Optimization of the Specific Energy Consumption of Fluidized Bed Opposed Jet Mills for High-Performance Materials

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Abstract. Fluidized bed opposed jet mills are a well-established technology for the production of ultra-fine, contamination-free powders in high-value applications, including industrial minerals, advanced ceramics, rare-earth materials, and chemical products. Their ability to deliver narrow particle size distributions while preserving particle morphology makes them indispensable for high-performance materials. However, high specific energy consumption (SEC), largely driven by compressed gas generation, remains a key limitation. This contribution reviews major application areas of fluidized bed opposed jet milling and focuses on strategies to significantly reduce SEC while increasing throughput. Process optimization measures are discussed with emphasis on increasing grinding gas temperature to enhance jet velocity and compressor efficiency, as well as on upstream pre-grinding using high-pressure grinding roller (HPGR) mills. The results demonstrate that a single HPGR pre-grinding step can reduce the SEC of subsequent jet milling by more than 20% and, in many cases, enable comparable increases in system capacity. These approaches not only improve economic performance but also contribute to greater ecological sustainability and can be retrofitted into existing production plants.

1. Background

Fluidized bed opposed jet mills represent a cornerstone technology for the production of ultra-fine, contamination-free powders in numerous high-value industrial sectors. With more than 800 installations in Europe and over 1,500 globally delivered by HOSOKAWA ALPINE Aktiengesellschaft, these mills have established themselves as a versatile and robust solution for comminution processes requiring precise particle size distribution (PSD) control at high throughput.

However, the specific energy consumption of jet mills is relatively high, which is also due to the low efficiency of the compressors. Therefore, optimizing the specific energy consumption (SEC) is a key objective for the further development of these mills. Moreover, the operating parameters have a significant impact on the SEC.

2. Applications of fluidized bed opposed jet mills

2.1. Industrial minerals

A central advantage of fluidized bed opposed jet mills is their ability to generate ultra-fine fillers while preserving particle morphology—critical for industrial minerals such as talc, wollastonite and other engineered fillers.

For example, very fine talc fillers are produced in large quantities in large fluidized bed opposed jet mills, which are operated using compressors in the Megawatt range. At the Hosokawa Alpine AG pilot plant, a TDG 200/400 was used to produce talc with a d_{97} of 1 µm. Despite these fine particle sizes, the SEM image shows platelet-shaped particles with a high aspect ratio (Figure 1).

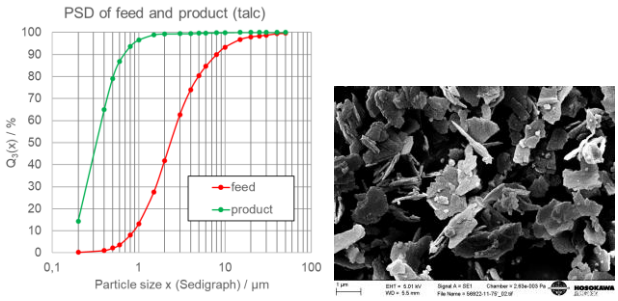

Figure 1. Particle size distribution (left) and SEM image (right) of a talc filler produced at the test centre using a TDG 200/400 fluidized bed opposed jet mill.

2.2. Ceramics and hard materials

For ceramics and hard materials, such as ATH, Al_2O_3, ZrO_2, SiC, B_4C, etc., fluidized bed opposed jet mills provide contamination-free grinding. Although no tools come into contact with these abrasive materials during grinding, the surfaces in the mill and its peripheral components that come into contact with the product must be protected against wear. For this purpose, linings made of ceramics or suitable polymers are used. The grinding wheels of the mills can also be made of solid ceramic or coated with ceramic.

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2.3. Rare-earth material

For the manufacturing of strong NdFeB-magnets the material needs to have a particle sizes and steep particle size distributions. In rare-earth processing, particularly pyrophoric neodymium used in permanent magnets, fluidized opposed jet mills support controlled-atmosphere milling with nitrogen circuits and low-oxygen environments. Due to the high demand of these materials, the scalability from lab- to industrial-scale is of vital importance.

2.4. Chemical products

In chemical applications, fluidized opposed jet mills are used to efficiently micronize temperature-sensitive materials, polymers, organic compounds, but also battery cathode active materials (LFP, NMC). Additionally, special design adaptations enable processing of low-bulk density materials such as silica and recovered carbon black, improving dispersion, bulk density, and material handling.

3. Optimization of the SEC

Although fluidized bed jet mills offer many advantages, their use is limited to high-quality materials. This is primarily due to their high specific energy consumption. Optimizing the SEC is therefore a key focus for many operators. In many cases, measures to reduce the SEC also led to higher mill throughputs, which results in improved utilisation of the equipment and profitability.

3.1. Grinding gas temperature

One essential measure is increasing the milling gas temperature. On the one hand, this increases the efficiency of the compressors. On the other hand, the jet speed, and thus the jet power, increases with temperature at the same pressure, resulting in a higher energy density in the mill. As can be seen in Table 1, the increase in temperature has a higher effect on the jet speed than the increase of the grinding gas pressure.

Table 1. Jet speed at different grinding gas pressure values at 20°C and 150°C, respectively.

Grinding gas pressure p_{abs} [bar]	Jet speed at nozzle [m/s]	
	@ 20 °C	*@ 150 °C*
2	325	391
3	398	478
4	439	527
7	501	602
9	524	629
11	540	649

3.2. Pre-grinding by HPGR mill

Another interesting option for reducing the SEC is the pre-grinding of feed materials using high-pressure grinding roller (HPGR) mills. Similar effects are already known in other applications, such as the grinding of cement in ball mills or of ores in wet stirred media mills.

The combination of pre-grinding in an HPGR mill, e.g., the Alpine Ecoplex mill ECP, with fine grinding in a fluid bed jet mill is shown in Figure 2. A single pass of the feed material through the HPGR mill is sufficient to reduce the SEC of the subsequent fine grinding in the fluidized bed opposed jet mill by more than 20%, which represents a significant savings potential given the high energy costs of jet milling alone.

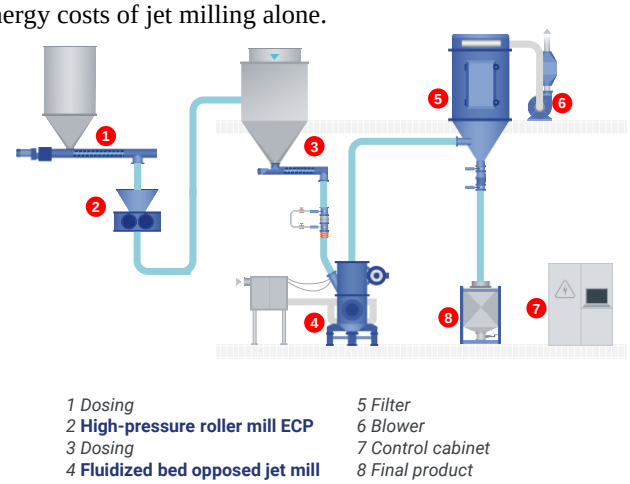

Figure 2. Combination of HPGR mill ECP and fluidized bed opposed jet mill AFG

This effect can be observed for brittle materials such as hard materials (SiC, B_4C etc.) or minerals (talc, limestone etc.). In many cases this reduction in SEC can be used to increase the capacity of the system by up to 20 % resulting in an improved utilization and profitability (Figure 3). Due to the higher output of the production line, the higher investment costs are amortized within a short time.

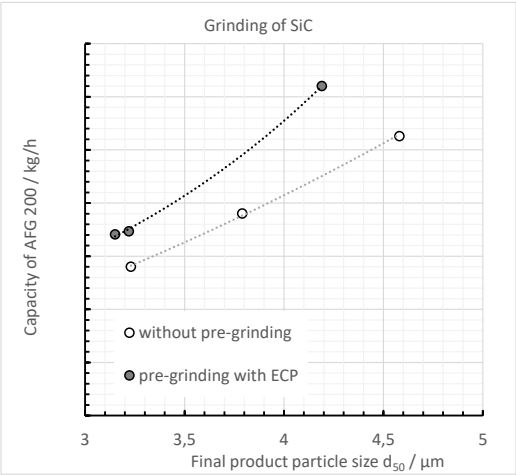

Figure 3: Throughput as a function of product fineness for the grinding of SiC with and without pre-grinding using an Alpine ECP HPGR mill

3. Conclusion

Fluidized bed opposed jet mills continue to evolve as enabling technologies for advanced powder engineering. There are various ways to significantly reduce the SEC (separation pressure) and thus increase the efficiency and ecological and economic sustainability of these grinding systems. Interesting approaches include increasing the grinding gas temperature and pre-grinding the feed material with HPGR mills. These mills can also be retrofitted into existing plants.

References

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[2] Wang, C., Nadolski, S., Mejia, O., Drozdiak, J., Klein, B. (2013). Energy and cost comparisons of HPGR based circuits with the SABC circuit installed at the Huckleberry Mine. 45th Annual Canadian Mineral Processors Operators Conference©, Ottawa, Ontario, January 22-24, 2013