

# Research on Processing Technology of Calcined Kaolin Powder Using a Fluidized Bed Jet Mill at Different Temperatures

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**Abstract.** The calcined kaolin powder was obtained using a fluidized bed jet mill at the temperatures 17°C and 280°C. The theoretical arithmetic, numerical simulation and experiment were used to compare and discuss the results at the two temperatures. The particle size  $D_{50}=2.401\mu\text{m}$  与  $D_{50}=2.003\mu\text{m}$  of kaolin powder was obtained. The theoretical arithmetic shows that the outlet velocity of the nozzle at the temperature 280°C is higher (38%) than that at the temperature 17°C. The grinding kinetic energy of the jet mill at the temperature 280°C is twice as that at the temperature 17°C. The numerical simulation of grinding cavity at the temperatures 17°C and 280°C shows that nozzle axial velocity is 513m/s at the temperature 17°C and nozzle axial velocity is 712m/s at the temperature 280°C. Therefore, the grinding particle size at the temperature 280°C is smaller than that at the temperature 17°C. The yields of calcined kaolin powder and energy consumption of jet mill are obtained through the experiment. The yield of calcined kaolin powder at the temperature 280°C is higher (14%) than that at the temperature 17°C. The energy consumption of air jet mill at the temperature 280°C is higher (30%) than that at the temperature 17°C. The results show that the calcined kaolin powder at the temperature 280°C is beneficial to grinding materials with the smaller particle size and higher yield than that at the temperature 17°C. Otherwise, the energy consumption of jet mill increase from the temperature 17°C to 280°C.

## Introduction

The kaolin powder has been widely used in the fields of papermaking, ceramics, plastics, coating, etc. [1-7]. In industry applications, the different grades of kaolin powder were classified based on fineness and whiteness. The fineness of kaolin used for the senior painting was lower than  $2\mu\text{m}$  [8]. Recently, the ultrafine kaolin has gradually used in the new materials of refractory castable, 4A zeolite and carbon-white, etc. [9-10]. The prepared kaolin was obtained from mechanical method. The prepared kaolin has the characteristics of fine size and high specific area [11-12]. The Chinese processing technic for grinding kaolin has a distance to the national level [13]. However, the grinding method has obtained a notable progress in China. Ding et al. experiment showed that the 90% particle size of calcined coal kaolin clay was lower than  $2\mu\text{m}$  using a wet grinding process [14]. Zhang et al. obtained that the mean particle size of calcined kaolin was lower than  $4\mu\text{m}$  using a mechanical kinetic energy mill [15].

However, the purity of kaolin has a great influence on its application. The Fluidized bed jet mill is suitable for grinding the kaolin. The jet mill has no pollution on the kaolin in the grinding process. The qualified size distribution of the kaolin can be obtained using jet mill [16]. The fluidized bed jet mill uses the compressed air as the grinding energy. The compressed air goes through the supersonic nozzle and into grinding chamber. Then, the compressed air induces the kaolin particles to grind. The gas with the high temperature has a higher dynamic energy than the gas with normal temperature [17]. When the compressed air is heated, the grinding process of kaolin particles are carried at the high temperature. The kaolin particles should have fine particle size using the same classifier and the yield production of kaolin powder increases.

The 2-3 mm size distribution of kaolin was chosen as the raw material in this experiment. The fluidized bed jet mill with three nozzles was used to grind the kaolin at the temperature 17°C and 280°C. The three aspects of theoretical arithmetic, numeric simulation and experiment were used to compare and discuss the kaolin particle size, yields, energy consumption and grinding kinetic energy. This can provide an environment-friendly way that prepares the high quality and high-yield kaolin powder.

## Experimental Apparatus and Parameters

### Raw Materials

The calcined kaolin was used in this experiment. The kaolin was obtained from the Guizhou. The Moh's hardness was 7-8. The particle size was 2-3 mm. The main chemical components were as follows using the XRF:  $\omega(\text{SiO}_2)=59.29\%$ ,  $\omega(\text{Al}_2\text{O}_3)=19.44\%$ ,  $\omega(\text{Fe}_2\text{O}_3)=14.14\%$ ,  $\omega(\text{CeO}_2)=2.15\%$ ,  $\omega(\text{TiO}_2)=1.98\%$ ,  $\omega(\text{K}_2\text{O})=1.27\%$ .

### Experimental Apparatus

The flow sheet is shown in Fig.1. The main apparatus and parameters: LNJH-60A type fluidized bed jet mill (Designed by Mianyang, Liuneng, Powder Equipment, Co., Ltd.), LNJ-36A type classifier (Power of motor is 4 Kw, Transmission ratio is 1.5:1), Y4-73 type induced fan (Power of motor is 15Kw, The maximum airflow is 1400 m<sup>3</sup>/h), OG-150W type air compressor (Power is 37 Kw). The 27 bags are installed in a filter. The dimensions of bag are  $\phi 120 \times 1500\text{mm}$  and the filtration area is 15 m<sup>2</sup>. The filter medium with the surface treatment can resistance to 300°C. Three nozzles are installed in the fluidized bed jet mill. The nozzle diameter is 5.8 mm and the Mach number is 1.98. The particle size of kaolin is measured using a laser particle size analyzer (Beckman Kurt LS13-320 type).

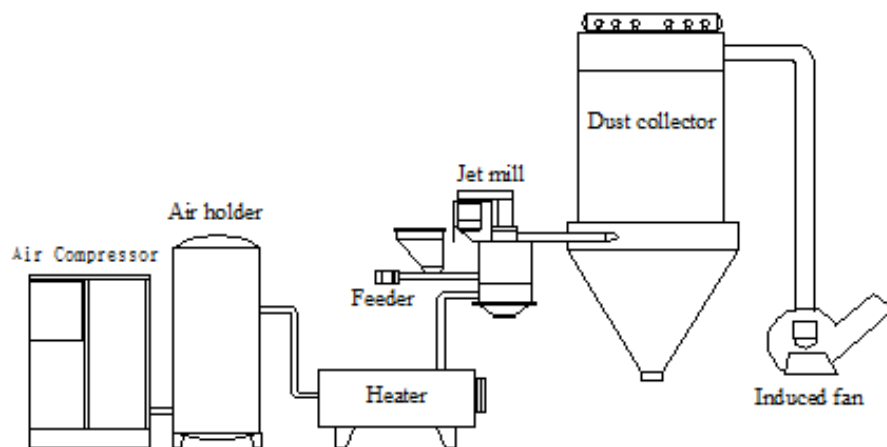


Fig.1 Flow sheet

### Experimental Process

The fluidized bed jet mill is used to prepare the kaolin powder in this experiment. The compressed pressure (0.76 MPa) can be obtained using an air compressor. The compressed air goes through the supersonic nozzles and is used to induce the kaolin particles to grind. In order to investigate the grinding process under the different temperatures, the compressed air is heated using a heater. The temperatures of the compressed air are controlled at the 17°C and 280°C. The 2~3 mm raw materials of kaolin go into grinding chamber using a screw feeding machine. The kaolin particles are grinded in the grinding chamber. The total system has a negative condition using an induced fan. The grinded particles go into classification section with the high-speed airflow. The qualified kaolin particles go into the turbo classifier and then are collected in a filter. The coarse kaolin particles are separated from turbo classifier and go into grinding chamber. The coarse kaolin

particles grind again in the chamber. The classification frequency is set to 38 Hz. The current values and kaolin yields an hour are recorded in the experiment. The particle size of kaolin is measured using a laser particle size analyzer.

## Results and Discussions

### Theoretical Arithmetic

**Outlet Velocity of Nozzles.** The supersonic nozzles are used in this experiment. Mach number is 1.98. The airflow is assumed as adiabatic stability. The outlet velocity  $u_*$  of nozzle at the temperature 17°C and 280°C are calculated as follow (1) [18]:

$$u_* = \sqrt{\frac{2k}{k-1} RT_1 \left[ 1 - \left( \frac{p_*}{p_1} \right)^{\frac{k-1}{k}} \right]} \quad (1)$$

Where  $k$  is entropy index and the value is 1.4. The  $R$  is gas constant and the value is 287J/(kg K). The backpressure of grinding section is -5kpa. The grinding pressure is 0.76Mpa. The pressure in formula (1) is absolute pressure. The inlet pressure  $p_1$  of nozzle is 0.76Mpa. The outlet pressure of nozzle is  $p_* = 5\text{kpa} + 101.325\text{kpa} = 0.106325\text{Mpa}$ . The inlet temperatures  $T_1$  of nozzle are 290.15K (17°C) and 553.15K(280°C), respectively.

Through the calculation from the formula (1), the  $u_*$  is 512m/s when the  $T_1$  is 290.15K. The  $u_*$  is 707m/s when the  $T_1$  is 553.15K. From the results, the airflow velocity at the 553.15K is higher to 38% than that at the 290.15K.

**Grinding Energy.** The materials are driven to grind with a high-velocity airflow in the grinding chamber. This is a lash process. The lash velocity determines the kinetic energy of particles. In the umklapp process, only partially kinetic energy of particles is transferred to crushing energy<sup>[18]</sup>, denoted by  $\Delta E$ . The particles has its broken energy, denoted by  $W$ . The kinetic energy of particle is denoted by  $E$ . The three relationship is  $E > \Delta E \geq W$ .

$$E = \frac{1}{2} m u_i^2 \quad (2)$$

$$\Delta E = \frac{1}{2} m u_i^2 (1 - \xi^2) \geq W = \frac{\sigma^2 m}{2E\rho} \quad (3)$$

The formula (4) is obtained from industrial experience for crushing the particles:

$$u_i \geq u^* = \sigma \sqrt{\frac{1}{E\rho(1 - \xi^2)}} \quad (4)$$

Where  $u_i$  is the particle velocity when the particles crush.  $u^*$  is a small required velocity to crush.  $\sigma$  is breaking point of the particles.  $E$  is elastic modulus.  $\rho$  is particle density.  $m$  is particle mass.  $\xi$  is recovery coefficient of particle velocity after crushing.  $\xi < 1$ .

From the formula (3), the required kinetic energies for particles with different sizes are different. Moreover, the ultrafine particle mass is difficult to measure. The kinetic energy of a single particle is not clearly calculated. In order to compare the grinding kinetic energy at the temperature 17°C and 280°C, the particle mass is assumed to unit mass. The grinding energies of particles at the nozzle outlet are compared at the temperature 17°C and 280°C. The grinding energies of particles are denoted by  $E_1$  and  $E_2$  at the temperature 17°C and 280°C, respectively. The outlet velocities of particles are denoted by  $u_{i1}$  and  $u_{i2}$  at the temperature 17°C and 280°C, respectively. From the formula (2):

$$\frac{E_1}{E_2} = \frac{u_{i1}^2}{u_{i2}^2} = \frac{u_{*1}^2}{u_{*2}^2} \quad (5)$$

Where the  $u_*$  is 512m/s when the  $T_1$  is 290.15K. The  $u_*$  is 707m/s when the  $T_1$  is 553.15K. From the outlet velocity of nozzles,  $E_1/E_2=0.524$ . Therefore, the grinding kinetic energy at the temperature 280°C is twice times than that at the temperature 17°C.

**Cut Size.** The particles are grinded in the grinding chamber. The qualified particles go into classifier and go through the classifier. The particles with the diameter higher than the cut size continue to grind in the chamber. The cut size formula [19-20] is as follow:

$$d_c = \frac{k}{n} \sqrt{\frac{Q}{\rho_s}} \quad (6)$$

Where  $d_c$  is the cut size of the classier;  $n$  is the rotation rate of the grading wheel;  $Q$  is the gas-flow rate through the grading wheel (standard conditions);  $\rho_s$  is the particle density;  $k$  is a coefficient that is related to structure and dimension of the grading wheel, and gas viscosity, etc.

In this study, the volume of a gas flow ( $Q_1$ ) is 6.6 m<sup>3</sup>/min at the temperature 17°C. The volume of the gas flow is 6.3 Nm<sup>3</sup>/min at the standard conditions. The volume of a gas flow ( $Q_2$ ) is 9.1 m<sup>3</sup>/min at the temperature 280°C. The volume of the gas flow is 4.54 Nm<sup>3</sup>/min at the standard conditions. The classification frequencies of classifier are the same under the two temperatures. Therefore, the rotation rates of classifier are the same, and the particle density is used. The cut size of the particles is in proportion to the volume of a gas flow. The results obtained from the formula (3) is as follow:

$$\frac{d_{c1}}{d_{c2}} = \sqrt{\frac{Q_1}{Q_2}} = 1.18 \quad (7)$$

From the above result, the fine particles are obtained at the temperature 280°C. The mean particle size at the temperature 17°C is 1.18 times than that at the temperature 280°C.

## Numerical Simulation

The model of the three nozzles in the chamber is designed using a software Gambit. Then, the computational fluid dynamics software (CFD) simulates and calculates the velocity fields of the nozzles and the grinding chamber. The inlet pressure of the nozzle is 0.76 MPa. The backpressure is -5 KPa. The gas temperatures are 17°C and 280°C, respectively. The axial velocity fields at the temperatures 17°C and 280°C are shown in Fig. 2.

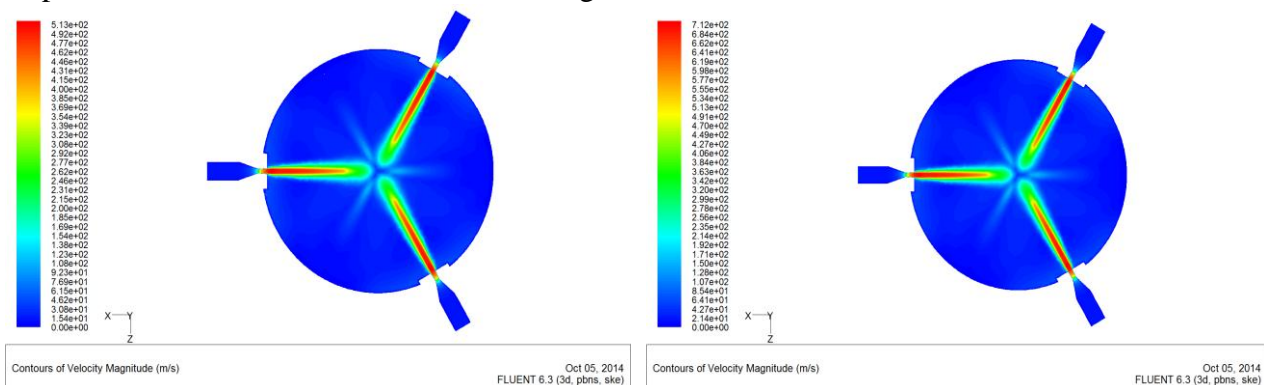


Fig.2 Axial velocity field of nozzle with 17°C and 280°C

The numerical simulation shows: maximum velocity of the nozzle is higher than 513 m/s at the temperature 17°C. The maximum velocity of the nozzle is higher than 712 m/s at the temperature

280°C. The acceleration effect of outlet gas flow of the nozzles on particles is more obvious at the temperature 280°C than that at the temperature 17°C. The gas velocity is higher than 38.79% at the temperature 280°C than that at the temperature 17°C. The axial velocities of the nozzles are shown in Fig.3.

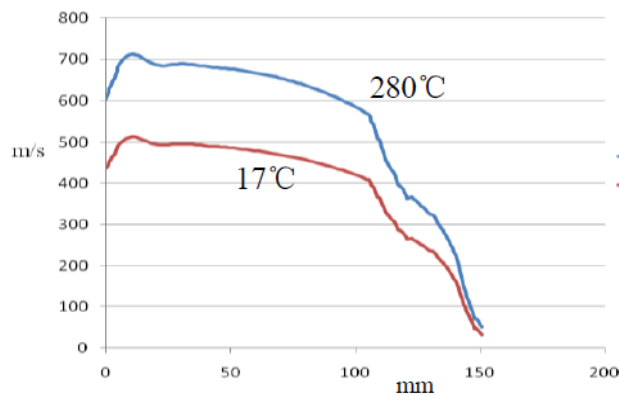


Fig.3 The nozzle axial velocity with 17°C and 280°C

It can be seen from the Fig.3, the numerical simulation results are consistent with the results obtained from the theoretical arithmetic. Based on the limit theorem of the particles, the grinded particles are mainly brittle crushing process using a jet mill, and the completion of fatigue comminution [20]. The particles go into the chamber induced by the gas. The higher the gas velocity of the nozzle is, the larger the kinetic energy will be. Then, the particles are beneficially to grind. The transient energy of the particle increases when the particles collide with each other. The obtained size of the particle is finer at the temperature 280°C than that at the temperature 17°C using a jet mill. Additionally, the production yield increases when the temperature increases from 17°C to 280°C.

### Experimental Results and Discussions

The two yields of kaolin powder are obtained at the temperature 280°C and 17°C. The yield of kaolin powder is 18.4 Kg/h at the temperature 17°C. The yield of kaolin powder is 21 Kg/h at the temperature 280°C. The particle size of kaolin is measured using a laser particle size analyzer (Beckman Kurt LS13-320 type). The mean particle size of kaolin powder is 2.401µm at the temperature 17°C. The mean particle size of kaolin powder is 2.003µm at the temperature 280°C.

Tab. 1 the systematic energy consumption with 17°C and 280°C

	17°C	280°C
Air compressor (Kw)	37	26.66
Heater (Kw)	0	36
Classifier (Kw)	4	4
Induced fan (Kw)	15	15
Total powder (Kw)	56	81.66
Energy consumption/ton (Kwh/T)	3043	3889

The power of the air Compressor is 37 Kw. The gas flow is 6.4 Nm<sup>3</sup>/min (standard condition, the gas temperature is 20°C and the atmospheric pressure is 101.325KPa). The power of the air Compressor at the temperature 280°C is obtained from the standard condition. The power of the air Compressor is 26.66Kw (37Kw/6.3m<sup>3</sup>/min×4.54m<sup>3</sup>/min) at the temperature 280°C. The consumption energy of the air heater is 36Kw from the 17°C to 280°C. The total power is obtained from an air compressor, an air heater, a classifier and an induced fan. Therefore, energy consumption of ton unit equals to the total power/yield×1000. The unit power is 1yuan/Kwh. For the same yields of the kaolin powder unit ton, the production cost of the kaolin powder is 3043yuan/ton at the temperature 17°C. The production cost of the kaolin powder is 3889yuan/ton at

the temperature 280°C.

The total powers are compared at the temperature 17°C. at the temperature 280°C, as shown in Table 1.

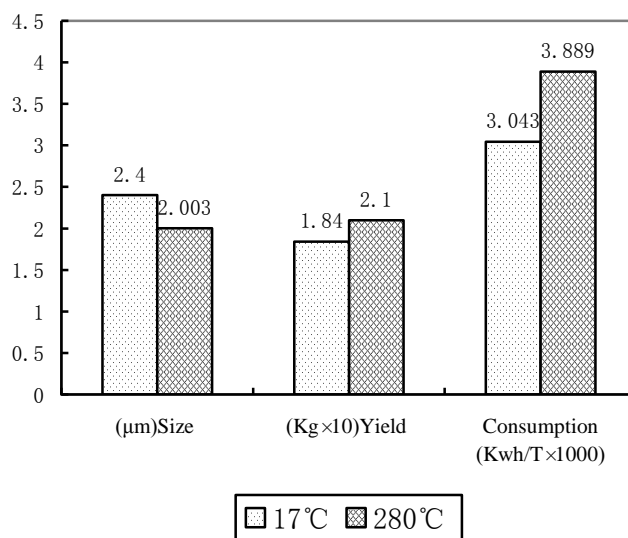


Fig.4 The particle size, fields and energy consumption with 17°C and 280°C

The particle size, yields and energy consumption/ton are compared at the temperature 17°C and 280°C, as shown in Fig.4. It can be seen from the Fig.4, the kaolin powder has the finer particle size at the temperature 280°C than that at the temperature 17°C. Sometimes, the production yields increase with the increase in the temperature. However, the energy consumption increase to 27.8% when the temperature increase from the 17°C to 280°C. These results are consistent with the results obtained from the theoretical arithmetic and numerical simulation.

## Conclusions

(1) The kaolin powder is obtained using an LNJH-60A type fluidized-bed jet mill (Designed by Mianyang, Liuneng, Powder Equipment, Co., Ltd.). The qualified kaolin powder has the narrow particle size distribution, and no pollution in the grinding process. The kaolin powders meet the demands for making the papermaking and the painting.

(2) Two results are compared at the temperature 17°C and 280°C. The outlet velocity is higher 38% at the temperature 280°C than that at the temperature 17°C. The yield increase to 14% when the temperature increase from the 17°C to 280°C. The total energy consumption is higher 28% at the temperature 280°C than that at the temperature 17°C.

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