Journal of Machine Construction and Maintenance
PROBLEMY EKSPLOATACJI
QUARTERLY
ISSN 1232-9312 2/2017 (105)
p. 117–122

Michał BEMBENEK, Ph.D. Eng.
AGH University of Science and Technology
Faculty of Mechanical Engineering and Robotics
al. Mickiewicza 30, 30-059 Kraków, Poland
e-mail: bembenek@agh.edu.pl

EXPERIMENTAL ANALYSIS OF CONSOLIDATED MATERIAL FLOW THROUGH A ROLLER PRESS WITH A NON-SYMMETRICAL COMPACTION UNIT

Key words: agglomeration, roller press, consolidation.

Abstract: One of the essential aspects of the operation of roller presses is the proper transfer of feed in the feeder. It has a significant influence on the correct course of the compaction and consolidation process, the product quality, and the intensity of the wear of the moulding components. This article presents the current knowledge about the flow of material in a gravity feeder. It has been noted that the works being published are only related to symmetrical compaction unit designed for briquetting. Considering the dynamic development of the dry granulation process in which the shape of the consolidated product is not important, visualisation tests were carried out to survey the flow of material in a non-symmetrical compaction unit used to agglomerate the material. Different configurations of the drive system have been taken into account, and the results so obtained have been included in this study. They were used to acquire knowledge about the phenomena occurring on the surface of the material with the operating elements and can help to further improve the roller press non-symmetrical compaction unit and to operate these machines in a correct way.

Analiza eksperymentalna przepływu scalanego materiału podczas eksploatacji prasy walcowej z niesymetrycznym układem zagęszczania

Słowa kluczowe: kawałkowanie, prasa walcowa, scalanie.

Streszczenie: Jednym z podstawowych zagadnień eksploatacji pras walcowych jest właściwe przemieszczanie się nadawy w zasobniku. Ma ono znaczący wpływ na prawidłowy przebieg procesu zagęszczania i scalania, jakość produktu oraz intensywność zużywania elementów formujących. W niniejszym artykule przedstawiono aktualny stan wiedzy dotyczący przepływu materiału w zasilaczu grawitacyjnym. Zwrócono uwagę, że publikowane prace dotyczą jedynie układów symetrycznych przeznaczonych do brykietowania. Ze względu na prężnie rozwijający się proces granulacji dwustopniowej, w którym kształt scalonego produktu nie jest istotny, przeprowadzono badania wizualizacyjne przepływu materiału w niesymetrycznym układzie zagęszczania służącym do kawałkowania materiału. Uwzględniono różną konfigurację układu napędowego, a uzyskane wyniki zamieszczono w niniejszej pracy. Posłużyły one do uzyskania wiedzy o zjawiskach występujących na powierzchni materiału z elementami roboczymi i mogą być pomocne do dalszego doskonalenia niesymetrycznego układu zagęszczania prasy walcowej oraz prawidłowej eksploatacji tych maszyn.

Introduction

Pressure agglomeration is one of the essential methods used to consolidate dusty and fine-grained materials [1, 17]. Whenever possible, in case of mineral materials and selected production waste materials, this process is carried out in roller presses [9]. In machines of this kind, the feed is consolidated in a compaction zone. It consists of elements that come in direct contact with the material, i.e. working rollers, feeder, and side sealings [10]. The correct flow of material in the compaction zone makes the roller press operate properly, because it reduces the unit energy consumption and allows the user to achieve high product efficiency along with its proper mechanical durability [1, 9]. The literature sources also prove that the above parameters are largely determined by the drive system configuration [8]. The article contains an overview of the current knowledge concerning the analysis of the way in which grained material moves in the roller press gravity feeder and presents the results of the author's independent tests of the grained material flow depending on the way in which the drive system is arranged in the roller press equipped in non-symmetrical compaction unit.

1. Current knowledge about material flow in roller press

The fine-grained material pressure agglomeration process involves pressures up to hundreds MPa. It can be divided into two stages. In the first stage, during which material particles packing is rearranged, relatively high compaction rates are obtained under small external forces. On the other hand, in the second stage, the particles are consolidated together and a quasi-continuous body is formed. In that case, much lower compaction rates are obtained under high values of external forces [9]. In both stages, the loose material properties including the Young module, the external and internal friction coefficient, and the side pressure coefficient change on a continuous basis. Based on the current knowledge, this does not allow modelling and simulating the fine-grained material transfer and consolidation process in the roller press by means of the available advanced computer tools [2, 13, 19, 20, 21]. Only visualisation tests can provide such information [11, 16]. They are especially usable for gravity feeders, since the feed transfer and the process parameters are predictable for forced flow feeders [3, 5]. The visualisation tests that have been carried out so far covered only the flow of material in a roller press with a symmetrical compaction unit used to manufacture briquettes with a parting plane. These experiments were performed in a specially adapted roller press with 450 mm diameter rollers, located at the Department of Manufacturing Systems of the AGH University of Science and Technology. Two model materials were employed in the tests: 2–6 mm diameter foamed polystyrene balls, and wood dust. To achieve a contrast, a part of the feed was dyed. The pre-treated material was arranged in a gravity feeder situated above the press rollers alternately into "white" and dyed layers with a height of about 20–30 mm. Subsequent experiments were recorded while accelerating the working elements to a circumferential speed of 0.1 m/s [11]. Characteristic phases illustrating the transfer of material in the gravity feeder were selected from the recorded test results. They were similar for both materials, i.e. the foamed polystyrene balls and the wood dust. Figure 1 shows the zones that were formed as the material was moving in the feeder [11]. It shows that the feed is supplied into the compaction and consolidation zone most intensively from the side charge areas (Area B, Fig. 1). Due to the contact with the roller surfaces, the material fills the moulding cavities and is taken by them. In the intensive feed transfer area, the feed forms a layer which sticks to the moulding rollers and moves along with them. In the central area of the charge (Area A, Fig. 1), the feed was observed to be moving slightly in a vertical direction by gravity [11].

The results of the visualisation tests for the symmetrical compaction unit designed for making briquettes are also included in the study [14]. Contrary to the experiments performed by the AGH University of Science and Technology, the study referred to focused on material deformations that occur in the process of its consolidation. A special test station (Fig. 2) for the production of special briquettes with a parting plane has been designed and built for this purpose. The results are presented in Figure 3 [14].

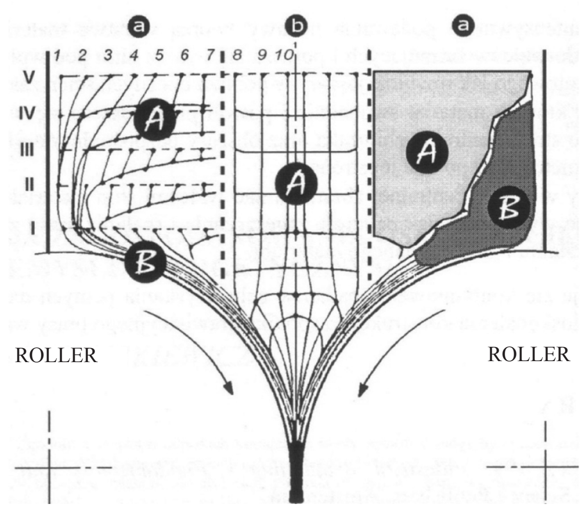

Fig. 1. Scheme illustrating the transfer of fine-grained material in a roller press gravity feeder when using a symmetrical compaction unit for briquetting: a – feeder side area, b – feeder central area, A – feed free flow zone, B – feed intense supply zone, I, II, III, IV, V – layers of material, 1, 2, 3…10 – situation of feeder cross-sections [11]

It shows that the briquettes become deformed to the largest extent during the initial compaction phase, especially in its upper part. As the rollers rotation angle increases, the relative maximum deformation of the briquette is reduced and the non-deformed zone gradually moves away from the lower part of the briquette upwards [14]. However, the type of the model material used for the visualisation tests, which was plasticine, may be questionable. It is a typical plastic material that actually behaves quite differently when under force than loose materials compacted in roller presses. Therefore, the tests referred to above do not represent the actual deformation of the feed while it is being consolidated in roller briquetting machines.

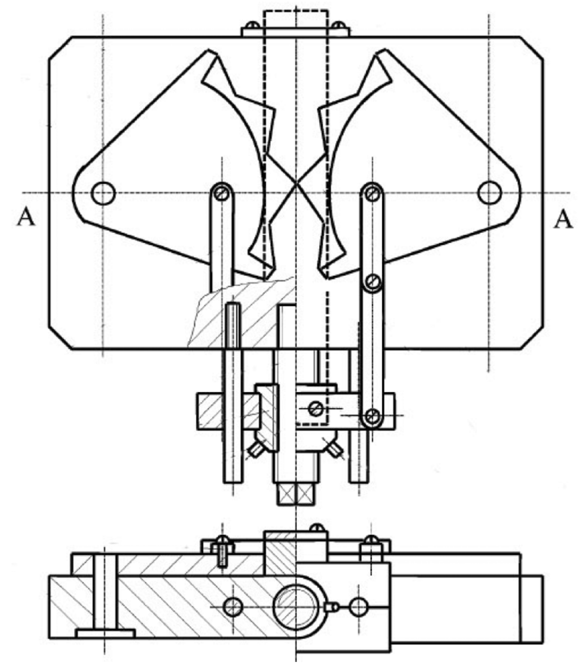

Fig. 2. Station for testing material deformations in the process of consolidation [14]

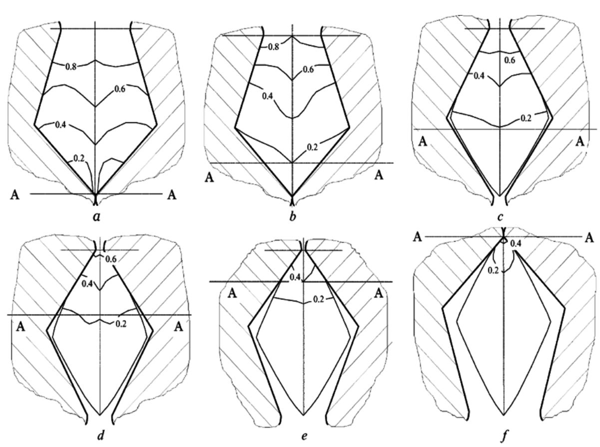

Fig. 3. The individual material deformation stages in the process of consolidation in the symmetrical compaction unit with relative deformation values depending on the roller rotation angle: a) φ = 0°, b) φ = 5°, c) φ = 10°, d) φ = 15°, e) φ = 20°, f) φ = 25° [14]

The analysis of the literature sources referred to shows that the visualisation tests were focused only on symmetrical compaction units of press machines. Still there is no information available the material behaviour in non-symmetrical unit feeders, which are more and more frequently used due to their advantages [1, 9]. Moreover, the impact of the drive system configuration on the unit energy consumption change has not been explained [8]. This provided inspiration for undertaking relevant tests.

2. Experimental visualisation tests of fine-grained material consolidation process in roller press

The system selected for testing loose material flow in a non-symmetrical compaction unit was a system designed for agglomeration (Fig. 4b). It consists of one flat ring and one profiled ring, and it is used in the first stage of the dry granulation process as well as other processes [4, 6, 7, 12, 18]. This solution allows obtaining higher efficiency than when using two flat rings (Fig. 4a); however, the production and the general intensity of the wear of the moulding surfaces are lower than that of the unit with mouldings protrusions on both sides [1]. Its additional advantage is that the working rings do not require their revolutions to be mutually synchronised, allowing only one roller to be driven and the torque to be transmitted to the other working element by means of frictional contact. This significantly simplifies the press drive system but, unfortunately, it increases the unit energy demand [8]. The reasons for selecting the compaction unit included the current emphasis on the minimisation of the costs of material consolidation in the dry granulation process in which this type of unit may be used.

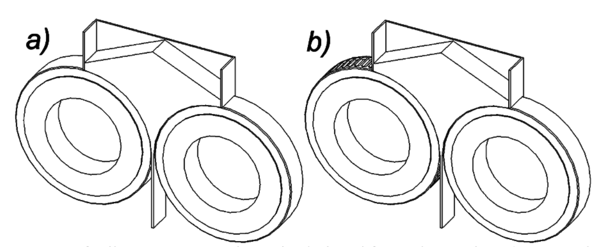

Fig. 4. Layouts of roller press compaction units designed for agglomeration: a) symmetrical, b) non-symmetrical

The scope of tests under the experiment schedule included visualisations of the flow of material in a non-symmetrical roller press where the following drive system was employed to drive the working elements:

– Both working rollers (the roller with moulding cavities and the flat one) were driven.
– Only one working roller was driven:
  • the roller with the cavities (the flat roller was the idle one), and
  • the flat roller (the roller with the cavities was the idle one).

The tests were carried out with the use of a LPW450 roller press. The video recording was performed with the Nikon D5000 camera equipped with the Nikkor 18–105 VR lens with image stabilisation. The recording was made with a resolution of 640x424 pixels and a frame rate of 24 frames/s. Two model materials were used for the visualisation tests, i.e. calcium hydroxide and mill scale, which were selected to obtain maximum contrast between the materials. The feed was arranged in the gravity feeder alternately in layers with a thickness of about 20–30 mm (Fig. 5) up to a height of approx. 200 mm. The experiment was recorded from the moment when the press drive system was turned on until the material was completely discharged from the feeder. The image recorder was installed about 1 m away from the compaction unit and the rollers were accelerated to a speed of 0.1 m/s. The tests were performed with a width of the gap between rollers of 5 and 9 mm. The flow of material for each configuration of the drive system with a specific gap was repeated three times, totalling 18 experiments.

The first compaction unit to be tested was the non-symmetrical one, where both working rollers were driven. Based on the analysis of the recorded results (Fig. 5), Figure 6 illustrating the transfer of the material in the feeder was produced. It has been found that a layer forms on the working surface of the profiled roller, and, as in case of the briquetting in symmetrical unit, the layer sticks to the roller (Area 2 in Fig. 6) and moves with the same rotational speed as the roller. The feed, staying in the zone adjoining the flat roller, is taken at a slower rate. Unlike in case of the profiled roller, no material layer is formed, but there occurs a clearly noticeable relative movement on the working surface between the non-profiled roller and the material. The feed is observed to slip over this roller. The remaining part of the material in the gravity feeder forms a wedge, which slowly moves vertically downwards (Area 1 in Figure 6). The feed is intensively taken by the rollers with transversal grooves and, as a result, the material wedge falling downwards gradually pours towards the roller with transversal grooves (Area 3 in Fig. 6b). When the gap width was reduced from 9 mm to 5 mm, the behaviour of the material did not change.

In roller presses, most often, two working rollers are driven. In the case of the non-symmetrical compaction unit designed to agglomerate material, it is possible to drive one of the rollers and have the torque transmitted onto the other roller through frictional contact. This solution significantly simplifies the drive system. This, however, causes the demand for energy necessary to power the agglomeration process to be increased [8]. In order to explain this phenomenon, further visualisation tests on the model material agglomeration process in a non-symmetrical unit with one driven roller were undertaken. Similar test results were obtained as in the previous case. The difference was only related to the thickness of the layer being formed and adjoining the profiled roller as presented in Table 1. In each experiment performed, the feed was delivered into the compaction zone at a slower speed by the flat roller, which was also the case in the arrangement of the drive system in which that roller was the driven one. This was caused by small external friction at the meeting point of the roller surface and the material surface, which was demonstrated by the slippage of the feed on its surface.

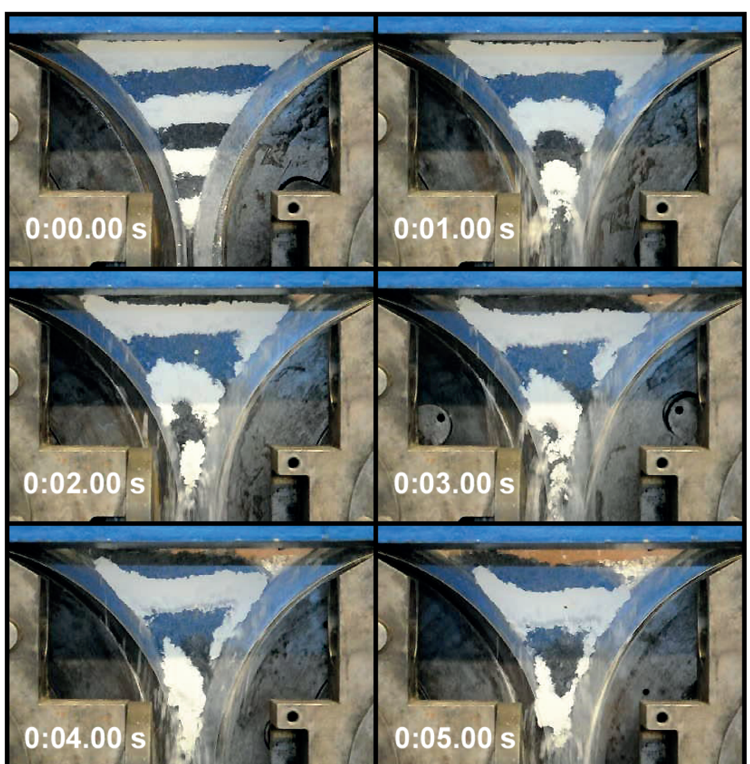

Fig. 5. Feed transfer phases in the gravity feeder for a non-symmetrical compaction unit designed to agglomerate fine-grained materials with two rollers being driven

Table 1. Thickness of the material layer adjoining the profiled roller depending on the way in which the drive system has been configured and the inter-roller gap width

Gap width [mm]	Thickness of the material layer adjoining the roller with the drive applied to:		
	two rollers [mm]	profiled roller [mm]	flat roller [mm]
5	20	26	22
9	20	37	23

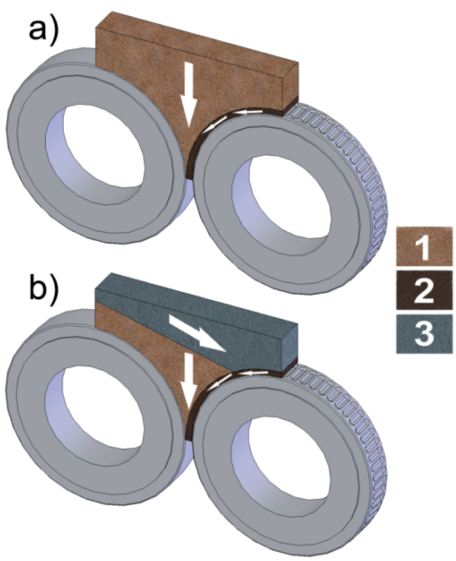

Fig. 6. Diagram illustrating the flow of loose material in the gravity feeder in a non-symmetrical compaction unit designed for the agglomeration of fine-grained materials: a) in the initial stage, b) in the final stage, 1 – wedge falling vertically downwards, 2 – zone in which the feed moves with the same rotational speed as the profiled roller, 3 – layer of material pouring over towards the profiled roller

During all experiments, the remaining part of the material staying in the gravity feeder formed a wedge (Area 2, Fig. 6) slowly moving vertically downwards. The roller with transversal grooves was intensely collecting the material, causing a part of the material forming the wedge to pour towards the profiled roller and filling up shortages in the feed near this roller (Area 3, Fig. 6). The test results have also shown that the feed was moving at the much slower speed when only the flat roller was the driven one.

Summary and final conclusions

While analysing the literary sources, it has been noted that the drive systems of roller presses may be configured in different ways, directly determining the course of the material consolidation process and the demand for energy [8]. Therefore, relevant tests were started to explain the behaviour of the feed in the roller press batching and compaction unit depending on how the drive system has been configured. As a consequence of the intensive development of the dry granulation process [4, 7, 15], the experiments began to employ a new solution, that is, the so-called non-symmetrical compaction unit that has been designed for agglomeration and in which one of the rollers is profiled while the other has a flat working surface. It is used to make mouldings with protrusions on one side. The tests have been performed for three different configurations of the drive system, i.e. when both working rollers are driven, when only the profiled roller is driven, and when only the flat roller is driven. The feed flow in the feeder has been found to vary depending on the working surface profile to which it adjoins. During the consolidation process, a layer forms on the surface of the profiled roller, and the layer sticks to the roller and moves with the same rotational speed as the roller. This layer of materials is not formed in case of the flat roller, but a relative motion occurs on the working surface and also a feed slippage effect can be clearly observed on this roller. Using the drive system for only one roller increases the thickness of the material layer sticking to the profiled roller. It has been found that, to ensure that the roller press is operated correctly and the feed is more effectively collected during the grained material consolidation process in the non-symmetrical compaction unit, it is preferable to obtain the maximum external friction at the point where the flat roller comes in contact with the material and to reduce its internal friction. Since the feed moves at a relatively low speed in the gravity hopper when only one roller is driven, this type of drive system should not be employed in the design of roller presses. It can be concluded that, in case of the agglomeration of material in a non-symmetrical compaction unit, considering the intensive flow rate of the feed from the profiled roller side, it is recommended to operate roller presses with a non-symmetrical gravity feeder. The higher energy demand caused by only one roller being used can be explained by the formation of a thicker layer of material that moves together with the profiled roller. It requires a higher degree of compaction to obtain a post-consolidation thickness corresponding to the inter-roller gap width than that of the layer which forms when two rollers are driven. It naturally results in higher energy expenditure. Supposedly, the torque transfer onto the other roller through frictional forces occurring on the contact surface between the material being consolidated and the roller additionally increased the demand for energy.

The tests should be continued to determine the preferable value of the external and internal friction coefficient to ensure the correct course of the consolidation process and to further enhance the design of the non-symmetrical compaction processes.

References

1. Bembenek M., Hryniewicz M.: Badania i opracowanie metody doboru układu zagęszczania prasy walcowej. [Research on and development of the method of selecting roll press compaction unit.] Wydawnictwa AGH, Kraków 2010.
2. Bindhumadhavan G., Seville J.P.K., Adams M.J., Greenwood R.W., Fitzpatrick S.: Roll compaction of a pharmaceutical excipient: Experimental validation of rolling theory for granular solids. Chemical Engineering Science. 2005, 60, 3891––389.
3. Dec R., Komarek R.: Testing performance of roll press force feed system. IBA Proceedings. 1993, 23, 65–75.
4. Flore K., Schoenherr M., Feise H.: Aspects of granulation in the chemical industry. Powder Technology. 2009, 189, 327–331.
5. Guigon P., Simon O.: Roll press design-influence of force feed systems on compaction. Powder Technology. 2003, 130, 41–48.
6. Freitaga F., Kleinebuddeb P.: How do roll compaction/dry granulation affect the tableting behavior of inorganic materials? Comparison of four magnesium carbonates. European Journal of Pharmaceutical Sciences. 2003, 19, 281–289.
7. Herting M.G., Kleinebudde P.: Studies on the reduction of tensile strength of tablets after roll compaction/dry granulation. European Journal of Pharmaceutics and Biopharmaceutics. 2008, 70, 372–379.
8. Hryniewicz M., Bembenek M., Gara P.: Dobór układu zagęszczania prasy walcowej do scalania materiału w dwustopniowej granulacji. [Selection of a roller press compaction unit for material consolidation in the dry granulation process.] Chemik: Nauka – Technika – Rynek. 2008, 9, 425–428.
9. Hryniewicz M.: Metoda doboru pras walcowych oraz opracowania założeń do ich modernizacji lub konstrukcji. [A method of selecting roll presses and making assumptions for their modernisation or construction]. Wydawnictwa AGH, Kraków 1997.
10. Janewicz A., Kosturkiewicz B.: Problem doboru konfiguracji układu zagęszczania prasy walcowej. [Adjustment of the roller press compaction unit configuration.] Zeszyty Naukowe Politechniki Białostockiej. Budowa i Eksploatacja Maszyn 2002. 9, 243–253.
11. Janewicz A., Kosturkiewicz B.: Wizualizacja grawitacyjnego dozowania nadawy do prasy walcowej. [Visualisation of gravity batching of feed into roller press]. Monografie Wydziału Inżynierii Mechanicznej i Robotyki AGH 2006. 32, 241–248.
12. Kleinebudde P.: Roll compaction/dry granulation: pharmaceutical applications. European Journal of Pharmaceutics and Biopharmaceutics. 2004, 58, 317–326.
13. Lecompte T., Doremus P., Thomas G., Perier-Camby L., Le Thiesse J.C., Masteau J.C. Debove L.: Dry granulation of organic powders – dependence of pressure 2D-distribution on different process parameters. Chemical Engineering Science. 2005, 60, 3933–3940.
14. Loginom Yu.N., Bourkine S.P., Babailov N.A.: Cinematics and volume deformations during roll press briquetting. Journal of materials Processing Technology 2001. 118: 151–157.
15. Mitchell S., Reynolds T., Dasbach T.: A compaction process to enhance dissolution of poorly water-soluble drugs using hydroxypropyl methylcellulose. International Journal of Pharmaceutics. 2003, 250, 3–11.
16. Peter S., Lammens R.F., Steffens K.J.: Roller compaction/Dry granulation: Use of the thin layer model for predicting densities and forces during roller compaction. Powder Technology. 2010, 199, 165–175.
17. Pietsch W.: Agglomeration Processes Phenomena, Technologies, Equipment. Wiley-VCH Verlag GmbH. Weinheim, 2002.
18. Santl M., Ilic I., Vrecer F.: Baumgartner S.: A compressibility and compactibility study of real tableting mixtures: The impact of wet and dry granulation versus a direct tableting mixture. International Journal of Pharmaceutics. 2011, 414, 131–139.
19. Sommer K., Hauser G.: Flow and compression properties of feed solids for roll-type presses and extrusion presses. Powder Technology. 2003, 130, 272–276.
20. Yehia K.A.: Estimation of roll press design parameters based on the assessment of a particular nip region. Powder Technology. 2007, 177, 148––153.
21. Zinchuk A.V., Mullarney M.P., Hancock B.C.: Simulation of roller compaction using a laboratory scale compaction simulator. International Journal of Pharmaceutics. 2004, 269, 403–415.