the size of nozzles was conformed. The simulation result about continuous phase airflow showed that the jetting air spiralled upward and the rate of it became lower simultaneously so the airflow was very effective for classification. The trajectory of single particle showed that at first the actual situation spiralled downward and then spiralled upward after got into the mill. The larger particle spiralled downward further and had more collision probability than the smaller one so they can be crushed more completely. The efficiency of classification was about 50% according to the simulation while the efficiency would be higher in the actual situation for the big particles could be crushed by collision. The size of the original rubber particles must not be more than 110 um for they would gather in the mill and cannot escape from it.

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