THE EFFECT OF AGITATOR SHAFT SPEED ON ENERGY CONSUMPTION OF A BALL MILL

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ABSTRACT

A laboratory ball mill refiner for chocolate and confectionery fat fillings consisting of vertical cylinder, equipped with a rotating shaft with arms, and filled with steel balls as a grinding medium has been used in the experiments. In this type of size reducing equipment, the feed material is comminuted between the moving media, the stirrer and the grinding chamber wall by compression and shear. The aim of the study was to examine the effect of agitator shaft speed on energy consumption of a laboratory ball mill. With constant mass of the steel balls (30 kg), the agitator shaft speed was increased from 10% to 100% of the maximum speed which coresponds to a speed of 50 rpm. The power consumption [W] was recorded upon which milling energy consumption [J/kg] has been calculated. The results were statistically analyzed using ANOVA. The increase of the agitator shaft speed, in steps of 10% to the maximum speed of 50 rpm, led to a statisticaly significant increase in milling energy consumption.

1. INTRODUCTION

Particle size distribution of solids is often an important quality factor while various types of size reducing equipment are used. Comminution equipment can be classified according to the process, the maximum size of product or by the predominant stress causing the comminution [1]. Size reduction is achieved by mechanical forces (compression, impact, and shear) that cause rupture. In any practical machine usually one of the forces is dominant and more important than the others [2].

Size reduction is also a very important unit operation in the production of chocolate (refining phase). During this operation cocoa solids and sugar crystals are reduced to the size that makes them small enough not to be detected on the tongue [3]. Usually it is carried out in a five roll mill with feed roll gap and roll speed as adjustable parameters [4]. It is followed by the phase of conching in which chocolate aroma is fully developing, and the newly created surface during the size reduction is covered with fat improving the flow properties [5]. However, these traditional production lines are relatively expensive with regards to investment, conduction and energy consumption especially for the medium-small size companies [3].

The objective of any kind of industrial production is to achieve high capacity, good product quality, followed by low investment and energy costs. New concepts and ideas only have chance of being successful if the yield as well as the quality of the finished products are not affected and requirements such as reduction of investment, operating and maintenance cost are met. Over the years possibilities and solutions have been sought out in order to find the alternative to traditional process and make it more efficient. The most common ones are based on using a ball mill [5]. They are vertical or horizontal cylinders (stationary tank), equipped with a rotating shaft with arms, filled to as much as 90% of the available volume with grinding media (usually steel balls) [6]. The mass and the balls are agitated by a shaft with arms, rotating at a variable speed [3]. The feed material is comminuted between the grinding media, the stirrer and the cylinder wall by compression and shear [6,7]. This kind of plant also could be used in the production of chocolate surrogates, cacao liquor, creams for

spreading, biscuit coatings and confectionery fat fillings [3]. Nevertheless, only a few papers have been published dealing with the issue of using the ball for these purposes [3,6,7,8].
The aim of this study was to examine the effect of agitator shaft speed on energy consumption of a laboratory ball mill.

2. MATHERIALS AND METHODS

Experiments were conducted using a laboratory ball mill constituted of a double-jacket cylinder, 0,25 m in diameter and 0,31 m in height (0,0152 m^3 in volume), containing 9,1 mm diameter water resistant steel balls and a stirring group. The vertical shaft with horizontal arms, while rotating, puts the steel balls in movement. The experiments were carried out at 35°C with the constant mass of the steel balls m=30 kg. The agitator shaft speed was increased from 10% to 100% (in steps of 10%) of the maximum speed which coresponds to a speed of 50 rpm.

The milling energy consumption, E [J/kg], was calculated by Eq.(1):

$$E = \frac{P\ t}{m} \tag{1}$$

Here m is the mass of the steel balls (30 kg) and t is the time of the grinding run (180 s) determined by the chronometer. Both m and t were kept constant during all grinding runs. The milling energy consumption during grinding runs was determined using the Network recorder MC750/UMC750 (Iskra MIS, Slovenia). Power readings, P [W], were recorded every 15 s, giving a total of 13 power readings during the 3 min interval of the grinding run. The results are expressed as mean ± standard deviation, as coefficient of variation, and as 95% confidence interval for mean values given by Student's t-distribution. The mean values of corresponding data (P) are used to calculate the milling energy consumption according to Eq.(1). The significance of the the differences between energy consumption obtained with different agitator shaft speeds were statistically analyzed using ANOVA (analysis of variance). All statistical analyses were performed using STATISTICA 10 software.

3. RESULTS AND DISCUSSION

Table 1. shows mean values, standard deviation, coefficient of variation, and 95% confidence interval for mean values given by Student's t-distribution, for the power readings recorded at different agitator shaft speeds. Also, the energy consumptions E [J/kg] calculated according to Eq (1) are given in Table 1.
Standard deviation and coefficient of variation show that at same agitator shaft speed, power readings varied to a extremly small extent with coefficient of variation below 0,3%. It also shows that the power measurements at same agitator shaft speed were highly reproducible. Since the mass of the steel balls (m = 30 kg) and the time of the grinding run (t = 180 s) have been kept constant throught the experiment, the power and energy consumption are directly correlated according to Eq.1 (the correlation coefficient is r = 1). This means that values of the basic statistic parameters, such as coefficient of variation, determined for the power readings can be directly transferred to energy consumption. Also, the correlation between the agitator shaft speed and power as well as the agitator shaft speed and energy consumption are very high (r = 0,996) giving almost a linear response as can be seen from figure 1.

Table 1. Power readings, energy consumption and basic statistical parameters

Power reading [W]	Agitator shaft speed - % of the maximum speed of 50 rpm									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1.	167,3	186,5	221,7	262,2	299,7	337,9	367,2	408,7	458,6	512,0
2.	167,3	185,8	221,4	262,7	299,2	337,0	366,0	408,5	458,4	511,3
3.	167,5	186,3	221,7	262,4	298,3	337,4	366,7	406,8	459,5	510,3
4.	167,8	186,5	221,4	261,7	298,3	336,5	366,0	407,5	458,1	511,1
5.	167,5	186,5	221,0	262,0	298,1	337,2	366,7	406,3	456,7	511,1
6.	167,5	187,0	220,7	262,7	298,3	336,5	367,0	406,6	457,7	511,1
7.	168,0	187,7	221,2	262,4	297,8	334,9	366,7	407,3	457,0	510,2
8.	167,3	186,5	221,2	261,5	298,5	336,3	365,3	406,1	457,2	508,8
9.	168,2	186,7	221,9	262,2	297,8	335,3	365,3	405,3	457,2	511,6
10.	168,5	187,7	221,7	261,5	298,8	336,3	365,8	406,3	455,8	510,4
11.	168,2	187,0	221,0	262,0	297,6	337,2	365,3	406,3	456,3	508,3
12.	168,2	186,7	220,7	262,0	298,0	337,0	365,8	407,1	456,5	509,2
13.	168,2	186,3	221,8	261,3	297,1	336,5	364,4	406,1	457,3	509,7
Mean value ± SD	167,81 ±0,43	186,71 ±0,54	221,34 ±0,41	262,05 ±0,45	298,27 ±0,68	336,61 ±0,82	366,01 ±0,82	406,84 ±0,97	457,41 ±1,03	510,39 ±1,13
CV	0,254	0,288	0,185	0,172	0,229	0,245	0,223	0,239	0,225	0,221
CI	167,81 ±0,25	186,71 ±0,33	221,34 ±0,25	262,05 ±0,27	298,27 ±0,41	336,61 ±0,50	366,01 ±0,49	406,84 ±0,59	457,41 ±0,62	510,39 ±0,68
Energy consumption E [J/kg]	1006,8	1120,2	1328,0	1572,3	1789,6	2019,7	2196,1	2441,0	2744,4	3062,3

SD - standard deviation
CV - coefficient of variation
CI - 95% confidence interval given by Student's t-distribution

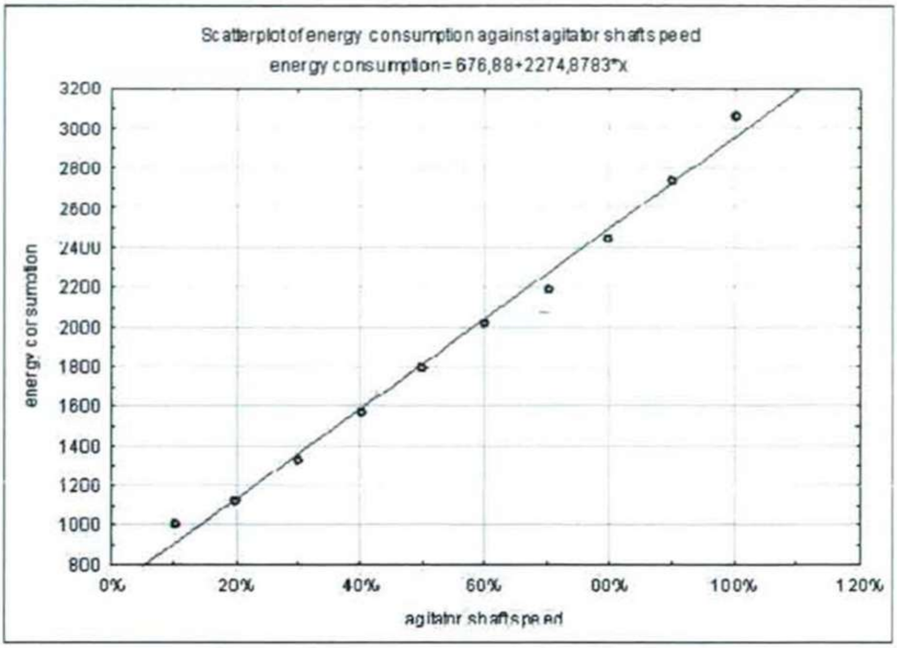

Figure 1. Effect of agitator shaft speed on milling energy consumption

Since power requirements and energy consumption are directly correlated, they both exhibited similar relationship as agitator shaft speed was altered. Increase of the agitator shaft speed from 10% to 100% (50 rpm) let to an increase in power requirement and milling energy consumption (table. 1). The results of the analysis of variance show that for every increase of 10%, increase in power requirements and milling energy consumption is statisticaly significant ($p<0,05$).

During any comminution operation, both material properties and milling methods affect particle breakage [9]. The factors affecting particle size reduction can be classified into those arising from the pshysicochemical properties of the material and those related to the design and operation of the milling equipment [10]. Beside energy consumption, the agitator speed also influences the magnitude of the stress and the relative contributions of compressive and shearing forces. The magnitude and the nature of the forces acting on particles will determine the degree of particle size reduction and energy required for grinding. In practice, the agitator should be run at lowest possible speed to meet the requirements of the process. However, in some cases, with slow agitator the particle size of the product and demands for increased capacity could not be met.

4. CONCLUSION

The consumption of energy in the process, esspecially in the process where large part of it is energy required for grinding, should be kept at the lowest possible level. The agitator shaft speed significantly influence the energy consumption of the ball mill. Therefore, the agitator should be run at lowest possible speed to meet the degree of particle size reduction that is needed (or any other product quality parameter), and handle the capacity of the process.

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