Automatic mixers for the synthesis of functional mixtures with desired properties from small batches

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Abstract. This study presents the advantages of automatic rotary, biorotary, conveyor mixers compared to existing designs of mixing devices. The relevance and novelty of the development are shown by obtaining a total batch of a mixed product with a given qualitative and quantitative characteristics from the available small batch mixtures, which differ in technological parameters. Quality control for the obtained mixtures is also analyzed.

Keywords: mixers for loose materials, the production of mixtures, degree of mixture homogeneity, deterministic formation of homogeneity, mixtures control and quality management, linear programming.

1. Introduction

Currently automatic rotary and conveyor mixers have been the only representatives in the class of mixing equipment capable to implement the processes of deterministic mixture homogeneity formation [1-8]. It is impossible to perform tasks solved with this class of machines by other types of equipment. Obtaining high-quality mixtures from loose and moist materials, averaging the properties of mixed ones from such components to ensure stable properties of the resulting system are relevant and in demand on the market [1-3]. Technologically, such problems can be solved in two ways. The first one involves conventional averaging of properties on the mixing equipment such as the balancing reservoirs, the homogenizers, etc. In this case, the properties of a general product party are summed up depending on the masses of its small batches. The second method involves the synthesis of a total finished product in the desired volume and with the necessary quality characteristics of the available small batches in different volumes and different functional parameters. Both the first and the second methods can be implemented on the same classes of mixing equipment. The difference is that in the first case the characteristics of the final product are within the properties of all small batches and integrated in the finished mixture in accordance with their proportions (ratios). In the second case it is possible, with the proposed technological approach [2,3,9,10], to control the quality characteristics of the total finished product, knowing the qualitative and quantitative characteristics of its components (small batches). This is a more complex task, but its technological solution allows one to obtain a total batch of a mixed product with specified properties and a given volume. This condition is necessary for some types of production. In this work, the process (method) to create such a mixture system with the given characteristics from small batches of such systems within the limits of the permitted functional parameters of the final mixture use and, thus, the total maximum possible mass (volume) is considered. In practice, this technology is implemented on automated continuous mixers, providing deterministic formation of mixture homogeneity from loose materials [9,10]. Theoretically, the problem is solved by linear programming [11,12].
The novelty of the development is a complex solution of the theoretical and technological problems, when the algorithms and results of qualitative mixture indicator calculations can be related to the technological schemes of its production and technical implementation on automated mixing modules. It is also the first time when it is possible to apply the results in engineering techniques for the development of technological processes to produce high-quality mixtures from loose materials and design productive highly automated mixing equipment.

2. Problem statement

It is necessary to synthesize a mixture with a given quality index from a certain number of mixtures or components, with similar indicators, but different from the one given in the mixture. There are \( n \) mixtures of \( A_1, A_2, ..., A_n \) with weight \( a_1, a_2, ..., a_n \), respectively, which contain a useful substance \( B \). In the mixture \( A_i \), the substance \( B \) has a mass \( b_i \), \( (i = 1, ..., n) \). Denote

\[
q_i = \frac{b_i}{a_i} - \text{the relative content of } B \text{ in the mixture } A_i.
\]

From these mixtures, a new mixture \( A \) with \( A_1, A_2, ..., A_n \) parts with weights \( p_1, p_2, ..., p_n \), \( (p_i \leq a_i) \) is composed. In the new mixture \( A \), the substance \( B \) has a relative content \( q \) determined by equation

\[
q_1 p_1 + ... + q_n p_n = q (p_1 + ... + p_n).
\]

Let's set the following task: with given values \( a_1, ..., a_n \); \( q_1, ..., q_n \); \( q \) to find the weight \( p_1, p_2, ..., p_n \) of the mixtures \( A_1, A_2, ..., A_n \), in which the mixture \( A \) has the greatest weight.

3. Problem solving algorithm

Mathematically this task has the following stating: to find a point \( (p_1, p_2, ..., p_n) \) in the \( n \)-dimensional space with the coordinates \( Op_1, ..., p_n \) for the variables \( p_1, p_2, ..., p_n \),

\[
F(p_1, ..., p_n) = p_1 + ... + p_n
\]

in which the function takes the maximum value in the cuboid defined by

\[
0 \leq p_1 \leq a_1 \\
... \\
0 \leq p_n \leq a_n
\]

if the condition (1) is fulfilled.

The equation (1) defines the plane in the space \( Op_1, ..., p_n \) that passes through the reference point \( O \). This plane intersects the parallelepiped (2) over a convex polyhedron \( D \) with vertices \( O, K_1, ..., K_m \), where \( K_1, ..., K_m \) are the points of plane intersection with the parallelepiped edges. Note that the plane (1) does not intersect all edges. From the convexity \( D \) and the fact that the function \( F(p_1, ..., p_n) \) increases mostly in the gradient direction of this function

\[
\text{grad} F = \left( \frac{\partial F}{\partial p_1}, ..., \frac{\partial F}{\partial p_n} \right) = (1; ..., 1),
\]

it follows: the maximum \( F \) is reached at some point \( K_1, ..., K_m \).

Therefore, first we find the specified points, calculate the values of the function \( F \) in them and then one of the points \( K_j \) at which the function \( F \) takes the maximum value.

We give the results of solving the problem for \( n = 3 \) considering the values \( a_1, a_2, a_3; q_1, q_2, q_3; q \) as the parameters. The mixtures \( A_1, A_2, A_3 \) are assumed to be numbered in the following way

\[
q_1 < q_2 < q_3.
\]

The first case: \( q_1 < q < q_2 \).

1.1. \( q \geq \frac{q_1 a_1 + q_2 a_2 + q_3 a_3}{a_1 + a_2 + a_3} \).
$D$ is parallelogram $OK_1, K_2, K_3$.

$$K_1 \left( \frac{q_3 - q}{q - q_3} a_3; 0; a_3 \right), \quad K_2 \left( \frac{q_2 - q}{q - q_1} a_2 + \frac{q_3 - q}{q - q_1} a_2; a_3 \right), \quad K_3 \left( \frac{q_2 - q}{q - q_1} a_2; a_2; 0 \right).$$

$$F = F(K_2) = \frac{q_2 - q}{q - q_1} a_2 + \frac{q_3 - q}{q - q_1} a_3 + a_3 = \frac{q_2 - q}{q - q_1} a_2 + \frac{q_3 - q}{q - q_1} a_3.$$

1.2. max $\left( \frac{q_1 a_1 + q_2 a_2 + q_3 a_3}{a_1 + a_2 + a_3} \right) < q < \frac{q_1 a_1 + q_2 a_2 + q_3 a_3}{a_1 + a_2 + a_3}$

$D$ is pentagon $OK_1, K_2, K_3, K_4$.

$$K_1 \left( \frac{q_3 - q}{q - q_1} a_3; 0; a_3 \right), \quad K_2 \left( \frac{q - q_1}{q - q_2} a_1 + \frac{q - q_3}{q - q_2} a_3; a_3 \right), \quad K_3 \left( a_1; a_2; \frac{q - q_1}{q - q_2} a_1 + \frac{q - q_2}{q - q_3} a_2 \right), \quad K_4 \left( \frac{q_2 - q}{q - q_1} a_2; a_2; 0 \right).$$

$$\text{max} F = F(K_1) = a_1 + a_2 + \frac{q - q_1}{q_3 - q} a_1 + \frac{q - q_2}{q_3 - q} a_2 = \frac{q_3 - q_1}{q_3 - q} a_1 + \frac{q_3 - q_2}{q_3 - q} a_2.$$

1.3. $\frac{q_1 a_1 + q_3 a_3}{a_1 + a_3} < q \leq \frac{q_1 a_1 + q_2 a_2}{a_1 + a_2}$

$D$ is trapezoid $OK_1, K_2, K_3$

$$K_1 \left( \frac{q_3 - q}{q - q_1} a_3; 0; a_3 \right), \quad K_2 \left( a_1; \frac{q - q_1}{q - q_2} a_1 + \frac{q - q_3}{q - q_2} a_3; a_3 \right), \quad K_3 \left( a_1; a_2; \frac{q - q_1}{q - q_2} a_1 + \frac{q - q_2}{q - q_3} a_2 \right), \quad K_4 \left( \frac{q_2 - q}{q - q_1} a_2; a_2; 0 \right).$$

$$\text{max} F = F(K_1) = \frac{q_3 - q}{q_3 - q} a_1.$$

1.4. $q \leq \min \left( \frac{q_1 a_1 + q_2 a_2 + q_3 a_3}{a_1 + a_2 + a_3} \right)$

$D$ is triangle $OK_1, K_2$.

$$K_1 \left( a_1; 0; \frac{q - q_3}{q - q_3} a_1 \right), \quad K_2 \left( a_1; a_2; \frac{q - q_3}{q - q_3} a_1 \right).$$

$$\text{max} F = F(K_2) = \frac{q_3 - q}{q_3 - q} a_1.$$

The second case. $q_2 < q < q_3$.

2.1. $q \leq \frac{q_1 a_1 + q_2 a_2 + q_3 a_3}{a_1 + a_2 + a_3}$

$D$ is parallelogram $OK_1, K_2, K_3$

$$K_1 \left( \frac{q - q_2}{q - q_3} a_2; \frac{q - q_2}{q - q_3} a_2 \right), \quad K_2 \left( a_1; a_2; \frac{q - q_1}{q - q_2} a_1 + \frac{q - q_2}{q - q_3} a_2 \right), \quad K_3 \left( a_1; 0; \frac{q - q_3}{q - q_3} a_1 \right).$$

$$\text{max} F = F(K_2) = \frac{q_3 - q}{q_3 - q} a_1 + \frac{q_3 - q}{q_3 - q} a_2.$$

2.2. $\frac{q_1 a_1 + q_2 a_2 + q_3 a_3}{a_1 + a_2 + a_3} < q < \min \left( \frac{q_1 a_1 + q_2 a_2 + q_3 a_3}{a_1 + a_2 + a_3} \right)$

$D$ is pentagon $OK_1, K_2, K_3, K_4$

$$K_1 \left( \frac{q - q_2}{q - q_3} a_2; \frac{q - q_2}{q - q_3} a_2 \right), \quad K_2 \left( a_1; a_2; \frac{q - q_1}{q - q_2} a_1 + \frac{q - q_3}{q - q_3} a_2 \right), \quad K_3 \left( a_1; 0; \frac{q - q_3}{q - q_3} a_1 \right), \quad K_4 \left( \frac{q_2 - q}{q - q_1} a_2; a_2; 0 \right).$$

$$\text{max} F = F(K_2) = \frac{q_2 - q}{q - q_1} a_2 + \frac{q_3 - q}{q - q_2} a_3.$$

2.3. $\frac{q_2 a_2 + q_3 a_3}{a_2 + a_3} \leq q < \frac{q_2 a_2 + q_3 a_3}{a_2 + a_3}$

$D$ is trapezoid $OK_1, K_2, K_3$.
With $n \geq 4$ a complete analytical solution is very cumbersome. Since $n = 4$, the parallelepiped (2) has 16 vertices and 32 edges. Excluding the four edges coming out of the point $O$, we get 28 edges, to look for the points of intersection with the plane (1).

4. Results and discussion
Solving the problem manually becomes difficult in general. On the compiled calculation program for specific values $q_i, a_i, q$ the following example was solved.

The number of small batches in the mixture $n = 4$, the mixture parameter $q = 0.17$.

Small batch volumes are $a_1 = 10$, $a_2 = 15$, $a_3 = 14$, $a_4 = 8$.

Small batch parameters are $q_1 = 0.2$, $q_2 = 0.1$, $q_3 = 0.15$, $q_4 = 0.3$.

The calculation results are as follows: at the specified values $q_i, a_i$ and $q$ in the parallelepiped (2) the plane (1) carves the polyhedron $D$ with vertices

$K_1(10; 12, 8571; 0; 0), K_2(9, 3333; 0; 14; 0), K_3(0, 3, 4285; 0; 8), K_4(0; 0; 12; 8), K_5(10; 0; 2857; 14; 0), K_6(10; 7, 9411; 14; 0), K_7(1, 3333; 0; 14; 8), K_8(10; 11, 1428; 14; 8)$

Thus, from four small batches with a total volume of $\sum_{i=1}^{4} q_i = 47$ units, with given characteristics $q_1 = 0.2$, $q_2 = 0.1$, $q_3 = 0.15$, $q_4 = 0.3$ the mixture with a given integral characteristic $q = 0.17$ in the volume of $43,1428$ units can be obtained.

5. Conclusion
The study determined by automatic mixing device class, it is possible to provide an optimal and balanced synthesis of high-quality mixtures from small maximum volume batches and the required quality level. The solution of this technological problem is cross-sectoral and can be implemented in different loose batch production. This makes it possible to achieve much better and more effective results compared to other methods of mixtures preparation on existing types of mixing equipment [9, 10, 13, 14]. With regard to the proposed automatic mixing machines, it allows one to simplify significantly the algorithms of products quality control in real production.
References

[1] Makarov Y I 1973 Apparatus for mixing bulk materials (M.: Machinostrojenije) p 216

[2] Lukash A N, Evseev A V and Chuvpilo A V 2000 Development of technologies and equipment for the preparation of loose materials mixtures Proceeding of Tula state University. Series: Mechanical engineering №5 pp 218-224

[3] Evseev A V, Paramonova M S and Preis V V 2018 A Quantitative Criterion for Quality Mixing Assessment for the Effective Unit of Mixed Products IOP Conf. Series: Journal of Physics: Conf. Series 1050 012025 doi: 10.1088/1742-6596/1050/1/012025

[4] Podgornyi Yu I, Martynova T G, Skeeba V Yu, Kosilov A S, Chernysheva A A and Skeeba PYu 2017 Experimental determination of useful resistance value during pasta dough kneading IOP Conf. Series: Earth and Environmental Science issue 87 082039 doi: 10.1088/1755-1315/87/8/082039

[5] Sokolchik P Yu, Stashkov S I and Malimon M V 2013 Forecast and quality management of heterogeneous loose mixtures Bulletin of the Perm national research Polytechnic University. Chemical technology and biotechnology (Perm) pp 64-83

[6] Weinekotter R and Gericke H 2000 Mixing of solids Kluwer academic publishers

[7] Arratia P E, Duong Nhat-Hang, Muzzio F J, Godbole P and Reynolds S 2006 A study of the mixing and segregation mechanisms in the Bohle Tote blender via DEM simulations Powder Technology vol 164 pp 50-57

[8] Khan Z S, Van Bussel F, Schaber M, Seemann R, Scheel M and Di Michel M 2011 High-speed measurement of axial grain transport in a rotating drum New Journal of Physics issue 13 105005. Doi:10.1088/1367-2630/13/10/105005

[9] Lukash A N, Evseev A V, Ovchinnikova T A, Vlasov K V and Karpukhina O V 2006 RF Patent № 2271243 Method of loose components mixing and device for its realization Publ 10.03.06. Bul № 7

[10] Lukash A N, Klusov I A, Evseev A V 1999 RF Patent №2129911 Method of loose components mixing and device for its realization Publ 10.05.99. Bul № 13

[11] Sierksma G and Zwols Yo 2015 Linears and Integer Optimization: Theory and Practice (CRCPress) ISBN 1-498-71016-9

[12] Barantseva E A, Ponomarev D A, Mizonov V E and Berthiaux N 2003 Nonlinear models of continuous loose materials mixing Proceedings of the XVI International conference "Mathematical methods in engineering and technologies MMTT-16" vol 10 (Saint-Petersburg) pp 116-117

[13] Evseev A V, Paramonova M S, Preis V V and Lobanov A V 2019 Experimental verification of a mathematical model of a deterministic formation of a mixture homogeneity for a diamond tool Non-ferrous metals №1 (913) DOI: 10.17580/tsm.2019.01.12 pp 78-87

[14] Evseev A V 2015 New criterion for assessing the mixing quality of loose materials News of Tula State University Series: Mechanical Engineering №11 (1) pp 139-147