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MODELING THE MILL OPERATION ACCORDING TO DENSITY OF MILL BATCH AND SPECIFIC CAPACITY**

Abstract

This paper presents a new method of modeling the technological parameters of mill for the new conditions of mechanochemical treatment of mineral resources based on the Buckingham hypothesis. The specific volume of designed mill is changed if there is a change in the charge density of the mill, and dependence of the change is determined using a criterion equation. After examining the most well-known dimensional criteria, it was observed that Damkohler's criterion would quantitatively model the specific volume and density of the mill batch.
Keywords: *specific volume, batch density, Damkohler's criterion*

INTRODUCTION

It is known that by changing the type of the milling bodies is different efficiency of grinding of mineral raw material and thus different grinding fineness. In this paper, a hypothesis on the density of the charge of the mill as an influential factor in the specific capacity of grinding certain mineral deposits. The aim of this modeling is the ability to predict the capacity of the mill in terms of changes in the charge density of the mill. Density of the batch mill is the sum of densities of balls in bulk density, material density and the density of water, which is located in the gaps between the spheres. The density of the charge depends on the type of milling body, and grinding efficiency is increased with the use of the higher density spheres. This paper studies the effect of changes in the specific capacity [1] of the industrial mills in operation of the mill charge density and the possibility of adaptation of the mill plant to increase the capacity of the mill. Variations in the specific capacity of the mill was carried out to determine the Damkohler criterion [2]. The good factor regarding the specific mill that was built in the silica sand separation plant in Lukic polje near Milici, on which are carried out tests, is that the motor of the mill can support higher density batch milling body, so that the realized tests can be carried out in practice.

MATERIALS AND METHODS

Plant for grinding the quartz raw materials in Milici operates with the following operating characteristics [3]: the mill ca

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pacity is q = 10 t/h with the grain size is 90% - 600 μm Power of mill motor is N=280 kW, and mill volume is V = 13 m^3. Mass of silex milling bodies in the mill is 9000 kg. The mill rpm is 17.8 mills/min. The mill is discharged through a branch, and the pulp density in the outlet is 1.125 kg/l which means that it has 18% solid in the pulp, (C: T is then 1:4.94). Material mass in the mill is 2.34 t. Grinding time is 14 minutes. Value of the Bond work index for quartz sand is 15.0 kWh/t. Variations in the specific capacity of the mill was carried out to determine the Damkohler criterion.

Density of mill batch

In order to carry out the grinding process in a mill the amount of material that is mechano-chemically treated have to be present to such an extent that the filling of empty space between balls is larger from 5 to 10% by volume relative to the volume of empty space in the mill, when the balls are present without material. Density of mill batch is the sum of ball densities in bulk state, material density and water density, which is located in the gaps between the balls, Equation 1. Density of filled gaps between the balls is actually the second summand in Equation 1 and it is expressed through the pulp density ρ_p. Density of charge in the mill [4] is ρ_p:

$$\rho_s = \rho_{vk} + 1{,}15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_p, \frac{kg}{m^3} \tag{1}$$

Where:

- ρ_{vk} - *Density of balls in bulk state in kg/m³*
- ρ_{sk} - *Density of material from which the ball is made, in kg/m³*
- ρ_p - *Pulp density in kg/m³*

Density of material from which the ball is made;

Fe cast - ρ_{sk} = 7800 kg/m^3

Silicate - ρ_{sk} = 2600 kg/m^3

Density of balls in bulk state;

Fe cast - ρ_{vk} = 4100 to 4200 kg/m^3

Silicate - ρ_{vk} = 1800 to 1900 kg/m^3

Calculating the Density Values of Mill Batch in the Site of Quartz Sand Separation "Lukic polje" near Milici

Density of mill batch in the industrial process of mill operation in the site of separation Milici, was calculated according to Equation 1

$$\rho_s = \rho_{vk} + 1.15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_p =$$

$$= 1800 + 1.15 \cdot (1 - \frac{1800}{2600}) \cdot 1125 =$$

$$= 2198 \frac{kg}{m^3}$$

The pulp density ρ_p is measured by mining pycnometer and scale for measuring of density. The pulp density ρ_p cannot be high when the charge is of the same material, or when balls and raw materials to be crushed are the same material. Experimentally, it was found that the required optimum thickness of the pulp is ρ_p = 1125 kg/m^3 or 18% Č, in order to ensure the movement of material through the mill. This fact was obtained visually recognizing higher viscosity of batches if the pulp density increases, which causes release of balls from mill when the effects of mechano-chemical treatment cease. Density of mill batch can be increased if the type of grinding bodies is changed and the steel balls with higher density are adopted instead of silex balls, and then the pulp density can be increased what is a prerequisite for increasing the specific capacity [4,5].

Specific Capacity of Tested Mill

In order to find the specific capacity of mill for different product sizes, a change was experimentally carried out for hour capacity [6,7] of mill at optimal pulp density. The experiment began with small hour capacity, which amounted to 4 *t/h* and pulp density ρ_p=1125 *g/dm*^{3}, when it was necessary to add 18.2 *m*^{3}/*h* of water. Then, about 98.5% of class -200 µm was obtained in the final product, Figure 1, curve 1.

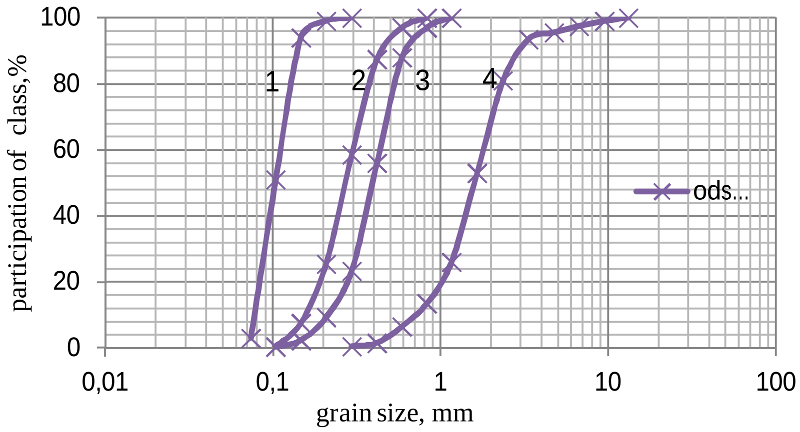

Figure 1 *Grain size distribution of grinding products Q = 4, 10, 15 t / h and grain size distribution of the starting sample*

After that, the hour capacity of mill was increased to 10 t/h, and the pulp density remained the same ρ_p=1125 *g/dm*^{3} when 45.6 *m*^{3}/*h* water had to be added, and when about 98% of class -600 µm was obtained in the final product, Figure 1, curve 2. In the third attempt, the hour capacity of mill was maintained at 15 *t/h* with the same pulp density ρ_p=1125 *m*^{3}/*h* when 68.4 *m*^{3}/*h* water had to be added, so about 97% of class -830 μm was obtained in the final product, Figure 1, curve 3. In the starting sample according to the developed grain size distribution, the contents of given size classes were: 0% -200 class μm 6% of class 600 μm and 12.3% -830 class μm, Figure 1, curve 4.

Specific capacity was able to be calculated using the formula 2 on the basis of data from Table 1. Specific capacity of the mill according to Magdalinović [1] is

$$q_{-d} = \frac{M}{V \cdot t} \cdot \left(\beta_{-d} - \alpha_{-d}\right) \left[\frac{kg}{m^3 \cdot s}\right] \quad (2)$$

Where:

q_{-d} - Specific capacity of the mill by the newly created accrual class

Grain size $-d$, in $kg/(m^3 s)$ (*d* is a square hole of sieve)

M - Mass of material in the mill, kg

V - Volume of the mill m^3

t - Grinding time, s

α_{-d} and β_{-d} Content of accrual size class $-d$ in the inlet and grinding product in parts of the unit.

Table 1 *Kinetic experiments of grinding in the industrial mill conducted to determine the specific capacity of mill by the newly accrual size class -d*

Capacity $Q\left[\frac{t}{h}\right]$	**Grinding time, t** $t=\frac{M}{Q}\cdot 3600[s]$	**Mass of material in the mill,** [M/kg]	**Volume in mill** [V/m^3]	**Content of accrual size class in grinding products and inlet**		$q_{-d}= =\frac{M}{V\cdot t}\cdot(\beta_{-d}-\alpha_{-d})$ $\left[\frac{kg}{m^3\cdot s}\right]$
				β_{-d}	α_{-d}	
4	2106	2340	13	0.98	0	$q_{-200}=0.084$
10	842.4	2340	13	0.97	0.06	$q_{-600}=0.194$
15	561.6	2340	13	0.97	0.12	$q_{-830}=0.272$

Mass of Material in Mill M

Mass of material for grinding is calculated by the formula 3 [1]

$$M=0.12\cdot V\cdot\Delta$$
$$=0.12\cdot 13\cdot 1.5\cdot 10^3=2{,}340\ kg \quad (3)$$

Where:

M - mass of material in mill, kg;

V - volume of mill m^3;

Δ - density of material in bulk density or material bulk density, kg/m^3;

0.12 - volume filling of empty space between the balls of the mill units.

Percentage of sample in a mill in the industrial grinding conditions in discharging through the sleeve is such that the bulk density occupies a space of 12% of the mill volume [6]. Such conditions are obtained when the level of mill filling with charge is 40%, and the empty space between the balls is of 30%, ($0.4\cdot 0.3=0.12$).

Volume of of mill V:

$$V=\frac{D^2\cdot\pi}{4}\cdot L=$$
$$=\frac{2.2^2\cdot 3.14}{4}\cdot 3.4=13\left[m^3\right] \quad (4)$$

Measured bulk density of material Δ:

$$\Delta=1.5\cdot 10^3\,kg/m^3 \quad (5)$$

EQUATION OF MODELING SPECIFIC CAPACITY OF THE MILL

According to the Buckingham π theorem, each equations contains υ of the associated physical quantities (υ, where υ = nd, ρ, D,, r .., etc.), between which unites m_1 values have independent dimensions of the size (M, L, t), which can be transformed into an equation that has m_1, and the dimensionless criteria and simplex, composed of those values [2,4]. This theorem is of great importance in the experimental and theoretical work. Dimensionless numbers encountered practically in solving any problems in chemical engineering. The formation of dimensionless numbers for a particular problem is the most easily achieved using the dimensional matrixes. Dimensional matrix consists of a square and remaining matrix. Rows of the matrix form the basis of size, and it will form a rank r matrix. The columns of the matrix represent the physical size or process parameters. Size of squares elementary matrices appear in all dimensionless numbers, while each element of the remaining matrix appears only in one dimensionless number.

Due to this reason, the remaining matrix should be comprised of the most important variables. Rearrange matrix (linear transformation) is done by the core matrix becoming a common matrix. After creation of a common matrix, dimensionless numbers arise in the following way. Each element of the remaining matrix, which is the numerator divided by the square of the matrix parameters that are graded below the number of the remaining elements of matrix. In the modeling process, where applicable chemistry reactions with transfer of impulse force and heat the criterion Damkohler (D_a) [2,3] as dimensionless units. Damkohler represents an equation modeling and specific capacity of the mill:

$$D_a = \frac{q_{-d}}{n \cdot \rho_s} \quad (6)$$

Where:

q_{-d} - specific capacity of mill according to the newly $-d$ accrual size class, $M/(L^3t^1)$

n - number of revolutions per unit time of t mill, $1/t$

ρ_s - batch density, M/L^3

Table 2 *Dimensional matrix of the Damkohler criterion*

	ρ_{up}	***d.***	***n***	q_{-d}
Mass M	1	0	0	1
length L	3.	1	0	3.
Time t	0	0	-1	-1
	Basic matrix			Remaining matrix

It only takes one dimensional linear transformation matrix I to -3 in the L line and ρ_{up} a column to zero, in order to be come converted dimensional matrix. Later should change character into t, so -1 to take the 1.

Table 3 *Renovated dimensional matrix*

	ρ_{up}	***d***	***n***	q_{-d}
M	1	0	0	1
3M + L	0	1	0	0
-t	0	0	1	1
	Basic matrix			Remaining matrix

The remaining matrix comprises one parameter, so

$$\frac{q_{-d}}{\rho^1 \cdot d^0 \cdot n^1} = \frac{q_{-d}}{\rho \cdot n} \equiv D_a$$

The Damkohler Criterion Values for Experimental Conditions

The Damkohler criterion value is calculated according to equation 6, and is given in Table 4 (column 5) for the following fineness of mechano-chemical treatment of 200 µm, 600 µm and 830 µm.

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Table 4 *Values of the criteria* D_a *for various specific capacities* q_{-d}

Measured capacity, $Q\left[\frac{t}{h}\right]$	**Specific grinding capacity,** $q_{-d}\left[\frac{kg}{m^3 \cdot s}\right]$	**Charge density in mill,** $\rho_s\left[\frac{kg}{m^3}\right]$	**r.p.m. of mill.** $n\left[s^{-1}\right]$,	**Value of Damkohler's criterion** $D_a = \frac{q_{-d}}{n \cdot \rho_{up}}$
4	0.084	2198	0.3	$D_a = \frac{q_{-200}}{n \cdot \rho_{up}} \cong 0{,}000127$
10	0.194	2198	0.3	$D_a = \frac{q_{-600}}{n \cdot \rho_{up}} \cong 0{,}000295$
15	0.272	2198	0.3	$D_a = \frac{q_{-830}}{n \cdot \rho_{up}} \cong 0{,}000413$

Density of mill charge can be significantly increased only if the higher density balls are used, and then to increase the specific grinding capacity that criterion D_a remains the same with those values given in Table 4 (column 5), and 6 according to the equation.

New Density of Mill Batch in a Case of Changing the Type Grinding Bodies

$$\rho_{up} = \rho_{vk} + 1.15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_{vm} =$$
$$= 4200 + 1.15 \cdot (1 - \frac{4200}{7800}) \cdot 1719 =$$
$$= 5112 \frac{kg}{m^3}$$

A new batch of density can be increased by changing the type of grinding bodies so that the instead silekx balls $\rho_{vk} =$ 1800 kg/m^3 the steel balls $\rho_{vk} = 4200$ kg/m^3 will be used. Pulp density can also be increased without the risk due to the increased viscosity of the pulp that reaches discharge batch of balls through the sleeve, and it is adopted to be about 68%, which is typical for this type of raw material and the type of mill, and then $\rho_p = 1719$ kg/m^3.

New Specific Capacity of Mill a Case of Changing the Type Grinding Bodies

A new specific capacity of mill for a new value of charge density can be obtained by calculation such as the value of criterion D_a for specific accounting of size class remain the unchanged. The requirement that the criterion D_a remained the unchanged for the new operating conditions of mill and the increased value of charge density in mill is that it must increase the specific capacity of mill for a given size class. After the new calculation of specific capacity, the grinding time can be easily calculated as well as the hour capacity of the mill as it is shown in Table 5.

Tabela 5 *New specific capacity of mill in using larger charge density in mill*

Calculated capacity, $Q\left[\frac{t}{h}\right]$	**Specific grinding capacity,** q_{-d} $\left[\frac{kg}{m^3 \cdot s}\right]$.	**Charge density in mill,** $\rho_s\left[\frac{kg}{m^3}\right]$	**r.p.m. of mill** $n\left[s^{-1}\right]$	**Value of Damkohler's criterion** $D_a = \frac{q_{-d}}{n \cdot \rho_{up}}$
10	0.209	5112	0.3	$D_a = \frac{q_{-200}}{n \cdot \rho_{up}} \cong 0.000127$
23	0.447	5112	0.3	$D_a = \frac{q_{-600}}{n \cdot \rho_{up}} \cong 0.000295$
35	0.635	5112	0.3	$D_a = \frac{q_{-830}}{n \cdot \rho_{up}} \cong 0.000413$

It is seen that it can be expected in the future at least two times higher capacity of grinding with a change of ball type, i.e. 10 t/h for the fineness of 85% 200 μm.

CONCLUSION

Specific grinding capacity according to the Damkohler criterion and equation 6 depends on the mill charge density, r.p.m. of mill and specific grinding capacity. In realization the idea to change the specific mill capacity, the charge density have to be changed, so from the criterion Damkohler equation it is easily to calculate the new higher specific mill capacity. With a change the type of grinding bodies (from silex balls to steel balls), it is possible to change the specific mill capacity or increase the fineness of 200 μm and that the capacity remains the same 10 t/h.

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MODELOVANJE RADA MLINA PREMA GUSTINI ŠARŽE MLINA I SPECIFIČNOM KAPACITETU**

Izvod

U radu je prikazana nova metoda modelovanja tehnoloških parametara rada mlina za nove uslove mehano-hemijskog tretmana mineralne sirovine na bazi hipoteze Buckinghama. Specifični kapacitet projektovanog mlina menja se ukoliko dolazi do promene gustine šarže mlina, a zavisnost te promene određuje se upotrebom kriterijumskih jednačina. Uvidom u većinu poznatih dimenzionih kriterijuma uočeno je da bi Damkohler-ov kriterijum mogao kvantitativno da modeluje specifični kapacitet i gustinu šarže mlina.

Ključne reči: *specifični kapacitet, gustina šarže, Damkohler-ov kriterijum*

UVOD

Poznato je da se promenom vrste meljućih tela ostvaruju različite efikasnosti mlevenja mineralne sirovine i time različita finoća mlevenja. U radu je postavljena hipoteza o gustini šarže mlina kao uticajnom faktoru na specifični kapacitet mlevenja odredjene mineralne sirovine. Cilj ovakvog modelovanja je mogućnost predviđanja kapaciteta mlina u uslovima promene gustine šarže mlina. Gustina šarže mlina jeste zbir gustine kugli u nasutom stanju, gustine materijala i gustine vode koja se nalazi u praznini između kugli. Gustina šarže najviše zavisi od vrste meljućih tela, a efikasnost mlevenja se povećava sa upotrebom kugli veće gustine. U ovom radu je ispitivan uticaj promene specifičnog kapaciteta [1] industrijskog mlina u funkciji gustine šarže mlina i mogućnosti adaptacije mlinskog postrojenja da bi se povećao kapacitet mlina. Variranje specifičnog kapaciteta mlina vršeno je da bi se utvrdio kriterijum Damkohlera [2]. Dobra okolnost u vezi sa konkretnim mlinom koji je ugrađen u pogonu separacije kvarcnog peska u Lukića polju kod Milića, i na kojem su izvršena ispitivanja, je ta što motor mlina može da podrži veću gustinu šarže meljućih tela, tako da se realizovana ispitivanja mogu sprovesti u praksi.

MATERIJAL I METODE

Postrojenje za mlevenje kvarcne sirovine u Milićima radi sa sledećim radnim karakteristikama [3]: kapacitet mlina je q = 10 t/h

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pri krupnoći od 90% - 600 μm. Snaga motora mlina je N=280 kW, a zapremina mlina je V = 13 m^3. Masa sileks meljućih tela u mlinu je 9.000 kg. Broj obrtaja mlina je 17,8 o/min. Mlin se prazni kroz rukavac, a gustina pulpe na izlazu je 1,125 kg/l što znači da ima 18% čvrstoga u pulpi, (Č:T je tada 1:4,94). Masa materijala u mlinu je 2,34 t. Vreme mlevenja je 14 minuta. Vrednost Bondovog radnog indeksa za kvarcni pesak je 15,0 kWh/t. Variranje specifičnog kapa-citeta mlina vršeno je da bi se utvrdio kriterijum Damkohlera.

Gustina šarže mlina

Da bi se vršio proces mlevenja u mlinu količina materijala koji se mehano hemijski tretira mora biti zastupljena u takvoj meri da je zapunjenost praznog prostora između kugli veća za 5 do 10% zapreminski u odnosu na zapreminu praznog prostora u mlinu kada su prisutne samo kugle bez materijala. Gustina n šarže mlina jeste zbir gustine kugli u nasutom stanju, gustine materijala i gustine vode koja se nalazi u praznini između kugli, jednačina 1. Gustina popunjene praznine između kugli je zapravo drugi sabirak u jednačini 1 i izražena je preko gustine pulpe ρ_p. G gustina šarže u mlinu [4] je ρ_s:

$$\rho_s = \rho_{vk} + 1{,}15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_p, \frac{kg}{m^3} \quad (1)$$

gde je:

ρ_{vk} - *gustina kugli u nasutom stanju, u kg/m³*

ρ_{sk} - *gustina materijala od kog je sačinjena kugla, u kg/m³*

ρ_p - *gustina pulpe, u kg/m³*

Gustina materijala od kog je sačinjena kugla;

Fe livene - ρ_{sk} = 7800 *kg/m³*

Silikatne - ρ_{sk} = 2600 *kg/m³*

Gustina kugli u nasutom stanju;

Fe livene - ρ_{vk} = 4100 do 4200 *kg/m³*

Silikatne - ρ_{vk} = 1800 do 1900 *kg/m³*

Izračunavanje vrednosti gustine šarže mlina u pogonu separacije kvarcnog peska „Lukića polje“ kod Milića

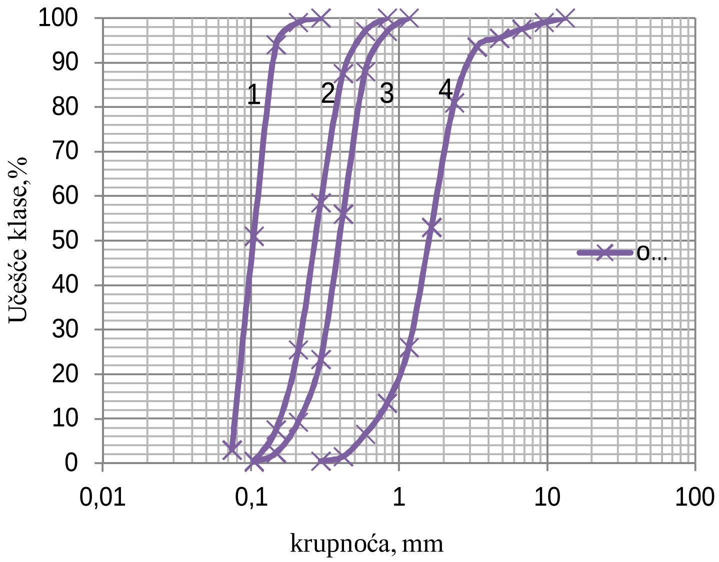
Gustinu šarže mlina u industrijskom procesu rada mlina u pogonu separacije Milići izračunali smo prema jednačini 1.

$$\rho_s = \rho_{vk} + 1{,}15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_p =$$
$$= 1800 + 1{,}15 \cdot (1 - \frac{1800}{2600}) \cdot 1125 =$$
$$= 2198 \frac{kg}{m^3}$$

Gustina pulpe ρ_p meri se rudarskim piknometrom i vagom za merenje gustine. Gustina pulpe ρ_p ne može biti velika kada je šarža od istog materijala, odnosno kada su kugle i sirovina koja se usitnjava od istog materijala. Eksperimentalno smo utvrdili da je potrebna optimalna gustina pulpe ρ_p = 1125 *kg/m³* ili 18% Č, da bi se obezbedilo kretanje materijala kroz mlin. Do ovakvog saznanja smo došli vizuelno uočavajući veću viskoznost šarže ukoliko se povećava gustina pulpe, a koja prouzrokuje izlazak kugli iz mlina kada prestaju efekti mehano-hemijskog tretmana. Gustina šarže mlina može da se poveća ukoliko se promeni vrsta meljućih tela i umesto sileks kugli usvoje čelične kugle sa većom gustinom, a tada može da se poveća i gustina pulpe što je preduslov za povećanje specifičnog kapaciteta [4,5].

Specifični kapacitet testiranog mlina

U cilju iznalaženja specifičnog kapaciteta mlina za različite finoće proizvoda eksperimentalno je vršena promena časovnog kapaciteta [6,7] mlina pri optimalnoj gustine pulpe. Eksperiment je otpočeo sa manjim časovnim kapacitetom koji je iznosio 4 t/h i gustinom pulpe ρ_p=1125 gd/m^3, kada je trebalo dodavati 18,2 m^3/h^1 vode. Tada smo dobili oko 98,5% klase -200 µm u finalnom proizvodu, slika 1, kriva 1.



Sl. 1. *Granulometrijski sastavi proizvoda mlevenja Q = 4, 10 i 15 t/h, kao i polaznog uzorka*

Nakon toga povećan je časovni kapacitet mlina na 10 *t/h*, a gustina pulpe ostala je ista ρ_p=1125 gd/m^3 kada je trebalo dodavati 45,6 m^3/h vode, i kada smo dobili oko 98% klase -600 µm u finalnom proizvodu, slika 1, kriva 2. U trećem pokušaju smo časovni kapacitet mlina održavali na 15 *t/h* sa istom gustinom pulpe ρ_p=1125 gd/m^3 kada je trebalo dodavati 68,4 m^3/h vode, pa smo dobili oko 97% klase -830 μm u finalnom proizvodu, slika 1, kriva 3. U polaznom uzorku prema urađenom granulometrijskom sastavu sadržaji pomenutih klasa krupnoće iznosili su; 0% klase -200 μm, 6% klase-600 µm, i 12,3% klase -830 µm, slika 1 kriva 4. Specifični kapacitet smo tada mogli izračunati prema formuli 2 na osnovu podataka iz tabele 1. Specifični kapacitet mlina prema Magdalinoviću [1] je:

$$q_{-d} = \frac{M}{V \cdot t} \cdot (\beta_{-d} - \alpha_{-d}) \left[\frac{kg}{m^3 \cdot s} \right] \quad (2)$$

gde je:

q_{-d} - specifični kapacitet mlina po novo stvorenoj obračunskoj klasi krupnoće *-d,* u kg/m^3/s (*d* predstavlja kvadratni otvor sita),

M - masa materijala u mlinu, *kg*

V - zapremina mlina, m^3

t - vreme mlevenja, *s*

α_{-d} i β_{-d} - sadržaj obračunske klase krupnoće -*d* u ulazu i proizvodu mlevenja u delovima jedinice

Tabela 1. *Opiti kinetike mlevenja u industrijskom mlinu sprovedeni da bi se odredio specifični kapacitet mlina po novostvorenoj obračunskoj klasi krupnoće -d*

Kapacitet $Q\left[\frac{t}{h}\right]$	**Vreme mlevenja, *t*** $t=\frac{M}{Q}\cdot 3600[s]$	**Masa materijala u mlinu** $[M/kg]$	**Zapremina mlina,** $[V/m^3]$	**Sadržaj obračunske klase krupnoće u proizvodu mlevenja i u ulazu**		$q_{-d}=$ $=\frac{M}{V\cdot t}\cdot(\beta_{-d}-\alpha_{-d})$ $\left[\frac{kg}{m^3\cdot s}\right]$
				β_{-d}	α_{-d}	
4	2106	2340	13	0,98	0	$q_{-200}=0{,}084$
10	842,4	2340	13	0,97	0,06	$q_{-600}=0{,}194$
15	561,6	2340	13	0,97	0,12	$q_{-830}=0{,}272$

Masa materijala u mlinu M

Masa materijala za mlevenje računa se prema formuli 3 [1]

$$M=0{,}12\cdot V\cdot\Delta=$$
$$=0{,}12\cdot 13\cdot 1{,}5\cdot 10^3=2340\ kg \qquad (3)$$

gde je:

M - masa materijala u mlinu, kg;

V - zapremina mlina, m^3;

Δ - gustina materijala u nasutom stanju ili nasipna masa materijala, *kg/m³*

0,12 - zapreminska zapunjenost praznog prostora između kugli u mlinu u delovima jedinice.

Procentualna zastupljenost uzorka u mlinu u industrijskim uslovimamlevenja kada je pražnjenje kroz rukavac je takva da u nasutom stanju zauzima prostor od 12% zapremine mlina [6]. Ovi uslovi se dobijaju kada je stepen zapunjenosti mlina šaržom do 40 % i za prazan prostor između kugli od 30 %, ($0{,}4\cdot 0{,}3=0{,}12$).

Zapremina mlina V:

$$V=\frac{D^2\cdot\pi}{4}\cdot L=\frac{2{,}2^2\cdot 3{,}14}{4}\cdot 3{,}4=13{,}m^3 \qquad (4)$$

Izmerena nasipna masa materijala Δ:

$$\Delta=1{,}5\cdot 10^3\ kg/m^3 \qquad (5)$$

JEDNAČINA MODELOVANJA SPECIFIČNOG KAPACITETA MLINA

Prema Buckinghamovom π teoremi svaka jednačina koja sadrži n_i povezanih fizičkih veličina (υ, gde je υ = n d, ρ, D, r .., itd.), između kojih m_i veličine imaju nezavisne dimenzije (M, L, t), može biti prevedena u jednačinu koja ima n_i do m_i bez dimenzionih kriterijuma i simpleksa, sastavljenih iz tih veličina [2,4]. Ova teorema ima veliki značaj u eksperimentalnom i teorijskom radu. Bezdimenzioni brojevi susreću se praktično kod rešavanja svakog problema iz hemijskog inženjerstva. Formiranje bezdimenzionih brojeva za određeni problem najlakše se postiže upotrebom dimenzionih matrica. Dimenziona matrica sastoji se od kvadratne i preostale matrice. Redovi matrica formiraju bazu dimenzija, a ona će formirati rang r matrice. Kolone matrice predstavljaju fizičke veličine ili parametre procesa. Veličina kvadrata osnovne matrice pojavljuju se u svim bezdimenzionim brojevima, dok će se svaki elemenat preostale matrice pojaviti samo u jednom bezdimenzionom broju. Iz ovog razloga preostala matrica bi trebalo da bude sastavljena od najvažnijih promenljivih veličina. Preuređivanje matrice (linearna transformacija) vrši se tako što jezgro matrice prelazi u zajedničku matricu. Nakon stvaranja zajedničke matrice bezdimenzioni brojevi nastaju na sledeći način. Svaki elemenat preostale matrice koji stoji u brojiocu deli se sa parametrima kvadratne matrice koji su stepenovani brojem ispod elementa preostale matrice. U području modelovanja procesa gde se primenjuju hemijske reakcije uz prenos impulsa sile i toplote koristi se kriterijum Damkohler (D_a) [2,3] kao bezdimenziona veličina. Damkohler predstavlja jednačinu modelovanja i specifičnog kapaciteta mlina:

$$D_a = \frac{q_{-d}}{n \cdot \rho_s} \tag{6}$$

gde je:

q_{-d} - specifični kapaciteta mlina prema novostvorenoj $-d$ obračunskoj klasi krupnoće, $M/(L^3 \cdot t)$

n - broj obrtaja mlina u jedinici vremena, $1/t$

ρ_s - gustina šarže, M / L^3

Tabela 2. *Dimenziona matrica Damkohler ovog kriterijuma*

	ρ_{up}	***d***	***n***	q_{-d}
Masa M	1	0	0	1
dužina L	-3	1	0	-3
Vreme t	0	0	-1	-1
	Osnovna matrica			Preostala matrica

Potrebna je samo jedna linearna transformacija dimenzione matrice I to -3 u L redu i ρ_{up} koloni na nulu, kako bi postala preuređena dimenziona matrica. Kasnije treba promeniti znak u t redu, tako da -1 pređe u 1.

Tabela 3. *Preuređena dimenziona matrica*

	ρ_{up}	***d***	***n***	q_{-d}
M	1	0	0	1
3M+L	0	1	0	0
-t	0	0	1	1
	Osnovna matrica			Preostala matrica

Preostala matrica sadrži jedan parameter pa je,

$$\frac{q_{-d}}{\rho^1 \cdot d^0 \cdot n^1} = \frac{q_{-d}}{\rho \cdot n} \equiv D_a$$

Vrednosti kriterijuma Damkohler za eksperimentalne uslove

Vrednosti kriterijuma Damkohler izračunavaju se prema jednačini 6, a date su u tabeli 4 (kolona 5) za sledeće finoće mehanohemijskog tretmana 200 µm, 600 µm i 830 µm.

Tabela 4. *Vrednosti kriterijuma* D_a *za različite specifične kapacitete* q_{-d}

Izmereni kapacitet $Q\left[\frac{t}{h}\right]$	**Specifični kapacitet mlevenja** $q_{-d}\left[\frac{kg}{m^3 \cdot s}\right]$	**Gustina šarže u mlinu** $\rho_s\left[\frac{kg}{m^3}\right]$	**Broj obrtaja mlina** $n\left[s^{-1}\right]$	**Vrednost Damkohler-ovog kriterijuma** $D_a = \frac{q_{-d}}{n \cdot \rho_{up}}$
4	0,084	2198	0,3	$D_a = \frac{q_{-200}}{n \cdot \rho_{up}} \cong 0{,}000127$
10	0,194	2198	0,3	$D_a = \frac{q_{-600}}{n \cdot \rho_{up}} \cong 0{,}000295$
15	0,272	2198	0,3	$D_a = \frac{q_{-830}}{n \cdot \rho_{up}} \cong 0{,}000413$

Gustina šarže u mlinu može značajno da se povećava jedino ako upotrebimo kugle veće gustine, a tada treba povećati i specifični kapacitet mlevenja, da bi kriterijum D_a ostao jednak sa onim vrednostima koje su date u tabeli 4, (kolona 5) i prema jednačini 6.

Nova gustina šarže mlina u slučaju promene vrste meljućih tela

$$\rho_{up} = \rho_{vk} + 1{,}15 \cdot (1 - \frac{\rho_{vk}}{\rho_{sk}}) \cdot \rho_{vm} =$$
$$= 4200 + 1{,}15 \cdot (1 - \frac{4200}{7800}) \cdot 1719 =$$
$$= 5112\ \frac{kg}{m^3}$$

Nova gustina šarže može se povećati tako što će se promeniti vrsta meljućih tela, pa će se umesto sileks kugli ρ_{vk} =1.800 kg/m^3 koristiti čelične kugle ρ_{vk} = 4.200 kg/m^3. Gustina pulpe takođe može biti povećana bez opasnosti da zbog povećanog viskoziteta pulpe dođe do pražnjenja šarže kugli kroz rukavac, i mi smo usvojili da ona bude oko 68% što je uobičajeno za ovu vrstu sirovine i tip mlina, a tada je ρ_p =1.719 kg/m^3

Novi specifični kapacitet mlina u slučaju promene vrste meljućih tela

Novi specifični kapacitet mlina za novu vrednost gustine šarže može se dobiti računskim putem tako što će vrednost kriterijuma D_a za određenu obračunsku klasu krupnoće ostati nepromenjena. Uslov da bi kriterijum D_a ostao nepromenjen za nove uslove rada mlina odnosno za povećanu vrednost gustine šarže u mlinu jeste taj da se mora povećati specifični kapacitet mlina za datu obračunsku klasu krupnoće. Nakon izračunavanja novog specifičnog kapaciteta lako se može izračunati vreme mlevenja i časovni kapacitet mlina što je i prikazano u tabeli 5.

Tabela 5. *Novi specifični kapaciteta mlina pri upotrebiveće gustini šarže u mlinu*

Izračunati kapacitet $Q\left[\frac{t}{h}\right]$	**Specifični kapacitet mlevenja** $q_{-d}\left[\frac{kg}{m^3\cdot s}\right]$.	**Gustina šarže u mlinu** $\rho_s\left[\frac{kg}{m^3}\right]$	**Broj obrtaja mlina** $n\left[s^{-1}\right]$	**Vrednost Damkohler-ovog kriterijuma** $D_a = \frac{q_{-d}}{n\cdot\rho_{up}}$
10	0,209	5112	0,3	$D_a = \frac{q_{-200}}{n\cdot\rho_{up}} \cong 0{,}000127$
23	0,447	5112	0,3	$D_a = \frac{q_{-600}}{n\cdot\rho_{up}} \cong 0{,}000295$
35	0,635	5112	0,3	$D_a = \frac{q_{-830}}{n\cdot\rho_{up}} \cong 0{,}000413$

Vidimo da se u perspektivi može očekivati najmanje dva puta veći kapacitet mlevenja sa promenom vrste kugli odnosno 10 *t/h* za finoću 85% -200 μm.

ZAKLJUČAK

Specifični kapacitet mlevenja prema kriterijumu Damkohler i jednačini 6 zavisi od gustine šarže mlina broja obrtaja mlina i specifićnog kapaciteta mlevenja. Kod realizacije ideje da se menja specifični kapacitet mlina morala bi se promeniti gustina šarže pa je iz kriterijumske Damkohler jednačine lako izračunati novi veći specifični kapacitet mlina. Uz promenu vrste meljućih tela (sa sileks kugli na čelične kugle) moguće je izvršiti promenu specifičnog kapaciteta mlina ili povećati finoću mlevenja na 200 μm a da kapacitet ostane isti 10 *t/h*. Ukoliko bi finoća ostala ista kapacitet bi se povećao 2,3 puta.

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