Measurement and analysis of parameters of the precise grinding system

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Abstract. The technological process of materials grinding, especially biological material with high oil content, is quite complex. There are several parameters that impact the performance and quality of the process (e.g. temperature, rotational speed). One of them is the air velocity at pneumatic conveying of grinding particles. The phenomena of pneumatic transport of seeds and its impact on product's quality and grinding capacity is not methodologically recognized so far. The paper presents the construction details of measurement and control system and results of the research obtained during the laboratory tests. The results of the tests and their analysis will be used for design of a commercial precise grinder, which allowed to reach the optimum product's capacity and quality, constituting the basis for biological diet supplements.

Keywords: size reduction, oilseeds, pneumatic conveying, biological food supplements, measurement system

1 Precision grinding system

The preparation of plant-based supplements, especially seeds with high oil content, requires a special design of the shredder and continuous control of the process parameters [1-4]. In order to obtain the required features of the material (without extracting oil), during precision grinding, the following parameters have to be controlled: rotational speed, linear speed of knife, material feeding speed and vacuum in the installation. Assuming a constant aspirator rate (Fig. 1 - D), too high feed flow rate (Fig. 1 - A) causes of the production of material with an inadequate particle size distribution. Based on various simulations [1, 3, 4], a material flow model was developed.

Fig. 1. Division of the technological line into measuring sections [5]

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The complete precise grinding testing line is shown in Fig. 2. A computer application making it possible to measurement of parameters of the grinding system, control the performing devices and to visualize the process variables, has been developed in the LabVIEW environment [6].

Fig. 2. View of the real test stand of precise seeds' grinding with pneumatic transport

Thanks to the identification of changes in the pneumatic installation, it became possible to optimally fill the grinder with material, obtaining the maximum process efficiency [7-10] and the desired form of seed fragmentation. In the preparation of dietary supplements, based on oilseeds, grinding particles should be within 0.6-0.8 mm, which guarantees very good mixing with liquids and high digestibility and assimilation by the body (Fig. 3).

Fig. 3. View of the seeds after grinding: golden flax and mustard

2 Impact of the grinder rotational speed on the pneumatic grinder transfer function

In the paper [5] a mathematical model of the pneumatic grinder system designated for the air flow through this system without grinding material was presented. This model was determined for one rotational speed of the grinder ($\omega_{gr} = 25 \text{ s}^{-1} \approx 157 \text{ rad} \cdot \text{s}^{-1}$). This raises the question: what is the impact of the grinder rotational speed on the air flow through the system. The answer to this question is illustrated in Fig. 4.

Fig. 4. Influence of the grinder rotational speed on the process line properties

From Fig 4, it can be clearly stated that this effect is negligible. Since the quality and efficiency of the grinding depends on the rotational speed of the grinder, it means that this speed can be selected freely without affecting the dynamic properties of the line, which greatly simplifies the possible control process. Finally, on the basis of Fig. 4, we can write transfer function of the grinding technological line for flow of pure air, in form of 1st order element with delay

$$G(s) = \frac{178.2e^{-2.68s}}{1.88s + 1} \quad (1)$$

Note, that this transfer function is different from those transfer function presented in [5]. This is caused by the change of the filter in the process line. The numerical parameters were determined in the same way as in [5] as the average value of all six measurements.

3 Extended mathematical model of pneumatic system

An important problem is to determine the impact of the grinded material added to the air (see Fig. 1) on the found mathematical model. First, it is necessary to determine after what time the charging cone can be opened from the start of the production line. It was assumed that when opening the charging cone, there should be a fixed air flow. In industrial practice, it is assumed that for a first order static element, the steady state is after time $t = 3T$, where T is the time constant of this element [1, 5]. In the analysed process $T = T_a$, after time $3T_a$ the vacuum value in the system will be equal to

$$\Delta p = \Delta p_{\text{inf}} \left(1 - e^{-\frac{3T_a}{T_a}} \right) = 178.2(1 - e^{-3}) = 169.3 \text{ Pa} \approx 0.95 \Delta p_{\text{inf}} \quad (2)$$

therefore, the opening time τ_v of the charging valve is at least

$$\tau_v \geq \tau_a + 3T_a = 2.68 + 3 \cdot 1.88 = 8.32 \text{ s} \quad (3)$$

for the presented analysis, it was adopted $\tau_v = 8.4 \text{ s}$.

Fig. 5. Steps to create a mathematical model

The mathematical model, the image of which is shown in Fig. 5, was obtained in the following steps:

Step 1 – curve $\Delta p1$

This curve is the result of the measurement on the test bench. After starting the aspirator time $\tau_v = 8.4 \text{ s}$ was waiting and the valve of conical feed hopper was opened. Flax seeds in the amount $m' = 0.041 \text{ kg} \cdot \text{s}^{-1}$ were added to the flowing air.

Step 2 – curve $\Delta p2$

It is a curve based on a mathematical model in the form of transfer function (1). In time, the equation of this curve has the form

$$\Delta p2 = \begin{cases} 0 & 0 \leq t < 2.88 \\ 181.1 \left(1 - e^{-\frac{t-2.88}{1.88}} \right) & t \geq 2.88 \end{cases} \quad (4)$$

Note that $\Delta p_{\text{inf}} = 181.1 \text{ Pa}$ different from that shown in (1) ($\Delta p_{\text{inf}} = 178.2 \text{ Pa}$).

Step 3 – curve $\Delta p3$

This curve is the result of subtraction $\Delta p1 - \Delta p2$ for $t \geq 8.4 \text{ s}$

Step 4 – curve $\Delta p4$

Curve $\Delta p4$ is a mathematical model of the experimental curve $\Delta p3$ in form

$$\Delta p_4 = \frac{k_s e^{-\tau_v}}{T_s s + 1} = \frac{23.34 e^{-8.4}}{5.03s + 1} \quad (5)$$

where: parameters τ_s and T_s found by the least squares method, by adjusting the curve in the form $k_s \left(1 - \exp\left(-\frac{(t - \tau_v)}{T_s}\right)\right)$ to results obtained by experimental test.

Step 5 – curve Δp_5

This curve (mathematical model of the pneumatic system in the grinder) is the result of subtraction $\Delta p_2 - \Delta p_4$. In time, the equation of this curve has the form

$$\Delta p_5 = \begin{cases} 0 \leq t < 2.88 & 0 \\ 2.88 \leq t < 8.4 & 181.1 \left(1 - e^{-\frac{t-2.88}{1.88}}\right) \\ t \geq 8.4 & 181.1 \left(1 - e^{-\frac{t-2.88}{1.88}}\right) - 23.34 \left(1 - e^{-\frac{t-8.4}{5.03}}\right) \end{cases} \quad (6)$$

Parameters of this model $k_s = 23.24 \text{ Pa}$ and $T_s = 5.03 \text{ s}$, for the current state of knowledge, should be determined experimentally for individual types of grains.

4 Conclusions

The influence of rotational speed of the shredder on the properties of the pneumatic system is negligible. The input element of the grinding line in the form of a conical feed hopper should be replaced with another element, e.g. a screw conveyor with adjustable speed. This change will allow you to control the output of the hopper, which has a significant impact on the quality and efficiency of grinding.

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