ANALYSIS OF THE IMPACT OF ROOF SHAPED ELEMENTS ON THE PROCESS OF MULTICOMPONENT GRANULAR PATTERN MIXING IN A FLOW MIXER

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Abstract: The paper presents results of laboratory studies on mixing inhomogeneous multicomponent granular pattern in a flow mixer. A ternary granular pattern was subject to mixing: yellow pea, sorghum and vetch. The mixer was equipped with roof shaped inserts. Roof shaped and double cone type inserts were used during tests. Mix quality was analysed in successive mixing steps on the basis of percentage analysis for each of the constituents. Then, the quality parameter of residual sum of squares was calculated. This provided grounds for determining mix quality changes in time, and insert impact on mixing process.

Key words: granular materials, mixing of granular materials, roof shaped inserts.

Introduction

Quality requirements for mixes are more and more stringent, which urges researchers and engineers to apply new constructional solutions based on analytical studies. Granular materials are mixed using various devices. One of the methods involves flow mixing using the funnel-flow system. Mixers of this type are used e.g. in cement and agricultural-food industry [Boss 1987, Joseph Antony et al. 2004].

The main problem in feeding stuffs production technologies is to obtain suitable quality while mixing inhomogeneous multicomponent granular patterns. This is due to the segregation effect [Boss 1987].

Research results presented by authors so far concern the impact of roof shaped inserts on quality of inhomogeneous binary mixes. Studies on mixing inhomogeneous granular patterns using funnel-flow system and RSI system inserts have proven that it is well-grounded to install these elements in silos. Completed studies have confirmed that obtained mix quality is higher, moreover mix state of equilibrium is reached in shorter time [Matuszek, Tukiendorf 2006]. Double cone type insert was originally designed for mounting in mass dumping silos. However, the research proved to be useful to improve granular constituents intermixing [Matuszek, Tukiendorf 2007].

Possible mixing time reduction owing to quick reaching the state of equilibrium indicates that multicomponent mix analyses should be carried out.

The purpose of the work

The purpose of the work is to analyse mixing process carried out using funnel flow system and the impact of roof shaped and double cone type inserts on the quality of multi-component granular mix (pea–sorghum–vetch).

Measurement test methodology

The tests were carried out in laboratory conditions using a flow mixer. The mixer consisted of two identical silos, which had the same dimensions: cylindrical section height – 200 mm, inside diameter – 150 mm, inside diameter of outlet hole – 30 mm (fig. 1). Mixing involved pouring the material ten times successively from one container into another one. The containers had dismountable structure, consisting of ten identical cross sections. This design of the containers allowed to observe the ratio of individual mix constituents in the whole bed. Detailed data concerning setup design was presented by the authors in the previous works [Matuszek, Tukiendorf 2006, 2007].

Multicomponent granular mix subject to mixing process contained the following components: yellow pea, sorghum, brown vetch. Table 1 shows basic properties of these constituents and their percentages in a mix.

Table 1. Properties of granular constituents

Granular mix constituent	Bulk density [kg·m^{-3}]	Mean particle size [mm]	Constituent percentage [%]
Yellow pea	771	6.95	60
Sorghum	697	3.94	30
Brown vetch	800	4.62	10

Prior to commencement of mixing process, grains of constituents each time were put in individual mixer rings (fig. 1).

Moreover, the researchers carried out series of tests for mixing without any supporting inserts.

The following roof shaped elements were used in the tests:

- roof shaped insert (dilation angle α=120° and base diameter d=70 mm). Roof shaped inserts were placed in upper part of each container, above the tenth cross section (Fig. 2).

- double cone insert (dilation angle α=120 °, cone base diameter d=30 mm, and cone height h=60 mm). Insert of this type was placed in lower part of each container (Fig. 3).

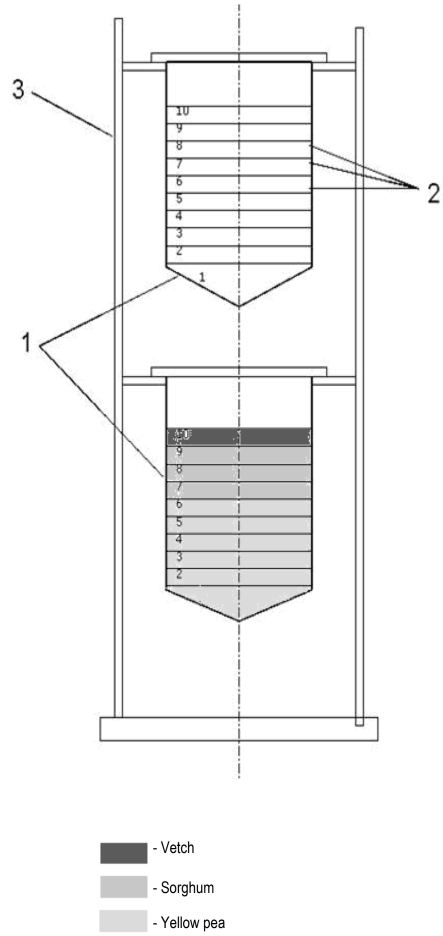

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Fig. 1. Mixer diagram with grain distribution in the container: 1 - containers; 2 - dismountable rings (rings 1÷6 – pea; 7÷9 - sorghum; 10 – vetch); 3 – frame

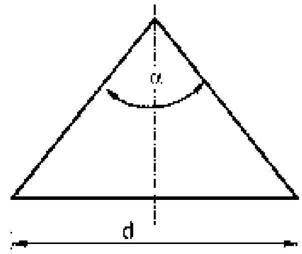

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Fig. 2. Roof shaped insert diagram. d - cone base diameter, α - dilation angle

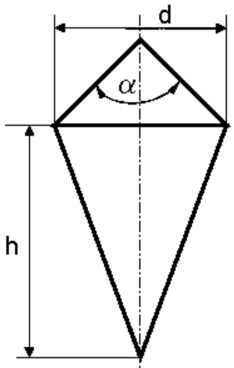

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Fig. 3. Double cone insert diagram. α - cone dilation angle, d - cone base diameter, h - height

After each of 10 mixing steps, the content from each of ten mixer rings was divided into individual mix constituents (pea, sorghum and vetch). Then, these constituents were weighed on an analytical balance with accuracy up to ± 0.1 g. Mass fractions of individual constituents were converted into percentages. Three container sections were chosen for further analysis – lower, central and upper (rings 1, 5, 10), which allowed to observe the ratio of individual constituents in the bed.

Measurement test results

Graphical interpretation of obtained results for change in percentage of constituents in successive mixing steps (flows 1-10) is shown for the selected fifth ring (Fig. 4, 5, 6). Moreover, the diagrams contain the line illustrating required ratio of individual constituents resulting from the ratios originally assumed in the research.

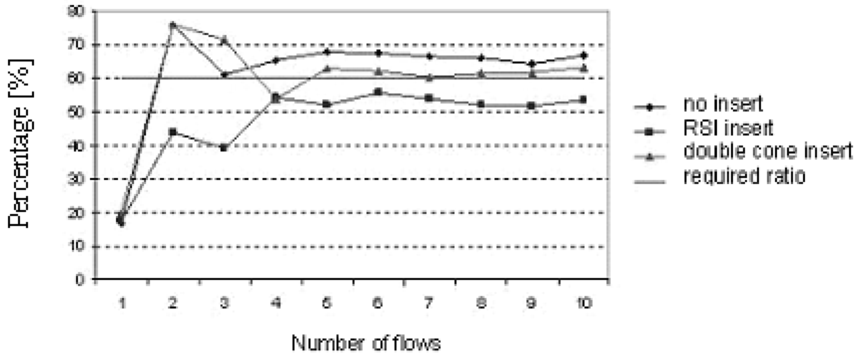

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Fig. 4. Change in percentage of yellow pea in successive mixing steps for the fifth ring

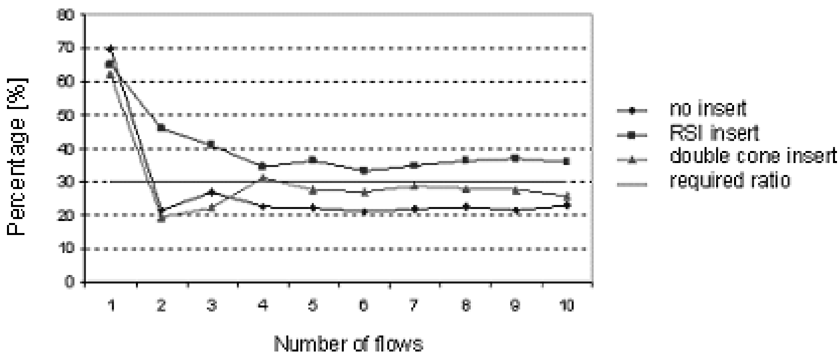

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Fig. 5. Change in percentage of sorghum in successive mixing steps for the fifth ring

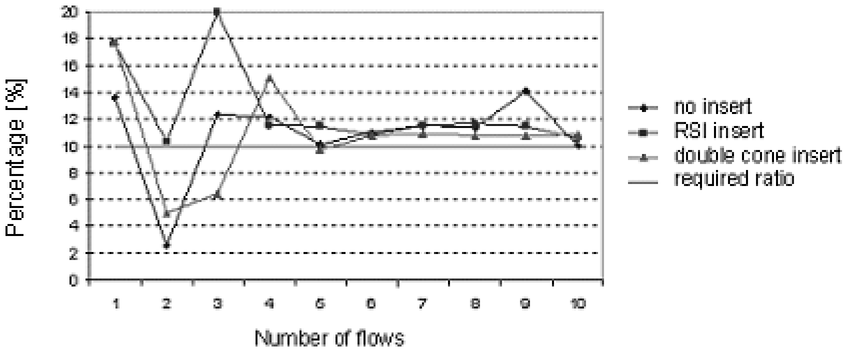

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Fig. 6. Change in percentage of brown vetch in successive mixing steps for the fifth ring

Individual diagrams (Fig. 4, 5, 6) show that during initial mixing steps changes in percentage of mix constituents fluctuate considerably. Further process continuation results in stabilisation of changes (reaching the state of equilibrium), and striving to obtain required percentage of constituents. It may be observed that adding extra elements affects mix ratio (percentage of individual constituents). However, results obtained at this stage do not provide information on mix quality.

At the next stage of tests the researchers used the parameter of granular mix quality - residual sum of squares.

Statistical analysis

The simple regression model was used to describe quality of ternary granular mix. Possibilities and usability of this statistical tool for describing multicomponent mix quality were presented in the work published by Królczyk, Tukiendorf [2007].

Modelling was carried out for two variables:

- dependent variable Y – target constituent percentage (pea 60%, sorghum 30%, vetch 10%),
- independent variable X – constituent percentage in successive flows (10 flows).

$$Y = b_0 + b_1 X + e \qquad (1)$$

where:

- b_0 – estimated β_0,
- b_1 – estimated β_1,
- e – observed errors, that is residues from adjustment of straight line to the set of observation results for both variables,
- X – independent variable,
- Y – dependent variable.

In the paper, the researchers employed analysis of errors (residues) observed as a result of adjusting straight line b_0+b_1X to the results of observation of both variables. Residual sum of squares (SSE), that is the sum of quadratic deviations from that straight line, was the parameter describing mix quality. Analysis of residue values informs how much observed results fit to the straight line. The better data fitting to the straight line regression model, the lower residue values. The SSE value of zero indicates that percentages of individual constituents in a successive flow have reached target values (optimal intermixing) [Aczel 2005].

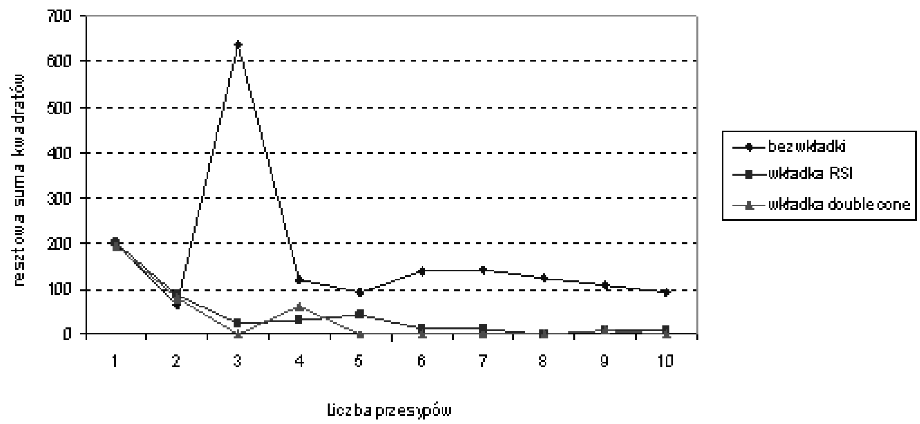
Sum of quadratic regression residues is defined as follows:

$$SSE = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} \left(y_i - \hat{y}_i \right)^2 \tag{2}$$

Where:

SSE – sum of quadratic residues,
e_i – error of i[th] observation,
y_i – observation result value – the value of constituent percentage in a successive flow,
$\hat{y}_i$ – value predicted from estimate obtained from regression line.

Obtained values of residual sum of squares for successive mixing steps are shown graphically (Fig. 7, 8, 9).



Resztowa suma kwadratów = Residual sum of squares; Liczba przesypów = Number of flows
bez wkładki = no insert; wkładka RSI = RSI insert; wkładka double cone = double cone insert

Source: own study

Fig. 7. Diagram showing changes in residual sum of squares depending on number of flows obtained for the first ring

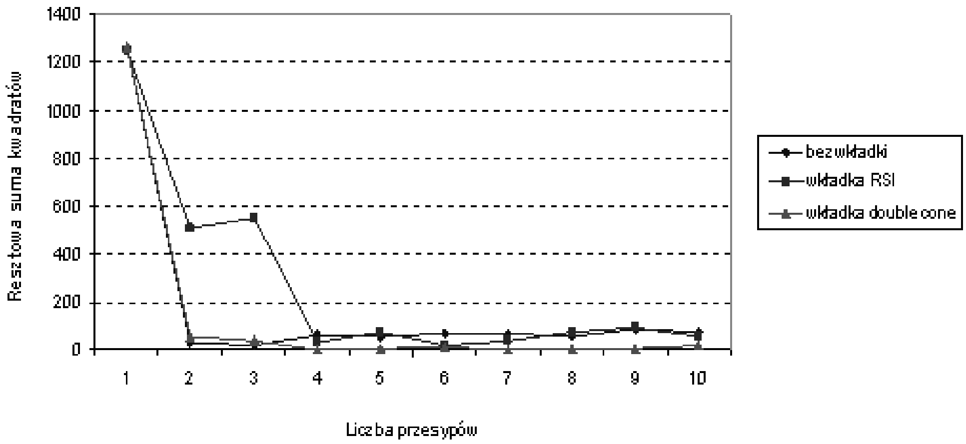


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Fig. 8. Diagram showing changes in residual sum of squares depending on number of flows obtained for the fifth ring

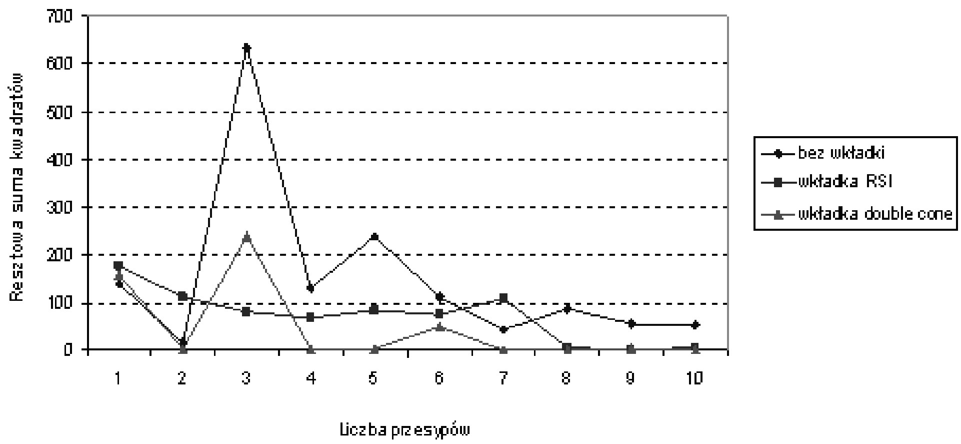

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Fig. 9. Diagram showing changes in residual sum of squares depending on number of flows obtained for the tenth ring

Obtained results prove the impact of employed inserts on improvement in the quality of multicomponent granular mix.

Same as in case of measurement test results, individual diagrams (Fig. 7, 8, 9) showing changes of residual sum of squares in successive mixing steps indicate abrupt changes occurring during initial mixing stage, whereas process continuation causes striving to reach the state of equilibrium (flows 6 through 10). Both RSI and double cone type inserts have influence on obtaining better effects – higher quality of final product. Minimum SSE value for mixing with RSI insert is 1.18, for double cone type insert – 0.17, whereas for the process without any extra elements used – 30.54. The best results were obtained for mixing with double cone type insert, which is proven by lowest values of residual sum of squares. In that case obtained percentage of individual components in final product is the closest to initially assumed ratios (pea 60%, sorghum 30%, vetch 10%).

Obtained results constitute an initial element of the authors' studies on the issue of mixing multicomponent granular patterns using the funnel flow system.

Conclusions

1. The process that involves mixing multicomponent patterns using funnel flow system, is characterised by abrupt changes at initial mixing stage (flows 1 through 5), followed by considerable stabilisation (steps 6 to 10).
2. Using roof shaped inserts improves final product (multicomponent mix) quality, which is reflected by obtained values of residual sum of squares.
3. Best results were obtained for mixing with double cone type insert. In case of this testing series, the values of residual sum of squares were lowest, which confirmed that obtained mix was characterised by optimal percentage of individual components.

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ANALIZA WPŁYWU ELEMENTÓW DASZKOWYCH NA PROCES MIESZANIA WIELOSKŁADNIKOWEJ MIESZANINY ZIARNISTEJ W MIESZALNIKU PRZESYPOWYM

Streszczenie. W pracy zaprezentowano wyniki badań laboratoryjnych mieszania niejednorodnej wieloskładnikowej mieszaniny ziarnistej w mieszalniku przesypowym. Mieszaniu poddano trójskładnikowy układ ziarnisty: groch żółty, sorgo i wyka. Mieszalnik wyposażano we wkładki daszkowe. Zastosowano wkładki typu roof shaped insert oraz double cone. Analizę jakości mieszanki w kolejnych krokach mieszania określano w oparciu o analizę udział procentowego każdego ze składników. Następnie obliczano parametr jakości: resztową sumę kwadratów. Na tej podstawie określano zmiany jakości mieszanki w czasie oraz wpływ wkładek na proces mieszania.

Słowa kluczowe: materiały ziarniste, mieszanie materiałów ziarnistych, wkładki daszkowe

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