IFPRI Review Brief
Milling Aids

The International Fine Particle Research Institute wishes to commission a comprehensive review of the use of grinding aids in milling of organic and inorganic materials. The review should include an overview of the types of grinding aids that are used and how they are used (i.e. in what types of mills for what materials), and what their impact is on energy consumption and milling rate. It should also include a critical discussion of the current understanding of the mechanisms by which grinding aids work. The scope of the review is limited to dry grinding of inorganic or organic materials with dry or liquid grinding aids (including steam), and it should include discussion of both positive and negative effects of the aids.

Use of Grinding aids in Dry Systems

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1. Introduction

In dry grinding processes fine powders are not easy to produce and to handle since attractive particle-particle forces become more decisive with decreasing particle size. In order to control these forces, chemical liquid or solid additives – so called grinding aids – are added to the process in many industrial dry fine grinding applications. The objective of their use is mostly to increase the product throughput, decrease the specific energy consumption or reach a desired product fineness. Depending on the product and the process, grinding aids are sometimes also used for improving the material-handling or for enhancing different product properties like the strength development of cementitious materials. Even though the benefits of grinding aids have already been shown in various experimental studies and industrial applications, their selection, dosage as well as knowledge about their mechanism of action are still based on empirical knowledge. The variety of applied substances, ground materials and target finenesses, available mill types and process designs, mill and process parameters as well as analysis methods complicate the development of a comprehensive understanding. In order to give a better overview on the different grinding aids, their applications as well as impacts on grinding processes, powder properties as well as product qualities, this review summarizes the major results of available studies on grinding aids in dry fine grinding systems. Thereby, their mechanisms of action on particle and bulk level are discussed. Also, the choice and limitations of grinding aids are critically considered.

2. Mechanism of action

Within this chapter, the different theories regarding the mechanisms of actions of grinding aids are discussed. Thereby, the different kinds of liquid and solid grinding aids are reviewed. In addition, the mechanisms of their distribution within the grinding chamber as well as spreading and adsorption phenomena on the particle surface are considered. The mechanisms of action are discussed by comparing the impacts of the grinding aids on surface energy, adhesion force, agglomeration as well as bulk and flow properties of the product powder.

2.1. Liquid, gaseous and solid grinding aids

In principal liquid, dry and gaseous grinding aids can be distinguished. The most important substance classes of these additives, like alkanolamines, mono- and polyvalent alcohols or carboxylic acids, are presented as well as novel substances like polycarboxylate ethers. In addition, the most important chemical and molecular properties and differences of the grinding aid species are summarized. To date, several hundreds of substances and mixtures have already been presented as grinding aids in the literature. Here, a wide-ranging overview of the most important components is presented for the most frequently investigated ground products. Thereby, it is also distinguished between dry, liquid and gaseous grinding aids as well as the targeted operation, whether fine (micron range) or ultrafine (submicron range) grinding. Furthermore, optimal grinding aid dosages as well as the corresponding increase of the specific surface area of the ground products are presented.

2.2. Distribution, spreading and adsorption

Within this chapter, the distribution of the grinding aid components within the grinding chamber is discussed, just like the wetting, spreading and adsorption mechanisms of the substances on the particle surface. Thereby, the impacts of the most important chemical and physical grinding aid parameters on these mechanisms are considered. Furthermore, investigations on the relation of molecular structure and adsorption mechanism are presented. Typical grinding aid concentrations are discussed with special regard to the adsorption capacity and thus the particle surface coverage. However, even though adsorption strength and capacity are crucial issues regarding the applicability of the grinding aid, it is concluded that there is no direct correlation between the adsorption energy and the grinding result. It is further shown, that liquid and dissolved additives are the favored species of grinding aids for both technical and economic reasons. On the one hand, they enable a fast and uniform dispersion via the gas phase as well as through surface contacts. On the other hand, they are easy to handle and to add to the process. Even though gaseous grinding aids may also fulfill these criteria, they are rarely applied since their strength of adsorption is very low, leading to a high discharge from the mill via mill ventilation.

2.3. Surface energy, adhesion force and agglomeration

In this chapter, mechanisms of actions of grinding aids are presented. It is shown, that the chemical and energetic surface properties of the product particles are altered as s a consequence of the grinding aid adsorption. Thereby, the most important theories regarding the mode of action – like (a) reduction of fracture strength (Rehbinder effect), (b) preventing of material coatings on grinding balls and mill equipment (decrease of adhesion) or (c) the decrease of the particle-particle adhesive forces (decrease of cohesion) – are compared and discussed critically. Nowadays, a direct impact of grinding aids on the fracture strength of the particles is assumed to be irrelevant for technical grinding even though a decrease of the surface energy by grinding aids was verified experimentally. The effects of grinding aids are rather attributed to a reduction of particle-particle and particle-wall interaction forces. Several studies indicate that the benefits of grinding aids are mainly achieved by changing adhesive forces and thus the state of agglomeration and powder dispersion. As these forces are reduced, the formation of strong agglomerates is decreased leading to both a more efficient grinding as well as a shift of the product quality or, in extreme case, the grinding equilibrium to higher finenesses. Simultaneously, the material coatings on grinding balls and mill equipment decrease. However, even though the reduction of material coating may have a positive effect on the grinding result, it is assumed to be only of secondary importance.

2.4. Bulk properties and powder flowability

Since the grinding aids are reducing the adhesive particle-particle interactions, they effect a change of the bulk and flow properties of the product powder. These powder characteristics have a strong impact on the grinding mechanism between the grinding media or tools, the material transport and retention time inside the mill as well as the downstream material handling. Hence, they are of crucial importance regarding the grinding results and product processability. Therefore, the most important studies on the impact of grinding aids on bulk and flow properties are summarized. Thereby, different grinding aids are compared by showing their impacts on values like the angle of repose, cohesiveness, powder flowability index and bulk density.

3. Grinding aids in grinding processes

The results available in literature regarding the impact of grinding aids on dry grinding processes are highly diverse and sometimes not very helpful or even contradicting. The reasons are as diverse as the presented results: The variety of (a) mill types, plant and process designs, mill and process parameters as well as grinding conditions, (b) ground products and target finenesses, (c) grinding aid components, mixture composition and grinding aid concentrations but also (d) analysis equipment and characteristic values complicate a comparison and a transfer of those results tremendously. Therefore, the findings available in literature are clustered in different subjects within this review.

3.1. Grinding aids in laboratory mills

This chapter reviews solely those published studies which are investigating grinding aids in laboratory mills. By considering solely batch-wise operated laboratory mills, any overlapping mechanisms like material transport or air classification can be neglected. In general, most of the present studies focus on mills using free moving grinding media, such as conventional tumbling ball mills, vibration ball mills and stirred media mills. Significantly fewer laboratory works were carried out by using other grinding machines like vibration rod mills, disk mills, roller mills, jet mills or even piston-die-presses. Moreover, the majority of the available studies deals almost exclusively with grinding processes of inorganic materials, while the research works on organic products are very rare. It is shown, that the conclusions of the single studies are not always compatible. Therefore, the collected results are categorized with regard to the mill type, ground product and added grinding aid. The aim of this chapter is to identify the most suitable grinding aids for certain products in dependence of the used mill. Thereby it is also critically discussed why both too low as well as too high concentrations lead to unsatisfactory effects.

3.2. Relation of stressing conditions and grinding aids

Based on the results shown above the question arises, how grinding aids may influence the stressing conditions inside the mill and thus the result of the grinding process. Besides the prevention of material coating and formation of strong agglomerates, the change of the product flow behavior may also lead to varying interactions with the grinding devices. Hence, different mechanisms are leading to overlapping impacts on the grinding performance. At this point, contradicting statements are found in the literature. Thereby, a few (in particular older) studies indicate no significant impact of the stressing conditions provided by the mill on the grinding result when using different grinding aids. In contrast to that, other studies emphasize the impact of grinding aids on the product flow behavior between the grinding devices and thus on the interaction of grinding aid and stressing condition. Additionally, a change of the radial movement of the mill charge was shown, leading also to deviating stressing conditions. It is concluded that a comprehensive understanding of these interactions is still missing. However, further insights into these mechanisms will be of high importance in order to enable the transfer of the available findings to new processes and applications.

3.3. Industrial grinding processes

At the beginning of this chapter the differences of the grinding aid efficiency in laboratory and industrial applications are outlined. By means of studies from the literature it is shown that the effects of the additives tend to be even higher in industrial processes compared to batch-wise operated laboratory mills. On the one hand, this may be explained by varying stressing conditions within those different mills. Also, the impact of temperature, which is normally much higher in industrial mills, is often emphasized as an important factor. On the other hand, grinding aids enable a positive effect on different levels simultaneously when grinding in complex industrial scale grinding plant. Based on studies focusing on industrial plants it is shown, how these additives are further influencing the overall process. As the chemicals often improve the flowability of the product powder, they affect the axial material transport as well as the mill retention time. Thereby, higher amounts of grinding aid may affect a low mill retention time as well as an increase of undesired backmixing inside the mill chamber. Furthermore, the separation sharpness of the air classifier can be improved significantly by applying grinding aids since these chemicals reduce the extent of agglomeration of the product particles. This in turn affects the amount of rejected material and causes therefore a reduction of the recirculation number as well as a change of the mill performance.

4. Influence of grinding aids on subsequent product properties

As the grinding aids mainly stay adsorbed on the product particles even after the grinding process they will cause further impacts on the subsequent processing as well as intermediate and final product qualities. Especially in the field of cementitious material, various investigations were already carried out regarding these effects.

4.1. Impact on rheological properties

At this point, the current scientific studies on the rheological properties of suspensions, which contain particles that were ground in dry processes with grinding aids, are reviewed. It is shown, that several common grinding aids are inducing changes of the corresponding viscosity, the water demand and yield strength. In addition to that, the required amount of further plasticizers and flow improvers varies with the applied grinding aid. It is further outlined, that the main reason for that is the stabilizing mechanisms of the grinding aid on the suspended particles, whereas the chemical structure of the grinding aid molecules is the most decisive parameter.

4.2. Further product properties

Since grinding aid applications were originally introduced in the finish grinding of cements, most of the studies regarding the impact of grinding aids on final product properties deal with construction materials. As this issue is not the focus of this review, only the most relevant papers are summarized here. They clearly show that the adsorbed grinding aid molecules may have a strong influence on the chemical hydration reactions of certain cementitious compounds. Thereby, different effects depending on the cement phase as well as the grinding aid component are observed. It is outlined, how the most important properties may be affected, including setting times of concrete or mortar pastes by accelerating or retarding effects as well as the strength development and final strength. Unfortunately, investigations on product properties apart from the construction sector are rare. Thereby, only a few studies reveal impacts of grinding aids on properties like color characteristics or crystallinity of the product particles. All together it is shown, that certain grinding aids may also cause negative effects regarding the final product properties, which excludes their industrial application even though they might have shown good performances in the grinding process.

5. Selection of grinding aids species and concentration

As it can be assumed from the reviewed studies, the selection of suitable grinding aids as well as optimum concentration is a very complex issue. The impacts of grinding aids on the processing as well as final product properties may complicate the choice of the grinding aid, just like other economic or ecological aspects. It is further shown that even by an exclusive consideration of the grinding process, the design of a grinding aid application cannot be reduced to a few single chemical or physical properties. However, it is concluded which of those parameters – like the chemical species, molecular structure etc. – have to be considered when looking for the right additive. Thereby, relations between the chemical structure and the coverage of the product particles, thus the optimum additive concentration are outlined. Further aspects like generally higher optimum concentrations in closed grinding circuits in comparison to open grinding processes are addressed. Moreover, a new laboratory method, which enables a more accurate grinding aid screening for industrial processes, is presented.

6. Conclusion

In the end of this review, a comprehensive conclusion is given. Thereby, the most important aspects for designing grinding aid applications are summarized. Furthermore, an outlook on possible future studies, which are required to close the gap regarding a better transfer of laboratory results to industrial applications, is presented.

IFPRI Review Brief

Characterization of Fluid Boundary Layers in High-Shear Multiphase Flows

The International Fine Particle Research Institute wishes to commission a comprehensive critical literature review of experimental methods and modeling approaches to describe high-shear flow of suspensions and dispersions, slurries, and pastes in confined flows at wall boundaries in processes such as extrusion and injection molding. This review should identify current practices and the state of the art in both experimental methods and modeling approaches. Of particular interest is the phenomenon of wall slip, which is fundamental to the response of high-solids fraction suspensions to mechanical deformation.

Outline

IFPRI Review on Wall Slip

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