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Současné trendy v procesech mletí

Today´s Trends of Comminution Processes

Summary

The lecture monitors the present state of development as well as its trends in the branch of Comminution. This monitoring is based on papers and lectures that were given at the choice of the most important conferences on Comminution that took place in the last year. The author of this paper comments on them from the point of view of Process Engineering basically. The author of this paper concentrates especially on the most dynamically developing area in this field of activity, the area of ultra-fine grinding. The lecture highlights especially the here under trends:

- Intensive search for mathematical-physical-material "process functions" that would provide for quantification of the efficiency of the transfer of the grinding energy to the required fraction of the product grain and do so for the given disintegrating equipment of the given size and operational capacity of the ground product of the defined material characteristics.
- Development of the DEM computer simulations that together with extensive experiments of the fracture behavior of materials under the conditions of enormous scale of deformation rates and temperatures are gradually taking the form of "multiphysics models" that are able to provide for high quality "process functions" mentioned here above. Due to that they have already established themselves in the process of designing the grinding equipment.
- Significant development of grinding equipment – especially of „High-Power-Density-Mills". These mills are designed for the purpose of being used in the area of ultra-fine grinding. Their use in the area of nano-grinding is already on the way. On one side, there is a rapid development of designs and on the other side, there is a parallel development of materials from which the working surfaces of mills and grinding media ("beads") shall be produced.
- Intensive research is taking place in the area of Surface Chemistry directed towards the development of surface active agents that must ensure the continuing separation of ground stock particles that ensue from the grinding process. Such agents must provide for both, for the further diminution of the ground stock particles and for elimination of the risk of their re-agglomeration.
- Big Boom of Mechanochemistry characterized by the use extraordinary high specific concentration of mechanic energy in the form of shear forces in the ground load and a significantly long time of the ground load exposed to such a force field. Under such the conditions surface reactions take place that would hardly occur if other methods were applied (such as hydration of Mn and Al oxides for the purpose of constructional ceramics...).
- Methods of computer supported design of grinding circuits and development of control methods for the purpose of grinding process quality assurance.

Souhrn

Přednáška monitoruje současný stav a trendy oboru Mletí. Základem tohoto monitoringu jsou referáty které zazněly na vybraných nejvýznamnějších odborných fórech tohoto oboru v průběhu posledních měsíců a jsou autorem glosovány především z hlediska Procesního inženýrství. Autor se zaměřuje v textu hlavně na nedynamičtěji se rozvíjející oblast tohoto oboru, kterou bezpochyby je oblast ultrajemného mletí. Přednáška zdůrazňuje především tyto trendy:

- Intenzivní hledání matematicko-fyzikálně-materiálových „procesních funkcí", které jsou schopny pro dané desintegrační zařízení příslušné velikosti a provozního prosazení mletého produktu definovaných materiálových parametrů, kvantifikovat efektivitu přenosu mlecí energie na požadovanou frakci zrna produktu.

- Rozvoj DEM počítačových simulací, které společně s velmi rozsáhlými experimenty lomového chování materiálů za podmínek enormní škály rychlostí deformace a teplot přechází do podoby „multiphysics models", které jsou schopny poskytnout jak kvalitní výše zmíněné „procesní funkce", tak se prosazují přímo do procesu navrhování mlecích zařízení.
- Výrazný rozvoj mlecích zařízení typu „High-Power-Density-Mills", které jsou konstruovány pro oblast ultrajemného mletí, směřující též do oblasti nano-mletí. Tento konstrukčně vývojový proces je provázen paralelním materiálovým výzkumem a vývojem antiabrazivních materiálů určených jak pro činné plochy mlýnů, tak pro mlecí náplně těchto mlýnů.
- Intenzivní výzkum oboru Povrchová chemie, směrovaný do vývoje povrchově aktivních činidel, které musí zajistit průběžnou separaci částiček meliva, vznikajících při procesu mletí a umožňují tak pokračovat v dalším snižování rozměrů částic meliva bez nebezpečí reaglomerace těchto částic.
- Rozmach oboru Mechanochemie, který nabízí využití mimořádně vysoké specifické koncentrace mechanické energie smykového pole v mlecí vsádce s výrazně dlouhou dobou expozice materiálu mlecí vsádky tímto polem, k proběhnutí povrchových reakcí, které lze jinými metodami obtížně realizovat (např. hydratace oxidů Mn a Al pro konstrukční keramiku…).
- Metody počítačového designu mlecích okruhů a rozvoj kontrolních metod pro udržování kvality mlecího procesu.

Key Words: fine particle grinding, ultrafine grinding, mineral processing, particle size, DEM, mill media, high energy mills, beads, milling, process functions, nano-particles, mechanochemistry, surface treatment.
Klíčová slova: jemné mletí, ultrajemné mletí, zpracování minerálů, granulometrie, DEM, mlecí tělesa, atritol, mletí, procesní funkce, nano částice, mechanochemie, povrchová úprava.

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1. INTRODUCTION

Like any other discipline belonging to the applied natural sciences, Chemical-engineering branch of Comminution is characterized by oscillating development: there were times of significant successes as well as times of depression, there were times when people expected a lot from this science and times when they were not interested much in it. In these days however, the very broad area of comminution is developing rapidly. What are the reasons behind this enormous boom? Firstly it is the intensive development of ultra-fine and nano-technologies which are directly dependant on the comminution processes. The fastest developing Comminution and the related interdisciplinary areas are especially among:

- Multiphysic´s models of grinding
- High-Power-Density-Mill´s design for nano-particles grinding
- Surface Chemistry and Particle surface treatment
- Mechanochemistry
- Particle-Solids Mechanics in ultrafine particles area
- Ultra-fine particles Separation
- Wear-proof materials use
- Grinding Circuits Design
- Monitoring, Sampling and Grinding process control
- Image Analysis control process
- Grain sizing apparatus
- Interaction of cellular tissues and nano-particles in mutual contact
- Environmental Engineering of nano-particle pollutants

The lecturer comments on facts evidencing the rapid development of these sciences – especially Process and Mechanical engineering – that were already mentioned in the selection of the most important meetings on Comminution that took place in the last months.

2. ULTRAFINE GRINDING PROCESS

Ultra-fine grinding process plays an important role in production fine powder for the manufacture of modern material such as ceramic materials, magnetic media, electronic materials and metal ceramic composites. Ultra fine iron oxide powders are used in various applications, including catalysis, pigment [1], recording media and ferrofluids. The ultra-fine grinding of minerals, such as chalcopyrite or sphalerite increases their reactivity, so that the valuable constituents can be easily leached [2]. High-energy ball milling process has been successfully used to synthesize nanometric ferrites materials. A recent breakthrough of nanomilling in stirred media mills allows production of particles as small as 10 nm [3].

In the area of the ultrafine grinding a lot of products are already processed in these days. But in the part of the products which applies especially to the nano-area – according to the internationally recognized scales in the area of materials finer that 150nm - we come across products used as testing products, samples or low volume items basically. No matter how promising future the nanomaterials have and no matter how overwhelming applications are tested in these days or already consumed in low volumes, the reality of the present large volume application of nanomaterials is rather sober. Majority of these products are used in the car industry (car bodies coating), in the construction industry (decorative coating) partly also in cosmetics and electronics, so basically in the area of surface treatment of the products for everyday use [4] (See Tab.1).

Table 1: Who is among the best and biggest customers using nanomaterials today?

function	product	nano-dditive
UV protection + transparency	• decorative wood coating • sun screens • laminating foils	SiO_2 Al_2O_3
scratch resistance + transparency	• automotive clear coat • furniture lacquers parquet • lacquers	SiO_2 Al_2O_3
refractive index (matching) + transparency	• displays • optical lenses fibers	ZrO_2
electrical conductivity + transparency	• LCD-display	ITO ATO

This statement does not want to underestimate the role that nanomaterials will certainly play in the future. This statement shall be interpreted as a suggestion or rather an incentive for everyone: we shall do our best not to miss this opportunity to be at the start of a new era! Hopefully it is still not too late for this.

3. ENERGY TRANSFER AND GRINDING MODELS

The Applied Physics of Solid Phase and Powder Technology as a branch of Chemical Engineering are among the branches of science that primarily deal with the processing of mineral matters. What do they strive for? While making use of the extensive computer simulations, they apply especially the Griffiths theory of fractures, their origin and impact on the grinding conditions. A theoretical model basis is created to explain the transfer of the grinding energy and its participation on the creation of the ground-stock particles with defined dimensions. The theoretical treatise of the breakage phenomenon is extremely difficult involving assumptions of either isotropy and random breakage or at least only some structural and directional anisotropy that can be taken into account by variables like the Poisson ratio or to be more exact by the Lame elasticity constants of the tensor representation of the Hook's law. From [5] it is already evident that this way does not lead us anywhere, despite our long-term and intensive efforts. The problem is that the formation of the stress field in the ground stock cannot be really controlled, the loading and material property variations make the process unchecked.

What helps us to reliably and exactly define the relations among the particular variables of grinding processes? Such formulas take the connections of "independent" material functions and procedural functions that define the impact of the grinding equipment into consideration. The material functions ensue from evaluations of the material tests on experimental set-ups, where either separate particles undergo destruction in the course of which the basic static as well as dynamic application of normal forces and tangential forces acting under given temperatures and speeds are tested. For each given force application, the ensuing fractions are evaluated, i.e. the number and weight of particles in each dimension range in the moment of force application.

3.1 Material Functions

For the formulation of material functions, the fracture behaviour and disintegrating behaviour of materials that were used as ground stock have to be evaluated, namely under the conditions that are as much close to the grinding conditions in the particular disintegrating equipment as possible.

Various laboratory rock breakage characterization tests have been developed for studying breakage phenomena and for designing and predicting the performance of industrial comminution equipment. These tests fall into three main classes:

- conventional rock and fracture mechanics measurements
  (Chevron bend fracture toughness test, Hopkinson Bar – see Fig.1, Brazilian Test, Ultra-Fast Load Cell …)
- single particle tests
  (Drop Weight Test, Twin Pendulum Apparatus…)
- standard grindability tests
  (Bond grindability tests – „operating work index“…)

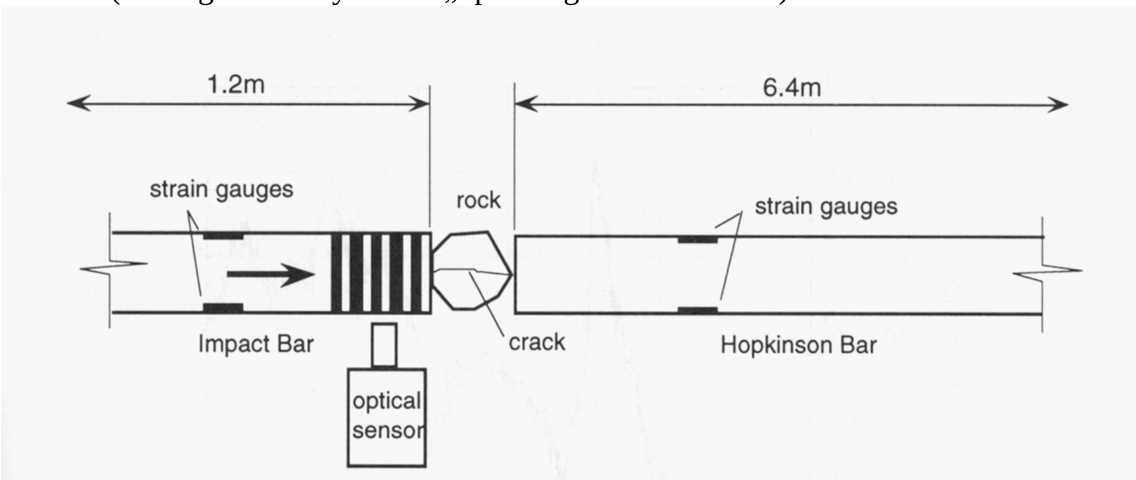

Figure 1: Experimental configuration of Hopkinson Pressure Bar

But much favoured by chemical engineers, and even for ultrafine grinding the only useful experimental procedure, seems to be the treatment of samples as a rate process. The kinetics of a grinding process can be studied with batch grinding tests on monosize samples. The typical procedure involves batch grinding the material within a certain size fraction, from which the breakage rate of that size fraction is determined, together with the breakage function of the material. The breakage function is essentially a size distribution resulting from breakage, usually expressed in matrix form. The results of the test are interpreted in terms of the population balance model, usually by estimating the values of the selection and breakage functions in the model.

3.2 Population Balance Model

There are several mathematical accesses to reach models describing the population balance for the process of developing particles in the milling conditions. One of the model which is frequently used is described [6]:

$$\frac{dm_i(t)}{dt} = -s_i \cdot m_i(t) + \sum_{j=i+1}^{k} b_{ij} \cdot s_j \cdot m_j(t) \qquad \text{for i=1,2,3…k} \qquad (1)$$

where: m_i [-] - the mass percentage of the feed size
s_i [s^{-1}] - the specific rate of the feed size
b_{ij} [-] - the size discretised breakage function
t [s] - grinding time

The solution of the population balance equation is found for the continuous mill as the function of a residence time distribution $\phi(t)$ in the form:

$$p_i = \int_0^t m_i(t) \cdot \phi(t) \cdot dt \qquad (2)$$

$$\phi(t) = K \cdot e^{-k \cdot t} \qquad (3)$$

where: p_i [kg.s^{-1}] - the total product in the size fraction
K,k [-] - material, process constants

3.3 Process Function

The process function combines the machine and the material function:
Among others it combines the characteristic parameters stress frequency and stress energy with the size and number of particles stressed at one stress event. Therefore, the process function is closely connected to the so-called product-related stress model [7].
For a given feed particle the product quality and fineness achieved in a comminution or dispersing process is determined by

- type of stress event including particle configuration
- how often each feed particle and its resulting fragments are stressed and, thus, by the number of stress events of a feed particle,
- how high the specific energy or specific force at each stress event is and, thus, by the stress intensity at each stress event.

In real grinding processes the feed particles and the resulting fragments are not stressed equally often with the same stress intensity. Thus, in detail number of stress events and stress intensity can only be characterized by distributions, not by single numbers.

Therefore, based on the machine and the material function described above the most important characteristic parameters of the process function are:

- stress intensity, or, if not known, the stress energy,
- stress number per feed particle, or, if not known, the total stress number
- energy transferred to the product particles as alternative to the total stress number (corresponds to the product of total stress number, and stress energy)
- energy transfer factor,
- quality function (product quality as function of stress intensity)
- breakage function
- selection function.

The quantitative determination of all the characteristic parameters of the process function for grinding is not possible yet.

3.4 DEM of Grinding Processes

One way leading to the description of relations and interdependencies between the grinding process and the quality of the ground stock is the use of the DEM method that due to the extensive development of IT attained remarkable objectives. The DEM modeling became therefore one of the generally acknowledged method that producers of equipment “Powder Technology” widely use when they design procedural parts of their products.

I will present the application of the DEM method on the example of the following grinding process: Grounded shall be the recycled concrete materials that were originally used as a construction material for panel houses in the housing estates of the formal German Democratic Republic. Then the material tests will be carried out. The DEM simulation itself shall be carried out in the course of the processing in impact crushers [8] see Fig.2 - Fig.5.

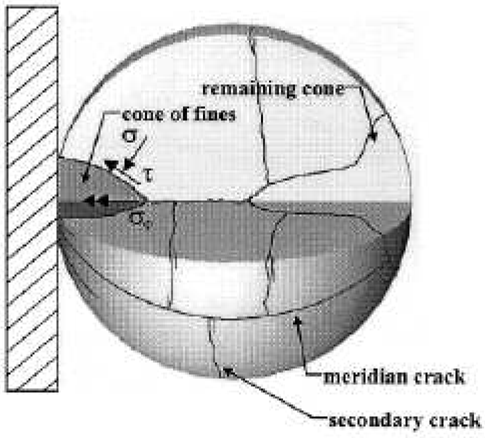

Figure 2: Crack pattern in a brittle sphere crashing into a wall

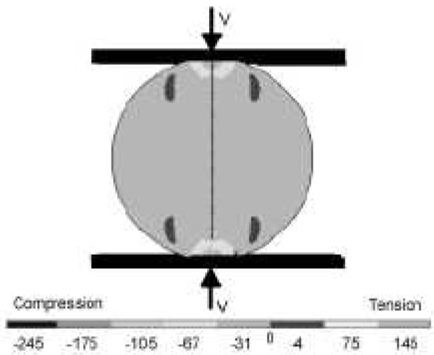

Figure 3: Stress distribution in MPa, v=20 m/s, t=0.2 ms.

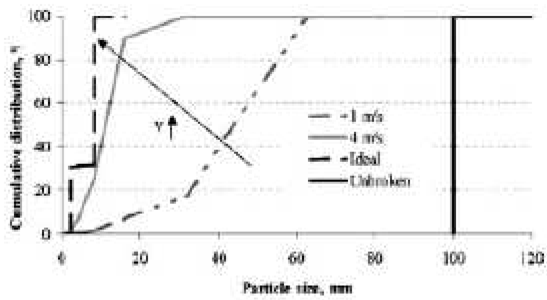

Figure 4: Particle size distributions (time 10ms).

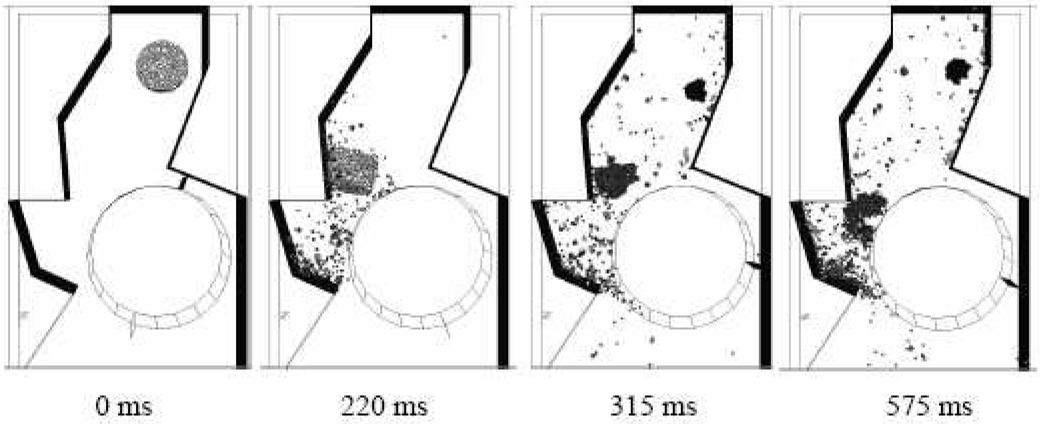

Figure 5: Time sequence of events in which a concrete cylinder is crushed in an impact crusher at a rotor tip speed of 20 m/s, obtained by a 3D-DEM-simulation.

3.5 How successful are we in formulating the process functions
Having combined the theory applicable to and practices existing in the area of defining the material functions as well as their relations to the process functions in the grinding equipment usually used for the normal grinding processes - applied in the course of material processing – prof. J. Herbst, his team in the METSO company and their theoretical background in Comminution Center, Salt Lake City, University of Utah (USA) are undoubtedly the most successful scientists of the very long last decades. This however does not apply to the ultra-fine grinding. Here – at least in respect to the publications and social hierarchy and position of the participants in the top conferences – the Keio University (prof. M. Senna), IMRAM, Tohoku University (prof. F. Saito), Technical University of Braunschweig (prof. A. Kwade), University of Erlangen-Nürnberg (prof. W. Peukert) a Penn State University (prof. V. M. Puri) are the best.

4. MODIFICATION OF THE SURFACE'S PROPERTIES
Changes in the surface's properties could be observed after grinding or co-grinding operations in these cases:

- **Grinding of anisotropic solids**.

In this case, the variations of properties result from the type of surface generated by grinding in particular when the crushed particles present an anisotropy of the crystal lattice and particularly surfaces of different natures: In the case lamellar particles, as talc, basal surfaces and side surfaces do not present the same properties.

- **Interaction between product and grinding atmosphere or grinding medium.**

Moreover than the mechanical effect itself, the grinding atmosphere can affect the surface properties like wettability of micronized products: The behaviour of some products during dispersion in water is drastically modified by using wet gas or of water vapor, instead of dry air, for air jet milling processes. These modifications may be explained by the possibility of water adsorption on the new generated surfaces.

- **Surface modification by co-grinding or dry-coating.**

4.1 Effects of Surface's Modification

- **Electrostatic properties**

Electrostatic properties of the particle surfaces and the resulting properties like cohesivity and flowability of the product, are sometimes other consequences of a grinding process: frictions between different elements of the milling device (rotor/stator), or products and walls, induce electrostatic charges at the surface of the particles. These electrostatic charges may also be kept or liberated (according to the powder's characteristics) resulting in a particular behaviour of the product [9] [10] [11].

- **Modification of the structure properties, amorphisation and mech-chem. effects**

One of the effects of mechanical action is to induce a deterioration of the order properties in the crystalline structure (amorphisation) conferring, on a certain thickness of the crystal lattice, behaviour properties different from those of the initial product.

- **Enhancement of dissolution properties on a single constituent** [12].

The induced change in the crystals structure can result in an abnormal increase in the dissolution's rate and sometimes in the ion product of activity in a stationary state. This effect, called hyper-solubility, is in particular used in pharmacy to increase the bioavailability of the active ingredients.

4.2 Surface Modification by Co-Grinding or "Dry"-Coating

The basic principle of surface treatment is evident from the following scheme (See Fig.6)

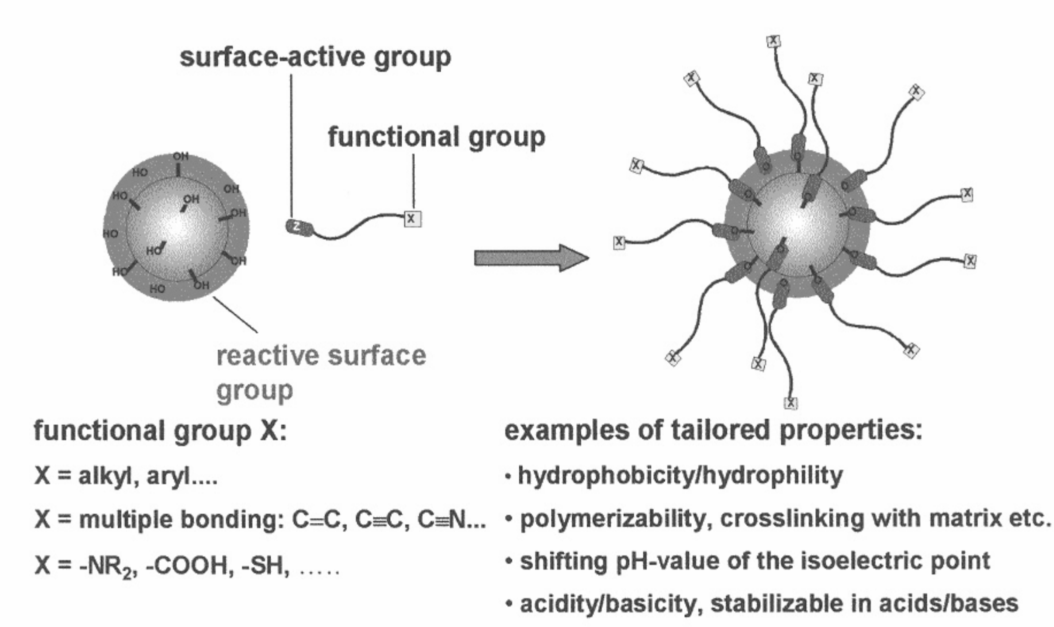

Figure 6: Schema of surface treatments

4.3 Equipment for Surface Treatments

Theoretically almost all mixing and grinding equipment with higher levels of tangential forces and higher volumes of mixed loads or ground stocks can be used. In case of application of the surface reactive liquids the intensive "Fluid Mixers" are usually used. In case of mechanical-chemical processes, the volumetric mills with high specific power input - usually High-Power-Density-Mills or special Hybridizers (see Fig.7) – are used.

The Hybridizer Nara (J) is one of the specialized apparatus for the surface treatment of powders in a dry mode. The Hybridizer consists of a very high-speed rotor, a cooled stator and a powder re-circulation circuit. The rotor's speed may be adjusted until 16000 rpm. Host and guest particles are simultaneously processed in the rotor's zone and recirculate in the machine through the cycle tube. In this device, particles coating is resulting from the embedding or filming of the guest particles onto the surface of the host particles by high impaction forces and heat of friction.

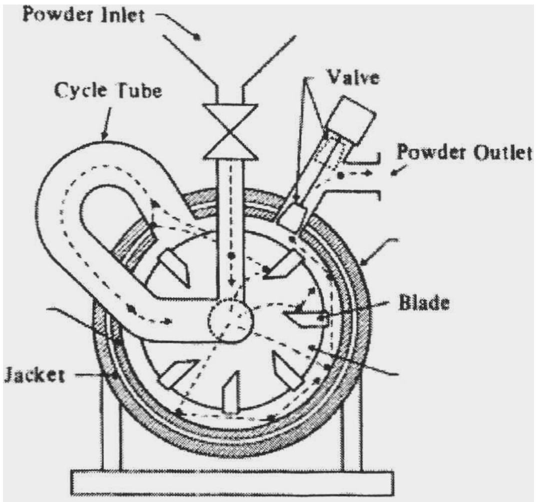

Figure 7: Schematic diagram of the Hybridizer Nara

Similar, the small quantity of a surface treatment fluid and the aftertreatment of final divided particles (e.g. precipitated) for the process is acceptable, too (see Fig.8).

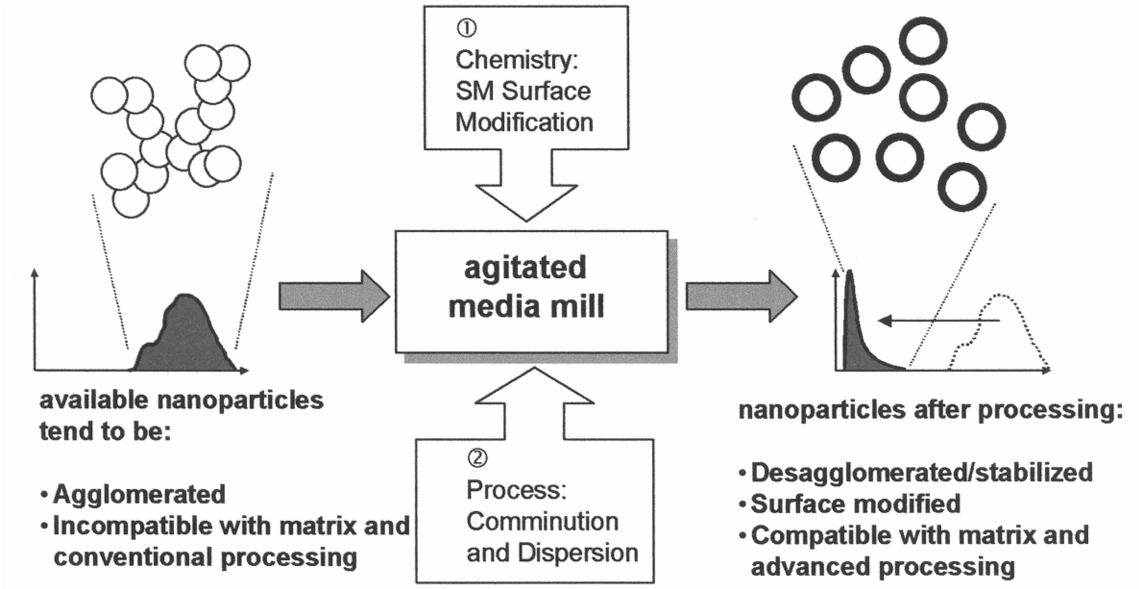

Figure 8: The aftertreatment process effects

5. MECHANICAL ACTIVATION

Mechanical activation is a phenomenon that has been generally known for a long time. Since the end of 70ies, mechanical activation has been the basis of Mechanochemistry as an independent science branch. Known as "mechano-chemical effects", physicochemical phenomena, with mechanisms different from those governing the classical "thermo-chemical" transformations, may be observed during grindings or co-grinding operations like chemical reactions at low temperature.

Due to the increasing fineness of grinding and increasing levels of specific energies in ultrafine grinding, the mechanochemistry is developing very fast. The here under specified applications are widely used:

- Mechanical activation of pyrite and arsenopyrite by grinding action which increases the rate of extraction of gold at low temperature by pressure oxidation.
- Production of mechanically activated rock flour fertilizers [13].
- Power stations coal ash wastes processing [14].
- Application of high-energy ball milling technique to obtain nanophase materials appears attractive for the potential large scale, economical production of such materials. Ultra-fine alumina powder is prepared by milling $AlCl_3$ and CaO.
- Likewise ultra-fine iron oxide powders, such as Fe_2O_3 and Fe3O4 carried out by milling CaO or Ca(OH)2 with FeCl3 .
- Ferrites with spinal structure, which have nanometric sizes are very important material in electronic application such as transformers, choke coil, noise filter and recording heads [15].
- Similar demands on the finer and better-crystallized barium titanate (BaTiO3, BT) are ever increasing for microelectronics - for multi-layered ceramic capacitor (MLCC).
- The complexation of drug substances with cyclodextrins in order to enhance their bioavailability. In this case a lot of new active molecules present very poor solubility in aqueous media and require, to be used, a significant increase of their dissolution rate and also of their bioavailability. One way to obtain this property is to realize a complex include. the drug molecule in cyclodextrins [12].
- Stability of a sparingly soluble drug, indomethacin (IM), was increased by compounded with SiO2.
- Hopeful research bioengineering projects have to be mentioned, too: Crystallinity of hydroxyapatite (HAp) in bioaffinitive disperse systems was increased by a wet mechanochemical treatment at room temperature.
- Silk fibroin (SF) and/or hyaluronic acid (HYA) were used as bio-organics. With the mechanochemical treatment, crystallite size and aspect ratio of HAp decreased and became closer to that of swine trabecular bone [16].

6. SORTS OF MILLS

The here under paragraphs summarize the most important principles that we can come across when looking at the range of mills available on our markets.

6.1 High-Compression Roller Mill

High-Compression Roller Mill (HCRM) designed by professor K. Schonert was patented in 1982. At that time this HCRM was one of the best product in the area of Powder Technology and in the following 15 years it was installed into micro-grinding technologies around the world. HCRM is based on an old technology of roller milling. This technology was applied in the Middle Ages; this was the way they crushed the corn. In the 19th century and in the first half of the 20th century we could see this reliable technology of milling and crushing, too. The distinctive element of professor Schonert´s patent was however not very innovative. (See Fig.9): What did he do then? He made use of the technology of roller mills that was generally known and used the new highly abrasive materials. He applied those materials to surfaces of grinding rollers. Then he made use of the then modern machining technologies that enabled him to create cylindrical surfaces with extreme exactness in respect to both, the cylindricity as well as the tiny surface roughness. A very sensitive hydraulics for the purposes of keeping the thrust pressure stable was added to the milling equipment. Such equipment can mill the usual “brittle” products up to the micron-area when the grinding ratio is around 10^3.

The truly charismatic prof. Schonert was awarded the most prestige price for engineering at the annual X.th European Symposium on Comminution. Even today we can come across the

HCRM with a wide range of modification when reading the offers of various producers. For example prof. J. Zegzulka, VŠB Ostrava, developed the original idea of HCRM further. Instead of having the original couple of rollers, he suggested one central roller with several smaller rollers (or pulleys) of graduated sizes and had it patented. Despite the fact that some people might find this combination strange and despite the fact that the maintenance of such mill is rather complicated, this type of mill found its customers and is a good seller among the products offered and produced by the company PS Engineering, Přerov, CZ.

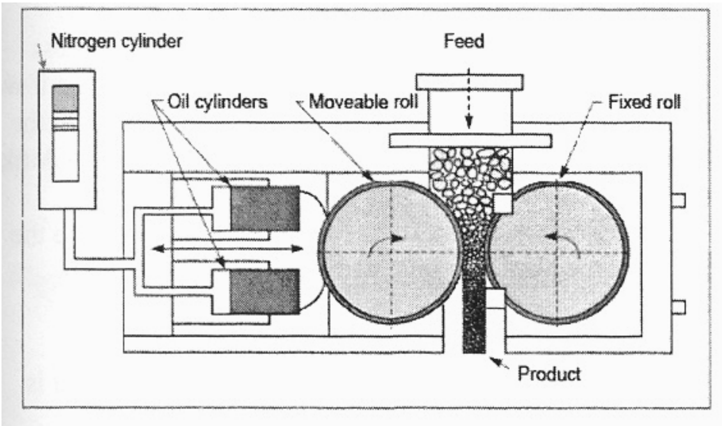

Figure 9: Schema of HCRM mill

For the working scheme of HCRM in its basic form please see Fig. 10. It was sold and installed into the microgrinding technologies under the brand name Ecoplex (Alpine, Augsburg, BRD – German Federative Republic, a member of the Hosokawa Micron Group). It documents the boom of the use of HCEM in the first half of the 90ies. Today additional disintegrators are installed behind the HCRM.

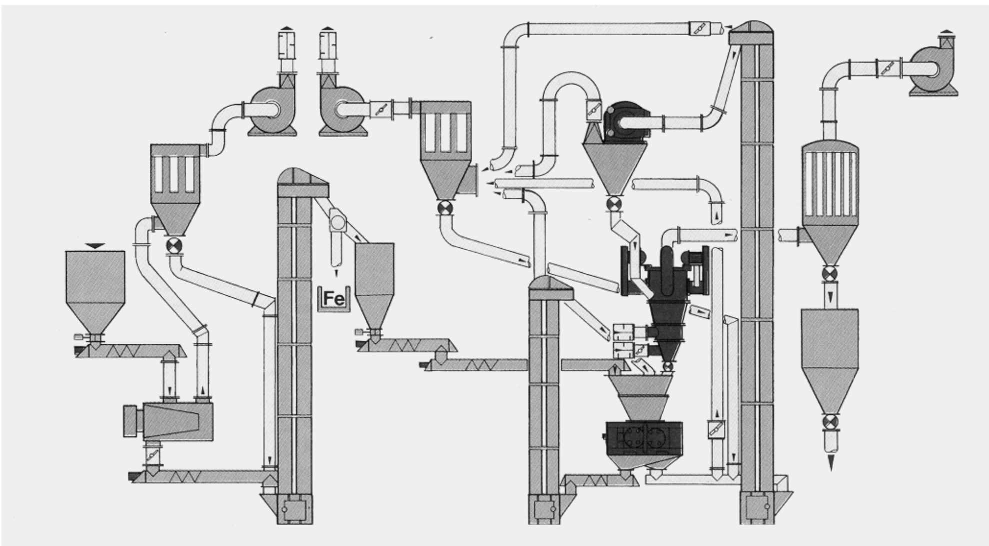

Figure 10: HCRM microfine fillers production flowsheet

6.2 Planetary Mills

The basic equipment dominating in the research, development and production of sub-micron materials since 80ies were the planetary mills. We know that even today these planetary mills are still widely used in renowned institutes such as IMRA, Sendai (JP), or Comminution Center, Salt Lake City (Utah, USA) [15]. On the contrary, in the area of "dry" grinding methods applied to grinding of ultrafine-particles, these planetary mills are among the rare theoretically applicable equipments. The well-known laboratory set-up of planetary mills that deals with the pilot-size planetary mills is shown in Fig.11.

Figure 11: Planetary mill in pilot-plant size

The similar but for laminar shape particles more suitable grinding regimes than in planetary mills offer Hicom Mills [17].

6.3 High-Power-Density-Mills

The planetary mills proved themselves very successful when used for the purpose of very fine grinding and microgrinding. However, we have to take into consideration the following facts: They are quite expensive, not "user-friendly" – i.e. not easy to operate, their maintenance is rather difficult. A solution eliminating most of the disadvantages characteristic for the planetary mills was found, even at the cost of lower intensity of grinding. It was found attritol, which is not correct but very often used name of fine ball beads and ground stock mixing media mills. These mills were developed in the 70ies of the 20th century by the German company Netzsch-Feinmahltechnik GmbH (German Federative Republic) in cooperation with the company Mount Isa Mines (MIM) Limited (AUS). Therefore there were attempts to call the whole group of ground stock mixing media mills "IsaMills". Even the experts find the terminology rather complicated. We can come across these mills referred to as „IsaMills", **„**High-Power-Density-Mills", **„**High energy mills", **„**Mixing Media Mills", „Attritols" and „Stirred Mills", „Stirring the pot – technology" … The names of these mills often derived from the lay-out or geometry of their rotors and building-in elements: for example „Tower Mills", „Disc mills", „Pin mills", „Annular gap mill with pins on stator and rotor"… And of course we mustn´t forget the trademarks under which their producers sell them.

As the here above number of the mill´s names indicate, these mills are widely used at present. There are produced on all continents. The patent literature concerning these mills as well as the product catalogues are extensive. Several patent application were lodged in the Czech Republic too. For example our team from the then Research Institute of Macromolecular Chemistry Brno (lead by dr. Žaloudík) applied for the patent that concerned the lay-out of the grinding elements and shapes of discs mixing the ground stock The patent application concerning the pearl mill installation in Pardubice followed. As an example of the usual vertical lay-out I would like to mention the present type of mill produced by the company Deswik (Fig. 12) [18].

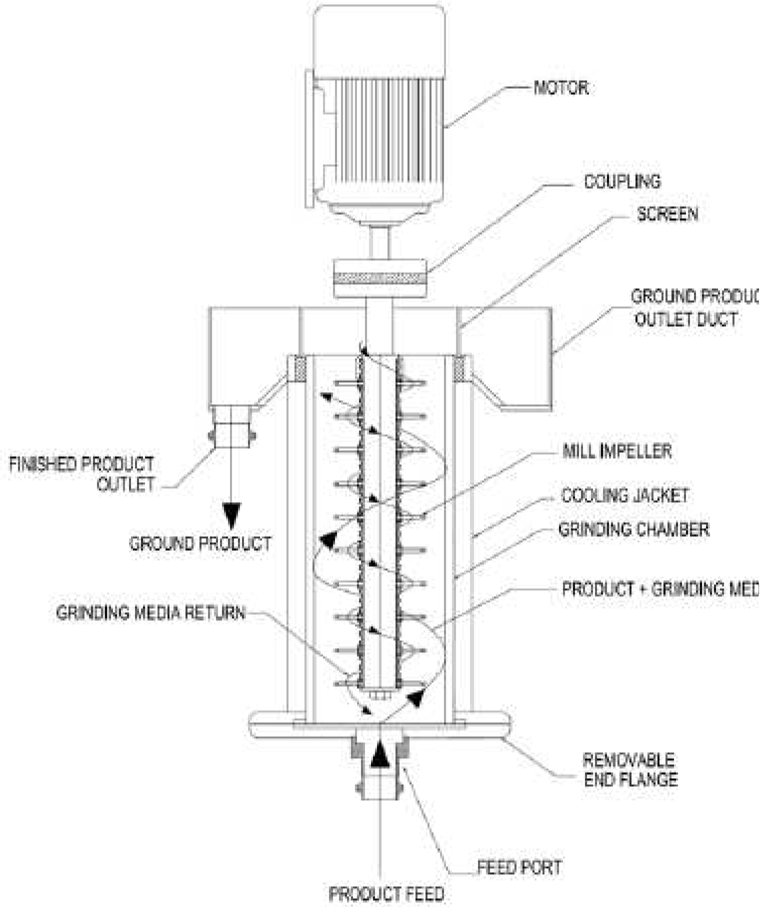

Figure 12: Schematic of a Deswik TM Ultra Fine Grinding Mill

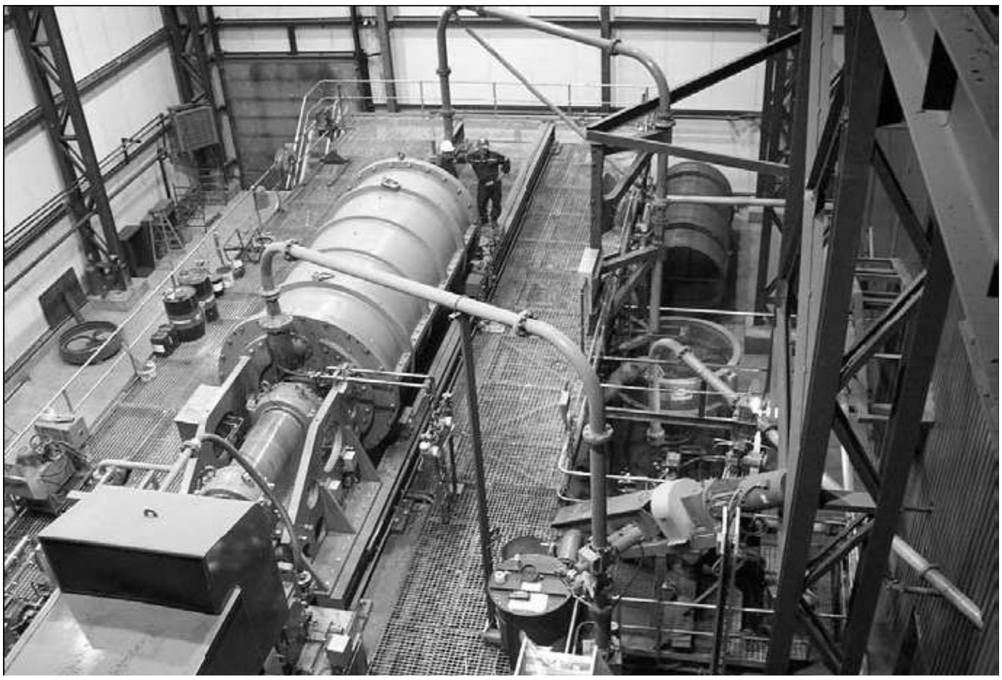

Figure 13: 2.6MW M10000 IsaMill Installation
(Photo Courtesy of [19] authors)

We can see the High-Power-Density-Mills in almost all areas of microfine and ultra-fine grinding. The biggest equipment of this type are the present IsaMills designed mainly for mechanochemical pre-treatment of ores with the view of their flotation with grain reduction up to the today´s fineness of d50=cca 40 μm and more. Considering the quality of the processed ores, the attempts to increase these equipments is understandable (see Fig.13) [19]. The company Xstrata Technology (AUS) is already planning to install 30m^3 of Mixing Media Mills [20].

6.3.1 MaxxMills

This equipment too belongs to the group of High-Power-Density-Mills and represent one of the most incongruous equipments of all. When introduced at the 10th European Symposium on Comminution, in Heidelberg (2002), there were only few experts who extolled and recommended those mills, believing that MaxxMills will replace the tube ball mills. The majority of experts present there at that time hardly accepted MaxxMill. In the view of the fact that HCRM was widely accepted from the moment of its introduction, we face a completely different situation. The basic principle of HCRM as well as its innovation (compared to the previous types of roller mills) was evident to everybody from the first sight. This is however not the case with the High-Power-Density-Mill of the type MaxxMil. What is raising the doubts? Firstly, the High-Power-Density-Mills have not been used for sufficiently long time. The experts in grinding have not forgotten the first reaction to this type of milling yet. What bothered them? These mills, their grinding equipment especially, were rather difficult to operate. Among other reasons of the MaxxMill distant acceptance there is the non-conventional lay-out of the device. There are too many novelties at a time (see Fig.14).

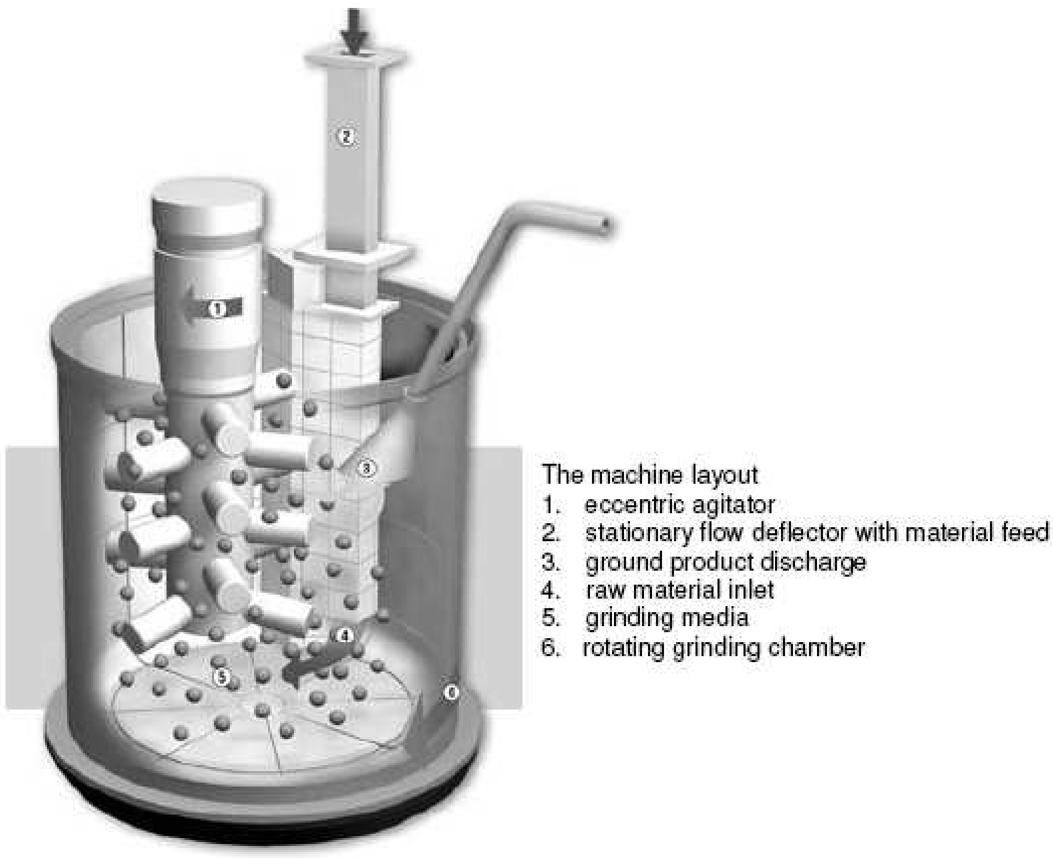

Figure 14: MaxxMill layout

There is a stationary “baffle” that provides for the feeding of the ground stock into the mill. The top product of the ground stock of the mill is taken out by a upper diffuser . And the conservative experts can hardly come to terms with the applied rotation movements of the whole vessel with the ground stock.

This mill was introduced five years ago. Now, the situation is changing slowly. Experts that have come across the MaxxMill appreciate the high flexibility of grinding regimes. As these mills can operate with almost “any” number of rotors (see Fig.15), forms of „pins“, under various combinations of rotations of the vessel and rotors, with various “beads” qualities, they can also accommodate to a wide range of ground stock qualities. Another positive, highly significant feature of these mills is the excess of specific grinding energy in the ground stock.

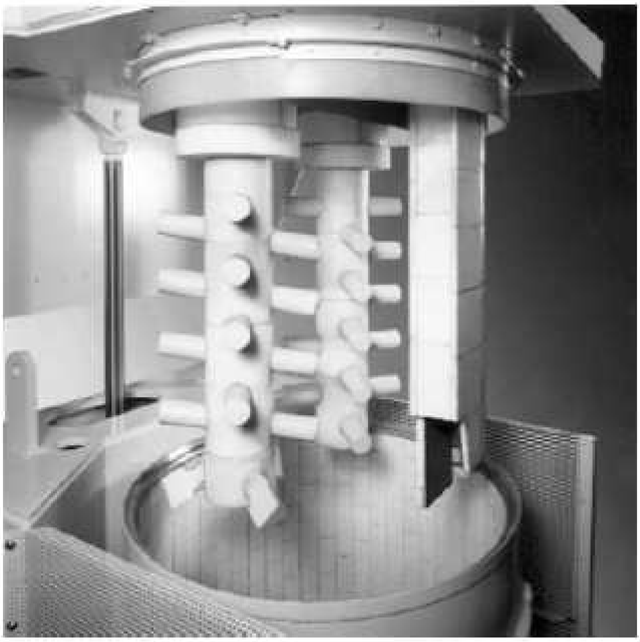

Figure 15: Plant size MaxxMill
(Photo Courtesy of Maschinenfabrik Gustav Eirich GmbH & Co KG)

Due to the here above, the grinding plant can be much smaller than a conventional plant of the same production capacity. For the purpose of secondary grinding, a relatively small MaxxMill can be put on series with a massive ball mill (see Fig.16). Which is great! Another big advantage of MaxxMills is their ability to operate in both, in the dry regime as well as in the wet regime! [21].

It is understandable that the massive acceptance and use of this type of grinding depends mainly on the long term good experience with this equipment. Its wear resistance as well as operational characteristics and maintenance, the unavailability time necessary for general overhauls, drive reliability and safety have to be verified. It is also an issue whether the concept of having the ground stock rotating alongside the vertical axes will be acceptable. The crucial issue will then be the costs connected with this type of grinding.

6.3.2 Nanoparticles milling equipment

An independent group of High-Power-Density-Mills are the Labyrinth Attrition Mills that are designed for the grinding of nanomaterials. A typical example of many tens of already existing variants is for example the MicroMedia from the Buhler group (D) (see Fig.17). The development departments specializing in nanoparticles quite often use this equipment for “wet” grinding.

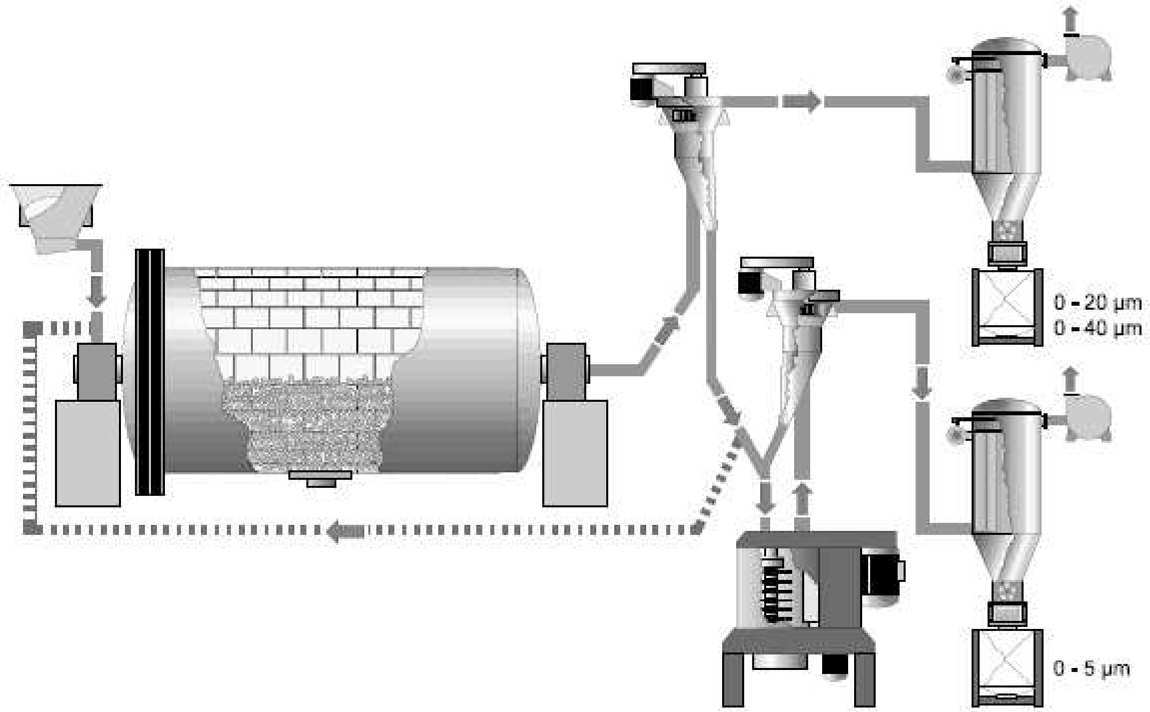

Figure 16: Fine grinding MaxxMills process

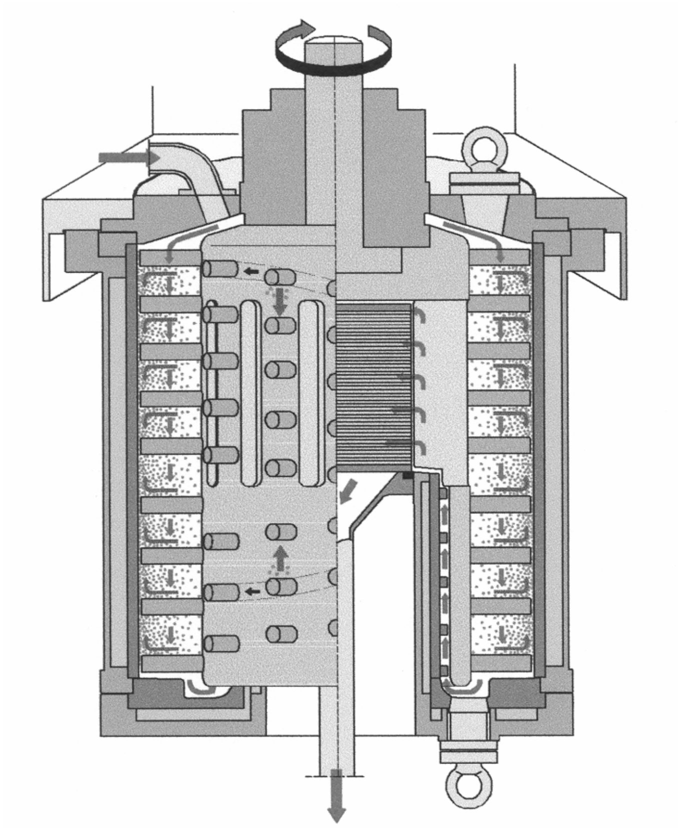

Figure 17: Labyrinth attrition mill

Enormous requirements in respect to time spent in the mill in the course of nano-grinding, power consumption and the follow-up manifestation of abrasion are evident. This is repeatedly mentioned in various publications, for example in [22]. From that publication is also the graph of specific power consumption necessary for processing of a-Alumina (see Fig.18) that I would like to show to support the here above statements.

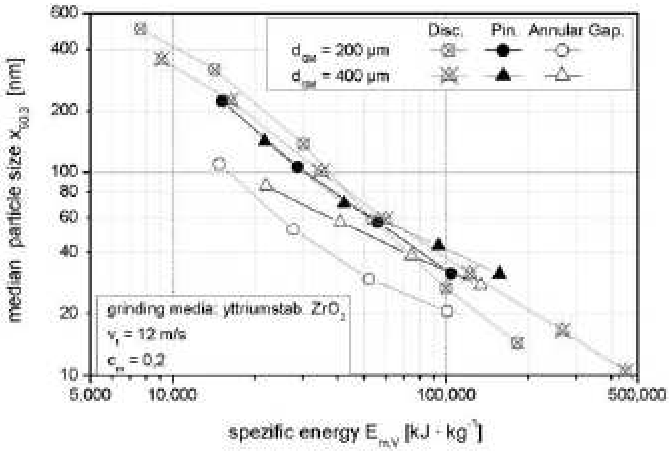

Figure 18: Specific energy of nano-milling

6.3.3 Grinding Media Beads

Stehr and Tabellion [4] mention the transfer of grinding technologies connected with the surface treatment in the area of nanoparticles production from the “common” use of grinding elements - the dimensions of which range from the order of hundreds of micrometer to tens micrometer in the industrial plants. In laboratories the experiments are carried out with grinding elements that are by two orders smaller [23].

Table 2: Survey of the today´s beads materials

Property/ Characteristic	Units	Mg-PSZ	Ce-TZP Mill Mates Plus®	Y-TZP	Fused Zirconium Silicate
Density	(g/cm^3)	5.6	6.3	6.0	3.8
Hardness (HV)	(Kgf/mm^2)	900	1160	1300	600
Fracture Toughness, K_{IC}	(MPa/m^{½})	4.6	12.0	11.6	5.0
Elongation		0.94	0.96	0.98	0.90
Crush strength	(lbs. force)	84	200	270	60
Bead Wear Rate (1 H Hydraulic Packing)	%	8.4	0.1	0.04	NA
Impeller Wear Rate	%	0.29	0.01	0.07	NA

As far as the size and materials are concerned that are used for grinding elements and structural parts that are in contact with the ground stock – the size of the stainless steal grinding elements used in these days is up to the fineness app. 0.8 mm only. Al and Zr silicates, respectively their oxides, are then usual material for production of grinding elements – the classical Mn of abrasive steal is no more frequent in the area of micro-grinding. Inadmissible is especially the contamination with 2+ ions of Fe and Mn. In the table Tab.2 [25] there is an overview of the materials that are widely used for commercial purposes in the ultra-fine grinding area.

6.4 Acoustic grinding

Advances achieved in this very attractive direction of grinding are only rarely presented at conferences and expert meetings. Therefore we can only make a simple statement that the company SEISHIN ENTERPRISE CO., LTD assigned a full range of acoustic jet "O" Mills to POWTEX ´06 [26]. The smallest of those mills is as big (or small) as the palm of human hand. (See Fig.19 and Fig.20).

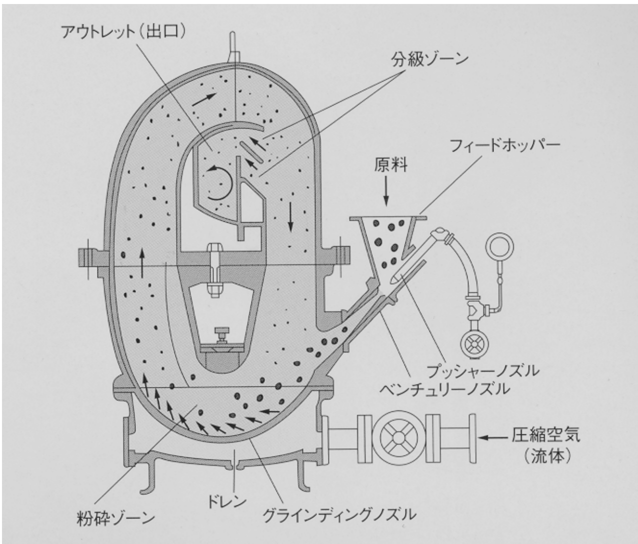

Figure 19: „O" Mill layout

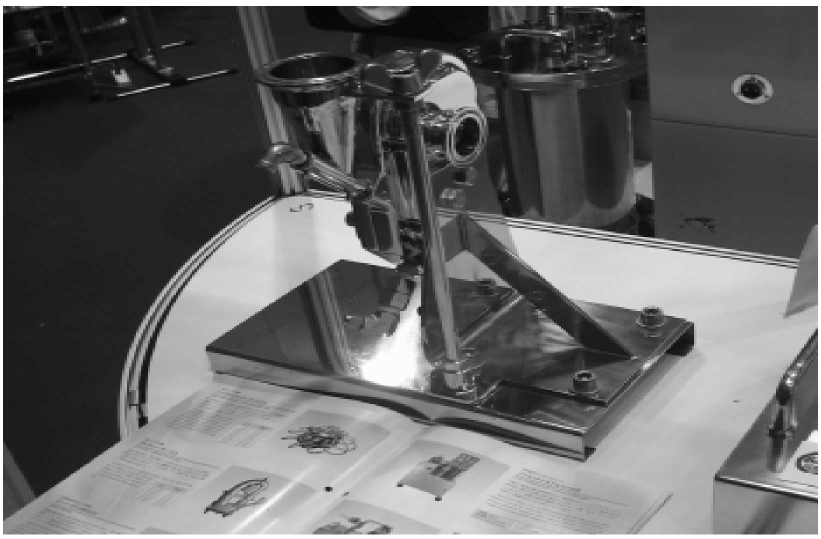

Figure 20: Laboratory „O" Mill

6.5 Other sorts of Grinding Equipment

It is a matter of course that not only the here above types of mills are innovated. All equipment used for the purpose of various types of disintegrating are innovated. I will mention in brief just some of the innovations:

6.5.1 Ball Mills

The size of the processing equipment increases in direct proportion to the amounts of ore being mined and processed. Stein [27] mentions the present limits of dimensions of ball mills: diameter up to 13m (SAG), length up to 25m and installed power input of up to 20 MW.

DEM modeling affected the design of Ball Mills too. To achieve optimal cataract movements of the ground load in the mill, we cooperate with Japanese partners in the field of shaping the “lining“ [28].

6.5.2 Jet mills

Lately there has been a tendency in the area of jet mills development to increase the grinding efficiency. For this purposes, the amount of acoustic component should be increasing and the higher homogeneity of the turbulent supersonic field in the grinding chamber should be a better one. Having been acquainted with the presentation of the new types of jet mills produced by the company Aishin Nano Technologies [26] and listen in to the Roth´s paper [29], we would dare to state that at least the second direction of the development – attempts to achieve a higher homogeneity of the grinding field are therein evident. (See Fig.21).

Figure 21: Jet Mills

6.5.3 Crushers

The development of DEM modeling had a positive impact on the development on crushers, too. The search for optimal shape of grinding chambers can progressively result in significant savings of vast power consumption, for which the crushers are well renowned [8].

From the latest product catalogue of the very conservative producer of grinding equipment

Pennsylvania Crusher Corporation [30] it is evident that even such an “ordinary” equipment as Hammer Crusher can be innovated. (See Fig.22).

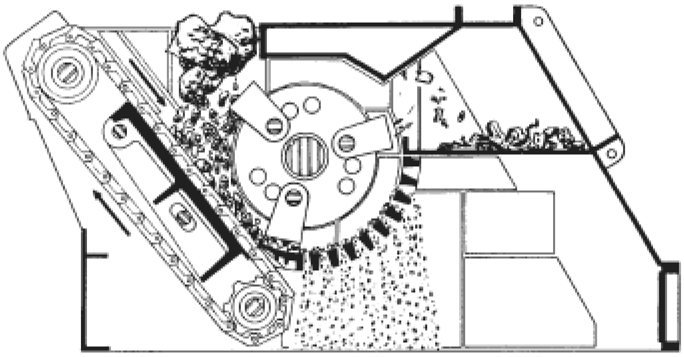

Figure 22: Hammer crusher

7. COMMINUTION PROCESSES CONTROL METHODS

In this lecture, there is not enough time for the analyses of the various control methods. In the comminution processes like in any other processes, the control methods have a significant impact on assuring the quality of the ground load and consequently the quality of the final product, and as such they play a very important role in these processes. At this moment I would like to mention at least one fact that is closely connected with the control methods: the 3D Tomography Imaging, which is probably one of the most dynamically developing areas related to the control of grinding processes. This method was further developed by Prof. Tom Dyakowski of Manchester University who died lately. Due to the rapid development of IT, imaging and medical technologies, this method is becoming a progressive tool for control of grinding processes and articulate solids flow in general. And that all not only in the area of fine particles [31], [26].

8. CONCLUSIONS

The sharp decrease in mineral mining in the Central Europe, complete transfer of limestone mining and processing to the hands of foreign companies, quick depletion of coal deposits, building stones, sandstones and aluminosilicates in general, dissolution of companies that produced equipment Mineral and Powder Processing in the Czech Republic, sale of the company PS Engineering resulting in the termination of development of some of the important mills out of the broad range of mills, the quick onset of globalization of the production of Mineral and Powder Processing equipment are among the most important factors that cause that the long-term interests in Mineral and Powder Processing is decreasing or that the technical public even gets disgusted with it. Only a few persons are well aware of the fact that the expected boom in nanotechnologies is closely connected with the development of Hi-Tech in the area of Ultra-fine Grinding and Separation. Whereas natural sciences, medical sciences and electronics on the university level of research and education have already answered the challenges brought by the era of nanotechnologies [32], the development and education in the field of processes and equipment for Comminution and Separation necessary for preparation of nanoparticles more or less equals to zero. This is a very sad fact, especially in the view of the fact that the Czech Republic has a long-term, rich and unique tradition of designing and process development. Which of the world powers can boast in such a tradition? And who knows today that „SKODA Elevator“, „LOSCHE Mill“, „NAUTA Mixer“, „ROTOFLUID” now widely produced and installed in the Powder Technology Equipments around the World originated in the Czechoslovak Republic not long ago.

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