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THE PERFORMANCE OF THE HIGH PRESSURE ROLL MILL: EFFECT OF FEED MOISTURE

The high pressure roll mill, HPRM, a newly invented size reduction equipment, has been recently added to the list of comminution machines and is classified as a highly efficient equipment. Although the HPRM is now already being operated in several full-scale size reduction plants, it has not yet been fully characterized. This is because the performance of the equipment is affected by numerous parameters that have to be investigated and optimized. The present paper is concerned with the effect of one of the important parameters, that is the feed moisture, on the HPRM performance. A dolomite feed of –8 mesh size distribution was used at different moisture levels, up to 10%, to demonstrate the effect of feed moisture on the product characteristics, and the mill operating and design parameters such as the applied load, specific energy, roller speed, and rollers gap. It was found that the feed moisture has a definite effect on both the product characteristics and the mill operating and design variables at different set load levels. It was also found that the operating parameters of the mill are interrelated in a well defined combination, and differences in the size distribution parameters of the product are reflections of this interrelated combination.

INTRODUCTION

Mineral processing consumes a large portion of the total generated electricity all over the world. It was estimated that about 5% of the electricity generated globally is consumed by the mineral processing plants. About 80% of this portion of energy is consumed in crushing and grinding of raw materials (National Materials Advisory Board, 1981). There is every indication that the energy cost of comminution will continue to rise in the comming years. Reasons for this lie in the continuously increasing cost of generating electricity and in the perceptible trend towards finer grinding of ores on an increasingly larger scale for mineral liberation from lower-grade ores, and for producing ultrafine particulates for emerging materials technologies. Although other methods of applying energy for size reduction (electrohydraulic, laser, thermal shocks, etc) have been proposed (National Materials

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Advisory Board, 1981), mechanical stresses remain the most practical means for carrying out industrial comminution. Thus, improvements in comminution efficiency of the size reduction machines by maximizing the energy utilization, either by optimizing the operating conditions or by improving the machine design, are urgent.

Although a definite definition of energy efficiency in comminution is not yet defined (Abouzeid, A.-Z.M., Fuerstenau D. W., to be published), energy utilization in conventional comminution machines is only a fraction of what is achieved in crushing single particles under slow compression (Schoenert K., 1979). This decrease in process efficiency can be attributed to a number of interrelated causes inherent to the design and operating conditions of size reduction machines, and the interparticle interaction effects that are inevitable whenever a particulate system is ground in confined or loose beds (Kapur P.C., Gutsche O., Fuerstenau D.W., 1993; Fuerstenau, D.W., Vazquez-Favela J., 1997).

The loose bed (uncofined system) comminution is represented by the tumbling mills such as ball mills. The confined bed comminution can be carried out using a choke-fed high pressure roll mill, which is the recently invented and commercialized mill that exhibits significantly enhanced energy efficiency (Kellerwessel H., 1990; Fuerstenau, D.W., Kapur P.C., 1995).

In confined bed comminution, energy is transferred directly to the charge mass, and breakage takes place by very high stresses generated locally at the contact points between the particles of the tightly compressed bed (Fuerstenau D.W., Shukla A., Kapur P.C., 1991). The high pressure roll mill, HPRM, is an example of the continuous grinding in the confined particle-bed mode. However, a completely confined particle-bed mode of grinding is difficult to attain in the HPRM because of the well known end effects that invariably result in some leakage of the feed. Though with this discrepancy from completely confined-bed mode of breakage, the HPRM is considered as energy saver unit of comminution compared with the conventional tumbling mills. It is possible to achieve energy savings of more than 50% of the specific energy commonly known to be consumed for size reduction of mineral comodities in conventional ball mills when a HPRM is used (Ellerbrock, H.-G., 1993, Patzelt, N., 1990). In addition, the HPRM reduces contamination of the product with iron during grinding. This latter feature saves steel wear consumption and produces clean products needed for subsequent processes in some special applications.

Several factors affect the performance of the HPRM among which are: the material properties, the granulometric composition of the feed, the feed moisture, the roll pressure, and the rate of applied stresses (Schoenert, K., Muller F., Schwechten D., 1990). One of the important operating parameters of the HPRM, that has not been given enough attention, is the feed moisture. The effect of this parameter is contravartial. Some authors report that moisture content of the feed does not appear to affect the reduction ratio-specific energy relationship (Lim, I.L., Voigt W., Weller K.R., 1996). Whereas others confirm that some effects of feed moisture on the performance of the HPRM have been observed (Patzelt, N., 1990; Schoenert, K., Muller F., Schwechten D., 1990; Fuerstenau D.W., Kapur P.C., Gutsche O., 1993). However, none of those who reported the effectiveness of moisture on the HPRM performance has investigated in details the effect of moisture on the behavior of the mill and its energy efficiency. Only some tests of preliminary nature were conducted to explore the effect of the feed moisture on the grinding efficiency (Fuerstenau D.W., Kapur P.C., Gutsche O., 1993).

This paper is concerned with a detailed study of the effect of feed moisture on the performance of the HPRM. It presents a thorough investigation of the effect of a wide range of feed moisture, up to 10%, on the product characteristics and the mill operating and design parameters such as: applied load, specific energy, mill speed, and rollers gap. Interrelations of the operating and design parameters on the product size distribution properties will also be illustrated.

MATERIAL, EQUIPMENT AND PROCEDURE

Material

The material used in this study is dolomite of –8 mesh particle size distribution of median size, X_{50}, of 1260 microns, and X_{80} of 1830 microns. The dolomite used was obtained from Salinas, California, and was prepared by stage-crushing in a laboratory roll crusher in closed circuit with an 8 mesh screen.

High pressure roll mill

The laboratory-scale HPRM is constructed with two counter-rotating rolls, each 200 mm in diameter and 100 mm in width. The bearings housing one roll are fixed, while the other roll can freely slide laterally in parallel with the adjacent roll through a Schmidt coupling device. The rolls are driven by a 37-kW variable-speed DC motor. A transducer attached to the drive shaft measures the roll torque, and the whole system is interfaced with a dedicated computer for recording the roller gap, roll torque, milling force, total energy, and roller speed, simultaneously. During an experimental run, an infrared emitter/receiver located at the top of the feeder column ensures that the feeder system is full of material by controlling the vibrating feed hopper. Product sample is collected by manually switching a cutter from one position to the other, activating a microswitch that starts the data aquisition system. At the beginning of each grinding experiment, the idling roll speed was set at approximately 26 rpm. The main controlling variable on the machine is the load applied to the roller. It was varied, on loaded rolls, from 4 to 11.6 ton, Fig. 1.

The moist feed material was prepared by adding the required amount of water to 3 kg of dry material to make a charge of a known moisture content. The moisture levels studied are 0.0, 2.5, 5.0, 7.5, and 10.0% water of the dry charge. Charges of moist material were added to the feed shaft and vibrating hopper. A colored dolomite bed of about 1/2 cm thick between each two differently moistened charges was used as an indication of the end of one charge and the beginning of the next one. However, about one kilogram of material between each two differently moistened charges (half a kilogram below the colored bed and half a kilogram above it) was rejected from the product to avoid interference between each two successive charges with different moisture contents. This arrangement leaves about 2 kg of product from each moisture level. These 2 kg product material of each moisture level were soaked in water for disintegration and screening. The product size distributions were obtained by the s' a dard wet-dry sieving procedure using a R b Tap sieve shaker.

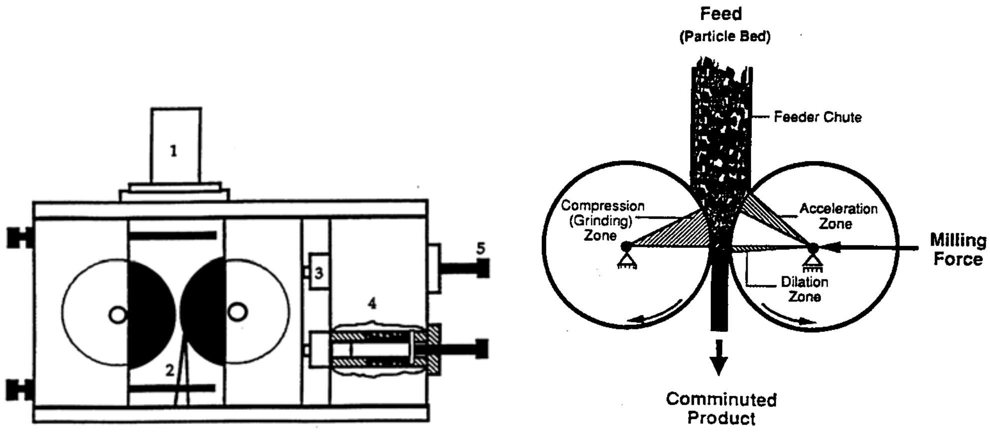

Fig. 1. High pressure roll mill; a) front view: 1 – feeder funnel, 2 – divider plate, 3 – load cell, 4 – force-cage with disc spring, 5 – spring bolt, b) schematic representation of comminution mechanism

RESULTS AND DISCUSSION

Three main aspects are discussed in this section. Although interrelated, each of these aspects will be discussed separately and then all the three aspects will be related to each other. One of these aspects is the effect of the feed moisture on the operating variables such as applied load, specific energy consumption, roll speed, and roller gap. The second aspect deals with the effect of the moisture level on the product size distribution, the rate of fines production, and the retained coarse material. The third aspect is the effect of the feed moisture on the energy efficiency in the HPRM.

Effect of feed moisture on operating variables

Five levels of feed moistures were investigated. The effect of each of these moisture levels was studied at different applied loads. In each of these series of experiments, the applied load was set at a specified load at 0.0% moisture. At the end of each experiment, all the operating parameters were read and recorded through the computer set up. These parameters were: load, average speed, net energy consumption, and rollers gap. The collected sample in each experiment was weighed and recorded, mainly for calculating the specific energy at the specified conditions, namely, load and feed moisture.

At each of the set load levels (the load value at zero moisture), the load was steadily decreasing as the moisture content was increased, Fig. 2. A first thought, that needs to be confirmed, for explaining this trend is that water acts as a lubricant between the particles within the material bed. This lubrication action minimizes particle-particle friction and helps compacting the particulate bed, reduces the bed thickness, and hence reduces the load.

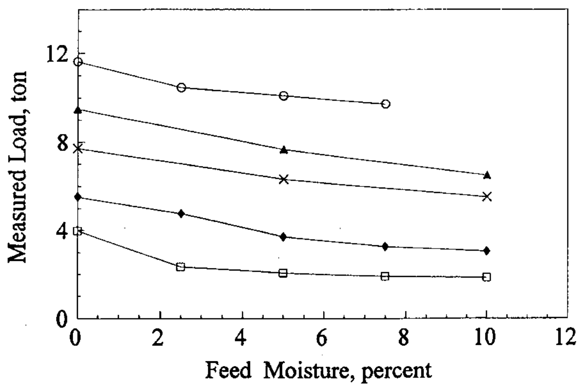

Fig. 2. Effect of feed moisture on the applied load at various load levels. The reference load level is the load set at 0% moisture

Unexpectedly, the roller gap decreased, at all load levels, as the moisture content increased (Fig. 3 a). The decrease in gap was significant up to 5% moisture, and then, the rate of gap reduction was less up to 10% moisture, i.e., the bed compaction reached a certain limit beyond which there was little voids for the material to squeeze in. From the above discussion, it can be seen that the applied load decreases with increasing the feed moisture (Fig. 2). This means that the roller gap should have increased (Fig. 3 b). However, it did decrease with increasing moisture. This confirms that the rate of product material bed extrusion increases as a result of water lubrication on the particles surfaces, and not a kind of roller slippage. This confirms the above mentioned idea of material lubrication by water.

As feed moisture increased, the measured roller speed, at all set load levels, increased (Fig. 4). This trend may be explained by the decrease in applied load with increasing the feed moisture. It was found that the roller speed decreases linearly, at all moisture levels, as the applied load increases (Fig. 5). Consequently, since the applied load decreases with increased moisture content, it is expected that the roller speed increases with increasing moisture content (Fig. 4). As discussed above, it should not be thought that the increase in roller speed with increasing the feed moisture is due to less friction (roller slippage) between the rollers and the material passing through them.

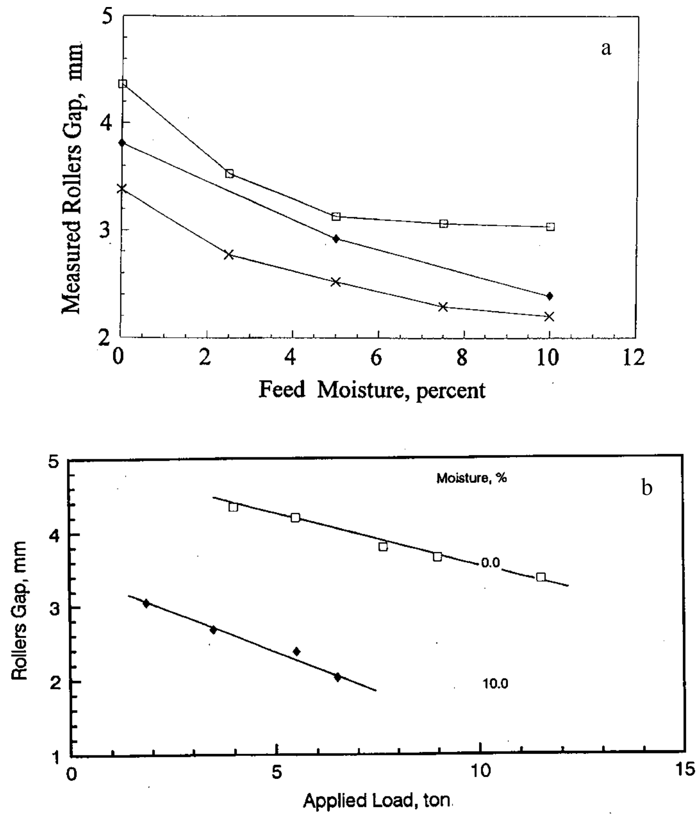

Fig. 3. Effect of feed moisture (a) and applied load (b) on the rollers gap at 0% and 10% feed moisture

The change in specific energy consumed in comminution as a function of feed moisture and applied load is more complicated. At smaller loads, i.e., lower specific energy levels, the specific energy decreases as the moisture content of the feed increases (Fig. 6). This is due to the decrease in applied load with increasing moisture content (see Fig. 2). At higher applied loads, the specific applied energy increases with increasing feed moisture (Fig. 6). This may be due to the following. As the bed becomes thinner by extrusion with increasing moisture content (Fig. 3), more energy may be absorbed in material comminution rather than being absorbed by cushioning through material friction as a result of high percentage of voids in the less compacted bed (in absence of the lubricating action of water). By studying Fig. 7 which presents the rate of increase in consumed specific energy with respect to the applied load at 0% and 10% moisture, it can be concluded that the rate of energy at any applied load, above 2 tons, is higher at 10.0% moisture than in the case of dry feed. At loads less than about 2 tons, the trend of energy utilization (extrapolated) at any load is lower in the presence of moisture than in the case of dry feed. Back to Fig. 6, it can be seen that the specific energy increases with increasing feed moisture at high levels of set loads, recalling that the applied load decreases with increasing moisture content (see Fig. 2). This phenomenon supports our proposed model for the improvement in energy utilization as a function of moisture content at high levels of applied loads as a result of water lubrication. It should be noted that at high moisture levels (above 7.5% water) some of the added water was squeezed out of the material bed and driven off in the form of droplets at the drum ends at high set loads. The effect of water squeezing out can be particularly observed at 10.0% moisture at high energy levels where the energy-moisture trend increases and then declines at high moisture content (Fig. 6).

Effect of feed moisture on product properties

In this section, the effect of feed moisture on product properties and specific energy utilization at different levels of applied loads will be presented and discussed. The main product properties are particle size distribution, percentage fines, and percentage coarse materials in the product.

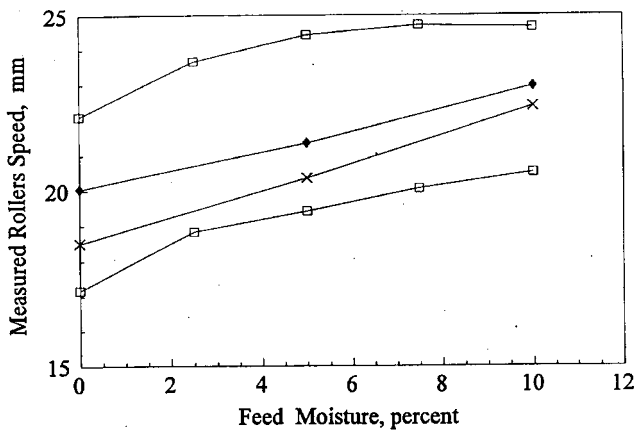

Fig. 4. Effect of moisture on the roller speed

Figure 8 presents the cumulative size distribution of the product material at various moisture levels at specific energy 0.6–0.8 kWh/t. At this level of specific energy, the percentage of fines proguced decreases as moisture increases. This is probably because the stage of compaction by water lubrication at low levels of applied loads produces less fines as lubrication increases as the material is going into more compaction and less breakage. At the same time, under these conditions, coarse particles suffer less nipping as they are protected by fine sizes during assested compaction. In addition, the load decreases with increasing feed moisture which means less energy is supplied to the particulate system.

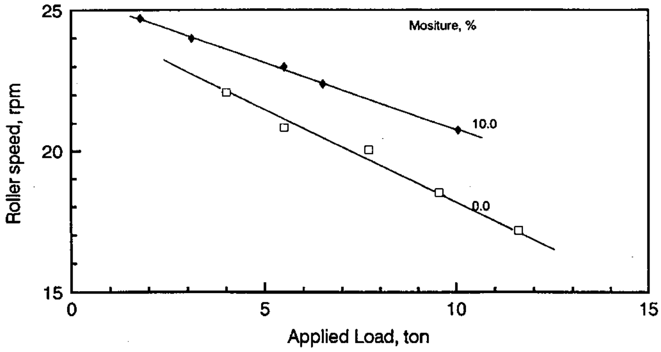

Fig. 5. Effect of applied load on the roller speed at 0 and 10% feed moisture

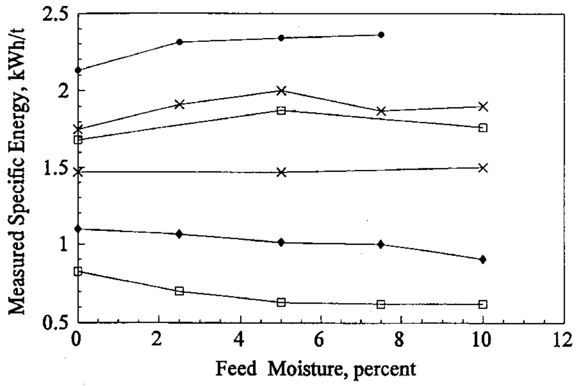

Fig. 6. Effect of feed moisture on the specific energy consumption at various energy levels. The reference energy level is the energy set at 0% moisture

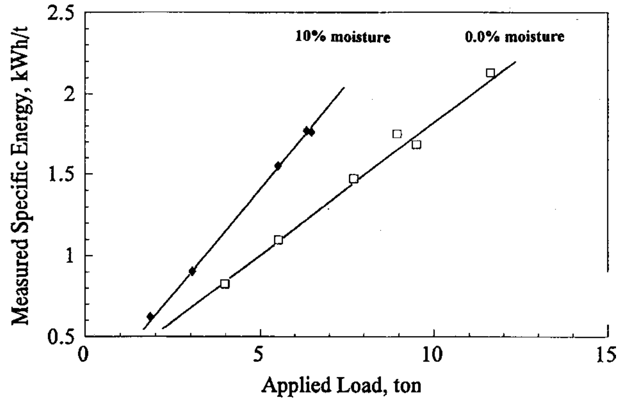

Fig. 7. Effect of applied load on the specific energy consumption at 0 and 10% feed moisture

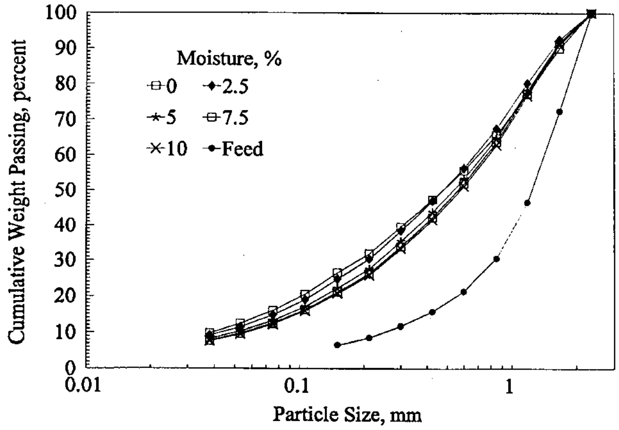

Fig. 8. Effect of feed moisture on the size distribution of the HPRM product at specific energy 0.6–0.8 kWh/ton

Figure 9 shows the cumulative size distribution of the product material at various moisture contents at a high level of consumed specific energy, 1.7–2.0 kWh/t. In this figure, it can be noticed that the effect of the various moisture levels is more significant in the disappearance of the coarse-size material rather than the appearance of the fine-size fractions. It is clear from Fig. 9 that the disappearance of the coarse-size material is faster at higher moisture levels. Attempts to explain the trends in both Figs. 8 and 9 will be discussed in the following paragraphs.

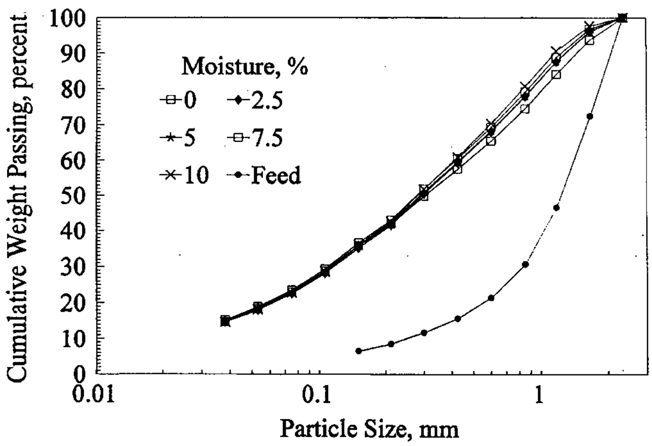

Fig. 9. Effect of feed moisture on the product size distribution of the HPRM product at set energy of 1.75 kWh/t

The rate of fines production, e.g., –200 mesh material is shown in Fig. 10. In general, there are no drastic changes in the rate of production of fines as a function of moisture contents which was confirmed by Fuerstenau et al. (1993). However, at low energy levels, the rate of fines production tends to decrease to some extent. At high energy levels, there is a tendency for the fines to increase slightly with increased feed moisture, but still, even at this high levels of energy, produced fines decrease with miosture at low moisture levels. The reasons for decreasing the production of fines at low energy levels has already been discussed earlier. At high energy levels, at low moisture contents, the amount of moisture (e.g., 2.5% water) was just enough to act as a lubricant. As the moisture increased beyond this level, internal friction of material decreased and coarse-size material was subjected to fracture and, hence, little more additional fines were produced (refer to Fig. 6).

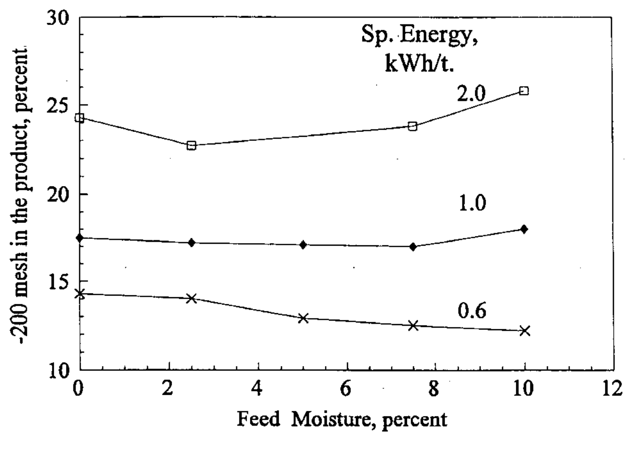

Fig. 10. Effect of feed moisture on the production of fines, –200 mesh

Figure 11 illustrates the trend of the amount of coarse material in, e.g., +20 mesh material, the product as a function of the moisture content at different applied specific energies. At low energy levels, there is a slight decrease in the coarse-size fraction as a function of feed moisture, whereas at high energy levels, there is a significant decrease in the coarse-size fraction. As discussed previously, at low energy levels, energy is utilized in compaction of material, with little breakage in presence of moisture. At high energy levels, more efficient breakage of the coarse-size material takes place as a result of less friction which facilitates squeezing the fines in the voids and, hence, nipping the coarse-size material. At moisture content less than 2.5%, the rate of decrease of coarse-size fraction is relatively high due to sudden change in feed properties from dryness to moist nature. Beyond 7.5% moisture, the rate of decrease in coarse-size fraction is significantly high probably due to the action of water squeezed into cracks and fractures, and hence, lowers the solids surface energy and facilitates the coarse-size breakage. In addition, in presence of enough water, the system behaves in a viscous way with fines squeezed out, mostly unaffected, leaving the coarse sizes for preferential breakage. This action, in a way, is similar to the action of rods on coarse-size fraction in a rod mill.

Figure 12 is a rearrangement of data in Fig. 11. It shows the rate of decrease of the coarse-size fraction as a function of the consumed specific energy. It is clear from Fig. 12 that, at any specific energy, specially at high energy levels, the rate of disappearance of the coarse-size fraction is higher at higher moisture contents. This means that the comminution efficiency is higher at higher moisture contents of the feed.

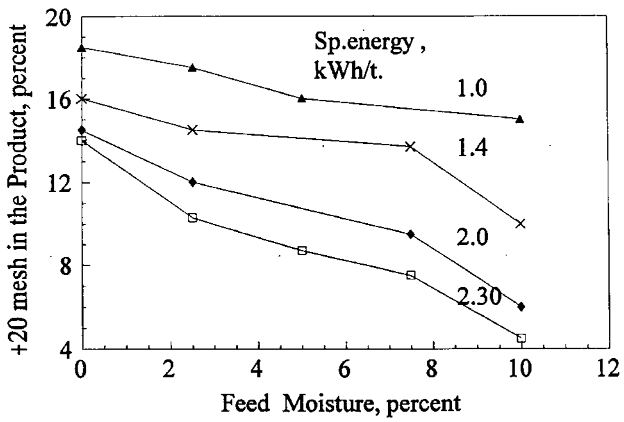

Fig. 11. Effect of feed moisture on the percentage coarse material, +20 mesh, in the product

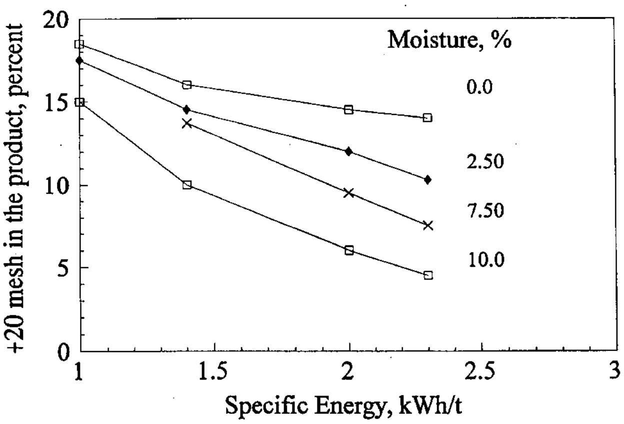

Fig. 12. The percentage coarse material, +20 mesh, in the product as a function of specific energy consumption

Effect of feed moisture on energy efficiency

From the foregoing discussions, it can be seen that the coarse-size fractions are more sensitive to moisture effect in the feed than the finer fractions, specially at higher energy levels. This lead us to use the reduction ratio at 80% of both feed and product as a parameter for correlating the energy efficiency of comminution as a function of feed moisture. Hence, the reduction ratio used in this text refers to X_{80f}/X_{80p}, i.e., X_{80} of the feed devided by X_{80} of the product. Fig. 13 shows that the reduction ratio as a function of moisture content decreases at low levels of the specific energy consumption, e.g., at 0.6 kWh/t. The reason for this trend has been discussed above. At higher energy levels, e.g., higher than 1 kWh/t, the reduction ratio increases as a function of the feed moisture. This increase in reduction ratio is more significant at higher energy levels. For example, at specific energy 2.3 kWh/t the reduction ratio increased from 1.9 for dry feed to 2.7 at 10.0% moisture, i.e., the reduction ratio, X_{80f}/X_{80p}, increased by 50% when the moisture in the feed was varied from dryness to 10.0%. Again, there is a plateau in the reduction ratio values between 2.5% and 7.5% water content. This plateau has been observed previously in Fig. 11.

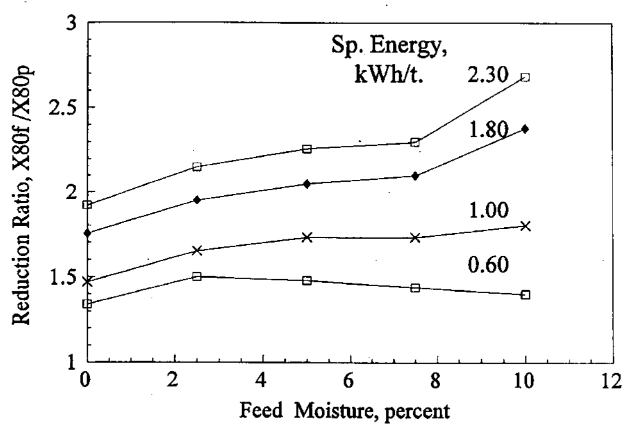

Fig. 13. Effect of moisture on the reduction ratio, X80f/X80p

The data in Fig. 13 is rearranged in Fig. 14 to represent X_{80f}/X_{80p} as a function of the consumed specific energy. It is obvious that the energy efficiency is improved significantly by increasing the moisture content of the feed. This effect was observed by Fuerstenau et al. (1993) when they used a moistened monosize fraction feed to explore whether moisture has an effect on the reduction ratio, X_f/X_{50p}. However, the moisture effect in the present work is more prominent for two main reasons. First, we used a feed with a wide range of size distribution, –8 mesh dolomite feed, which can hold the amount of water added, up to 10.0% water. Second, the reduction ratio X_{80f}/X_{80p} is more sensitive to changes in product size distribution properties than X_{50f}/X_{50p} or the percentage fines produced in the product. Fig. 14 shows that at low specific energy, e.g., around 0.6 kWh/t, the reduction ratio X_{80f}/X_{80p}, is reversed, i.e., the reduction ratio decreased with increasing the moisture content of the feed material. This confirms the observation demonstrated in Fig. 7.

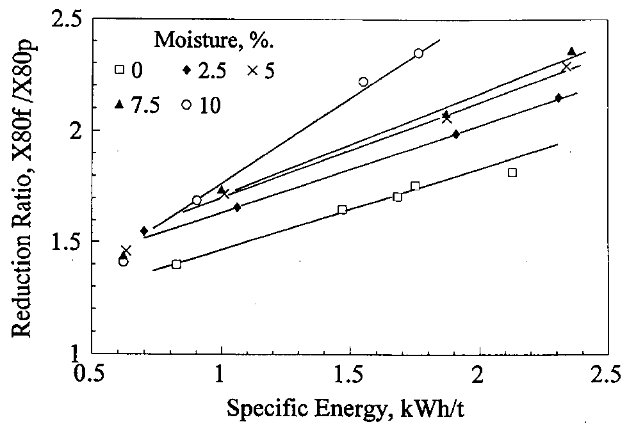

Fig. 14. The reduction ratio, X80f/X80p,
as a function of specific energy consumption

CONCLUSIONS

The effect of feed moisture on the operating and design variables of the high pressure roll mill, HPRM, as well as the properties of the product size distribution and energy efficiency, is investigated in details. This study reveils the following conclusions:

Effect of moisture on operating and design parameters

- At all loading levels, the applied load decreased with increasing the feed moisture. The rate of decrease in load with respect to moisture was almost the same at all levels of loading.
- The rollers gap decreased as the feed moisture increased. This may be attributed to the high rate of material extrusion due to decrease of material internal friction as a result of water lubrication.
- The measured roller speed increased at all loading levels as the feed moisture increased. This is expected, because the applied load decreased with increasing the feed moisture..
- At low energy levels, the measured specific energy decreased with increasing the moisture content. At high energy levels, the consumed specific energy increased with increasing moisture. Again, this is possibly due to squeezing fines in voids and cavities, i.e., the moist feed behaves as a viscous-like material, giving chance for coarse-size fractions to be nipped and consume more specific energy. Hence, the rate of increase in specific energy consumption, with respect to applied load, was observed to be higher with moistened feed than with dry feed.

Effect of moisture on size distribution properties

- At low applied loads, and hence low specific applied energy, the extent of comminution decreased with increasing moisture. This is probably due to decrease of applied load with moisture, and utilization of applied energy mainly for compaction as a result of less internal particulate friction. At high applied loads, the efficiency of coarse-size particles breakage is higher at higher moisture levels, whereas the difference in production of fines is not significant.
- At all levels of applied energy, the change in production of fines, –200 mesh, is not significant. On the other hand, the rate of reduction of coarse-size fractions, + 20 mesh is significantly higher at higher levels of applied specific energy as feed moisture increased.

Effect of moisture on energy efficiency

The reduction ratio, $X_{80f}/X_{80p,}$ was used to correlate the energy efficiency as a function of feed moisture. It was found that at low specific energy, the reduction ratio decreased with increasing the moisture content of the feed. At higher levels of applied energy, the reduction ratio increased significantly with increasing feed moisture.This rate of increase of the reduction ratio is higher at higher values of applied energy. At 2.3 kWh/t applied energy, the increase in the reduction ratio from dryness to 10.0% moisture was about 50% of the value of the reduction ratio at 0.0% moisture. This indicates that there is a definite increase in energy efficiency as the feed moisture is increased.

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Fuerstenau D.W., Abouzeid A.-Z.M., Badania wysokociœnieniowego m³yna walcowego: wp³yw wilgotnoœci nadawy. *Fizykochemiczne Problemy Mineralurgii*, 32, 227–241 (w jêz. angielskim)

Wysokociśnieniowy młyna walcowy (*high pressure roll mill*, HPRM), nowe urządzenie do rozdrabniania, uzupełnił ostatnio listę maszyn do rozdrabniania i jest uznawany jako bardzo sprawne urządzenie do mielenia. Chociaż HPRM jest już stosowany w kilku zakładach na skalę przemysłową, nie został on jeszcze całkowicie poznany. Wynika to z faktu, że praca HPRM zależy od wielu parametrów, które muszą zostać przebadane i zoptymalizowane. Niniejsza praca dotyczy wpływu jednego z ważnych parametrów rozdrabiania – wilgotności nadawy do mielenia, na działanie HPRM. Do badań zastosowano ziarna dolomitu o rozmiarze –8 mesh przy różnej jego wilgotności (do 10%), aby wykazać wpływ wilgotności na charakterystykę produktu mielenia i takich parametrów pracy młyna jak obciążenie, energia właściwa, szybkość poruszania się walca i odległość między walcami. Stwierdzono, że wilgotność nadawy ma wyraźny wpływ zarówno na charakterystykę produktu mielenia jak i zmienne parametry pracy młyna przy różnych stopniach wypełnienia młyna nadawą. Stwierdzono, że parametry pracy młyna są ze sobą ściśle powiązane i że różnice w składzie ziarnowym produktów mielenia odzwierciedlają te powiązane.