The investigation of pressures exerted by the densifying material on the wall of the closed densification chamber

Sławomir OBIDZIŃSKI, Roman HEJFT - Department of Agricultural and Food Techniques, Faculty of Mechanical Engineering, Bialystok University of Technology

Please cite as: CHEMIK 2012, **66,** 5, 453-460

Introduction

The process of pressure agglomeration is most often realized in working systems:

- with a closed densification chamber
- with an open densification chamber
- with a partly open densification chamber
- in a "flat die – densifying rollers" or "ring die – densifying rollers" system
- in a "sleeve – densifying worm" system.

According to Hejft [9], pressure agglomeration of broken-up plant materials is conducted most often in devices with an open working chamber. Due to the simple construction of the operating system, higher efficiency (compared to a closed chamber), process continuity, easy material charging, these devices have been applied in production lines for granulating and briquetting.

In industrial practice, densification in a closed chamber is not used broadly. It is commonly used as a research method which enables the verification of equations (models) of densification and the determination of the distribution of tensions in the compacted material [16], as well as the assessment of materials' susceptibility to agglomeration [11] which, according to Hryniewicz [10] is understood as the ability to create, under pressure, a solid piece form with required endurance parameters**.**

According to Czaban and Kamiński [2, 3], material constants (i.e. yield point equivalent, parameters C, D, E of the porosity function and the Prandtl friction factor) obtained using process identification in a closed chamber, determined based on registered courses of experimental forces acting on the densification piston, bottom of the densification chamber and on the sidewalls of the densification chamber, may be used for modelling and analyzing the energy consumption of densification processes of fodder mixtures realized in industrial granulation devices.

Demianiuk et al. [5, 6] in their studies of densifying spruce sawdust used a closed axisymmetric die for measuring the value of the actual external friction factor. For this purpose, the values of pressure on the densification piston, on the die bottom and the distribution of radial pressures along the forming die were measured in the closed die.

Following Skonecki [16], the result of tests in a closed chamber are formulas (empirical equations) of the dependency of the material density on the densification pressure. They may be used after determining constant parameters for tested materials for which they were developed and are true in the strictly defined range of densification pressures.

Tests on the process of densifying plant materials in a closed chamber were conducted by many other researchers. Ghazanfari et al. [7] compacted timothy hay at different humidity and pressure values in a closed chamber. Gilbert et al. [8] densified different types of grass, while Razun et al. [15] compacted waste in the form of palm kernels on a hydraulic press in a "piston – closed chamber" system with different densification pressures and temperature.

Also Adapa et al. [1], determining the densification characteristics of different types of hay, used the "piston – closed chamber" system with the possibility of regulating the process temperature. A similar workstation with a closed chamber and process temperature regulation for determining the densification characteristics of waste from cutting down olive trees was used by Carone et al. [4].

According to Skonecki [16], the uniformity and degree of material densification in a closed chamber is influenced by the following parameters: value of the external pressure and the rate of its increasing, value of the normal pressure to the side die surface, value of the factor of the materials friction against die walls, die and stamp geometry, the quotient of the agglomerate height and diameter, physical and chemical properties of the material (particles), volume of air contained in the agglomerate.

The purpose of the work was to determine the impact of the die length and the temperature of the densification process on the values of radial (side) pressures exerted by the densified material on the walls of the closed densification chamber.

Material and methods

Research material

For the purpose of testing, a full-portion DK-Finiszer fodder mixture was used with 16% humidity. This mixture is used for feeding chickens and broilers from the 6th week until the end of the fattening; moreover, as provided by Laskowski [12], it is used for determining the production output of fodder production plants.

Particle size composition of the **DK-Finiszer** fodder mixture is presented in Figure 1.

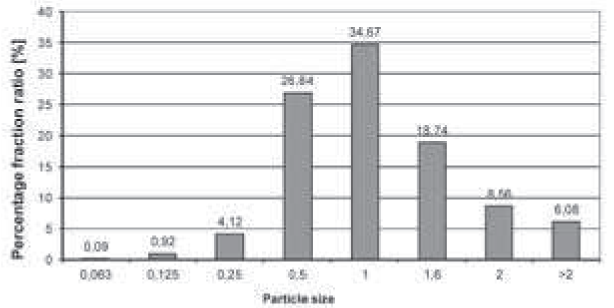


Fig. 1. Particle size distributions of the DK-Finiszer fodder mixture

In the tested fodder mixture, the dominating fractions include 1.6-mm particles which constitute 28% of the mass composition of the mixture as well as 2-mm particles (approx. 21%) and 1-mm particles (approx. 20%).

Testing methods

Tests of the densification process were carried out at the investigative stand SS-3 (Fig. 2) [14].

The stand is composed of a hand press 1, at the basis of which an open densification chamber 3 was assembled (with an 8-mm diameter) into which the tested material was charged. The densification chamber 3 was heated from the top with a special thermostat element 4 to which, using ducts 7, water from the ultrathermostat 9 was supplied thanks to which it is possible to regulate the process temperature. The densification of the mixture was carried out using piston 6, with a deformeter sensor allowing for a registration of forces acting on the piston.

The SS-3 stand was fitted with a control and measuring apparatus which allows for a simultaneous measurement and registration: of forces acting at the densification piston 6, forces acting at the densification chamber walls (on pistons placed at a different height of the densification chamber 3), forces acting at the bottom of the densification chamber and the displacement of the densification piston (using a displacement sensor 8).

Signals from the system of deformeters on the densification piston 6, on pistons placed in side walls, at the bottom of the densification chamber and signals from the displacement sensor 8 were brought to the deformeter bridge 11, and then registered with a recorder 12 (coupled with a computer 13) in the form of binary files which were subjected to further processing using Microsoft Excel.

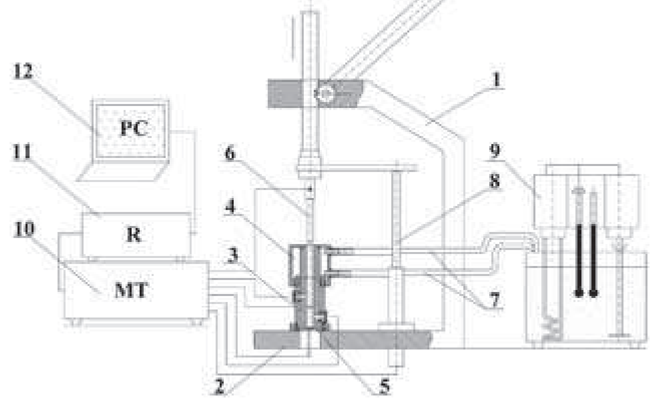
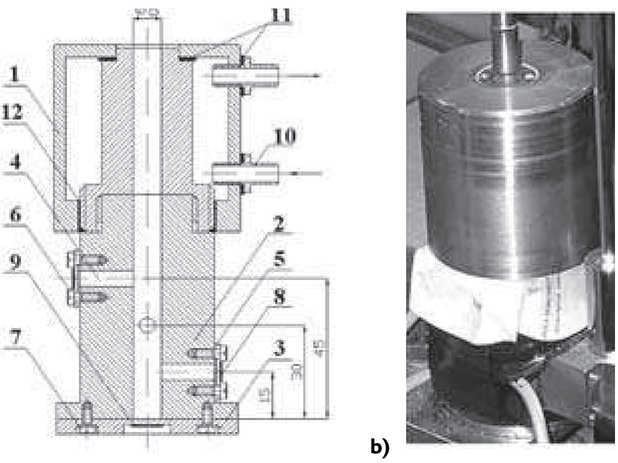


Fig. 2. Schema of the SS-3 investigation stand granulation [13, 14]: 1–press, 2–basis, 3–densification chamber, 4–heat exchanger, 4a–heating band, 5–chamber bottom, 6–densification piston, 7–flexible ducts, 8–displacement sensor, 9 – multichannel recorder, 10 – temperature regulator, 11 – computer

In Figure 3 a special densification chamber used in the SS-3 stand was presented.



a) b)

Fig. 3.The special densification chamber used in the stand SS-3 [14]: a) the schema of the densification chamber: 1- the element heating the chamber, 2-densification chamber, 3-the bottom of the chamber, 4-pistons for the measurement of radial pressures, 5-beams, 6-screws fixing beams, 7-screws fixing the bottom of the chamber, 8,9-deformeter of the type TFm-10, 10-the inlet, 11,12-gaskets b) the view of the chamber

In the densification chamber, measuring pistons 4 were placed at the height of $h_1=15$ mm, $h_2=30$ mm, $h_3=45$ mm from the chamber basis for measuring radial pressures. Piston 4 exerts pressure on beam 5 to which deformeters (TFm-10) 8 are attached.

Before measurements, the densification chamber and the raw material samples (placed in tightly sealed test tubes) were properly heated to the required temperature.

Tests of the densification process were carried out for temperatures of 20, 30, 40, 50, 60, 70, 80 and 90°C, densifying 20 2-g samples.

Result and discussion

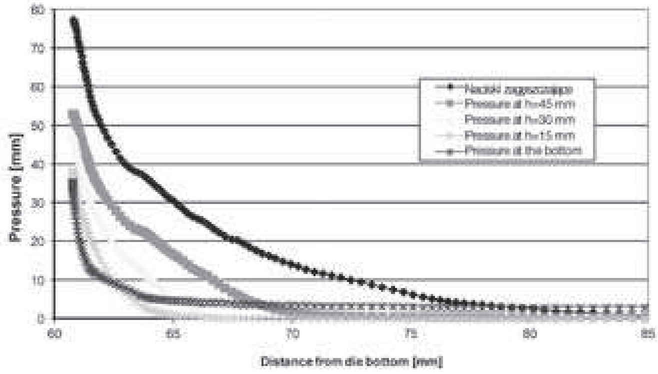


Fig. 4. The course of the pressure in the function of distance from the bottom of the closed chamber (densifying the the mixture DK-Finiszer in the temperature 50 °C)

From the obtained course of pressures (Fig. 4) it may be seen that together with getting closer to the bottom of the chamber values are increased of densification and radial pressures as well as of forces acting on the bottom of the densification chamber. At a process temperature of 50°C, approximately 61 mm from the bottom of the chamber densification forces achieve their maximum values. Of a similar nature are radial pressures and pressures acting on the die bottom. They obtain maximum pressures only when the densification piston is approx. 61 mm from the die bottom.

Figure 5 presents an exemplary distribution of radial pressures in the function of the densification chamber length during the densification of the mixture in a closed chamber at 50°C, together with an equation describing radial pressures in the function of distance from the bottom of the densification chamber.

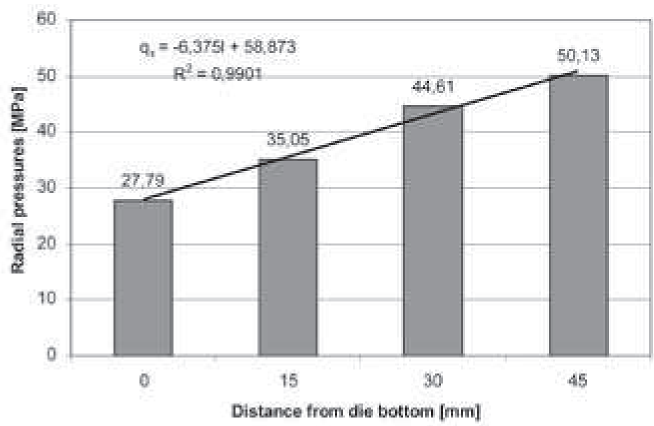


Fig. 5. The radial pressures expansion on the chamber length during the densifying of the DK- Finiszer mixture in the closed chamber in the temperature of the process 50 °C

The distributions of radial pressures on the length of the densification chamber during the densification of the mixture in a closed chamber at a different process temperature are of a very similar nature to the one presented in Figure 5. Thanks to the conducted tests it was possible to determine that changes of the values of radial pressures exerted on the die length (distance from the die bottom) during the densification of the fodder mixture in the closed chamber may be illustrated with the following equation:

$$q_x = a_4 \cdot l + b_4 \qquad \textbf{[MPa]} \qquad (1)$$

where:
l - distance from the die bottom [mm]
a_4, b_4 – equation factors

Coefficients $\boldsymbol{a_4}$, $\boldsymbol{b_4}$ of equation (1) for the tested process temperature with a densification pressure of approx. 74 MPa were placed in table 1.

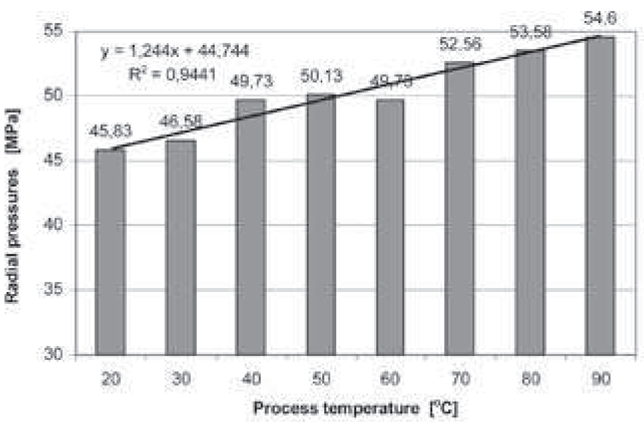
Table 1

The value of coefficients a_4 and b_4 of equation (1) describing the course of radial pressures on the length of the closed densifying chamber

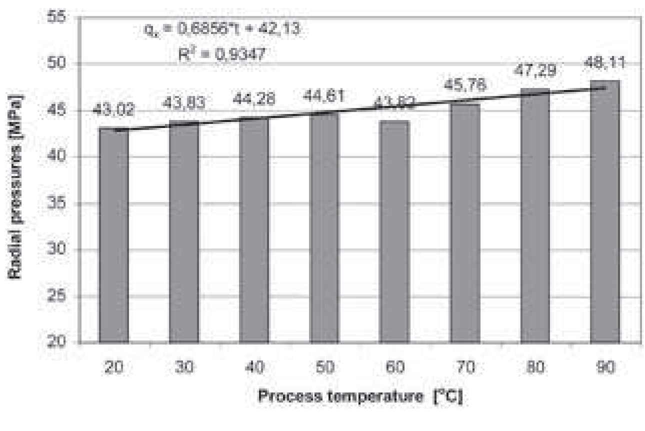
Temperature [°C]	Coefficients		Coefficient of correlation R^2
	a_4	b_4	
20	-7.47	54.65	0.9320
30	-7.05	55.07	0.9533
40	-7.73	58.37	0.9903
50	-6.38	58.84	0.9901
60	-7.35	57.45	0.9897
70	-8.02	60.94	0.9954
80	-7.13	60.65	0.9780
90	-7.12	61.52	0.9719

An example of the impact of process temperature on the values of radial pressures 45 mm from the bottom of the densification chamber was presented in Figures 6÷8.

a)



b)



c)

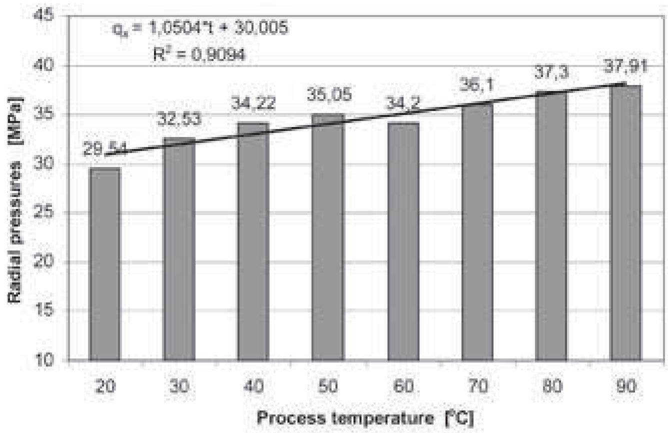


Fig. 6. The dependence of the radial pressures from the temperature got during densifying the DK- Finiszer mixture in closed chamber on height from the bottom of the chamber: a) 45 mm, b) 30 mm, c) 15 mm

The increase of the process temperature leads to an increase of radial pressure values at specific die heights. At 60°C, a rapid conversion of starch and its joining with humidity starts. A reorientation occurs of particles in the created agglomerate, which leads to a decrease of radial pressures (Fig. 6). Further increase of process temperature causes an increase of radial pressures as a result of a pressure increase inside the chamber (humidity evaporation at heightened pressure).

Thanks to the conducted tests, it could be stated that changes of radial pressure values under the influence of a densification process temperature at each of the tested distances from the bottom of the densification chamber (distances from the die bottom) during densifying the DK-Finiszer fodder mixture in a closed chamber may be illustrated with the following equation:

$$\boldsymbol{q_x = a_l * t + b_l} \qquad \text{[MPa]} \qquad (2)$$

where:
t – densification process temperature [mm]
a_l, b_l – equation factors

Conclusions

The designed and fitted special densification chamber used at the investigative stand enables the determination of the impact of the densification chamber length and process temperature on the radial pressure values obtained during the densification process.

Together with getting closer to the die bottom during densification a decrease occurs of radial pressures acting on the walls of the closed densification chamber.

The increase of process temperature from 20 to 90°C leads to an increase of radial pressure values at different die heights. The increase of radial pressures occurring together with the increase of temperature is related to the increase of pressure inside the chamber as a result of humidity evaporation.

The impact of the densification chamber length (distance from the die bottom), as well as of the densification process temperature on radial pressure values during the densification of the fodder mixture in a closed chamber may be illustrated using a linear function equation.

The obtained distributions of radial pressures on the die length at different temperatures allow for determining the coefficient of friction and its changes on the length of the die.

Literature

1. Adapa P., Lope Tabil L., Greg Schoenau G.: *Compaction characteristics of barley, canola, oat and wheat straw*. Biosystems Engineering 2009, **104**, 335-344.
2. Czaban J.: *Ciśnieniowa aglomeracja pasz w układzie roboczym granulatora*. Praca doktorska. Politechnika Białostocka 2000.
3. Czabana J., Kamiński Z.: *Energochłonność prasowania mieszanek paszowych w komorze zamkniętej*. IV Międzynarodowa Konferencja Naukowo-Techniczna: Motoryzacja i energetyka rolnictwa „Motrol'2003". Lublin, 19-21 maja 2003.
4. Carone M.T., Pantaleo A., Pellerano A.: *Influence of process parameters and biomass characteristics on the durability of pellets from the pruning residues of Olea europaea L.* Biomass and Bioenergy 2010, 1-9.
5. Demianiuk L.: *Brykietowanie rozdrobnionych materiałów roślinnych*. Praca doktorska. Politechnika Białostocka, Białystok 2001.
6. Demianiuk L., Hejft R., Seweryn A.: *Doświadczalna analiza sił i odkształceń występujących podczas brykietowania materiałów drobnoziarnistych w komorze zamkniętej*. Zeszyty Naukowe Politechniki Białostockiej. Nauki Techniczne nr 130. Mechanika 1999, **21**, 73-94.
7. Ghazanfari A., Opoku L., Tabil L. Jr.: *A stady on densification of timothy hay at different moisture content*. Asian Journal of Plants Sciences 2007, **6** (4), 704-707.
8. Gilbert P., Ryu C., Sharifi V., Swithenbank J.: *Effect of process parameters on pelletisation of herbaceous crops*. Fuel 2009, **88**, 1491-1497.
9. Hejft R.: *Ciśnieniowa aglomeracja materiałów roślinnych*. Biblioteka Problemów Eksploatacji. ITE, Radom 2002.
10. Hryniewicz M.: *Metoda doboru pras walcowych oraz opracowanie założeń do ich modernizacji*. Rozprawy monografie 1997, **58**, Wydawnictwa AGH, Kraków.
11. Laskowski J., Skonecki S.: *Metoda określania parametrów zagęszczania materiałów pochodzenia biologicznego*. III Ogólnopolska i II Międzynarodowa Konferencja Naukowa. Rozwój teorii i technologii w technicznej modernizacji rolnictwa. Olsztyn 1994, 29-33.
12. Laskowski J.: *Studia nad procesem granulowania mieszanek paszowych*. Praca habilitacyjna. Wydanie Akademii Rolniczej w Lublinie 1989.
13. Obidziński S.: *Wpływ temperatury na jakość produktu w procesie granulowania pasz*. Inżynieria Rolnicza 2003, **8** (50), 339-345.
14. Obidziński S.: *Granulowanie materiałów roślinnych w pierścieniowym układzie roboczym granulatora*. Praca doktorska. Politechnika Białostocka, Białystok 2005.
15. Razuan R., Finney K.N., Chen Q., Sharifi V.N., Swithenbank J.: *Pelletised fuel production from palm kernel cake*. Fuel Processing Technology 2011, **92**, 609-615.
16. Skonecki S.: *Modelowanie ciśnieniowego zagęszczania materiałów roślinnych*. Rozprawy Naukowe Akademii Rolniczej w Lublinie, Zeszyt 279, Lublin 2004.

Work performed as part of the Project (grant) MNiSW N N504 488239

Sławomir OBIDZIŃSKI - Assistant Professor of the Department of Agricultural and Food Techniques on the Faculty of Mechanical Engineering in Bialystok University of Technology. Area of the scientific work: the pressure agglomeration of plant materials, the structure and the use of machines of the farm and food industry.

e-mail: obislaw@pb.edu.pl, telephone: (085) 746-92-82

Roman HEJFT – Professor (Sc.D) - head of the Department of Agricultural and Food Techniques on the Faculty of Mechanical Engineering in Bialystok University of Technology. Area of the scientific work: the pressure agglomeration of plant materials, the structure and the use of machines of the farm and food industry.