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EFFECT OF PARTICLE SIZE OF FRAGMENTED WHEAT ON ENERGY REQUIREMENTS IN THE PROCESS OF EXTRUSION

Stanisław Skonecki, Janusz Laskowski

Department of Food Industry Machinery Operation, University of Life Sciences in Lublin

Summary. The paper presents the results of a study on the effect of mean particle size on energy requirements in the process of extrusion and on the index of material susceptibility to compaction, for grain of two wheat cultivars - Juma and Maltanka. The results showed that energy requirements at the particular stages of extrusion depend both on the mean particle size and on the wheat cultivar and moisture. It was found out that with an increase in the degree of grain fragmentation and moisture there is a decrease in the work of extrusion and in the value of the index characterising the susceptibility of the material to compaction. An increase in the mean particle size causes a decrease in the susceptibility of the material to agglomeration.

Key words: mean particle size, wheat, energy requirements, extrusion

Nomenclature:

k_c – coefficient defining the value of unit total work of compaction related to density increment, $[(J \cdot g^{-1}) \cdot (g \cdot cm^{-3})^{-1}]$,
L_a – work of compaction determined till point B on the curve of compaction [J],
L_c – total work of compaction determined till point C on the curve of extrusion [J],
L_c' – unit total work of compaction $[J \cdot g^{-1}]$,
L_s – work of compression (work between points B and C on the curve of extrusion) [J],
L_w – work of extrusion (work between points C and D on the curve of extrusion) [J],
L_1 – total work of extrusion [J],
m – weight of a sample of the material [g],
S – percentage of work of extrusion relative to the total work of extrusion [%],
ρ_c – material density in the compaction chamber (point C on the curve of compaction) $[g \cdot cm^{-3}]$,
ρ_n – initial density of material in the chamber (bulk density) $[g \cdot cm^{-3}]$,

INTRODUCTION

In the process of granulation, biological raw materials are subjected to the effect of forces acting between the roller and the die, causing their compaction and then outflow (extrusion) through the forming duct of the die. The effect of various raw materials on that process depends on their physical and chemical properties, and on the adopted process parameters [Hejft 2002, Kulig et al. 2001, Laskowski et al. 2005]. The properties of raw materials determine the energy requirements of the process, and thus their susceptibility to pelleting. One of the material factors that affect the energy requirements of pelleting is the degree of fragmentation (particle size of the material). Studies have shown that the best suited for pelleting are materials with particle sizes within the range from 0.4 to 2 mm, i.e. at fine and medium levels of fragmentation [Angulo et al. 1996, Behnke 2001, Le Deschault de Monredon 1991, Wondra et al. 1994]. Kulig and Laskowski [2006, 2008], on the basis of research on barley, wheat and lupine, demonstrated that the effect of material particle size on the energy requirements of pelleting depends also on the temperature of the material after its conditioning. They found out that the unit requirements of thermal energy, energy of pressing and total energy of pelleting decrease with an increase in the degree of fragmentation of the material. The presented research is concerned with pelleting and permit a general estimation of the energy requirements of the process. Detailed analysis of energy requirements, covering both compaction and extrusion of materials, can be performed in laboratory conditions, in studies on the process of extrusion [Laskowski and Skonecki 2001]. In earlier studies the authors determined the effect of moisture of corn meal, oats and wheat on the process of extrusion [Laskowski and Skonecki 2003], and gave the extrusion process parameters for a number of raw materials and fodder blends [Laskowski et al. 2005].

The objective of the study presented here was determination of the effect of mean particle size (degree of fragmentation) of fragmented wheat grain on energy requirements in the process of extrusion and on the susceptibility of the material to compaction (agglomeration).

MATERIALS AND METHODS

The material used in the study was grain of two wheat cultivars - Juma and Maltanka. The grain was fragmented by means of a H III/3 beater mill in five different ways - using screens with various mesh sizes and a variant without a screen. For each wheat cultivar five samples of test material were obtained and the mean particle size was determined for every sample. Measurements were made in accordance with the standard PN-89/R-64798 using a laboratory screening set type SZ-1 (the screen set used had mesh sizes of 0.095, 0.18, 0.315, 0.5, 0.8, 1.0, 1.2, 1.6, 2.0 and 3.2 mm, sample weight was 100 g, and screening time was 5 min.). The mean particle sizes for grain samples of wheat cv. Juma were 0.62, 1.11, 1.40, 1.69 and 1.99 mm, and for those of cv. Maltanka – 0.63, 1.05, 1.37, 1.65 and 1.96 mm.

The extrusion process tests were conducted at the temperature of 60°C on samples of wheat grain with moisture levels of 14, 16 and 18% (+/-0.2%). Moisture was determined with the drier method in accordance with the standard PN-76/R-64752.

The extrusion test station included a strength tester type ZD40 [Laskowski et al. 1995, Laskowski and Skonecki 2003] and a pressing assembly with a concentric extrusion aperture with diameter of 6 mm (elastic deformation chamber diameter was 25 mm, piston travel velocity was 0.3 $mm \cdot s^{-1}$). All extrusion tests were made in three replications for raw material samples with weight of m=20 g.

In the course of the tests the extrusion characteristics were recorded (Fig. 1) – the relation between force (F) and piston displacement (s). The individual stages of the process of extrusion have been characterised in the work by Laskowski and Skonecki [2001].

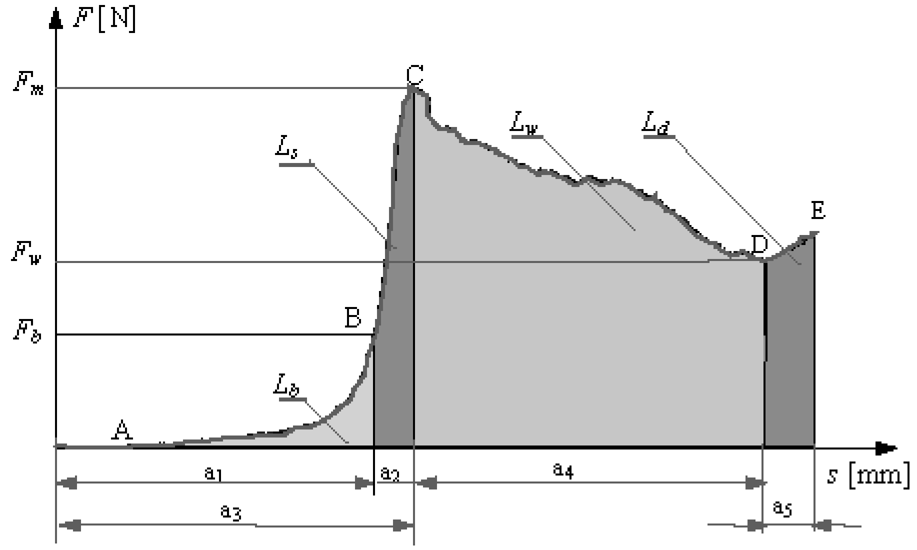

Fig. 1. Characteristics of extrusion process: a_1 - phase of compaction, a_2 - phase of elastic deformation, a_3 - pressing, a_4 - phase of extrusion, a_5 - phase of ultimate extrusion [Laskowski and Skonecki 2001, 2003]

The material undergoes compaction until the threshold of outflow (point C). Next, outflow of the material takes place, at decreasing force (F), until the threshold of extrusion (point D). The final stage of the process (the so-called phase of ultimate extrusion a_5) covers the outflow of the "dead zone" of the material and from the threshold of extrusion there is an increase in the value of force (F) with piston movement (s). Recording of that phase is necessary for the determination of parameters for point D.

The curve of extrusion (Fig. 1) was used to determine the energy requirements, i.e.:

- total work of compaction L_c (L_c=L_b+L_s),
- work of extrusion (L_w),
- total work of extrusion L_t (L_t=L_c+ L_w).

Calculation was made of the percentage share of the work of compaction relative to the total work of extrusion S ($S = 100 \cdot L_w \cdot L_t^{-1}$).

The maximum density of material in the chamber was calculated (ρ_c), and the unit total work of compaction L_c' ($L_c' = L_c \cdot m^{-1}$). Those parameters were used to determine the coefficient k_c characterising the susceptibility of the material to compaction {$k_c = L_c' \cdot (\rho_c - \rho_n)^{-1}$}.

For each wheat cultivar determination was made of the relations of the studied features Y (L_c, L_w, L_t, S oraz k_c) with the mean particle size d_s and moisture w, using an equation with the general form of:

$$Y = a + b \cdot d_s + c \cdot d_s^2 + d \cdot w + e \cdot w^2 + f \cdot d_s \cdot w. \quad (1)$$

The calculations were made using the SAS Enterprise Guide 3.0 software, determining the significance of coefficients of regression (t-student test) and the significance of the regression equation (adopting a significance level of 0.05). Non-significant variables were eliminated from the equation.

RESULTS

The calculated regression relations are given in Table 1. The data in Table 1 present the significant coefficients of the regression equations and the coefficients of determination R^2. The relations of the studied features to the mean particle size d_z for the particular moisture levels are given in Figures 2 - 6.

As follows from the obtained results (Table 1; Fig. 2 - 4), it can be concluded that the character of changes in the work of compaction L_c, extrusion L_w and in the total work of extrusion L_k in relation t the mean particle size is similar for the raw materials studied. The work values L_c, L_w and L_k increase with an increase in particle size and decrease with an increase in the moisture level of the material. For each degree of fragmentation, the work values were the highest for materials with moisture level of 14 %. Higher values of the works were noted for grain of wheat cv. Maltanka.

Table 1. Coefficients of regression equations for the relation of the studied features to mean particle size d_z and moisture content of the material w

Wheat cultivars	Feature	Equation coefficients						R^2
		a	b	c	d	e	f	
Juma	L_c	247		45.8		-0.53	-4.95	0,973
	L_w	-6229		125.6		972.3	-34.1	0,941
	L_k	-7515	821.2	201	1093	-36	-61.2	0,969
	S	68.8	5.41	-2.06	1.094			0,962
	k_c	-19.8		3.47	4.52	-0.172	-0.389	0,978
Maltanka	L_c	-298	112.4	27.4	57.04	-2.05	-8.518	0,987
	L_w	1319		130.1		-2.853		0,977
	L_k	1207	511.4	144.8		-2.173	-31.3	0,984
	S	133.2		-1.064	-6.389	0.22	0.149	0,953
	k_c	-24.5		2.842	4.894	-0.179	-0.266	0,985

The highest work of compaction L_c = 194 J (Fig. 2), work of extrusion L_w = 1292 J (Fig. 3) and total work of extrusion L_k = 1486 J (Fig. 4) were obtained for wheat cv. Maltanka with moisture w = 14% and mean particle size d_z = 1.96 mm. The lowest values of those works were obtained for wheat cv. Juma with moisture w=18% and particle size d_z = 0.62 mm (L_c = 30 J (Fig. 2), L_w = 362 J (Fig. 3) and L_k = 392 J (Fig. 4)).

Analysing the particular works of extrusion for the given moisture values one can note that with an increase in the mean particle size of the studied wheat cultivars their values increase by 60-90%. As an example, the values of L_c, L_w, L_k were the highest for wheat cv. Maltanka with moisture of 14%, and for the mean particle size increase within the range from 0.63 to 1.96 mm they were L_c = 102-194 J, L_w = 755-1292 J, L_k = 857-1486 J, respectively. Generally, it can be stated that values of the works of compaction and extrusion decrease with an increase in the degree of fragmentation of moisture level of wheat grain. The values of the energy requirements of the process of extrusion also depend on the wheat cultivars.

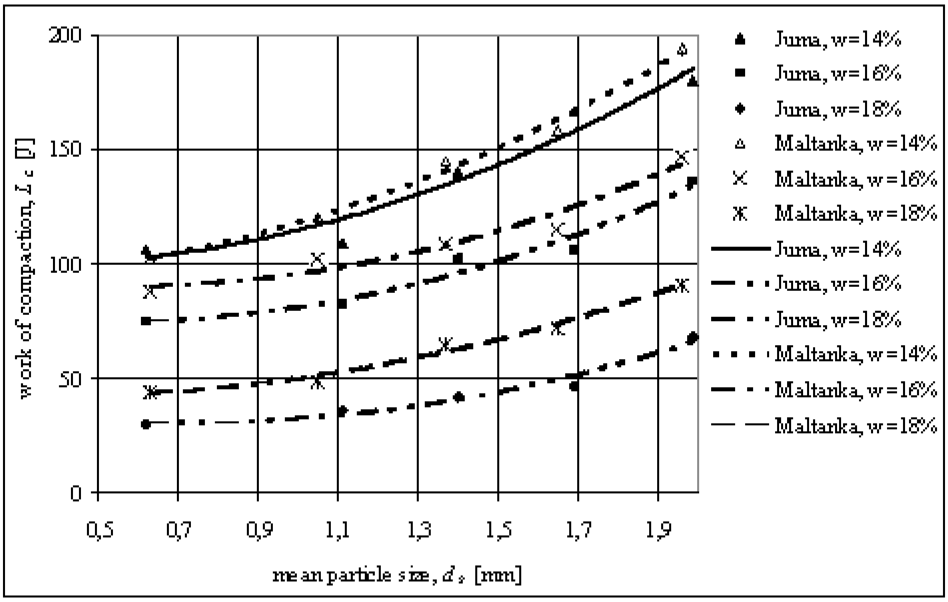

Fig. 2. Relation of the work of compaction L_c to mean particle size d_s for particular levels of w of wheat cv. Juma and Maltanka

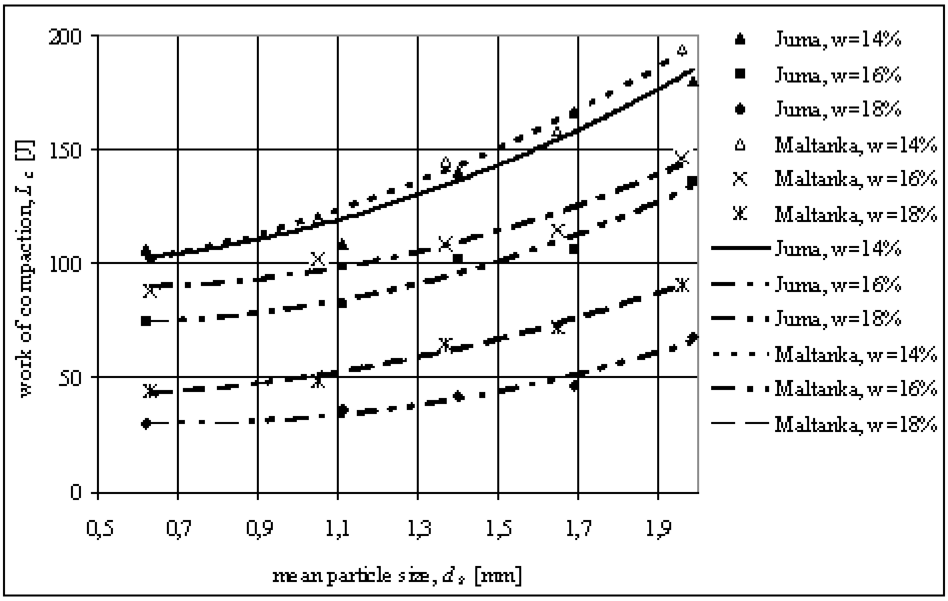

Fig. 3. Relation of the work of extrusion L_w to mean particle size d_s for particular levels of w of wheat cv. Juma and Maltanka

In estimation of energy requirements in extrusion it is important not only to determine the values of work for the particular stages of the process, but also the share of those works relative to the total work of extrusion. Fig. 5 presents the relations between the share of energy of the phase of extrusion S and the particle size d_s for the wheat cultivars studied. As can be seen in Fig. 5, an increase in the particle size is accompanied by a slight decrease in the work of extrusion S. Therefore, greater work is required for the compaction of material before its outflow begins.

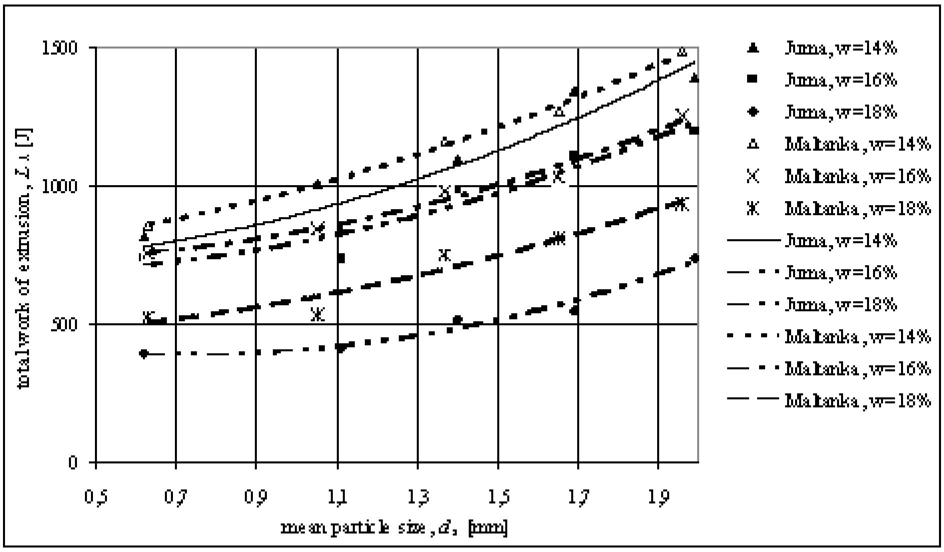

Fig. 4. Relation of the total work of extrusion L_k to mean particle size d_s for particular levels of w of wheat cv. Juma and Maltanka

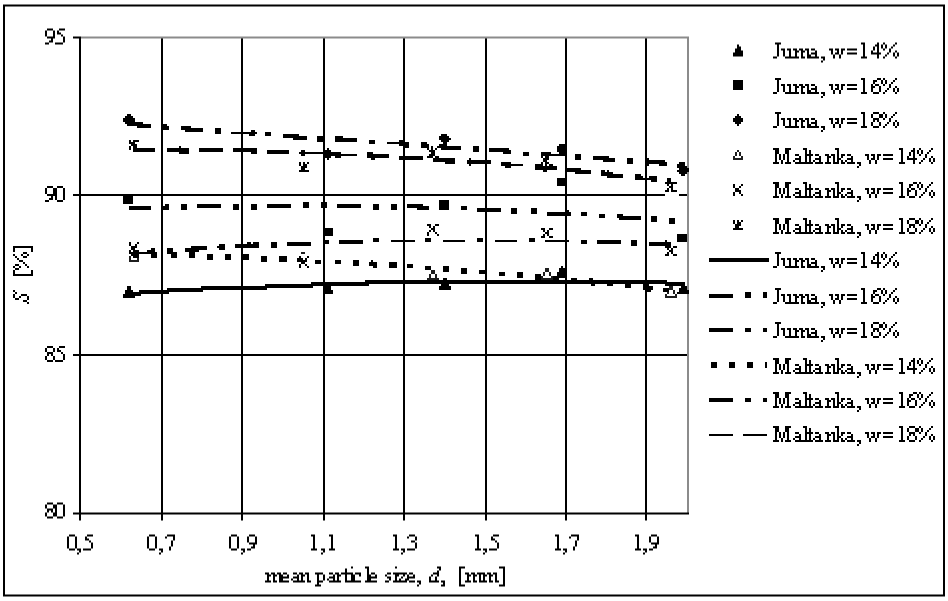

Fig. 5. Relation of the share of the work of extrusion in the total work of extrusion S to mean particle size d_s for particular levels of w of wheat cv. Juma and Maltanka

A notable effect of moisture on the share of the work of extrusion is observed. High values of S, within the range of 90-92%, were obtained for raw materials with moisture level of 18%. Decrease in the moisture content to 14% caused a decrease in the value of S to approx. 87%. Therefore, raw materials with lower moisture require more energy for compaction, which may be attributed to increased friction and drag till the outflow of the material.

Energy requirements for compaction indicate the susceptibility of materials to compaction (agglomeration). This information is provided by the value of coefficient k_c defined as the unit work of compaction related to density increment. The lower the value of that coefficient the higher the capacity of a material for agglomeration. Changes in the value of coefficient k_c relative to the mean particle size and moisture (Table 1; Fig. 6) are similar to changes in the work of compaction.

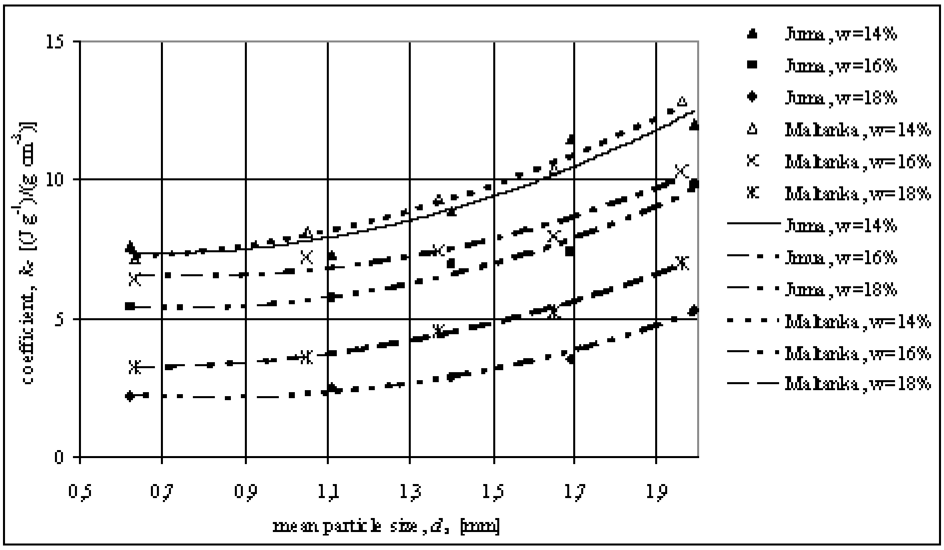

Fig. 6. Relation of the value of coefficient k_c to mean particle size d_c for particular levels of w of wheat cv. Juma and Maltanka

Coefficient k_c increases with an increase in the mean particle diameter and decreases with an increase in moisture level of the wheat cultivars under study. The values of the coefficient were the highest for wheat cv. Maltanka with moisture of 14% (from 7.17 to 12.78 $(J \cdot g^{-1}) \cdot (g \cdot cm^{-3})^{-1}$). For the same material, but with moisture of w=18%, the value of coefficient k_c increased with an increase in the mean article size, from 3.25 to 6.98 $(J \cdot g^{-1}) \cdot (g \cdot cm^{-3})^{-1}$. The lowest values of k_c were obtained for wheat cv. Juma with moisture of 18% (from 2.19 to 5.32 $(J \cdot g^{-1}) \cdot (g \cdot cm^{-3})^{-1}$). As shown by the tests, materials with greater degree of fragmentation have better agglomeration capacity. The results of this study support the relations obtained in the study on the process of agglomeration of cereal meal [Kulig et al. 2001].

CONCLUSIONS

1. Energy requirements in the process of extrusion depend on the mean particle diameter, moisture, and wheat cultivars.

2. Values of energy in the phases of compaction and extrusion were the highest for materials with the largest particle size and the lowest moisture content of the materials.

3. The share of the work of compaction was found to increase with an increase in the degree of fragmentation and moisture of the material. Greater amounts of energy are required in the case of materials with lower moisture and larger mean particles diameters.

4. An increase in the mean particle diameter causes a decrease in the agglomeration capacity of the material.

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WPŁYW WIELKOŚCI CZĄSTEK ROZDROBNIONEJ PSZENICY NA NAKŁADY ENERGII W PROCESIE WYTŁACZANIA

Streszczenie: Przedstawiono wyniki badań nad określeniem wpływu średniego wymiaru cząstek na nakłady energii w procesie wytłaczania oraz na wskaźnik podatności materiału na zagęszczanie rozdrobnionych ziaren dwu odmian pszenicy Juma i Maltanka. Wyniki wykazały, że nakłady energii poszczególnych faz wytłaczania zależą zarówno od średniego wymiaru cząstek, wilgotności jak i odmiany pszenicy. Stwierdzono, że ze wzrostem stopnia rozdrobnienia i wilgotności maleje praca zagęszczania, praca wytłaczania oraz współczynnik charakteryzujący podatność materiału na zagęszczanie. Zwiększenie średniego wymiaru cząstki powoduje zmniejszenie podatności materiału na aglomerowanie.

Słowa kluczowe: średni wymiar cząstek, pszenica, nakłady energii, wytłaczanie