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SIZE DISTRIBUTION OF MAIZE MILLED PARTICLES OBTAINED BY USING A HAMMER MILL

Ioan BUDĂCAN, Dumitru POP, Ioan DROCAŞ

Abstract: *The size distribution of the ground particles is an important indicator due to which the quality of the final particles resulted from grinding process is measured. For example, in the animals food industry in order to get the desired recipe, the proper dimension of the feed particles is settled and that's the target dimension that need to be obtained after the grinding process. In the present study the particles size distribution of ground maize particles was measured with a vibratory sieve shaker with sieve dimension of 2.5, 1.25, 0.63 and 0.5 mm. The grinding process was conducted with a horizontal hammer mill and for it three different sieve sizes were used: 4, 6 and 8 mm. For the determination of the maize ground particles size distribution, Rosin – Rammler function was used. The minimum coefficient of determination obtained was* $R^2 = 0.975$. *The current research is useful for the determination of the sieve dimension, hammer configuration and grains moisture level that must be used in order to obtain the desired dimension and size distribution of the ground particles.*

Key words*: sieve dimension, maize, grinding, Rosin-Rammler function, size distribution.*

1. INTRODUCTION

The grinding process is generally an energy consuming process used for the fragmentation of different particles in many industries. In animals food industry the fragmentation process parameters must be well fitted all together in order to obtain the desired size dimension of final particles. This way, the necessities of animals settled with the recipe are well satisfied. The grinding process of particles has as direct effect the size reduction of them, characterized by the modification of size, shape and new surface creation. Naidu and Singh [8] established that the decrease of corn flour particles improves the hydrolysis yields. Chundawat *et* al. [5] studied the influence of corn stover size reduction particles and separation process of the hydrolysis process.

The size reduction of different types of materials was analyzed in several studies.

In one of this studies there was found the well fitted size distribution of alfalfa forage ground with a hammer mill on log normal distribution (Yang *et* al. [9]). In other study there was discovered the way that sieve opening dimension influence the size distribution of wheat and barley straws, corn stover and switch grass (Mani *et* al. [7]). Bitra et al. [2] took as controlling factor the sieve size of a knife mill in order to determine particle size of switch grass chop.

A big step forward in the grinding industry was done in the moment of implementing the utilization of mathematical function as a method for the determination of ground particles size distribution. Log-normal, Rosin-Rammler and Gaudin-Schuhmann functions are the most used three theoretical models in present with above stated purpose, and them are applied for all sort of materials. Based on variance analysis, Rosin-Rammler function was proven as best fitted model.

The aim of this paper is the evaluation of the results obtained when Rosin-Rammler function was applied for maize grains grinding with a hammer mill.

2. MATERIALS AND METHODS

In the current study one type of maize grains was used, but with two different moisture levels (m1 – dry maize 11.1%, m2 – wet maize 17.6%). The difference of grains moisture was achived by separating in two the whole quantity of grains and than watering half of them and storing the obtained quantity for 48h. The device used for the determination of the moisture level was a moisture meter Farmpro Grain (Supertech Agroline).

A horizontal hammer mill (MB 7.5 from S.C. TEHNOFAVORIT S.A. Bontida) was used for the grinding process and its power was 7.5 kW. In order to be able to have different configurations of the hammer mill, three types of sieves and two types of hammer were used.

The sieves were named generically s1, s2 and s3 with the sieve opening dimension of 4, 6 and 8 mm. The two types of hammer didn't have differences in length, width or tickness only in the configuration of the active zone (one was created with more steps as it can be seen in [4]. A Lutron DT-2234B digital tachometer (with $\pm(0.05\% + 1\ \text{digit})$ accuracy) was used for the measurement of the rotor velocity. The hammer mill is an integrated part of a compound feed production installation that is working at the University of Agriculture and Veterinary Medicine Cluj-Napoca [3].

The size distribution of ground maize particles was done according to ASABE S424.1 standard [1]. The separation process of particles was done with a vibratory sieve shaker Retsch AS300 (fig. 1). Four sives with different dimension of the opening were used (2.5, 1.25, 0.63 and 0.5 mm). The separation process had the duration of 1 minute. After that, the material from each sive was collected and than weighted with an electronic balance Kern PCB ($\pm$0.1 accuracy).

Fig. 1. Vibratory sieve shaker Retsch AS300

As it was previously stated, the size distribution of the ground particles was done in accordance with ASABE standard, and the equations used for determination of geometric mean dimension and geometric standard deviation are as follows [1]:

$$\bar{X}_i = \sqrt{X_i \cdot X_{(i-1)}} \tag{1}$$

$$X_{gm} = \log^{-1}\left[\frac{\sum(M_i \log \bar{X}_i)}{\sum M_i}\right] \tag{2}$$

$$S_{gm} = \log^{-1}\left[\frac{\sum\left(M_i\left(\log \bar{X}_i - \log X_{gm}\right)^2\right)}{\sum M_i}\right]^{1/2} \tag{3}$$

where:

$\bar{X}_i$ - geometric mean dimension of particles on *i*th sieve, mm;

X_i - the diameter of the sieve opening of the *i*th sieve, mm;

$X_{(i-1)}$ - the diameter of the sieve opening of the *(i-1)*th sieve, mm;

X_{gm} - geometric mean dimension, mm;

S_{gm} - geometric standard deviation;

M_i - the mass of the material retained on sieve ith, g.

The cumulative undersize mass of the ground particles in percent was calculated using Rosin-Rammler equation:

$$M_{CU} = 100\left[1 - e^{-\left(\frac{D_p}{a}\right)^b}\right] \qquad (4)$$

where:

M_{CU} - cumulative undersize mass, %;

D_P - particle size, assumed to be equivalent with the diameter of the sieve opening, mm;

a - Rosin-Rammler size parameter, mm;

b - Rosin-Rammler distribution parameter (skewness parameter).

By rearranging equation (4), one can find a relation that is useful in calculating the undersize particles dimension of a known amount of material that passed from a given sieve:

$$D_p = \mathrm{a}\left[-ln\left(1 - \frac{M_{CU}}{100}\right)\right]^{1/b} \qquad (5)$$

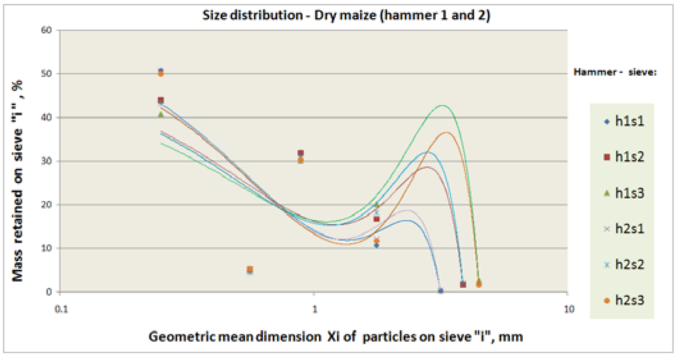
Applying equation (5) for two representative sieves, the Rosin-Rammler parameters "a" and "b" can be calculated, and therefore it will be easy to calculate the particles dimension of any undersize known amount of material (in percent).

3. RESULTS AND DISCUSSIONS

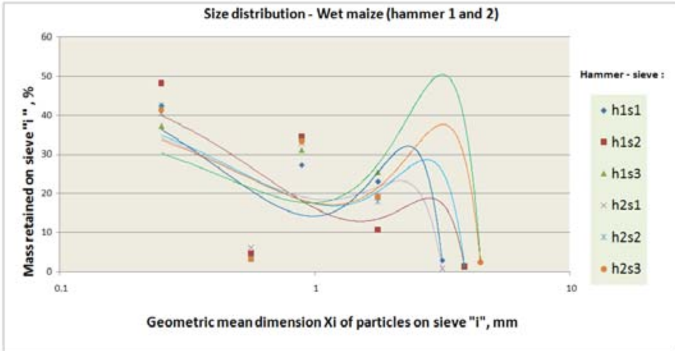
Size distribution of particles

Maize ground particles mass percent retained on each vibratory sive shaker sieve, in relation to geometric mean length, $\bar{X}_i$, of particles on each sieve, following log-normal distribution for all the hammer mill screens is represented in figure 2.

A skewness can be observed to the left, and the reason for it is the fact that the majority of the ground particles were smaller than 1 mm („fine particles").



a)



b)

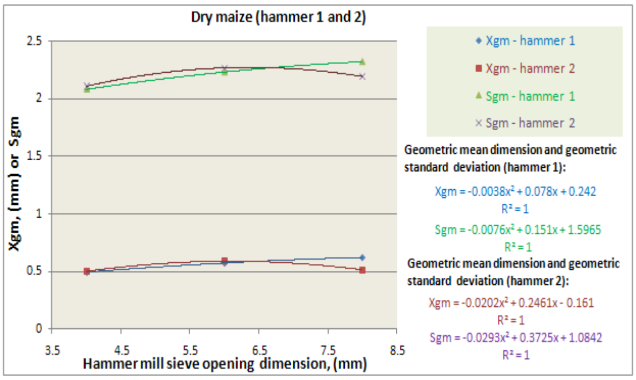
Fig. 2. Distribution of the ground wheat particles on vibratory sieve shaker: a) for dry wheat; b) for wet wheat.

If we want to appreciate what is the total percent of the fine particles, then we have to add the percent corresponding to 0.5 mm and 0.63 mm respectively plus the percent of the material on the sieve shaker pan. By doing this and by using *hammer 1*, we found a percent between 76.4% (sieve 3) and 88.2% (sieve 1) for dry maize grains (fig. 2a), and from 71.4% (for sieve 3) to 87.4% (for sieve 2) for wet maize grains (fig. 2b). In the situation in which *hammer 2* was used in the grinding process, the values of the total mass of particles finer than 1 mm varies between 79% (for sieve 2) and 86.8% (for sieve 1) for dry grains, and from 78% (for sieve 3) to 79.8% (for sieve 2) for wet grains. As one can see is the fact that the differences between the minimum and maximum total material mass smaller than 1 mm has sinignifically decrease.

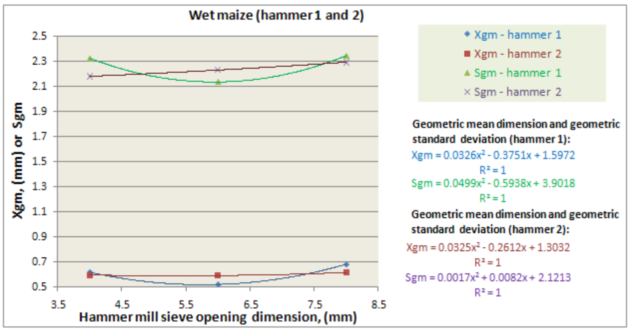
Geometric mean dimension and geometric standard deviation

The mean geometric dimension of dry maize ground particles increase from 0.493 mm (sieve

1) to 0.621 mm (sieve 3) when *hammer 1* was used for grinding (fig. 3a). In comparison, when *hammer 2* was used, the values of geometric mean dimension of ground particles had bigger values (0.5 mm for sieve 1 and 0.588 mm for sieve 2) with the only difference in the value of mean particles dimension obtained when sieve 3 was used (0.514 mm).



a)



b)

Fig. 3. Variation of geometric mean dimension (X_{gm}) and geometric standard deviation (S_{gm}) of wheat grains: a) dry grains; b) wet grains.

When wet maize grains were ground (fig. 3b), the opposite trend was observed: the values of geometric mean dimension of ground particles were bigger when using *hammer 1* than in the case of using *hammer 2* (between 0.519 mm to 0.681 mm, besides 0.590 mm to 0.614 mm). The only deviation from this rule was observed for the 6 mm sieve dimension (sieve 2), where the value of the mean geometric dimension of the ground particles for *hammer 1* (0.519 mm) was smaller than the one obtained (0.588 mm) when *hammer 2* was used.

The variation of the geometric mean dimension obtained after grinding due to hammer type, sieve opening dimension and grains initial moisture can be analyzed in table 1. By analyzing the results, a correlation can be observed between Rosin-Rammler size parameter *a* and geometric mean dimension of ground particles: the bigger the values of geometric mean dimension, the smaller are the values of parameter *a* (as general trend) .

Table 1

Estimated values of geometric mean dimension, geometric standard deviation, and parameters of Rosin-Rammler equation and its coefficient of determination for hammer grinding of maize grains.

Grinding process indicative (hammer type, sieve number, moisture level)	Geometric mean dimension, Xgm, mm	Geometric standard deviation, Sgm,	Rosin-Rammler size parameter, a, mm
h1 - s1 - m1	0,493	2,079	1,471
h1 - s2 - m1	0,572	2,229	1,222
h1 - s3 - m1	0,621	2,318	1,110
h1 - s1 - m2	0,618	2,325	1,068
h1 - s2 - m2	0,519	2,136	1,386
h1 - s3 - m2	0,681	2,346	0,967
h2 - s1 - m1	0,500	2,106	1,444
h2 - s2 - m1	0,588	2,265	1,183
h2 - s3 - m1	0,514	2,191	1,421
h2 - s1 - m2	0,595	2,181	1,159
h2 - s2 - m2	0,590	2,231	1,175
h2 - s3 - m2	0,614	2,294	1,121

Table 1 – continuation

Grinding process indicativ (hammer type, sieve number, moisture level)	Rosin-Rammler distribution parameter, b	Coefficient of determination, R^2
h1 - s1 - m1	1,254	0,986
h1 - s2 - m1	1,186	0,988
h1 - s3 - m1	1,134	0,992
h1 - s1 - m2	0,999	0,988
h1 - s2 - m2	1,309	0,980
h1 - s3 - m2	1,125	0,978
h2 - s1 - m1	1,200	0,985
h2 - s2 - m1	1,140	0,986
h2 - s3 - m1	1,172	0,988
h2 - s1 - m2	1,247	0,993
h2 - s2 - m2	1,207	0,977
h2 - s3 - m2	1,190	0,975

The values of geometric standard deviation, S_{gm}, had generally an ascending trend (when increasing the dimension of sieve opening), and this happened regardless of hammer type or grains moisture level.

When grinding dry grains with *hammer 1*, the values of geometric standard deviation took values between 2.079 and 2.318, and in the case of using *hammer 2* from 2.106 to 2.191 (with a deviation in the situation of using sieve 2, case in which 2.265 was the resulted value for this parameter). In the second situation in which wet maize grains were ground, when *hammer 1* was used, the values of geometric standard deviation had values between 2.325 and 2.346 m (with a deviation in the situation of using sieve 2 - 2.136) and between 2.181 and 2.294 when *hammer 2* was used.

As a conclusion, the values for geometric mean dimension and geometric standard deviation change principally due to the modification of sieve opening dimension.

4. CONCLUSIONS

As a controlling factor for the determination of the maize ground particles the sieve opening dimension was used, but it was shown that also the hammer type and grains moisture had an influence as well.

Rosin-Rammler equation fitted size distribution data of ground maize particles with a coefficient of determination $R^2 > 0.975$. Rosin-Rammler size parameter a is inversely proportional with geometric mean dimension X_{gm} of the material particles.

The geometric mean dimension of the particles increased with increasing the dimension of the sieve opening (for both wet and dry grains) regardless hammer type. In the case of geometric standard deviation, the values increased with increasing the sieve opening dimension regardless hammer type or grains moisture, but bigger values were observed for wet maize grains comparing with those obtained for dry grains.

The size distribution of ground particles can be use successfully for the selection of hammer configuration and material moisture level. This two process parameters must be selected in such way that we achieve from the grinding process the desired size distribution of the ground particles.

5. ACKNOWLEDGMENT

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Distribuția pe clase de dimensiuni a particulelor de porumb măcinate cu ajutorul unei mori cu ciocane

Rezumat: *Distribuția pe clase de dimensiuni a particulelor de material măcinat este un indicator important cu ajutorul căruia este evaluată calitatea produsului final rezultat în urma măcinării. Spre exemplu, în industria obținerii furajelor concentrate folosite la hrana animalelor, pentru a putea obține rețeta dorită, dimensiunea potrivită a particulelor de material final este stabilită în prealabil, aceasta fiind dimensiunea țintă ce se dorește a fi obținută în urma procesului de măcinare. În studiul de față distribuția pe clase de dimensiuni a produsului măcinat a fost evaluată cu ajutorul unui clasificator cu site prevăzut cu patru site având dimensiunea ochiurilor sitei de 2.5, 1.25, 0.63 şi 0.5 mm. Procesul de măcinare s-a realizat cu ajutorul unei mori cu ciocane cu rotor orizontal. Trei tipuri diferite de site au fost folosite, având dimensiunea ochiurilor sitei de 4, 6 şi respectiv 8 mm. Pentru determinarea distribuției pe clase de dimensiuni a particulelor de porumb rezultate în urma măcinării s-a folosit funcția lui Rosin – Rammler. Coeficientul minim de determinare obținut a fost* $R^2 = 0.975$. *Lucrarea de față este utilă pentru determinarea dimensiunii ochiurilor sitei, configurației ciocanelor şi umidității optime a produsului inițial, astfel încât să se obțină dimensiunea dorită a particulelor de măciniş.*

Ioan BUDĂCAN, PhD student, Technical University of Cluj-Napoca, The Department of Mechanical Systems Engineering. E-mail: budacan_ioan@yahoo.com, phone number: +40 740 409 671, Cluj – Napoca, România.

Dumitru POP, professor, PhD, Technical University of Cluj-Napoca, The Department of Mechanical Systems Engineering, E-mail: Dumitru.Pop@omt.utcluj.ro, Cluj – Napoca, România.

Ioan DROCAŞ, professor, PhD, University of Agriculture and Veterinary Medicine Cluj-Napoca, The Department of Technical and Soil Sciences, E-mail: drocas_i@yahoo.fr, Cluj – Napoca, România.