11-12/2009

CHEManager EUROPE

GIT VERLAG GmbH & Co. KG, Darmstadt, Germany

www.gitverlag.com

THE NEWSPAPER
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Going "Green" Using Steam

Economical Jet Milling of Inorganic Materials and Dry Grinding into the Nanometer Range

New Possibilities – Two topics of paramount importance to producers of mineral powders and other inorganic materials are the economical production of high quality products and the production of sub-micron powders in a dry state. Two new processes in the field of jet milling have been developed with this in mind. The article describes how the use of steam as a grinding medium provides significantly higher discrete energy input to increase size reduction capability in a jet mill, while using the properties of steam to enhance the classification process to produce material fineness that was previously impossible to achieve in a dry process.

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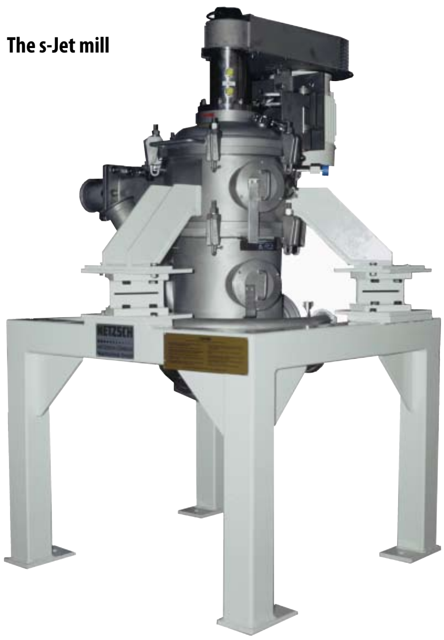
The s-Jet mill



Steam is the oldest utilization of thermal energy known to mankind. Much of the electrical energy is generated by large power plants (coal, gas and nuclear), and steam generation is integral to this process.

Large power plants operate with a degree of primary energy efficiency of approximately 40 %. Transformation and line losses cause an additional loss of approximately 10 %. When the electricity arrives at the user, it has a 36 % degree of efficiency when compared to the primary energy. From the electrical energy input to the compressor to the adiabatic energy in the mill, the overall energy efficiency is further reduced. In the generation of high pressure compressed air, the overall efficiency is 58 % from the two stage compressor, times 36 % from the power station for a combined efficiency of only 21 %. Even from the higher efficiency single stage compressor, with 78 % efficiency times 36 % from the power station, the combined energy efficiency is still only 28 %.

Let us review the generation of pressure in a gaseous medium. A compressor draws in the gas and compresses it, resulting in a reduction of gas volume and an increase in pressure. Simultaneously, waste heat is produced which can be used but only up to a certain degree. As we know, if a second compression step is needed, intermediate cooling becomes necessary and so the thermal energy fraction is zero. This makes it clear why economic pressure generation from gases has to be limited to a single stage compressor.

Pressure generation with steam is a completely different situation: A boiler with water is heated, steam is produced and with the help of a boiler feed pump pressure is achieved in the boiler. While steam is now removed from the boiler the same pump feeds the tank with fresh water, in the same quantity as is currently being discharged as steam.

Energy is fed into the water tank in the form of heat; which is responsible for turning the liquid medium into steam and maintaining it as steam. There is an advantage of the liquid medium as liquids are naturally incompressible. They retain their volume no matter how much pressure they are subjected to. Therefore, a much higher pressure can be generated in a liquid than in a gaseous medium. Therefore, why not just use steam as the grinding medium?

Dry Grinding through Steam

To make finer particles, higher jet velocities are needed. How do we achieve higher jet velocities than those possible with normal compressed air? We change the type of gas and use steam. Jet velocities of up to 1,200 m/sec can be achieved with steam. This is nearly double the jet velocity that can be achieved using compressed air in either of the two situations described above. Remembering that the kinetic energy is the product of half the mass of the particles multiplied by the square of their velocity, it is easy to see that the discreet energy input on the particles increases nearly fourfold with steam. The global energy flow also increases by a factor of approximately 2.6, depending on the steam pressure. At a given particle size, the unit capacity can be increased by a similar factor as compared to air.

It is easy to understand that the higher discrete energy input, due to higher impact velocity, can contribute to higher fineness. But in a fluidized bed jet mill, we are still using the same internal classifier which is normally incapable of classification in the nanometer range. So how does steam really help us reach high fineness?

Classification Process

In actual practice, after the energy flows have collided with each other with increased impact force and the particles between them have ground themselves to nanometer scale sizes, the fluid migrates upwards to leave the mill through the classifier. At the same time the rising flow "drags" particles of every size along with it.

The drag force is responsible for the fact that the particles in the classifier are ultimately transported to the discharge opening of the classifier. However, the larger particles must be prevented from leaving the mill at the same time. How does this occur?

The air classifier (a radial rotor with paddles or blades) rotates. The speed of rotation (up to 140 m/sec) subjects the particles to centrifugal force. The particles are dragged by the drag force spirally inwards at the same rate as the speed of rotation in the "potential vortex" towards the rotor's discharge opening. The centrifugal force acts against this and tries to transport the particles to the outside into the space around the rotor. Therefore, only particles up to a specific size manage to achieve the path into the discharge opening and are thus collected by a downstream filter.

If we take a closer look at the particles and the forces acting on them we find that drag force is a function of:

- the cross-sectional area of the individual particle: its diameter, its size;

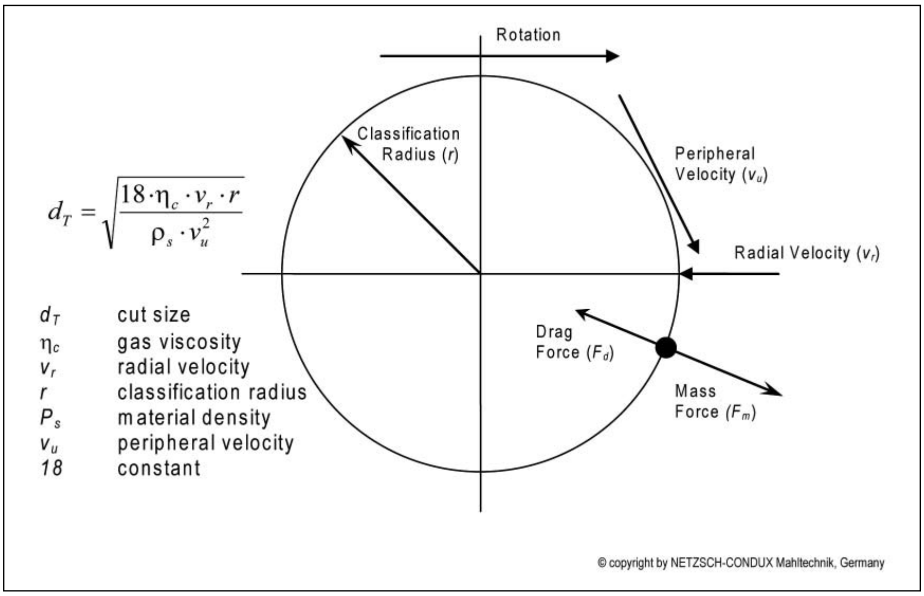
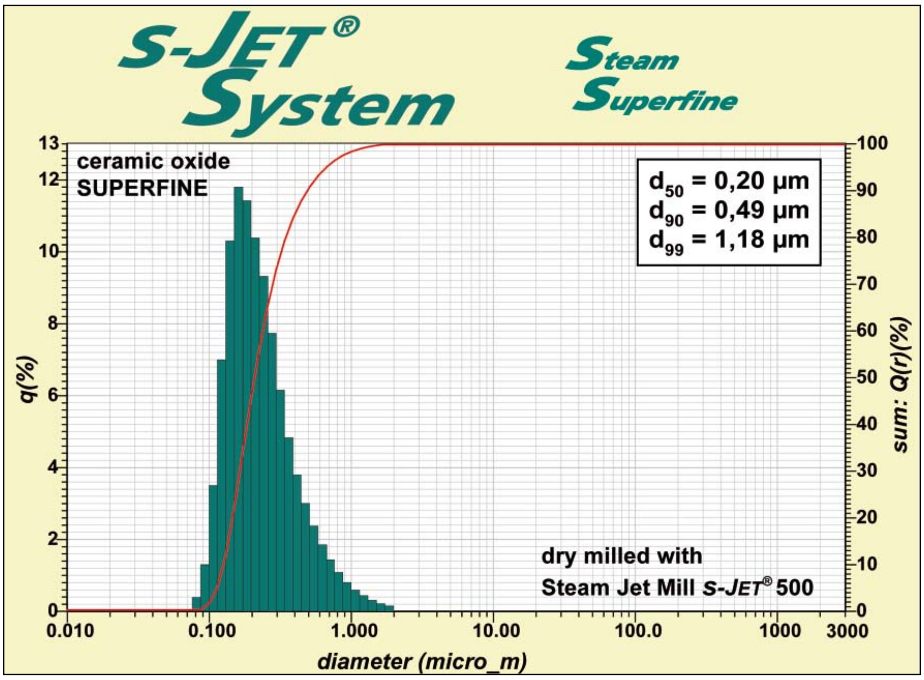


Diagram showing the classifier process



Ceramic oxide superfine

- the relative velocity (the velocity with which the gas flows past the individual particle); and
- the drag coefficient (flow resistance).

These interacting factors now try to drag the particles into the classifier. Centrifugal force (mass force) is a function of the mass (i.e. the weight) of the particle and the circumferential acceleration.

This means that the greater the circumferential velocity and the greater the mass of the particles, the greater the centrifugal force as well. Or in other words, the greater the centrifugal force, the lower the possibility that the particles can be pulled back inwards by the drag force. As a result, particles above the critical size remain in the mill and can be subjected to a further grinding process.

The constant increase of the classifier speed, an idea practiced to date to produce finer classified material no longer has the desired effect. The initial circumferential velocity (and thus ultimately the centrifugal force) is limited by the mechanical parts of the classifier.

The velocity of the potential vortex, i.e. the spiral flow between the bladed edge and the discharge opening of the air classifier could be increased by any amount by restricting the diameter of the discharge opening, according to the formula: Circumferential velocity times radius = constant

In the current example this would mean: If the radius becomes smaller the circumferential velocity increases, therefore the total value of the product of the two remains constant. Nevertheless, this idea must remain theory, because air and other gases, cannot be easily accelerated beyond their speed of sound. Therefore nature sets the limit for classification. Further, since all gases are compressible media, an enormous pressure would be necessary to achieve the required high velocities. Pressure generation is energy intensive which is costly. This is one of the reasons why maximum velocities of 200 m/sec are used in practice to produce centrifugal force.

Beyond Drag Force and Mass Force

We know the effect of increasing circumferential velocity and also its limitations. Beyond this, what can be done to enable us to control the finer particle sizes that can be achieved with the higher discreet grinding energy input from steam?

The solution is to use gases which have a lower dynamic viscosity and a higher speed of sound than air, or vapors, which have the same tangible properties as a gas. Steam, already used for the grinding process, fills this requirement.

Because steam has a higher sound velocity than air, we can achieve a substantially higher circumferential speed of the gas flow. Thus, the acceleration of the particles increases as well. If, for example, the circumferential velocity increases from 200 to 300 m/sec, this means an increase by a factor (squared) of 2.25. This increase in circumferential velocity alone also increases the effective centrifugal acceleration 2.25 times.

Centrifugal force is in turn mass times acceleration, which means the centrifugal force can be increased by the same value as the centrifugal acceleration. This is the decisive step which now enables us to overcome the limit to the nanometer range. The reduced dynamic viscosity also contributes to reducing the drag force on the particles. These two factors combined reduce the cut point of a classifier by a factor of 0.63. Which means if the classifier can produce a cut point of 1µ in air, it can produce a cut point of 0.63µ in steam.

Conclusions

The process of using steam as the grinding fluid in a fluidized bed jet mill opens new doors for the production of nanometer size particles with steep particle size distributions in a dry process. Steam is the enabler to produce both a finer particle size distribution in the grinding process and a finer cut point in the classifier. Steam can also be used for coarser particle size distributions with a significant increase in unit capacity due to the higher global energy flow to the jet mill.

Table 1

Grinding Process	Low pressure Air	Steam
Grinding parameters	4 bar (abs), 225 °C	40 bar(abs), 350 °C
Relieved (inside mill)	1 bar (abs), 140 °C	1 bar (abs), 140 °C
Jet speed [m/s]	572	1190
Density relieved [kg/m3]	0.87	0.53
Sound velocity relieved [m/s]	410	510
Dynamic viscosity relieved [kg/ms]	2.41×10^{-5}	1.42×10^{-5}

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