The method selection of roll press forming elements to consolidate the fine material

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Introduction

Pressure agglomeration of fine materials realized in a roller press occurs in broadly understood production processes. This is a result of the benefits brought about by the consolidation of the raw or waste material. In the pharmaceutical industry, a large refinement degree of fillers and drug carriers, as well as their small bulk density decide about the fact that their original form is not suitable for tablet pressing [2, 4, 6, 8]. Because of this, they are subjected to a 2-stage granulation. It involves consolidating fine material, usually in roll presses and then crushing and dividing it into suitable grain classes. This way, a half-product is obtained with a larger bulk density and a lower required density degree. The application of such prepared component allows for decreasing the stroke of the tablet pressing machine's working punch. This also facilitates material flow, e.g. during dosing and limits its dusting to a large degree [6]. Another advantage provided by consolidating and then crushing agglomeration products is the unification of the structure of drugs, especially those containing components which are difficult to dissolve in water, e.g. naproxen, nifedipine and carbamazepine, without the need for hot agglomeration, or using a solvent [10].

Two-stage granulation is a new process, especially with regard to other materials than those used in the pharmaceutical industry and for this reason it is subjected to continuous improvement. It is used increasingly more often in manufacturing final products, e.g. certain fertilizers. The powdery character of components used for creating fertilizers often does not allow for their direct use in agricultural production. For this reason, suitably prepared mixtures are given a consolidated form and are then crushed in order to obtain a strictly defined grain fraction [1, 7]. Depending on the demand for this type, the granulate may be produced in integrated consolidating-crushing equipment or, in the case of a necessity to obtain large outputs – in technological lines. The same way may be used for consolidating certain post-filtration chemical industry waste suitable for fertilizing soil [12].

A new product which constitutes an interesting offer for the energy industry is a high surface area calcium sorbent for fluidal burners [3, 9]. The starting material for its production is powdery calcium hydroxide. After the addition and thorough distribution of water, it is brought to a consolidated form, and then crushed and subjected to classification in order to obtain a suitable grain class. The fine calcium sorbent obtained using 2-stage granulation is characterized by a developed texture which leads to a significant increase of its specific surface area when compared to the starting material.

The costs of producing the granulate using 2-stage granulation depend to a large degree on the way of consolidating the starting material. In the case of consolidating the material in a roll press, it is important to select a suitable configuration of the densification unit and forming elements with a properly shaped working surface. This was shown in experiments whose method and obtained results were presented in the article. Experience resulting from the realization of cognitive and utilitarian works served as inspiration for developing a method which would enable the selection of suitable press forming elements for consolidating fine materials. It is anticipated that it will play an increasingly bigger role in relation to the development of an asymmetrical densification unit of the roll press.

Methodology

Experimental research of the process of consolidating fine materials was conducted using an LPW 450 roll press (Fig. 1) with a roller diameter of 450 mm, constituting part of the laboratory installation for studying the process of fine material consolidation at the AGH Department of Manufacturing Systems. The model material used for experiments was calcium hydroxide. It was produced at the Trzuskawica Lime Plant (Zakłady Przemysłu Wapienniczego Trzuskawica S.A.) in accordance with norm PN-EN 459-1:2003 and came from one batch. Its initial humidity equalled approx. 0.2%, the bulk density – 0.47 g/cm^3, while the average grain diameter – 19.9 μm. Distilled water was used as binder. Testing the process of consolidating calcium hydroxide was carried out in a symmetrical and asymmetrical densification unit using forming rings with a working surface allowing for obtaining (Tab.1):

- briquettes in the form of 40x30x20 mm drops with a volume of approx. 13 cm^3
- briquettes in the form of a 31x30x13 mm]saddle with a volume of approx. 6.5 cm^3
- mouldings with two-sided 52x18x4 mm lateral protrusions with a cavity volume of approx. 4.3 cm^3
- mouldings with one-sided 52x18x4 mm lateral protrusions with a cavity volume of approx. 2.2 cm^3.
- During tests, the width of the gap between rolls equalled:
- for briquetting a ≈ 1.5 mm
- for consolidating in a unit allowing for obtaining mouldings with two-sided lateral convexities a ≈ 3 mm
- for consolidating in a unit allowing for obtaining mouldings with one-sided lateral convexities a ≈ 5 mm.

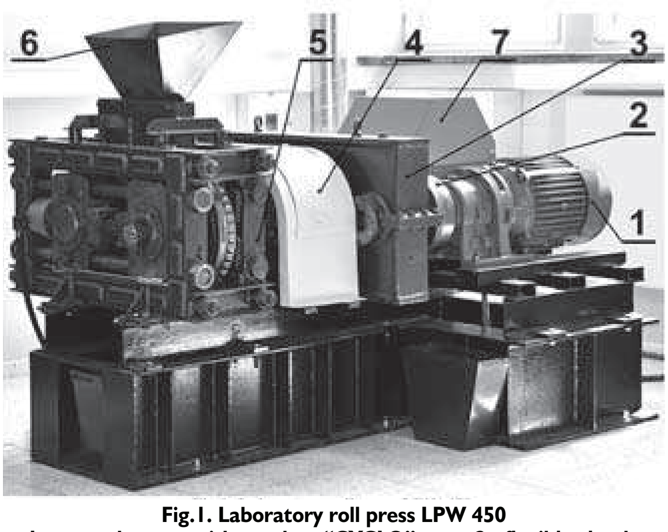

Fig.1. Laboratory roll press LPW 450
1 - geared motor with gearbox "CYCLO" type, 2 - flexible clutch, 3 - gearbox, 4 - housing Oldham and friction clutch, 5 - forming rolls frame, 6 – gravity feeder, 7 – slidable roll support hydraulic station

The size of the gap during the production of mouldings from calcium hydroxide in a roll press was selected so that the output of both densification units would be the same. Experiments were conducted at a peripheral speed of forming rolls equal to 0.1; 0.2; and 0.3 m/s. The calcium hydroxide prepared for consolidating was dosed into the densification area of the LPW 450 laboratory roll press. The briquetting machine was fitted with a gravity charge. Due to the fact that the consolidated calcium hydroxide:

- requires a high level of densification – considerably higher than the majority of materials subjected to agglomeration in roll presses
- cannot be initially compacted using a worm feeder [3]
- it was decided to feed it twice into the densification area of the press.

Table. 1

Forming elements used in researches

	Roll press forming rings	
	for briquetting	**for creating mouldings**
symmetrical	for creating briquettes in the form of drops 	for creating mouldings with one-sided convexities 
asymmetrical	for creating briquettes in the form of a saddle 	for creating mouldings with two-sided convexities 

During tests of the consolidation process of calcium hydroxide, the active power was measured of the electric current consumed by the press's main motor and its frequency converter. Measurements were performed using a universal analyzer of power network parameters with an analysis of Nanovip Plus harmonics. Data activation was done using a portable PC with a sampling frequency of 0.5 Hz. The consolidated material was subjected to seasoning for 24 h. Due to difficulties in comparing the mechanical properties of briquettes and mouldings, a new method was proposed for determining the quality of the consolidated product, i.e. a test of susceptibility of the consolidated material to crushing. It involves weighing 500 g of consolidated material on a WS-23 scale, crushing it in a laboratory hammer crusher with a crushing chamber diameter of 0.2 m and grid with a gap of 3 mm with hammer stroke rates equal to 5.7; 8.5; 11.4; 14.2 and 17.4 m/s. From the crushed material a grain class of 0.63 – 2.0 mm is separated and its ratio in the crushed product is determined. The selection of grain fraction was dictated by the grain size which should be characteristic for the high surface area calcium sorbent created from calcium hydroxide using the granulation method [3, 5, 9].

Test results

Figure 2 contains results of testing the unit energy demand for the realization of the process of consolidating calcium hydroxide in different densification units. The experimentally determined susceptibility of the consolidated material to crushing was presented in Table 2. The lowest value of the total unit energy demand equal to 6.1 kWh/Mg was obtained for a working surface of forming elements used for producing briquettes with a separation surface, consolidating $Ca(OH)_2$ with an addition of 17.5% of water and a peripheral speed of rolls equal to 0.3 m/s. The largest susceptibility of calcium hydroxide to 2-stage granulation, amounting to 55.4%, was noted in the case of crushing briquettes in the form of a saddle. They were obtained by consolidating calcium hydroxide with a 20.0% addition of water, with a peripheral roll speed of 0.1 m/s and large total unit energy demand amounting to 28.8 kWh/Mg.

Table 2

Selected results of susceptibility of consolidated material to crushing for various compaction units

	Roll peripheral speed [m/s]	**0.1**	**0.2**	**0.3**	**0.1**	**0.2**	**0.3**	**0.1**	**0.2**	**0.3**
	Water addition [%]	**17.5**			**20.0**			**22.5**		
briquettes in the form of a drop	Total unit energy demand for the briquetting process **[kWh/Mg]**	8.91	7.41	6.11	10.56	9.34	6.98	10.78	9.38	7.09
	Amount of energy for briquetting $Ca(OH)_2$ out of which. after crushing. 1 [Mg] of granulate is created with a grain fraction of 0.63 – 2.0 [mm] **[kWh/Mg]**	18.19	14.71	**12.22**	20.00	17.43	12.97	20.11	17.37	13.28
	The largest obtained flow-off of the grain fraction after crushing a given batch of consolidated material 0.63 – 2.0 [mm] **[%]**	49	50.4	50	52.8	53.6	53.8	53.6	**54**	53.4
	Stroke speed during the crushing process. for which the largest flow-off was obtained **[m/s]**	5.7	5.7	5.7	5.7	8.5	8.5	8.5	8.5	8.5
briquettes in the form of a saddle	Total unit energy demand for the briquetting process **[kWh/Mg]**	37.31	27.12	25.53	28.79	24.26	22.46	23.87	22.48	20.86
	Amount of energy for briquetting $Ca(OH)_2$ out of which. after crushing. 1 [Mg] of granulate is created with a grain fraction of 0.63 – 2.0 [mm] **[kWh/Mg]**	67.59	50.23	49.10	51.98	46.48	42.86	44.21	41.95	**39.50**
	The largest obtained flow-off of the grain fraction after crushing a given batch of consolidated material 0.63 – 2.0 [mm] [%]	55.2	54	52	**55.4**	52.2	52.4	54	53.6	52.8
	Stroke speed during the crushing process. for which the largest flow-off was obtained **[m/s]**	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4	17.4

mouldings with two-sided convexities	Total unit energy demand for the consolidation process **[kWh/Mg]**	13.55	10.99	11.84	14.97	13.18	9.48	12.76	10.14	9.17
	Amount of energy for consolidation $Ca(OH)_2$ out of which. after crushing. 1 [Mg] of granulate is created with a grain fraction of 0.63 – 2.0 [mm] **[kWh/Mg]**	26.57	21.13	22.95	29.48	25.83	18.16	23.54	19.28	**17.04**
	The largest obtained flow-off of the grain fraction after crushing a given batch of consolidated material 0.63 – 2.0 [mm] **[%]**	51	52	51.6	50.8	51	52.2	**54.2**	52.6	53.8
	Stroke speed during the crushing process. for which the largest flow-off was obtained [m/s]	14.2	14.2	14.2	8.5	8.5	8.5	8.5	8.5	8.5
mouldings with one-sided convexities	Total unit energy demand for the consolidation process **[kWh/Mg]**	19.24	14.97	11.81	18.04	13.05	10.97	14.41	13.54	10.77
	Amount of energy for consolidation $Ca(OH)_2$ out of which. after crushing. 1 [Mg] of granulate is created with a grain fraction of 0.63 – 2.0 [mm] **[kWh/Mg]**	35.62	27.52	21.64	33.97	24.76	**20.93**	28.58	27.63	21.59
	The largest obtained flow-off of the grain fraction after crushing a given batch of consolidated material 0.63 – 2.0 [mm] **[%]**	54	54.4	**54.6**	53.1	52.7	52.4	50.4	49	49.9
	Stroke speed during the crushing process. for which the largest flow-off was obtained **[m/s]**	8.5	8.5	8.5	8.5	8.5	8.5	5.7	5.7	5.7

When analyzing test results it was stated that in some cases a little lower grain fraction flow-off 0.63-2.0 mm was obtained in comparison to the maximum one, with a considerably smaller unit energy demand for consolidating $Ca(OH)_2$. This served as inspiration for determining the total energy demand in the process of consolidating such amount of material which enables the production of 1 Mg of granulate with an assumed grain fraction. The results of suitable calculations were placed in Table 2.

Based on the analysis of results from experimental tests it was stated that the shape of the working surface of roll press forming elements has a considerable impact on the power consumption of its transmission system and on the susceptibility of obtained mouldings on the production of granulate in the process of crushing. A forming surface properly selected with regard to material properties ensures the obtaining of a large press output with a possibly small unit energy demand and preservation of good product quality.

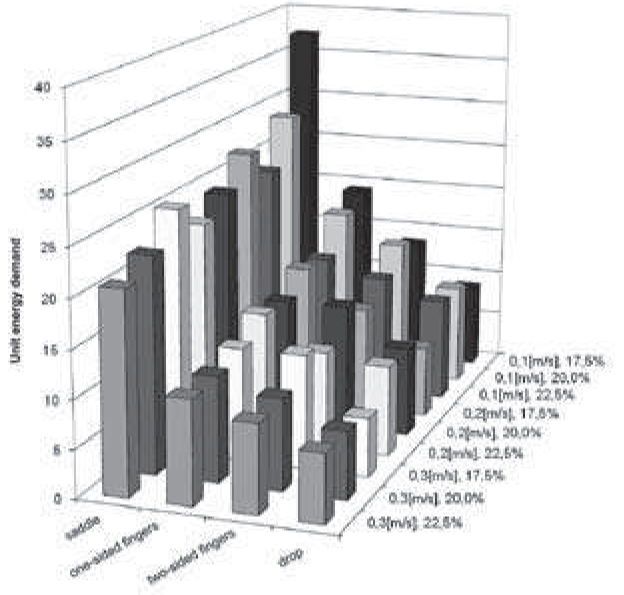

Fig. 2. Dependence of the total unit energy demand from the peripheral speed of the rollers and the amount of water added to the Ca (OH)2 for various compaction units

Method of selecting roll press forming elements for consolidating material

The method whose procedure is presented in figure 3 involves five main stages, during which the following is performed:

- an assessment of the fine material's susceptibility to consolidation
- a selection of configuration of the roll press densification unit
- an experimental verification of the correctness of selecting the densification unit
- simulation tests of the fine material's consolidation process in a press with a specified densification unit configuration
- a selection of geometric construction features of roll press forming elements.

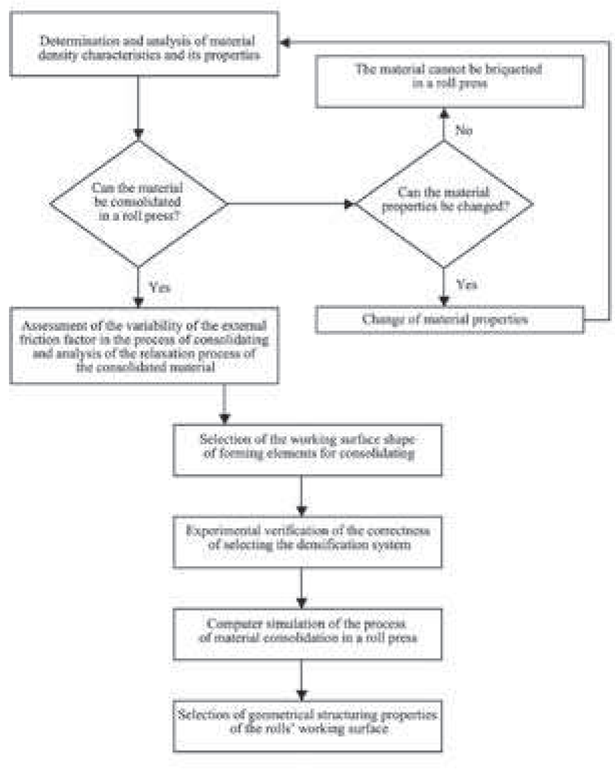

Fig. 3. The procedure for selection of roll press forming elements

In the first stage, an assessment is performed of the fine material's susceptibility to consolidation based on the characteristics of its densification determined experimentally. This allows for determining:

- the possibility of consolidating a given material in a roll press
- the minimum value of unit pressure ensuring the creation of durable mouldings
- the level of material densification
- the course of the material's relaxation (underexpansion) after consolidation.

The roller press may consolidate fine material with progressive densification characteristics. In case of a degressive or degressive-progressive character, usually an attempt is made to change material properties.

The second stage involves a selection of a suitable configuration of the press's densification unit which is made based on the requirements of the potential user of the briquetting machine and an analysis of elastic-plastic features of the material and its relaxation after consolidation. Then a decision is made regarding the manner of its feeding to the densification area and the shape of the working surface of rolls. If the consolidation of the material requires a large degree of densification or it has a tendency to be suspended in the gravity dispenser, it is recommended to use a worm feeder. If the material does not have features of a quasi-plastic body or is not characterized by a large elastic strain after the abatement of pressure, a symmetric densification unit should be used in accordance with the current state of knowledge. The shape of the working surface of rollers is decided by the external friction coefficient which often depends on the unit pressure and changes its value during the course of consolidation. A large external friction coefficient causes an intensive using up of the working surface of rolls. In such a case it is justifiable to use forming elements with lateral grooves because of their lower production costs and easier regeneration. At a low external friction coefficient it is favourable to produce briquettes in the form of a drop because this takes place with the smallest energy expenditure. For the purpose of consolidating fine materials with features of a quasi-plastic body or characterized by a large elastic strain after the abatement of pressure, forming elements should be used for producing briquettes in the form of a saddle.

The third stage is an experimental verification of the correctness of selecting the densification unit of the press. This requires possessing a suitable laboratory base for conducting experiments in order to determine the possibilities of obtaining briquettes with a satisfactory mechanical strength.

The fourth stage involves simulation tests of consolidating fine material in a press with a specified configuration of the densification unit. Their purpose is especially to determine the relation between the volume of grooves and the maximum value of unit pressure. Conducting this type of tests requires having a special software.

In the fifth stage, based on results of simulation tests a selection is made of geometric construction features of the working surface of rolls in such a way so that the consolidated material fulfils the assumed strength requirements.

Summary

As shown in the experimental tests, the type of roll press forming elements for consolidating fine materials has a significant impact on mechanical properties and energy expenditure. Because of this, attention should be paid to its proper selection. The method described in this article is useful for this purpose. It was developed based on previous experience resulting from the realization of works of a theoretical nature as well as tests conducted per order of the industry. In order to perfect the method, it is necessary to expand knowledge on the subject of new configurations of the asymmetric densification unit [13, 14]. This requires conducting further experimental tests. One should aim at a deeper understanding of the mechanism for using up roll press forming elements with different groove shapes, which may be helpful also in predicting the durability of these elements.

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