

EFFECTS OF CONDITIONING METHODS ON ENERGY CONSUMPTION DURING PELLETING

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Summary. The paper presents the results of studies on the effects of conditioning methods on energy consumption during pelleting of selected plant raw materials. Steam conditioning was compared to cold conditioning. Electrical and thermal energy consumption in the pelleting process were determined. It was found out that steam conditioning allowed to reduce electrical energy consumption (on average by 30%), as compared to cold conditioning. Total energy consumption during pelleting was lower in the case of cold conditioning.

Key words: pelleting, conditioning, energy consumption

Nomenclature:

E	– amount of thermal energy consumed during conditioning, [kJ]
E_c	– thermal energy consumption, [kJ·kg ⁻¹]
E_p	– electrical (pressing) energy consumption, [kJ·kg ⁻¹]
E_g	– total energy consumption, [kJ·kg ⁻¹]
m_g	– weight of pelleted product, [kg]
m_s	– weight of ground grain leaving the conditioner, [kg]
p	– calculated significance level,
P	– power consumption, [kW]
P_p	– steam pressure, [kPa]
r	– Pearson's correlation coefficient
R^2	– coefficient of determination
T_k	– steam conditioning temperature, [°C]
W_s	– moisture content of raw materials after cold conditioning, [%]
α_i	– assumed significance level.

INTRODUCTION

Feed mixture pelleting is connected with considerable energy expenditures, usually varying from several to about 70 kWh·t⁻¹ [2, 6, 7, 9]. According to Thomas [8] such a high variation between unit values of energy inputs results from the fact that feed mixtures subjected to treatment are characterized by different physicochemical properties, and the process is carried out applying different technical and technological parameters, and various types of pellet mills.

Energy consumption during pelleting is a sum of electrical energy expenditures for raw material pressing, and thermal energy supplied with water vapor. As reported by Beumer [1], while pelleting mixed feeds for pigs, an average demand for electrical energy consumption is 46.6 kWh·t⁻¹, and for thermal energy in the form of steam – 29.8 kWh·t⁻¹.

The authors dealing with these problems differ in their opinions about the effects of steam on total energy consumption during pelleting. According to Friedrich [3], the amount of steam added is 1 to 3%. This author demonstrated that during steam conditioning the reduction in electrical energy costs was higher than the increase in the costs of steam generation. On the other hand, Kikiewicz et al. [4] claimed that steam conditioning, carried out to facilitate feed mixture pelleting, was unprofitable since it increased total costs of energy consumption in the process. However, these authors did not consider the effects of steam on changes in the state of some components, and improvement in granule cohesion. Furthermore, their considerations were based on theoretical calculations of thermal energy inputs during pelleting.

Taking into account the above-mentioned opinions, the objective of the present study was to compare steam and cold conditioning in the aspect of energy consumption during pelleting.

MATERIALS AND METHODS

The experimental materials included ground barley, maize, wheat, oats, pea and lupine, and lucerne meal. The raw materials were ground through a 3-mm hammermill screen. After grinding the materials were brought to a constant moisture content of 14%.

Steam and cold conditioning was carried out in a barrel type conditioner. In the first case the materials were brought to five temperature levels, i.e. 50, 60, 70, 80 and 90°C. The desired temperature was achieved by treatment with water vapor under the pressure of 200, 250, 300, 350 and 400 kPa. In the other case cold water was added to the ground materials, to achieve the moisture of 14, 16, 18, 20 and 22%. The materials were pressed in an Amandus Kahl pellet mill, type 14-175, equipped with a 20-mm thick die with a 4-mm diameter hole.

The experiment was performed on a prototype test stand equipped with computer systems enabling to make a detailed analysis of thermal and electrical energy demand, dependent upon both the properties of materials, and technical and technological parameters of the process. A detailed description of the test stand and methods applied to determine thermal and electric energy consumption is given in references [5].

Thermal energy consumption during steam conditioning was calculated as a quotient of heat used in the process and weight of ground grain leaving the conditioner, determined at equal time intervals according to the formula:

$$E_c = \frac{E}{m_s} \text{ [kJ} \cdot \text{kg}^{-1}] \quad (1)$$

In order to estimate the electrical energy consumption during pressing, the value of work performed by the pellet mill was calculated in the same time interval over which the press efficiency was determined. Energy consumption was calculated by the formula:

$$E_p = \frac{\int_{t_1}^{t_2} P(t) dt}{m_g} \text{ [kJ} \cdot \text{kg}^{-1}] \quad (2)$$

Total energy consumption during pelleting with steam conditioning was determined as the sum of thermal and electrical energy, according to the formula:

$$E_g = E_c + E_p \text{ [kJ} \cdot \text{kg}^{-1}] \quad (3)$$

The relationships between the parameters of conditioning and energy consumption in this process were analyzed using STATISTICA procedures, at a significance level $\alpha_i = 0.05$. The form of equation was chosen applying backward step regression. The significance of regression equation coefficients was analyzed with the Student's *t*-test. The model's adequacy was verified with the Fisher test.

RESULTS

Electrical (pressing) energy consumption during pelleting with steam are shown in Figure 1. Mean values of this parameter varied from 120 to over 200 $\text{kJ} \cdot \text{kg}^{-1}$. The rate of changes in energy consumption was the fastest in the temperature range of $50 \div 70^\circ\text{C}$. When the temperature of conditioning was changed from 80 to 90°C , differences in energy consumption became statistically insignificant ($p > 0.05$) for such raw materials as lupine, maize and barley.

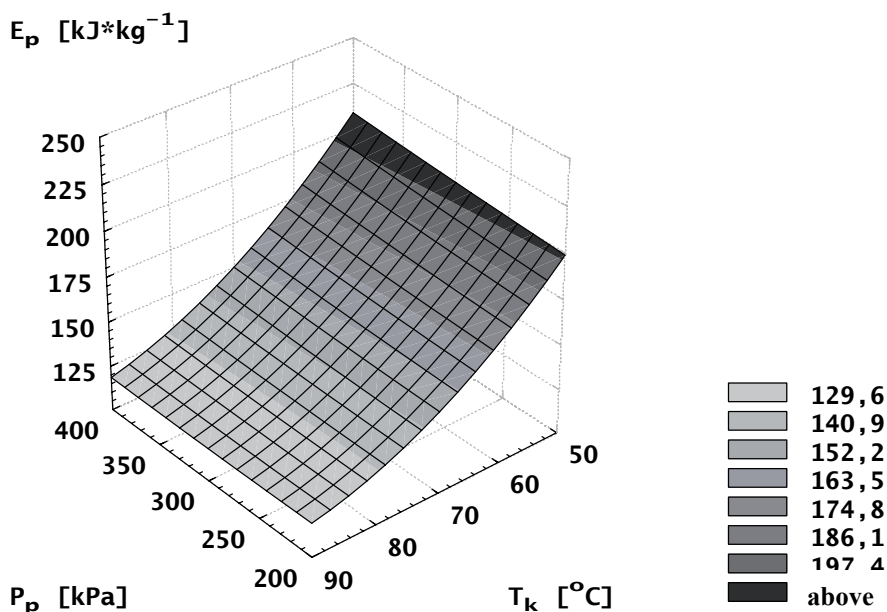


Fig. 1. Dependence of electrical energy consumption (E_p) on conditioning temperature (T_k) and steam pressure (P_p) (means obtained for seven raw materials examined)

An analysis of the effect of steam pressure shows that statistically significant changes in energy consumption occurred at the temperature of 50 and 60°C . With a further increase in conditioning temperature this effect became insignificant. This indicates that at lower temperatures of conditioning an important role is played by moisture content of materials, resulting from steam pressure. The additional, positive effect observed at higher temperatures may be associated with starch gelatinization. However, this effect was not recorded in the case of raw materials with a high fat content (maize and lupine) and lucerne, characterized by a high fiber content and low treatability

by pressing (no statistically significant differences). Thus, it seems that changes in moisture content of materials observed in both cases were too low to induce changes in the value of the analyzed parameters, as reflected by the regression equations presented in Table 1.

Table 1. Regression equations describing the effects of conditioning temperature (T_k) and steam pressure (P_p) on electrical energy consumption (E_p)

RAW MATERIAL	EQUATION	A	B	c	d	R2
Wheat	$E_p = A T_k^2 - B T_k + C P_p + D$	0.0353	7.221	0.0343	458.8	0.981
Maize	$E_p = A T_k^2 - B T_k + D$	0.0081	2.07		217.42	0.945
Barley	$E_p = A T_k^2 - B T_k + C P_p + D$	0.0236	4.822	0.0393	338.02	0.972
Oats	$E_p = A T_k^2 - B T_k + C P_p + D$	0.021	4.433	0.002	321.03	0.971
Pea	$E_p = - B T_k + C P_p + D$		2.97	0.0021	340.06	0.940
Lupine	$E_p = A T_k^2 - B T_k + D$	0.0266	5.042		316.73	0.931
Lucerne	$E_p = A T_k^2 - B T_k + D$	0.105	19.53		1157.38	0.967

Figure 2 illustrates the results of an analysis of thermal energy consumption, electrical energy and total energy consumption during pelleting with steam conditioning. The above data show that a rise in the temperature of hydrothermal treatment in a range of 50÷70°C caused a decrease in the unit value of total energy expenditures during pelleting. When a temperature of 70°C was exceeded, the value of the parameter examined increased considerably. Equations describing the effects of steam conditioning on total energy consumption during pelleting are shown in Table 2.

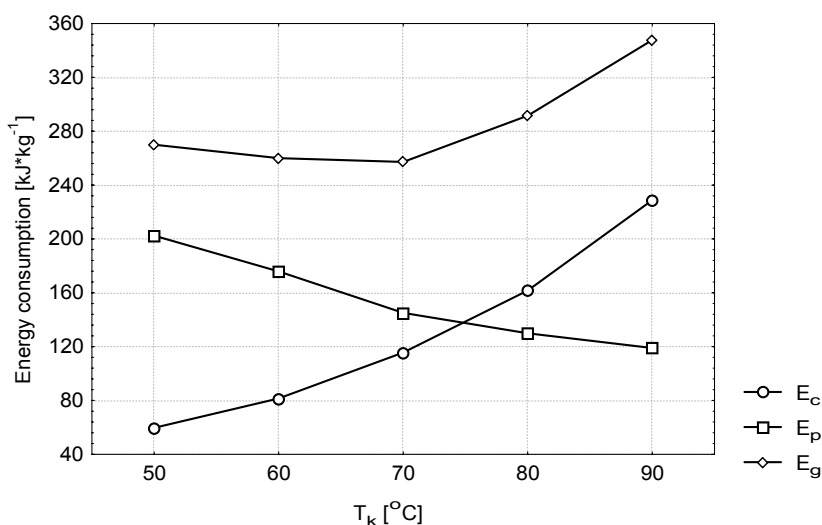


Fig. 2. Dependence of thermal energy consumption (E_c), electrical energy (E_p) and total energy consumption (E_g) during pelleting with steam conditioning on conditioning temperature (T_k) (means obtained for seven raw materials examined)

Table 2. Regression equations describing the effect of conditioning temperature (T_k) on total energy consumption (E_g) during pelleting with steam conditioning (mean values obtained for five steam pressure levels)

RAW MATERIAL	EQUATION	A	B	C	R ²
Wheat	$E_g = AT_k^2 - BT_k + C$	0.0592	8.027	496.92	0.948
Maize	$E_g = AT_k^2 - BT_k + C$	0.0453	4.501	294.46	0.949
Barley	$E_g = AT_k^2 - BT_k + C$	0.0988	10.95	534.28	0.979
Oats	$E_g = AT_k^2 - BT_k + C$	0.042	4.055	322.65	0.935
Pea	$E_g = AT_k^2 - BT_k + C$	0.0531	7.107	462.51	0.883
Lupine	$E_g = AT_k^2 - BT_k + C$	0.0791	8.61	412.82	0.97
Lucerne	$E_g = AT_k^2 - BT_k + C$	0.37	46.783	1979.41	0.985

Electrical energy consumption during pelleting with cold conditioning is shown in Figure 3. Its mean values ranged from 114.32 to 593.11 kJ·kg⁻¹. Also in this method of pelleting the highest energy consumption was noted for lucerne, which results from its chemical composition. In the case of lucerne and pea, an increase in moisture content is directly proportional to a decrease in pressing energy consumption ($r > -0.96$).

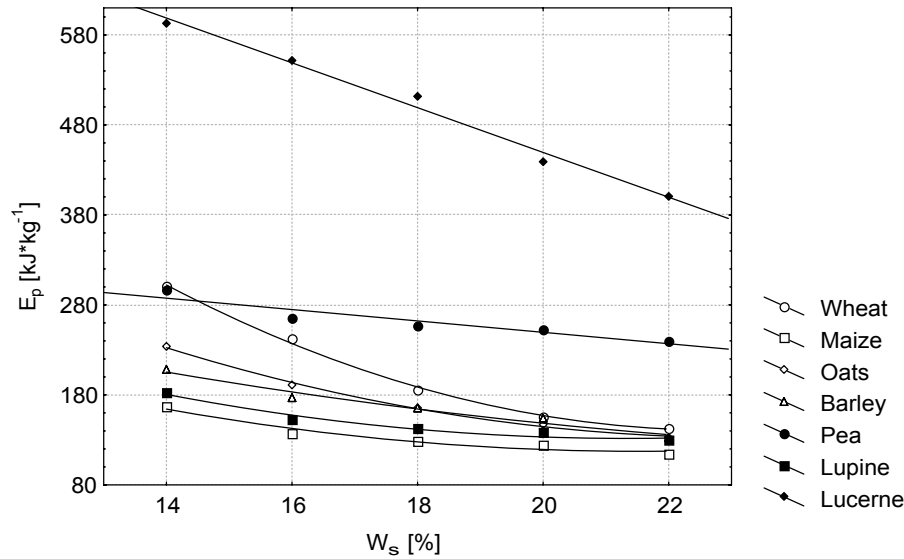


Fig. 3. Dependence of electrical energy consumption (E_p) on moisture content of raw materials (W_s) during pelleting with cold conditioning

The relationships obtained for the other experimental raw materials were described by quadratic equations (Table 3).

Table 3. Regression equations describing the effect of moisture content of raw materials (W_s) on electrical energy consumption (E_p) during pelleting with cold conditioning

RAW MATERIAL	EQUATION	A	B	C	R ²
Wheat	$E_p = AW_s^2 - BW_s + C$	2.09	95.24	1226.1	0.996
Maize	$E_p = AW_s^2 - BW_s + C$	1.173	54.53	765.86	0.997
Barley	$E_p = AW_s^2 - BW_s + C$	0.8256	35.56	500.35	0.956
Oats	$E_p = AW_s^2 - BW_s + C$	0.011	8.693	323.94	0.956
Pea	$E_p = -BW_s + C$		32.38	613.6	0.951
Lupine	$E_p = AW_s^2 - BW_s + C$	0.9041	38.613	543.9	0.961
Lucerne	$E_p = -BW_s + C$		0.6904	728.38	0.959

Figure 4 presents a comparison of energy consumption at both conditioning methods for the experimental raw materials. The obtained results suggest that hydrothermal treatment applied during pelleting causes, in most cases, an increase in total energy consumption. Steam conditioning turned to be more advantageous only in the case of pea.

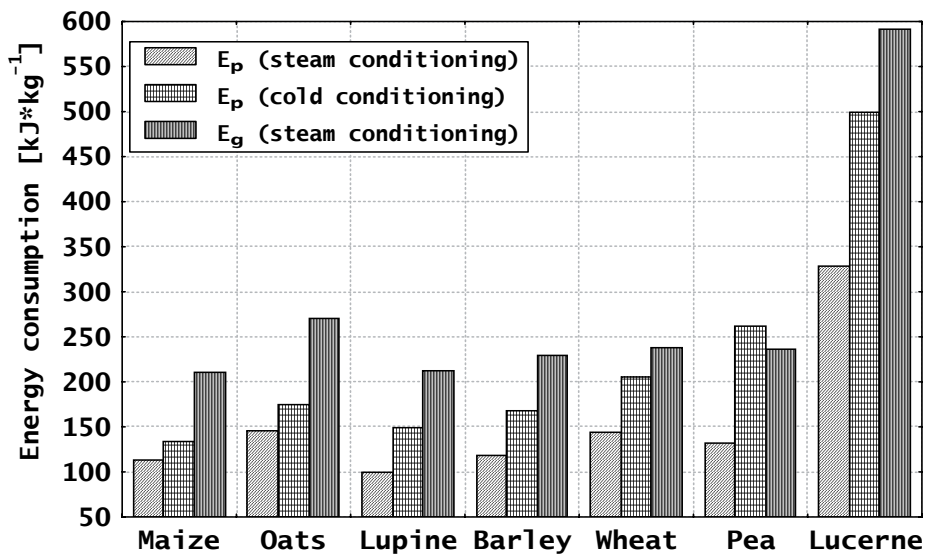


Fig. 4. Effects of raw material and conditioning method on electrical energy consumption (E_p) and total energy consumption during pelleting with steam conditioning (E_g)

As regards electrical (pressing) energy consumption, better results can be achieved for hydrothermal treatment. This tendency would be probably even more visible in the case of dies with a higher degree of compression (in the present study the compression degree was 1÷5). The improvement in pressing conditions of raw materials subjected to hydrothermal treatment enables

to increase wear resistance of the pressing unit. Steam conditioning of plant materials seems to be a better solution, taking into account the advantages of prolonged use of the pressing unit and improved nutritional properties of thermally treated products. This conclusion is also confirmed by everyday industrial practice.

CONCLUSIONS

1. Electrical energy consumption decrease with an increase in the temperature of treatment (steam conditioning) and moisture content of raw materials (cold conditioning). Hydrothermal treatment of raw materials enables to reduce the value of this parameter (on average by 30%), as compared to cold conditioning.

2. As concerns energy consumption, the optimum conditioning temperature for the majority of plant materials is 70°C. When this temperature is exceeded, total energy consumption during pelleting is affected first of all by thermal energy supplied with the steam.

3. Assuming constant thermal energy consumption for treatment of materials characterized by the given physicochemical properties (treatability by pelleting), total energy consumption of the process depends on the parameters.

4. Energy expenditures for pelleting are dependent upon the properties of raw materials, mostly on their chemical composition. It follows that estimation of energy consumption during pelleting requires separate studies for each case.

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