CONSIDERATIONS REGARDING THE ACCURACY OF DOSING EQUIPMENTS FOR AGRO-FOODS BULK SOLIDS THAT USE VIBRATORY FEEDING SYSTEMS

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Abstract: *The paper presents the types, forms and frequencies of errors that appear during the process of dosing bulk solids from food industry and agriculture, using volumetric and gravimetric dosing systems. Methods of calculation are described for the experimental dosing stand with vibratory feeding systems. In the end, the article presents examples of errors determined during the experimental work done with three types of agro-food bulk solid materials.*

Key words: *volumetric dosing, standard deviation, bulk solids.*

1. Introduction

Metering accuracy represents an important characteristic quality, being the tolerance between desired and real metered flow. As a possible definition metering accuracy could be described as the maximum permissible deviation of the metered flow or volume for a set of prescribed values (see Figure 1).

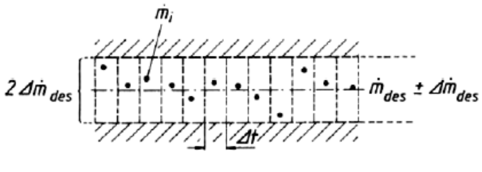

Fig. 1. *Metering accuracy as tolerance range of the desired value* [4]

It represents a quality statement concerning the metering arrangements that regard warranty conditions between manufacturer of the dosing systems and beneficiary. In the measuring technique there is a problem of assuring a certain limit of measurement error and measuring incertitude. In order to check the metering accuracy, a methodology for determination and calculation are required as well as agreements concerning the definition of the error value.

When verifying the metering accuracy according to the accepted methodology the dosing errors must be found within the tolerance range as seen in Figure 1 representing a tolerance range for a desired value m_{des} and the actual measured values m_i. Metering accuracy relative to the desired value can be calculated using the following expression:

$$S_T = \pm \frac{\Delta \dot{m}}{\dot{m}_{des}} \cdot 100\% = \frac{\Delta m}{m} \cdot 100\%. \qquad (1)$$

Value deviations from the desired dose occur because of varied reasons as seen in Figure 2. It can be observed that in the case of adjustable metering devices the desired

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value is set at the metering automation panel. The total error is the sum of the errors received from the following areas: setting errors (*SS*), measuring error (*SM*) and transmission error (*STr*) (see Figure 2a).

In the case of dosing machines with volumetric metering devices the desired value is based on the calibrated characteristics of the dosing system and the dosing machine, which can be operated manually or, depending on the hardware and software, applied as a function of the automation system. Deviations come from setting (*SS*) and calibration (*SCa*) errors (see Figure 2b). In this example the accuracy of the metering dose is strongly influenced by the calibrated characteristic of the dosing machine elements and the material to be dosed [4].

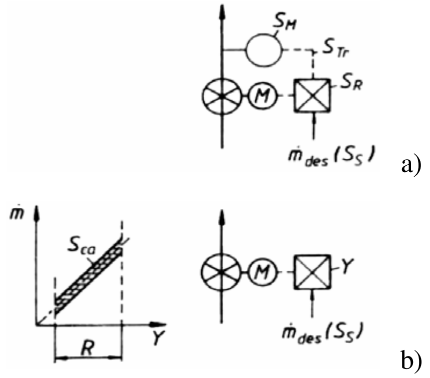


Fig. 2. *Reasons for desired value deviations:* (*a*) *regulated metering;* (*b*) *volume dispensing metering -* S_S *setting error;* S_M *measuring error;* S_R *regulating error;* S_{ca} *calibration error;* S_{Tr} *transmission error* [4]

2. Momentary and Mean Value of Dosing Measurements

The time related distribution of the metered flow for all batch volume dosing systems fluctuates randomly or pulsates systematically (see Figure 3).

The mean value $\dot{m}$ is derived formally from the momentary value $\dot{m}(t)$ by integration within the time basis $\Delta t = t_2 - t_1$, according to the following:

$$\dot{m} = \frac{\int_{t_1}^{t_2} \dot{m}(t)dt}{t_2 - t_1}. \tag{2}$$

In Figure 3 (position 1 and 3) the correlation between the mean value and the time basis Δt is shown. In the case of the borderline, were the time basis is very small, the mean metered flow follows the momentary value that fluctuates from zero to maximum.

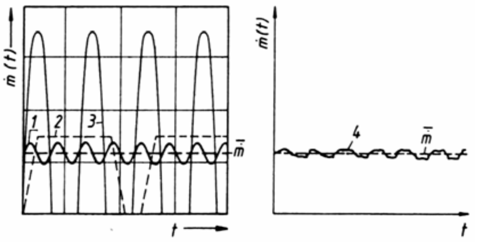


Fig. 3. *Momentary and mean value of the metered flow: 1, 2, 3 - systematic fluctuation (screw, chamber and vibration metering device); 4 - random fluctuations of a metering device conveying constantly versus time* [4]

It can be concluded that for the pulsating flow there must be a sufficiently long time span in order to obtain an accurate measurement of the mean value.

3. Calculation of the Metering Error

Comparing experimental metering errors it can be concluded that the measured value lot can be assumed to be distributed approximately normally but there are many random error influences as seen in Figure 4a [2], [3].

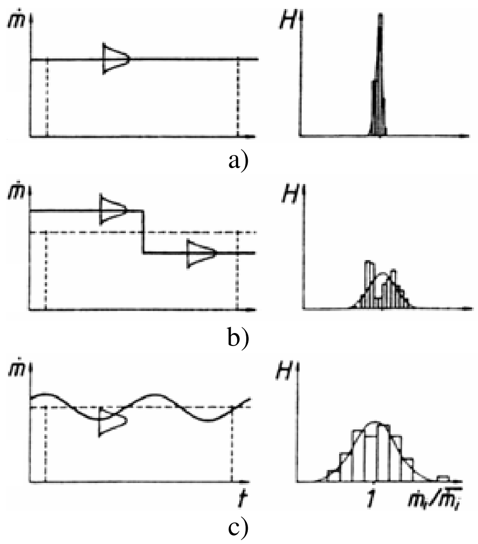


Fig. 4. *Measured value lot distribution determined by experiments (screw feeder):* (*a*) *normal distribution;* (*b*) *"camel hump" distribution;* (*c*) *periodic mean value fluctuations; H - sample distribution* [4]

A so-called "camel hump distribution" can be observed if the metered flow fluctuates between two mean values caused by air bubbles in the case of the metering pumps or flow disturbances for screw feeders (see Figure 4b). Periodic fluctuations cause an oscillation of the normal distribution error generated by filling shocks in the case of screw feeders (see Figure 4c). The distortion of the normal distribution by un-randomly systematic fluctuations indicates systematic errors.

A practical example of error evaluation for a screw dosing system is shown in Figure 5. A correlation between the sample distribution and function *H*, written in equation 3 can be seen:

$$H_m = \frac{1}{S\sqrt{2\pi}} \cdot \exp\left(\frac{(\dot m_i - \dot m)^2}{2S^2}\right). \qquad (3)$$

For the measured mass values $\dot m_i$ and the arithmetic mean flow $\dot m$ the relative standard deviation s_v can be calculated using the following equation:

$$s_v = \frac{1}{\dot m} \cdot \sqrt{\frac{\sum_1^z (\dot m_i)^2}{z-1}}. \qquad (4)$$

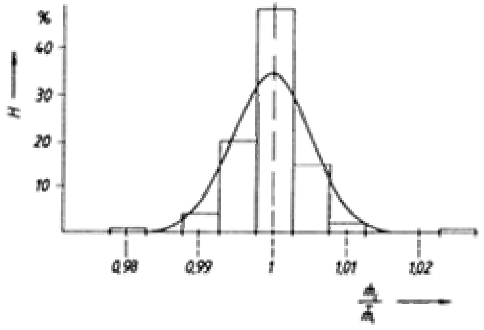


Fig. 5. *Presentation of error evaluation for the screw dosing system:* *$\dot m$ = 3548; s_v = 1.86 · 10 − 2* [4]

4. Error Propagation

The measuring result of the flow or volume metered for most metering procedures is made up of several influencing variables $\dot m = f(x_1, x_2, ..., x_n)$.

Small, systematic errors propagate according to the following equation 5:

$$\frac{\Delta \dot m}{\dot m} = \frac{1}{\dot m} \sum_1^z \frac{\delta f}{\delta x_z} \cdot \Delta x_z. \qquad (5)$$

Small, accidental errors with known standard deviations $S_1 ... S_z$ of influencing variables, $x_1 ... x_n$ propagate according to the Gauss law of error propagation as follows:

$$\frac{S_{\dot m}}{\dot m} = \sqrt{\sum_1^z \left(\frac{\delta f}{\delta x_z}\right) \cdot S_x^2}. \qquad (6)$$

The determination of the metering errors requires special test installations and equipment that must be engineered together with the metering systems according to the type of material used in the dosing process such as that for bulk materials in which scales or measuring bins should be used and for fluids' level measurement flow metering instruments will be the most appropriate to use [4].

5. Experimental Results

For the experimental research on the influence of functional parameters of the vibrating feeder on the dosing precision, an experimental stand was developed, a representation of its construction being presented in Figure 6 [3]. The vibrating dosing system uses an electromagnet to produce the vibrations on the conveying vibration chute. Depending on the value of the vibration parameters (amplitude and frequency) the bulk solids will flow accordingly (see Figure 7). An important advantage of this dosing method is that material is fed in the weight cell 1 uniformly and with smaller impact on the weight scale. The dosing system is periodically fed with material from hopper 6, and is to be refilled at the moment when the minimum level of material in the hopper is reached. According to the characteristics of the dosed materials, different technical solutions can be used for placing some agitators in such a way as the material to flow properly on the vibrating chute 3 as well as possible so as to obtain a material flow dependent only on the vibration parameters.

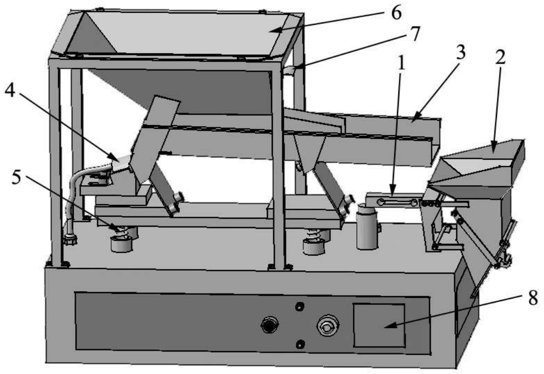


Fig. 6. *Sketch of the gravimetric dosing stand with volumetric vibrating feeder: 1 - weight cell; 2 - weight scale; 3 - vibrating chute; 4 - magnetic vibration drive units unit; 5 - springs; 6 - feeding bin; 7 - sliding gate; 8 - control panel* [1]

The stand is controlled from panel 8 where the parameters of the dosing process are established.

The vibration chute is powered by an electromagnet, which is controlled by the microcontroller and the computer connected to automation panel 8. An inductance sensor is attached to the vibration chute, and is used to obtain the value of the real amplitude. The final adjustments for the fine dosing are made by adjusting the amplitude scale vibration to a lower value so that only a small amount of material to be fed on the weight scale 2. The precision of this dosing system is relatively good if proper material flow could be assured to prevent mechanical bridging and flushing of material [2].

The stand allowed the study of the vibrations' amplitude A and material layer thickness h relative to the dosing precision for different agro-food materials.

Measurements were made using the same amplitude for the rough feed and only for the fine feed different values for the amplitude were used.

After setting up the dosing parameters, the level of the material layer on the vibrating chute 3 (see Figure 6) was adjusted using the sliding gate 7 from the exit of the material from the feeding bin 6. For each set of measurements the same quantity of material in the feeding bin was used in order to ensure similar conditions for each material tested. The weight cell 1 measured the final dose.

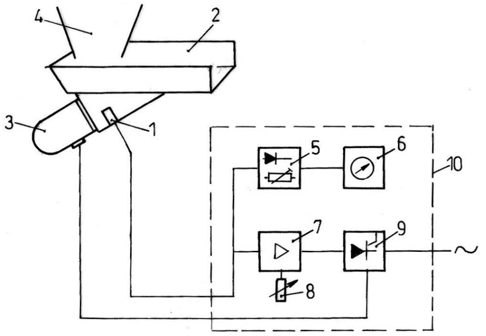
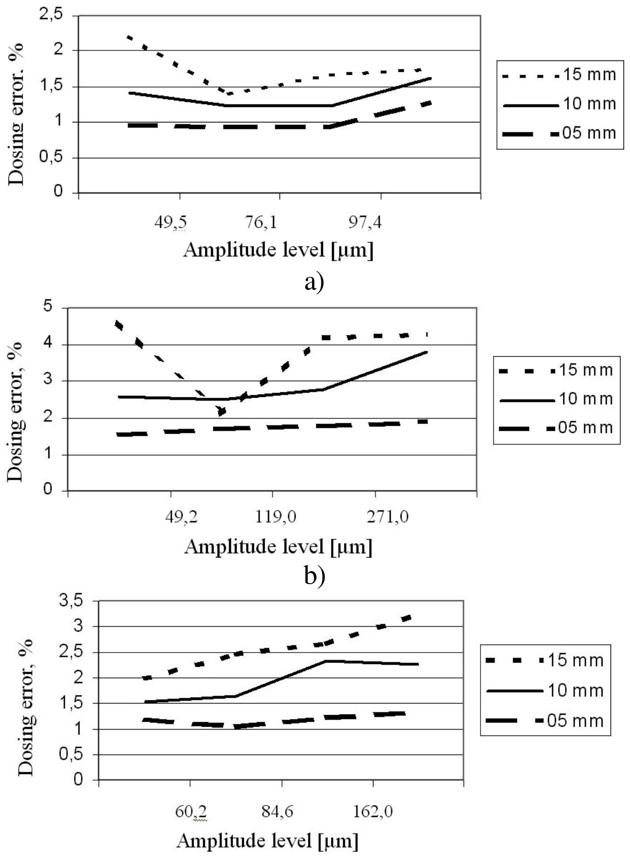


Fig. 7. *Automatic control of the vibration amplitude: 1 - acceleration sensor; 2, 4 - vibration feeder; 3 - vibrator; 5...10 - controller*



a)

b)

c)

Fig. 8. *The influence of the amplitude level and material thickness layer regarding the dosing precision for three different materials with dosing batch of 100 g:* (*a*) *wheat flour;* (*b*) *wheat pollard;* (*c*) *wheat semolina*

For the analysis of the influence of material properties and of the dosing process parameters on the precision of the dosing process, the following characteristics were targeted:

- 3 types of materials with different flow characteristics were used: wheat flour, wheat pollard and wheat semolina;
- 3 levels of the material layer on the vibrating chute: h1, h2, h3;
- 3 levels of the amplitudes for fine feeding: A1, A2, A3;
- 3 weights for the final dose of the material: D1, D2, D3 (3).

A number of 729 tests were conducted. The results were set against the established dose so that the deviations from the reference value could be observed. Some of the most relevant examples for wheat flour are presented in Figure 8.

6. Conclusions

From the analysis of the theoretical and experimental results the following main conclusions can be inferred:

- the dosing precision decreased with the growth of the vibrations' amplitude;

- for the same vibrations' amplitude the larger the dose batch, the higher dosing precision was obtained;

- dosing precision is higher when the material thickness is smaller.

From the observations made on the obtained results it can be seen that the amplitude during the dosing process is very important and a static regime of the vibrations amplitudes does not ensure a proper feeding of the material on the weight scale. For the high precision of the doses an automated regime is proposed for the amplitudes to be adjusted according to the reached value of the weight scale and monitor flow in such way as to be controlled. In order to improve the feeding with material and prevent the occurrence of the "material on air" effect a shutting down of flow gate should be installed at the end of the vibrating chute with a progressive shut down in such way as to limit the flow in the last part of the feeding process for the free flow materials and to shut down the flushing effect.

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