



SPECIFIC ENERGY CONSUMPTION FOR REDUCING THE SIZE OF MAIZE GRAINS USING A HAMMER MILL

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Abstract: *By measuring the energy requirement for grinding maize grains and by fitting the obtained data into Rittinger, Bond and Kick models, a decision can be taken about the reduction theoretical model that best fits the current process. Useful information can be obtained from this, in order to decide what would be the energy required for the grinding process based on the required dimension of the final particles, the moisture level of initial particles and based on the configuration of the hammers. Maize grains were milled using a hammer mill MB 7.5 (7.5 kW) with three sieve 4, 6 and 8 mm opening dimension. A direct relationship was drawn taking into account the specific grinding energy requirement and the hammer mill sieve opening dimension. The next step was to fit the data on specific grinding energy to Rittinger, Bond and Kick models. The results showed that the best fitted model with a coefficient of determination was Rittinger model.*

Key words: *Bond, Rittinger, Kick, specific energy, size distribution, grinding process, maize grains.*

1. INTRODUCTION

Grinding process of grains is very important for the downstream processes in animal food industry. Because this process is a high energy consuming one used in feed grain processing, it is important to be able to predict the required energy for its completion. For size reduction, mechanical energy is needed to breakdown the material and also to overcome the friction between the moving parts of the machine. The amount of energy properly used for size reduction is not more than 1% [8], and by having such big energy loss (up to 99%) is important to understand the grinding process in order to reduce the required energy.

The reduction process of initial particles inside the hammer mill is due to: impacts with the hammers, impacts with the walls of the grinding chamber, the frictions and impacts of the particles themselves, and finally due to the friction of the particles with the sieve opening sharp edges. If we want to analyze the performance of a hammer mill, the criteria by

which this analysis is done is the specific energy consumption and the size distribution of the final particles. Lopo [5] concluded that the energy consumption of grinding biomass depends on the ratio of the material particles size distribution before and after grinding, moisture content, particles material density, bulk density of the final material, the feed rate of the material and the machine parameters. Specific energy consumption increased when sieve opening size decreased [4].

As previously mentioned, the energy consumption in the grinding process is high. Samson [9] recorded a specific energy consumption of 161.64 for the grinding of switch grass with a hammer mill. Ghorbani [4] recorded a 30.51 for grinding 18 mm alfalfa chops when grinding with hammer mill sieve size of 1.68 mm and 5.65 when grinding 12 mm alfalfa chops with 4.76 mm sieve size. Mani [6] has grinded corn stover with moisture level of 6.2% with a hammer mill having the sieve sizes of 0.8, 1.6

and 3.2 mm and specific energy consumption was 79.2, 53.28 and 25.2 respectively.

Different methods have been used by different researchers for the measurement of grinding energy. Ghorbani [4] used for the grinding of alfalfa chops with a hammer mill a watt-hour meter connected to a data logging system. Manlu [7] used torque and speed sensors connected to the engine shaft in order to measure the specific grinding energy required for grinding Oak wood chips.

Bond, Rittinger and Kick theoretical models were used over the years for the prediction of energy consumption during grinding process. Fellows [3] discovered that all this grinding models have given good results based on the type of grinding for which they were used: Kick model is suitable for coarse grinding, Bond model for intermediate grinding and Rittinger model is best fitted for fine grinding.

The aims of this paper are:

- the measurement of the specific grinding energy for milling maize grains with a hammer mill having three different sieve sizes;
- fit the experimental measured data into the three grinding models;
- determine which of the three models is best fitted on the current grinding case study.

2. MATERIALS

The initial quantity of maize grains that were prepared for grinding had an initial moisture of 11.1%. This quantity of material was divided in two parts. One of the resulting quantities was watered and then stored for 48h in order to get it to another level of moisture. After this period of time, the moisture of the grains was again measured using a moisture meter Farmpro Grain (Supertech Agroline). The recorded value was 17.6%. For the grinding process, samples of 19 kg were used and for each configuration of the hammer mill (hammer type, sieve openings dimension, moisture level of grains) three repetitions were performed.

2. APPARATUS

The experimental study was conducted with a hammer mill MB 7.5 (S.C.

TEHNOFAVORIT S.A. Bontida) powered by a 7.5 kW electric motor [2]. The hammer mill rotor has four rows of hammers, and on each row 4 hammers are assembled. Two different hammer types were used in order to have a perspective also on the influence of hammer configuration on milling parameters [2]. The only difference between them is in the active zone of the hammer, *hammer 2* being designed with more cutting edges [2].

The hammer mill is a part of a complex installation used for production of compound food for Farm Industry purpose. This installation is currently working at University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca.

A dedicated device (Metrawatt Co. model Mavowatt 45) was used for measuring several parameters of the grinding process. Its configuration is presented in figure 1.

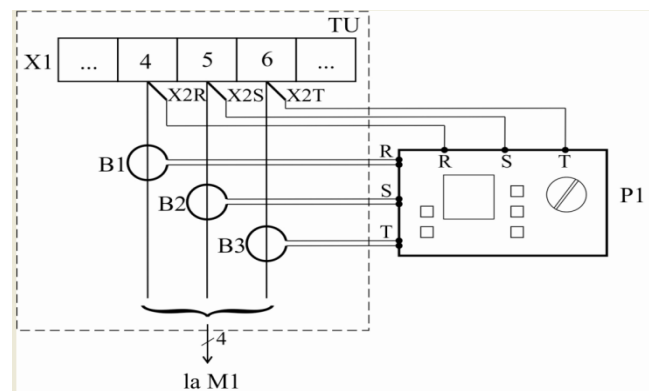


Fig. 1. Mavowatt 45 energy and power disturbance analyzer (P1 – the measuring device; TU - control panel of the machine; X1...4,5,6.. – device plugs; X2R, X2S, X2T - the location where the plugs were mounted; R, S, T – voltage inputs; B1, B2, B3 – current transducers, M1 – electric motor; 4 – electric motor power supply)

The details regarding the parameters that can be obtained as well as its operation may be found in [2].

3. METHOD

The *grinding process* was conducted for samples of maize grains having a mass of 19 kg that were feed into the hammer mill, and the total time required to ground them was recorded. Also, with the Energy and Power

Disturbance Analyzer the power drawn by the hammer mill motor during operation was also obtained. The specific grinding energy was calculated as a ratio between the net input electric energy (kWh) and the weight of the maize sample that was milled (in our case).

For the determination of *particle size distribution* after the milling process, samples of 500 g were taken for analysis. The size distribution analysis of the ground particles was done according ASABE standard S424.1 [1]. A vibratory sieve shaker Retsch AS300 was used for the separation process. This device is composed of four sieves with the openings dimensions of 2.5, 1.25, 0.63 and 0.5 mm. After the separation process (that took 1 minute) the material was collected from each sieve at a time and than weight with an electronic balance Kern PCB with ±0.1 accuracy.

The specific grinding energy consumption can be calculated with the next relation:

$$E_s = C \int_1^2 \frac{dD}{D^n} \quad [kWh/t] \quad (1)$$

where:

- specific energy consumption ();
- the differential size;
- D – dimension of the particles;
- C, n – constants.

In the case of Kick energy consumption theory the value of the constant *n* in equation (1) is 1. The value given by Rittinger to this constant was 2. According to him, the fragmentation process of particles is principally a shearing process, and due to this fact the energy consumption is proportional with the new surface created. After Bond theory the value for constant *n* is 3/2. Based on all this assumption, the form of equation (1) for all this theories are as follows [4]:

$$E = C_K(D_1 - D_2) \quad (2)$$

$$E = C_R(1/D_2 - 1/D_1) \quad (3)$$

$$E = C_B(10/\sqrt{D_2} - 10/\sqrt{D_1}) \quad (4)$$

In the above equations is the dimension of the particles before grinding and is the dimension of the particles after it.

For the *statistical analysis* the function LINEST from Microsoft Excel software was used. In all grinding cases based on the calculated specific grinding energy and on the initial and final dimension of the particles the constants , and were predicted with a coefficient of determination and MSE (mean square error). The next step was to determine the predicted specific grinding energy by using this predicted constants.

In order to determine the accuracy of the fitted models, the percentage of relative errors of the predicted energy consumption were calculated with the relation:

$$Error = \left(\frac{\text{predicted } E_s}{\text{measured } E_s} - 1 \right) \times 100 \quad [\%] \quad (5)$$

4. RESULTS

Particle size distribution

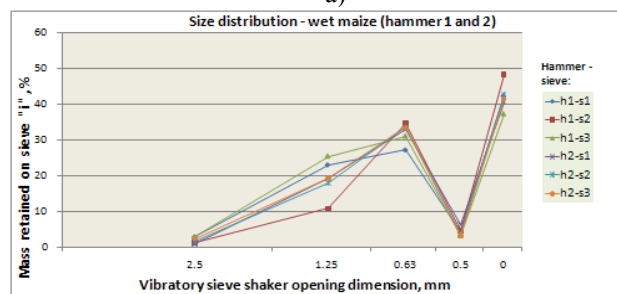
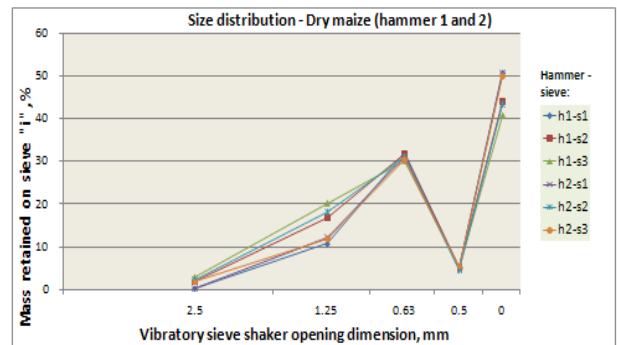


Fig. 2. Particles size distribution for ground maize in the case of grinding: a) dry grains; b) wet grains.

The particles size distribution for ground material is shown in figure 2. Whether wet or dry maize grains were ground, and irrespective

of the hammer and sieve used, it can be noticed that in most cases the amount of material that remains on the sieve with an opening dimension of 0.63 mm is over 30%.

Another aspect that can be noticed is that in the case of grinding dry maize grains the amount of fine material passing through 0.5 mm sieve opening dimension and lands on the vibratory sieve shaker pan is higher than for grinding wet maize grains (between 40.8% and 50.8% in first case and between 37.2% and 48.2% in second case).

It is also observed that on the 1.25 mm sieve opening dimension remains more material in the case of grinding wet maize grains than for grinding dry one.

Energy requirement for grinding

The specific grinding energy consumption for grinding maize grains is shown in table 1. It can be observed that the specific energy consumption decreases with increasing sieve opening dimension irrespective of the hammer type or maize grains moisture. The sharpest decrease was observed in the case of wet maize grains ground with hammer 1 (38.8%) and lowest in case of dry maize grains ground with hammer 2 (16.1%).

Table 1

Specific energy consumption for grinding maize grains

Hammer type - grains moisture level (1 – dry grains, 2 – wet grains)	Sieve opening dimension, mm	E_s , kWh/t
h1 – p2	4	7.22
	6	5.49
	8	4.42
h2 – p2	4	5.28
	6	4.67
	8	4.13
h1 – p1	4	4.63
	6	4.65
	8	3.75
h2 – p1	4	6.03
	6	5.19
	8	5.06

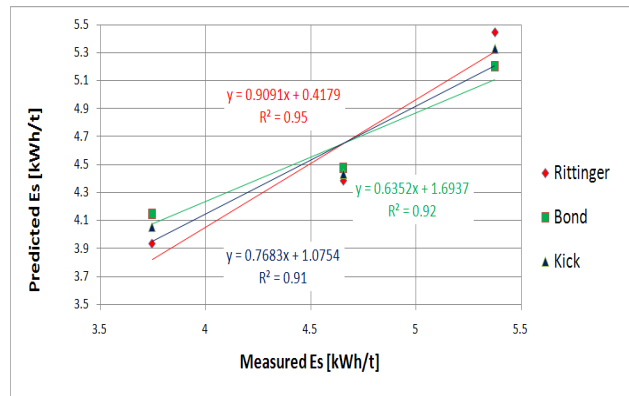
Theoretical model for specific grinding energy consumption

The specific energy consumption (E_s) data for grinding maize grains were fitted to three theoretical models (Rittinger, Bond and Kick) by using LINEST function of Microsoft Excel software. The estimated constant (C) for each model, the coefficient of determination R^2 and the mean square error (MSE) for the predicted values with respect to measured values are given in Table 2.

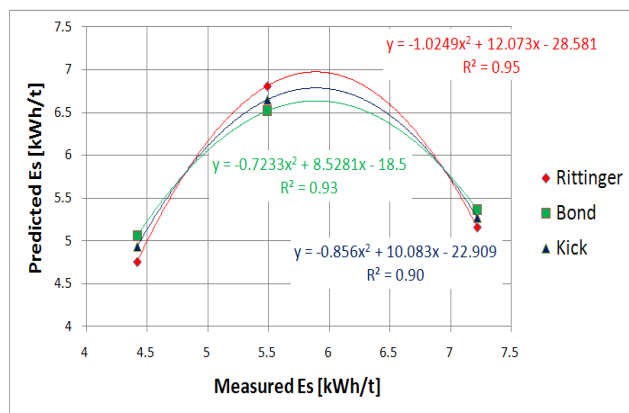
Table 2

Estimated constants (C) of the three models

Theoretical model		MSE (Mean square error)			
		Hammer 1 – dry maize	Hammer 1 – wet maize	Hammer 2 – dry maize	Hammer 2 – wet maize
Rittinger	C_R	4.27	5.75	4.76	4.81
	R^2	0.95	0.95	0.96	0.92
	MSE	2.39	17.45	5.33	4.42
Bond	C_B	0.68	0.89	0.77	0.74
	R^2	0.92	0.93	0.94	0.89
	MSE	3.34	18.66	5.5	4.78
Kick	C_K	0.72	0.96	0.81	0.8
	R^2	0.91	0.90	0.92	0.85
	MSE	3.70	19.43	5.82	5.63



a)



b)

Fig. 3. Comparison of measured and predicted specific grinding energy in the case of grinding with hammer 1: a) dry grains; b) wet grains

The predicted by the Kick model had the highest error in all cases. For all the experimental tests Rittinger model had the lowest MSE and the values of the coefficient of determination were higher than 0.92.

In figure 3 a comparison between predicted and measured values of specific grinding energy in the case of using hammer 1 is represented. Irrespective of the moisture level of the grains the coefficient of determination had the biggest values for Rittinger model. The same trend was observed in the case of using hammer 2 for grinding maize grains (fig. 4). Whether using hammer 1 or 2 for the grinding process, it can be seen that the theoretical model of Kick is the least accurate, the values of the determination coefficient recorded the lowest values.

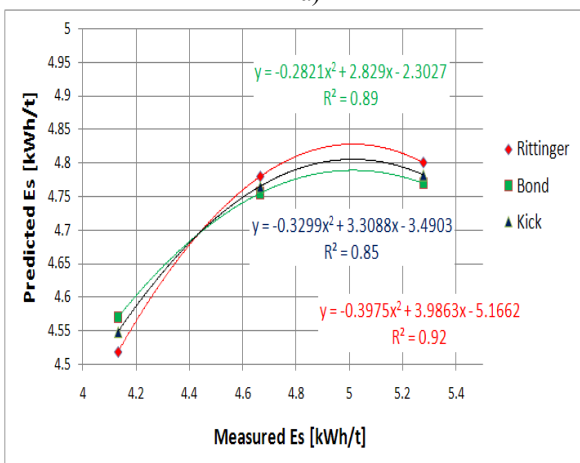
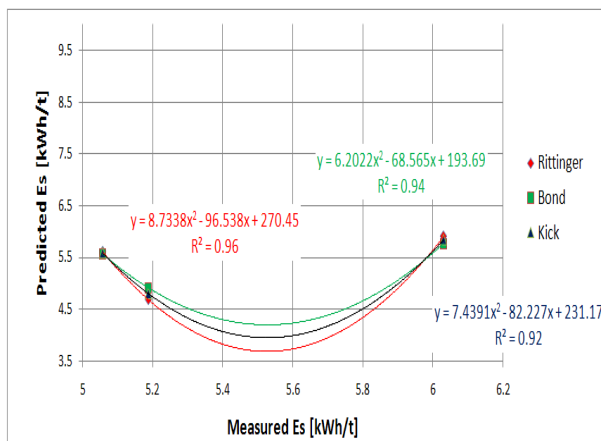


Fig. 4. Comparison of measured and predicted specific grinding energy in the case of grinding with hammer 2: a) dry grains; b) wet grains

Table 3 shows the percentage of error between the predicted values and the measured one for the specific grinding energy. In the majority of the cases, the values of the relative error (calculated with relation 5) are lower in case of Rittinger theoretical model.

Table 3
Percentage of error for the predicted specific energy consumption

Sieve dimension, mm	Percentage of error					
	Hammer 1 – dry maize			Hammer 1 – wet maize		
	Rittinger	Bond	Kick	Rittinger	Bond	Kick
4	-1.57	4.43	6.47	-28.48	-25.6	26.9
6	3.07	3.84	3.80	24.06	18.7	21.1
8	-1.03	3.36	6.82	7.69	14.5	11.6

Continuation

Sieve dimension, mm	Percentage of error					
	Hammer 2 – dry maize			Hammer 2 – wet maize		
	Rittinger	Bond	Kick	Rittinger	Bond	Kick
4	-2.08	-4.32	-3.16	-9.04	-9.63	-9.38
6	-9.64	-5.28	-7.41	2.44	1.91	2.14
8	10.88	10.1	10.4	9.35	10.59	10.0

5. CONCLUSIONS

When using the sieve with 4 mm opening dimension and the hammer 1 the highest value (7.22 kWh/t) of specific grinding energy was recorded for wet maize grains and the lowest value (4.63 kWh/t) for grinding dry maize grains.

For 6 mm sieve opening dimension the highest value (5.49 kWh/t – for wet grains) and the lowest value (4.65 kWh/t – for dry grains) of specific grinding energy were recorded also when hammer 1 was used for the grinding process.

When the sieve with the biggest opening dimension (8 mm) was used, the highest value for the specific grinding energy (5.06 kWh/t) was recorded for dry grains and hammer 2, and the lowest value (3.75 kWh/t) for dry grains and hammer 1.

In the all cases the values of specific grinding energy decreases with increasing the sieve opening dimension.

Among the three theoretical models that were analyzed, the Rittinger model based on its lowest mean square error (2.39), and a coefficient of determination bigger than 0.92 best predicted the specific grinding energy.

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Influența umidității semințelor de cereale asupra parametrilor procesului de măcinare

Rezumat: Prin măsurarea energiei necesare pentru măcinarea boabelor de porumb și prin potrivirea datelor obținute în modelele lui Rittinger, Bond și Kick, se poate decide care dintre aceste modele reprezintă cel mai precis procesul de măcinare de față. Se pot obține astfel informații utile în vederea aproximării energiei necesare pentru realizarea procesului de măcinare având ca date de pornire dimensiunea finală a particulelor pe care dorim să o obținem, umiditatea inițială a boabelor de măcinat și configurația ciocanelor. Boabele de porumb au fost măcinate cu ajutorul unei mori cu ciocane MB 7.5 (7.5 kW) pentru care trei tipuri diferite de site au fost folosite având dimensiunea ochiurilor de 4, 6 respectiv 8 mm. Între energia specifică la măcinare și dimensiunea ochiurilor sitei s-a observat o dependență directă. Următorul pas a fost procesarea datelor obținute pentru energia specifică în cadrul modelelor lui Rittinger, Bond și Kick. Rezultatele au arătat faptul că cel mai potrivit model având un coeficient de determinare a fost modelul lui Rittinger.

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