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EFFECT OF CONDITIONING PARAMETERS ON PELLET TEMPERATURE AND ENERGY CONSUMPTION IN THE PROCESS OF PLANT MATERIAL PRESSING

Ryszard Kulig, Janusz Laskowski

Department of Food Processing Machines, University of Life Sciences in Lublin

Summary: This paper presents the results of an experiment investigating the effect of conditioning parameters on the temperature of the resulting pellet and the energy consumption in the process of plant material pressing. The obtained values were within the range of 64 to 90.5ºC for steam conditioning and from 46.5 to 95ºC for conditioning with the addition of water. It was found that the friction coefficient during pressing is minimised to a satisfactory level when the temperature of raw material before pressing is raised to 70ºC. There exists a very strong linear dependency between pellet temperature and pressing energy consumption ($r = -0.995$; $p<0.01$ for steam conditioning, and $r = 0.996$; $p<0.01$ for conditioning with the addition of water).

Key words: pellet temperature, pressing energy, pelleting, conditioning.

Nomenclature:

E_p – unit pressing energy expenditures [$kJ*kg^{-1}$],
p – calculated level of significance,
P_p – water vapour pressure [kPa],
r – Pearson's linear correlation coefficient,
R^2 – coefficient of determination,
T_g – temperature of pellet after passing through the die [^oC],
T_k – temperature of raw material after steam conditioning [^oC],
W_s – moisture content of raw material after conditioning with the addition of water [%],
α_i – adopted level of significance.

INTRODUCTION

The energy effectiveness of the pelleting process can be indirectly determined based on the temperature of the pellet after passing through the die. The increment in temperature from its initial value is indicative of friction between the material and the walls of die channels. According to Welin [20], the temperature increment should not exceed 15ºC in the pelleting process involving steam conditioning. If the temperature increase is higher, the excess energy demand for pressing is converted into useless friction heat.

The range of changes in the temperature of the resulting pellet is determined by the physical and chemical properties of the processed material [4, 22] as well as by the technical and technological parameters of the process [1, 17, 18]. Raw materials with a high content of starch [2, 6], protein [5] and, in particular, fat [9], have a lower friction coefficient than materials with a high fibre content [7, 19]. The temperature and moisture content of loose material before pressing are also significant in this context [3, 11, 15, 21]. In practice, the most desirable values are within the range of 45÷90^{o}C and 13÷18% as regards moisture content [12, 13, 14, 16]. According to a study conducted by Laskowski and Skonecki [10], an increase in raw material temperature before pressing leads to a drop in compacting pressure due to changes in the coefficient of friction between the material and the walls of matrix openings.

This paper is a continuation of research conducted by the Department of Food Processing Machines at the University of Life Sciences in Lublin to investigate the effect of physical and chemical properties of plant material on the pressure agglomeration process. It analyses the effect of conditioning parameters on the temperature of the resulting pellet and energy consumption in the process of plant material pressing.

MATERIALS AND METHODS

The experimental materials comprised seven feed raw materials (barley, maize, wheat, oats, pea, lupine and dried lucerne) ground in a H-950 hammer mill equipped with a Φ 3mm sieve. After grinding, the material was brought to a constant moisture content of 14%. The initial temperature of the material was 20ºC.

The pelleting process involved steam conditioning and conditioning with an addition of water (cold pelleting). As regards steam conditioning, the studied material was brought to five temperature levels: 50, 60, 70, 80 and 90^{o}C. The required temperature was obtained by treatment with water vapour at five pressure levels: 200, 250, 300, 350 and 400 kPa. For the purpose of conditioning with an addition of water, the material was treated with cold water and brought to moisture content levels of 14, 16, 18, 20 and 22%.

The experiment was performed on a test stand equipped with an LW 69 steam vapour generator, a blade conditioner, an Amandus Kahl L-175 pellet mill (die with 4 mm mesh size, 20 mm in thickness) and computer systems for the measurement of steam, heat and electric energy consumption. A detailed description of the test stand and the methods applied to determine steam, heat and electric energy consumption is presented in the referenced materials [8].

Pellet temperature was measured with the use of a laboratory thermometer with the precision of ±0.5^{o}C. The resulting material was collected directly from the pressing unit into a thermally insulated vessel with a thermometer. The result was the mean temperature from ten measurements.

The analysis of dependencies between the parameters of the pelleting process was carried out using the statistical procedures in STATISTICA application at a significance level of $\alpha_i = 0.05$. The form of equation was selected by means of backward step regression. The significance of regression equation coefficients was analysed with Student's t-test. Model adequacy was verified with Fisher's test.

RESULTS

The temperature of pelleted material after passing through the die, subject to material temperature after conditioning and water vapour pressure, is shown in Fig. 1. The obtained values ranged from 64 to 90.5ºC. The obtained results indicate that for most of the analysed raw materials, the friction coefficient during pressing is reduced to a satisfactory level when the temperature of material after conditioning is raised to 70ºC. The authors also noted that the differences in the temperature of various pelleted materials were significantly minimised as conditioning temperature increased. The above is probably due to greater heat intensity and a higher moisture content of the material under the applied conditioning parameters.

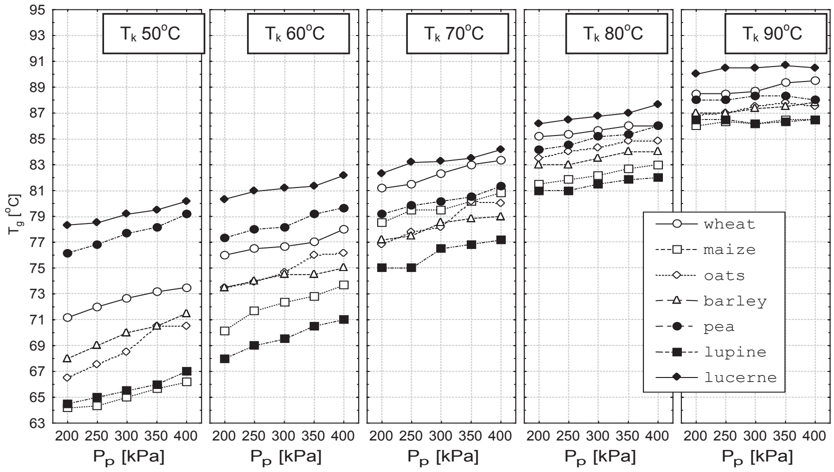

Fig. 1. Dependency between pellet temperature after passing through the die (Tg), conditioning temperature (T_k) and water vapour pressure (P_p)

As a result, when conditioning temperature is increased to 90ºC, pellet temperature is lower than hydrothermal processing temperature (except for lucerne). This is probably due to the fact that the process in which heat is collected from the pellet by evaporating water is most intense under those conditions.

The impact of water vapour pressure is also significant in the analysed case. The increase in pressure, in particular at lower conditioning temperatures, is always accompanied by an increase in pellet temperature. This is likely to be caused by the lower moisture content of raw material when higher water vapour pressure is applied at identical processing temperature. Yet the observed differences usually do not exceed 3ºC and are practically non-existent at a conditioning temperature of 90ºC. A quantitative specification of the determined dependencies is presented in Tab. 1.

Table 1. Regression equations describing the effect of conditioning temperature (T_k) and water vapour pressure (P_p) on the temperature of pellet after passing through the die (T_g)

Raw material	Equation	**A**	**B**	**C**	**D**	R^2
Wheat	$T_g = - AT_k^2 + BT_k - CP_p + D$	0.0054	1.1146	0.0091	26.8657	0.955
Maize	$T_g = - AT_k^2 + BT_k - CP_p - D$	0.0108	1.993	0.0133	11.7432	0.991
Barley	$T_g = - AT_k^2 + BT_k - CP_p + D$	0.0063	1.2622	0.0156	16.8032	0.988
Oats	$T_g = BT_k + CP_p + D$		0.4401	0.0155	39.2866	0.992
Pea	$T_g = -AT_k^2 - BT_k + CP_p + D$	0.0027	0.1863	0.0112	76.7485	0.99
Lupine	$T_g = BT_k + CP_p + D$		0.3345	0.1101	50.1681	0.974
Lucerne	$T_g = -AT_k^2 + BT_k + CP_p + D$	0.0009	0.3248	0.0084	62.5738	0.988

The above observations are also validated by the results obtained in respect of the cold pelleting process (Fig. 2). In this case, a higher moisture content of all the investigated materials prior to pressing decreases friction between the material and the walls of the pellet mill die. Lucerne pellet was characterised by the highest temperature (in both pelleting methods). The above results are intriguing because lucerne is marked by the highest moisture content after steam conditioning, yet due to its high fibre content (23.5%), the friction coefficient is highest during lucerne pressing. Similar findings were reported in respect of materials with a low fat content (wheat and pea). Materials rich in fat, i.e. maize and lupine, are least sensitive to temperature increase after pressing in the die. The lubricating properties of fat are most visible at both lower processing temperatures (steam pelleting) and a lower moisture content of the material during cold pelleting.

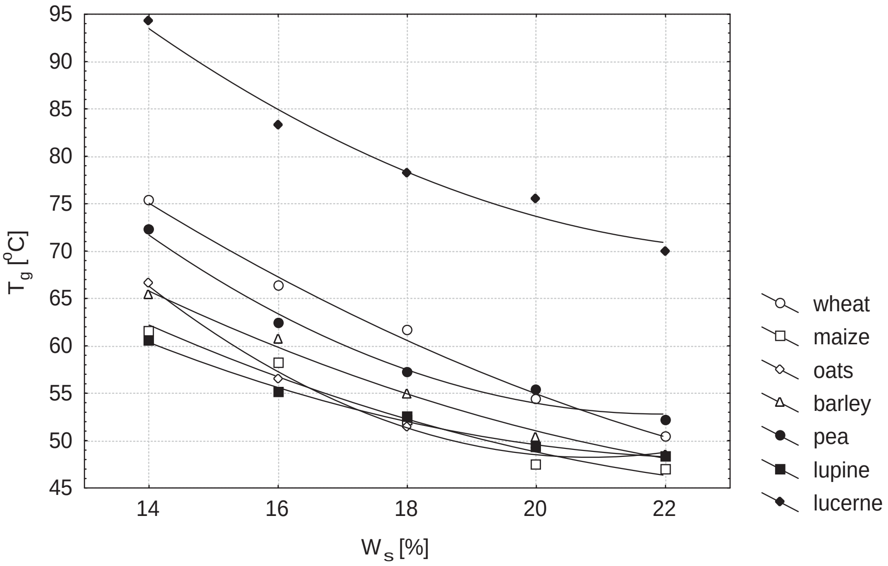

Fig. 2. Dependency between pellet temperature after passing through the die (Tg) and the moisture content of raw material (W_s) (conditioning with the addition of water)

Regression equations describing the effect of the raw material's moisture content on the temperature of the resulting pellet are presented in Table 2.

Table 2. Regression equations describing the effect of raw material's moisture content (W_s) on pellet temperature after passing through the die (T_g) (cold pelleting)

Raw material	Equation	**A**	**B**	**C**	**R^2**
Wheat	$T_g = AW_s^2 - BW_s + C$	0.1345	7.92	159.65	0.988
Maize	$T_g = AW_s^2 - BW_s + C$	1.125	6.48	128.47	0.969
Barley	$T_g = AW_s^2 - BW_s + C$	0.3869	16.11	216.2	0.992
Oats	$T_g = AW_s^2 - BW_s + C$	0.1274	6.79	135.92	0.987
Pea	$T_g = AW_s^2 - BW_s + C$	0.2988	13.11	196.76	0.983
Lupine	$T_g = AW_s^2 - BW_s + C$	0.1458	6.75	126.4	0.987
Lucerne	$T_g = AW_s^2 - BW_s + C$	0.2399	11.45	206.85	0.976

The results of the study investigating the effect of pellet temperature on unit pressing energy expenditures are presented in Fig. 3 and 4. The obtained results point to a very strong linear dependency between the analysed parameters.

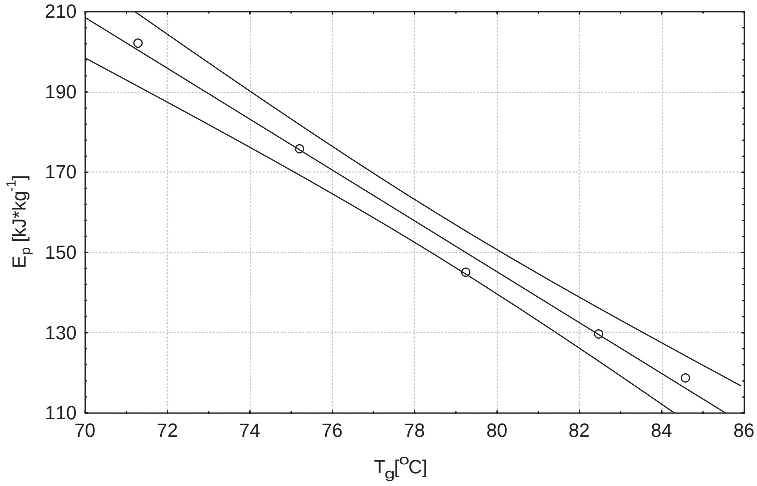

Fig. 3. Dependency between unit pressing energy expenditures (E_p) and pellet temperature after passing through the die (Tg) (steam conditioning)

A very strong negative correlation ($r= -0.995$; $p<0.01$) was determined for steam conditioning, while the conditioning process with the addition of water is indicative of a positive correlation ($r=0.996$; $p<0.01$)

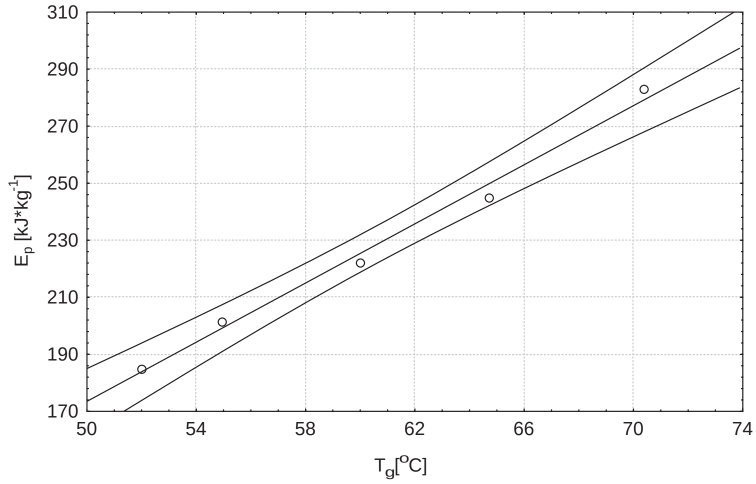

Fig. 4. Dependency between unit pressing energy expenditures (E_p) and pellet temperature after passing through the matrix (Tg) (conditioning with the addition of water)

The above dependencies can be illustrated by multiple linear regression models:
<u>for steam conditioning:</u>

$$E_p = -6.34T_g + 652.37 \; ; \; R^2 = 0.992, \quad (1)$$

for conditioning with the addition of water:

$$E_p = 5.183T_g + 85.623; \; R^2 = 0.993. \quad (2)$$

CONCLUSIONS

The following conclusions can be drawn from the conducted experiment:

1. The applied conditioning parameters determine changes in pellet temperature and pressing energy consumption. The increase in material temperature during steam conditioning minimises friction resistance between the material and the walls of the matrix channel, thus reducing the increment in pellet temperature and decreasing energy consumption of the process. The effect of the properties of raw materials on the energy consumption of the process decreases as the temperature of conditioning exceeds 70°C.
2. Conditioning with the addition of water, regardless of its contents, leads to a much higher increase in the temperature of the pellet after pressing in the die (by 38,5°C on average) than in steam conditioning (by 10°C on average). The properties of raw materials affect an increase in the temperature and energy consumption of the process.
3. The temperature of the pellet obtained from raw materials with a high fat content is on average 8.5% lower (steam conditioning) than the temperature of the pellet produced from raw materials with a high fibre content and 33% lower in comparison with conditioning with the addition of water. The lubricating properties of fat are most visible at both lower conditioning temperatures (steam pelleting) and a lower moisture content of the material during cold pelleting.
4. The increment in the temperature of the pellet after passing through the die in comparison with the temperature of the raw material prior to pressing is a good predictor of energy consumption of the pressing process due to a very strong linear dependency between those parameters.

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WPŁYW WARUNKÓW KONDYCJONOWANIA NA TEMPERATURĘ GRANULATU I ENERGOCHŁONNOŚĆ PRASOWANIA MATERIAŁÓW ROŚLINNYCH

Streszczenie. W pracy przedstawiono wyniki badań wpływu warunków kondycjonowania na temperaturę otrzymywanego granulatu w powiązaniu z energochłonnością procesu prasowania materiałów roślinnych. Uzyskane wartości zawierały się w przedziale od 64 do 90,5^{o}C dla kondycjonowania parowego i od 46,5 do 95^{o}C dla kondycjonowania z dodatkiem wody. Stwierdzono, iż wzrost temperatury materiału przed prasowaniem do wartości 70^{o}C niweluje w sposób zadawalający wartość współczynnika tarcia w czasie prasowania. Wykazano istnienie bardzo silnej liniowej zależności pomiędzy temperaturą granulatu a energochłonnością prasowania ($r= -0,995$; $p<0,01$ dla kondycjonowania parowego i $r=0,996$; $p<0,01$ dla kondycjonowania z dodatkiem wody).

Słowa kluczowe: temperatura granulatu, energia prasowania, granulowanie, kondycjonowanie.