Putting the (steam) pressure on dry grinding

From the generation of adiabatic energy through to the breakthrough in nano-range particles, a joint development in economical jet milling of industrial minerals and dry grinding in the sub-micron range is described by *Dr Roland Nied*

AS WE ALL know, the miniaturisation of materials is a bit problematic. If we are satisfied with particle sizes around two micrometres, then the dry grinding method will be used. However, if particle sizes within the nano-range are required, the only solution to date has been the wet method – with the disadvantage that for many applications the moisture then has to be removed from the powdered product. And that can cost a lot.

So the question remains: how can the miniaturisation of materials be advanced with the dry method – considering the economic aspects as well?

The answer exists with a joint development of Netzsch-Condux Mahltechnik GmbH in Hanau and Dr Nied Consulting in Bonstetten near Augsburg.

Adiabatic energy

As is known, adiabatic energy is the energy that prevails at the moment when the material to be ground gets between the energy flows and is shattered into particles. The Bonstetter engineer had his doubts whether a two-stage high-pressure method can always be the ideal solution for the generation of adiabatic energy.

For example, let us assume we wanted to produce oil-free compressed air with 9 bars and decide to use the two-stage high-pressure method. In concrete terms this means: in an initial step we first compress the air (at a temperature of 180°C) to 3 bars.

However, in order to achieve 9 bar discharge pressure, a second compression step is required. Because its mechanical environment cannot withstand loading at 180°C, the temperature must first be reduced to 40 degrees with an inter-cooler, with the consequence that the heat removed is lost forever.

This waste heat is not only a loss of generated energy, it is also reflected in the running costs for the energy generator (ie. compressor). And if the motto that "what comes out at the end is decisive" is ultimately true, the following formula clearly shows in black and white the imbalance of the cost/benefit ratio:

$$E_{ad} = \frac{k}{k-1} \cdot m \cdot R \cdot T_0 \cdot \left[1 - \left(\frac{P_e}{P_o}\right)^{\frac{k-1}{k}}\right]$$

In this example the user is only able to "harvest" 55% of their original energy input to the compressor.

The alternatives?

Dr. Ing. Roland Nied advocates the single-stage low-pressure method. Here the air is compressed to a maximum 4.5 bar in only one compression step; at a temperature of up to 225°C. "By dispensing with the intermediate cooling process we not only do not lose any energy but instead can fully utilize it" emphasised the consultant. And you will agree: the result – the compressor efficiency – is quite respectable at 78%! The decisive criterion must be stated.

30% energy savings.

The increased compressor efficiency in the single-stage low-pressure method results in approximately 30% energy savings compared to the two-stage high-pressure method. This does not mean that from now on the single-stage low-pressure method could always replace the two-stage high-pressure method for every application! Instead, Dr Nied asks us to bear in mind that even low-pressure methods are tied to certain prerequisites.

For example, it is necessary to ensure that the properties of the materials introduced to the grinding process do not change (almost all inorganic substances fall into this category) under the influence of high temperatures (up to 225°C).

In addition, it must be clarified that the specific adiabatic energy consumption in the low-pressure method is not higher than that of the high-pressure method – which is also the case with many inorganic substances.

Dry into the nano-range

Let us remind ourselves: the miniaturisation of materials takes place when they get between (at least) two energy flows and are shattered into many small and extremely small particles when the energy flows meet.

The velocities under which this all takes place play a decisive role. It is these velocities that ultimately determine the particle size to which the ground material can be pulverised. The logical conclusion from this is: we must lend the individual energy-jet more impact force (impact energy, which is ultimately nothing other than kinetic energy or, in the language of the physicist, the product of half the mass of the particles multiplied by the square of their velocity).

Impact energy through steam

Increase in impact energy also depends on the increase in the jet inlet velocity. And this in turn triggers fluid mechanics suction capability, which means: the particles are completely "drawn in" by the energy-jet, "enter into" the jet and are accelerated by it, up to its own jet velocity.

This also means that the velocity of the particle depends on the velocity of the jet, ie. the velocity of the particle can never exceed the velocity of the jet (in air around 550 metres/sec max).

But how do we achieve new, higher jet velocities? – "We change the type of gas, deliberately use steam" says Dr Nied. "After all, jet velocities of up to 1,200 metres/sec can be achieved with steam. However, above all, the kinetic impact energy of the particles increases four-fold!"

Let us look at 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. If a second compressor stage 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 (and therefore, logically, to possible velocities of up to 550 metres/sec).

Pressure generation with the help of steam is a completely different situation. A boiler with water is heated, steam is produced and, with the help of a boiler feed pump, overpressure is achieved in the boiler.

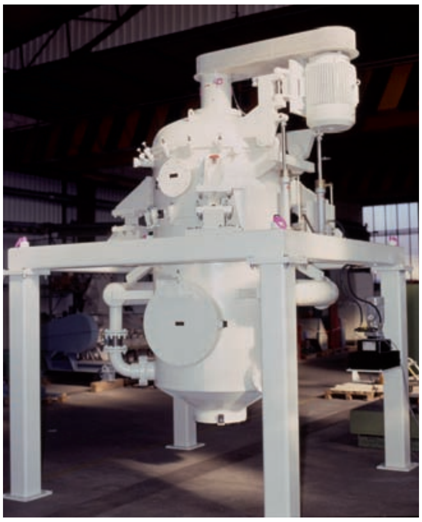
While steam is now removed from the boiler the same pump "feeds" the tank with fresh water, in the same quantity as is currently being discharged from it as steam.

Energy is fed into the water tank in the form of heat, which is responsible for turning the liquid medium into steam and

Patented grinding nozzles "H-Type" from Netzsch-Condux

Courtesy Netzsch-Condux

Fluidized Bed Jet Mill Type CGS 100



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Fluidized Bed Jet Mill Type CGS 71

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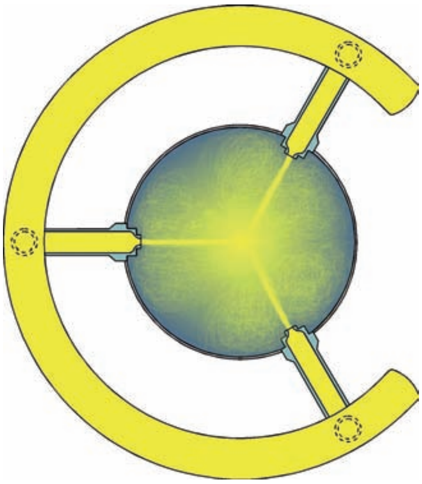
Typical nozzle arrangement



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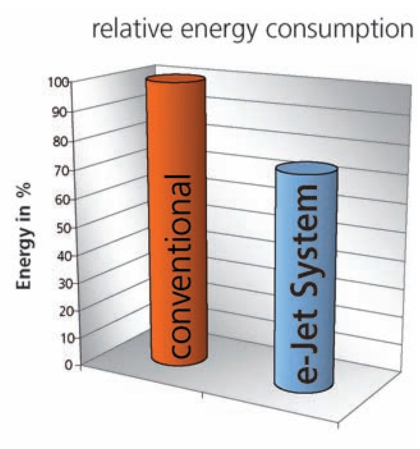
Energy savings with the new e-Jet System by Netzsch-Condux



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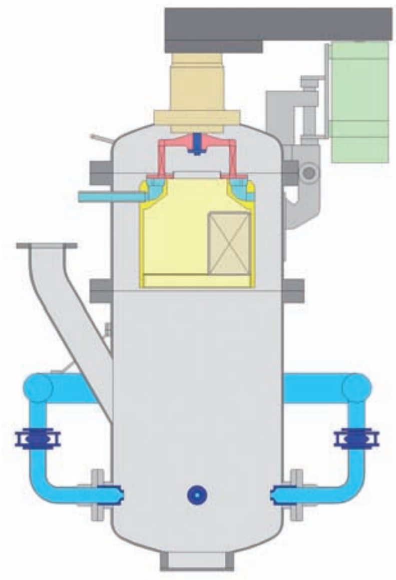
Operating principle of Fluidized Bed Jet Mill CGS



Courtesy Netzsch-Condux

maintaining it as steam. That energy (also called evaporation enthalpy) is effectively lost for any further use.

Liquid medium advantage

Liquids are naturally incompressible. They retain their volume no matter how much pressure they are subjected to. In other words, a much higher pressure can be generated in a liquid than in a gaseous medium.

Our feed water pump generates pressure in the boiler. But as energy loss has to be accepted (the key term being evaporation enthalpy) the feed water pump also has to work with the highest possible pressure against the steam pressure in the boiler.

The optimum pressure for gases is approximately 3.5 bar overpressure; for steam it is 150 bar overpressure or higher. The efficiency in the generation of steam is roughly the same as for the generation of compressed gases beginning at approximately 40 bars. Therefore, emphasises Dr Nied "Everything I add increases the total efficiency of my steam system".

However, let us return to actual practice. After the energy flows have collided with each other with increased impact force and the particles between them have ground themselves to nano-scale sizes, the fluid migrates upwards – in order to leave the mill through the classifier. At the same time it "drags" particles of every size with it on "piggyback".

Drag and centrifugal force

During this "journey upwards" the particles are subjected to the so-called "drag force", the force 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. The only question is how?

Let's visualise it. The air classifier (a radial rotor with paddles or blades) rotates. Its speed of rotation (up to 140 m/sec) subjects the particles to centrifugal force. While the particles are now dragged by the drag force spirally inwards at the same rate as the speed of rotation (in the so-called potential vortex) to 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, ultimately only particles up to a specific size manage to achieve the path into the discharge opening and thus be collected by a downstream filter. This size – as already mentioned at the beginning – is currently two micrometres at best.

If we take a closer look at the particles and the forces acting on them we find:

Drag force:

- the cross-sectional area of the individual particle: its diameter, its size;
- the relative velocity (the velocity with which the gas flows past the individual particle);
- the drag coefficient (flow resistance);

These interacting factors now try – as previously mentioned - to drag the particles into the classifier.

Centrifugal force: its function is the result of:

- the mass (ie. the weight) of the particle
- the circumferential acceleration.

This means, 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.

Focus on velocities

The constant increasing of the classifier speed, an idea practiced to date to miniaturise the classified material, no longer has the desired effect. The initial circumferential velocity (and thus ultimately the centrifugal force) cannot be increased any further because the mechanical parts of the classifier would not withstand this.

The velocity of the potential vortex, ie. 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 x 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 gases (and air is a gas mixture after all) cannot be easily accelerated beyond the speed of sound. So nature sets us a limit here.

Apart from that, all gases are compressible media, and an enormous pressure would be necessary to achieve the required high velocities. But pressure generation costs energy and this has to be paid for. By the way, this is also one of the reasons why maximum velocities of 200m/sec are used in practice to produce centrifugal force.

So what do we do?

"The answer is easy" says Dr Nied. "We use gases which have a higher speed of sound than air, or vapours, which have the same tangible properties as a gas. The speed of sound in steam for example is around 500 m/sec (note: in air it is 330m/sec). The speed of sound in hydrogen or helium is even higher."

Thanks to the substantially higher circumferential speed of the gas flow, the acceleration of the particles logically 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. The result: this increase in circumferential velocity alone also increases the effective centrifugal acceleration 2.25 times.

The decisive step

Centrifugal force is in turn mass x 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 nanometre range.

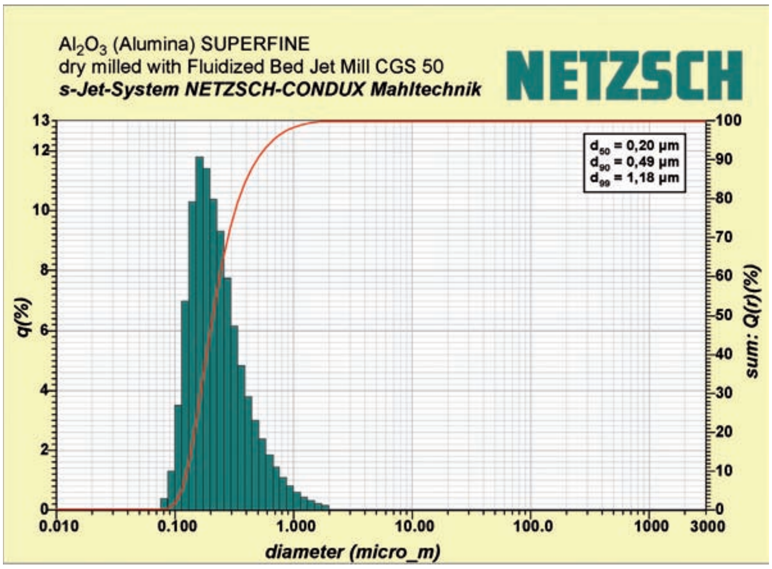
With their most recent work on the current topic, Dr Nied Consulting is not only sensitizing technicians and engineers about the cost of producing grinding energy; but also gaining the attention of the economically responsible persons among users.

Because, surprisingly enough, in the past the practical world's interest in alternatives to the two-stage high-pressure method has been met with conservatism. Justifying the ignorance of business management to the actual facts should be more difficult now that the management consultants have given their clients a formula to precisely calculate the monetary effect and thus the potential increased profit of the various options described above.

The energy savings in the low-pressure e-Jet method and the generation of nano-scale particles with the s-Jet method have already been through their baptism of fire in operationally tried and tested plants installed by customers of Netzsch-Condux Mahltechnik GmbH.

Contributor: Dr. Roland Nied, Consultant of Netzsch-Condux Mahltechnik GmbH Hanau, Germany and Mr. Joachim Gerstenberg, autonomous journalist, Germany.
Stephen Miranda, director of sales, Netzsch-Condux Mahltechnik GmbH Hanau, Germany is presenting a paper on this topic at IM19 Athens.

Possible superfine powder through dry grinding with the new s-Jet System by Netzsch-Condux



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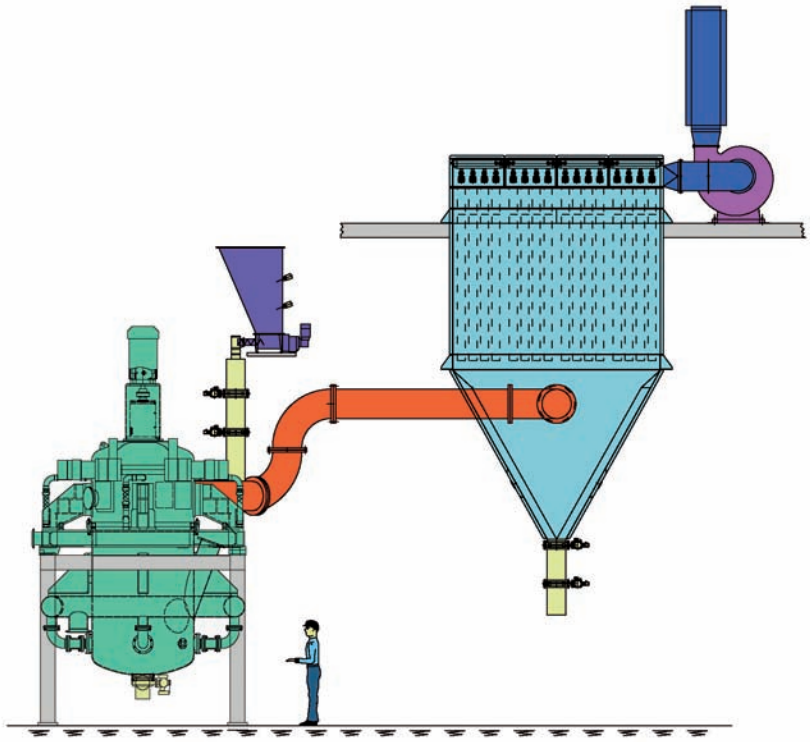
Grinding installation with Fluidized Bed Jet Mill Type CGS



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