Accuracy of discrete metering devices in relation with the criterion of formed mixture quality assessment

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Abstract. The article considers the quality indicator (criterion) of the resulting mixture products as a two-parameter function of the metering devices accuracy and the parameter of the final effective mixture (product) application. The first parameter is intermediate and considers the functional characteristics of the single-piece produced an effective dose of a mixture with a given (required) volume or mass. The second parameter reflects the results of the final task to use mixture products or a product in total. Such a technological approach is advisable when it is difficult to describe the process of forming the mixture quality by one parameter, or when taking into account a large number of factors affecting the mixture quality obtained, and the result becomes biased. Then the second parameter is worked into the structure of the criterion for quality mixing assessment, taking into account the ultimate goal of using a mixed product or the product this mixture is included into. In this case a significant number of factors affecting the mixture quality and the effectiveness of its use according to two generalized parameters can be considered. The first typical classical parameter that affects the quality directly during mixing is the accuracy of the constituent component dosing. The second output parameter of the finished product comprehensively describes the efficiency of its use. The final parameters of the mixtures application can be determined experimentally, analyzed, and they, in turn, integrally cover the entire spectrum of many diverse factors affecting the mixture quality and the effectiveness of its use.

Keywords: production automation, algorithms and monitoring of the mixture quality control, mix production, mixture quality criterion, homogeneity formation, process modelling.

1. Introduction

The application of two, and in future, a larger number of parameters in quality mixing assessment of loose materials will provide for stepwise management in the production technology of mixtures and directly during their application. Such a scheme is appropriate in cases where the mixture is not directly the final product, but it is an integral part of the finished product for the consumer and directly determines the functions of its use. In this case, a two-stage quality control of the mixture will link and take into account the technological parameters of the metering devices affecting the maintenance of a given ratio of small batch components into the finished mixture, and also makes the control algorithm of quality indicators for using the finished product transparent at almost all stages of its production. Using the obtained ratio and their software application will monitor the state and quality management of the entire production and process chain.

Types of metering devices may be different, as it does not affect the application of the proposed method. Mixing equipment is a high-performance linear or rotary automated mixing modules.

The relevance of the development is that for the first time in the mixing production of loose or other components, a criterion for quality mixing assessment is proposed to be introduced, and it has two or
more parameters. Not only parameters affecting the quality of the final mixture can be differentiated, but also some functional groups, thus the quality management of the finished mixed products is simplified, and the calculated quality characteristics are as close to those obtained in actual production as possible. Functional groups of parameters are also considered to be as calculated as empirical.

2. Problem statement
Let there be a main primary parameter (result) of the mixture $R_{e_f}$, final application (by analogy with the generally accepted coefficient of variation $\nu_c$), is the production component of the quality criterion, and the secondary effective parameter $\bar{V}_j$ characterizing the output characteristics of the process of the mixture practical application in the finished product it is the loose component of the quality criterion. The secondary parameter is technologically and correlatively related both to the primary parameter and to some characteristics of the mixing (metering) technology. Mixture is a discrete structure [1], consisting of $\bar{m}_j$ the required number of single elements of $j$-th small batch with an average mass of these units and $p$ given share of $j$-th small batch in mixture ($j = 1, ..., J$). The mixture is synthesized as a discrete set of unit masses (volumes) made up of small batches of these masses with similar, but slightly different physicochemical properties, which is determined by the specifics of the production of small component batches. The article determines a logical connection between all these parameters, including statistical experimental data. Then the efficiency of using the final product can be controlled, it also includes a discrete mixture at all stages of its production, and most importantly, when taking into account and managing the parameters of the preparation processes of the mixture itself [2-4].

3. Solution algorithm
The author has developed a criterion for the quality mixing assessment of discrete products with a small scatter of unit masses and their other characteristics for each small batch within the mixture [1]. The proposed criterion is the final predicted value of the product $R_{e_f}$, dependent on intermediate value $\bar{V}$, in violation of the ratio of unit elements of mixed small batches in a mixture unit. Using this approach excludes the destructive control methods for quality mixing assessment due to the established dependence $R_{e_f}$ on the degree of feeder pulsation (stability of operation), ensuring the metering output of unit elements of small batches

$$R_{e_f} = \left[ \frac{1}{n-1} \sum_{i=1}^{n} \left( \frac{m_{ij} - \bar{m}_j}{m_j} - p_j (\bar{V}_j - \bar{V}) \right)^2 \right]^{\frac{1}{2}}$$

where, $m_{ij}$ is actual number of unit elements of $j$-th small batch in $i$-th predicted mix unit ($i = 1, ..., n$); $\bar{m}_j$ is the required number of unit elements of $j$-th small batch in the predicted mixture unit with the average mass; $p$ is a given share of $j$-th small batch in mixture ($j = 1, ..., J$); $\bar{V}_j$ is a secondary effective parameter of a mixture using $j$-th small batch; $\bar{V}$ is the predicted (ideal) value of the secondary effective parameter of the mixture, while respecting the specified ratio of mixed small batches

$$\bar{V} = \sum_{j=1}^{J} p_j \bar{V}_j.$$

The technology was tested in linear mixing machines of deterministic homogeneity formation; its mixture homogeneity is achieved by imposing dosed flows of small lots on each other on a continuously moving conveyor [5]. Accuracy (mathematical expectation of productivity) and stability
The supply of single elements is carried out by feeder single-piece in linear mixing machines of deterministic homogeneity formation. Therefore, the absolute (single-piece) amplitude of the single elements supply of \( j \)-th small batch can be determined by elementary counting the real number of unit elements \( j \)-th small batch, corresponding to the time interval for the filing of all small batches with a total amount equal to the mass per unit of the mixture. If condition (2) is not observed, it is necessary either to feed the flow with elements of the missing small batches, or emit outgoing units of the mixture, which requires the creation of determining homogeneity linear mixing machines with a rather complex mixing quality control system and functional units.

In the case of designing linear mixing machines of deterministic homogeneity formation without feeding metering devices, the task of establishing the dependence \( R_{cV} \) on the parameters of number distribution of unit elements in small batches in a unit of the mixture, as well as the determination for a given permissible value \( R_{cV} \) possible absolute and relative amplitudes of the numbers of unit elements in small batches in units of the mixture and productivity amplitudes of the metering devices.

It is experimentally stated [1-3, 5-7], that with sufficient accuracy for practice, the number of unit elements of each small batch follows the normal distribution law characterized by the expectation of their number \( m_j \) and standard deviation \( \sigma_j \).

Then deviation \( \Delta V \) of the secondary parameter due to violation of the mixed small batches ratio, caused by both systematic (inaccurate adjustment of the metering devices, etc.) and random factors (accidental missing of the certain small batches elements to the gripping bodies of the dispensers, uneven rotation of the metering devices elements, etc.), can also be estimated by expectation \( \Delta \bar{V} \) and variance \( D_{\Delta \bar{V}} \) [8-9]

\[
\Delta \bar{V} = \sum_{j=1}^{J} \frac{m_j - m_j}{m_j} p_j (\bar{V}_j - \bar{V}) ;
\]

\[
D_{\Delta \bar{V}} = \left[ \sum_{j=1}^{J} \frac{m_j - m_j}{m_j} p_j (\bar{V}_j - \bar{V}) \right]^2 - \left[ \sum_{j=1}^{J} \frac{m_j - m_j}{m_j} p_j (\bar{V}_j - \bar{V}) \right]^2 ,
\]

where \( \bar{m}_j \) is mathematical expectation of the number of unit elements of \( j \)-th small batch.

However, the deviation component of the secondary parameter caused by systematic factors, fine tuning parameters, can be minimized and with sufficient accuracy for practice to state that \( \bar{m}_j = \bar{m}_j \).

With this assumption \( \Delta \bar{V} = 0 \), and the deviation of the initial velocity will be characterized by the variance
\[ D_{\Delta V} = \sum_{j=1}^{J} \frac{D_j}{m_j} p_j^2 (\bar{V}_j - \bar{V})^2 + 2 \sum_{j \neq \chi} \frac{\sigma_j \sigma_\chi}{m_j m_\chi} p_j p_\chi (\bar{V}_j - \bar{V})(\bar{V}_\chi - \bar{V}) , \]

where \( D_j \) is dispersion of the number of unit elements \( j \)-th small batch \( \sigma_j, \sigma_\chi \) are standard deviations of the number of unit elements, respectively of \( j \)-th and \( \chi \)-th small batches.

Then dissipation \( R_{vc} \) of the primary parameter of the product caused by the violation of the ratio of small batches, is equal to

\[ R_{vc} = \sqrt{\sum_{j=1}^{J} \frac{D_j}{m_j} p_j^2 (\bar{V}_j - \bar{V})^2 + 2 \sum_{j \neq \chi} \frac{\sigma_j \sigma_\chi}{m_j m_\chi} p_j p_\chi (\bar{V}_j - \bar{V})(\bar{V}_\chi - \bar{V})} . \] (3)

The number of metering devices in linear mixing machines of deterministic homogeneity formation is usually much more than the number of batches to be mixed, and dispensers are distributed between small batches in accordance with a given ratio of these batches, therefore the productivity of all \( W \) metering devices are either equal or close to each other. In this case, the required number of unit elements of \( j \)-th small batch is

\[ \bar{m}_j = m_0 W_j , \]

where, \( m_0 \) is the number of unit elements issued by one metering device, \( W_j \) is number of metering devices feeding single elements of \( j \)-th small batch; wherein \( W = \sum_{j=1}^{J} W_j \).

Due to self-sufficiency of the metering devices, the dispersion \( D_j \) is equal to the sum of the dispersions of the performance of the metering devices feeding the single elements of \( j \)-th small batch.

Then from equation (3) after a series of transformations, there can be determined the maximum possible relative amplitude (stability) \( \delta_{m_0} \) of one metering device productivity of a linear mixing machine for deterministic homogeneity formation, which ensures the specified mixing quality

\[ \delta_{m_0} = \frac{\sigma_{m_0}}{m_0} \leq \frac{R_{vc}}{V \sum_{j=1}^{J} p_j (K_j - 1)} , \] (4)

where, \( \sigma_{m_0} \) is standard productivity deviation of a single metering device in a linear mixing machine for deterministic homogeneity formation, \( K_j \) is a speed coefficient of \( j \)-th small batch

\[ K_j = \frac{\bar{V}_j}{V} . \]

4. Results and discussion

Formula analysis (4) shows that when forming common batches to obtain the required value of the secondary parameter \( \bar{V} \) the lowest requirements for the stability of the metering devices will correspond to the choice of the available small batches of components, which ensures the smallest (by module) value

\[ C = \sum_{j=1}^{J} \frac{\bar{p}_j (K_j - 1)}{\sqrt{W_j}} . \]

In case of average masses equality of all small batches unit elements, the number of metering devices \( W_j \), feeding elements of \( j \)-th small batch, respectively, make up the share \( \bar{p}_j \) of the total metering devices number \( W \).

Then
\[ C = \frac{1}{\sqrt{m}} \sum_{j=1}^{j=1} p_j (\bar{K}_j - 1). \]

It is obvious that the best conditions for ensuring quality mixing will be in the case when value \( C \) of small batches, having \( \bar{K}_j < 1 \), is equal to value \( C \) of small batches having \( \bar{K}_j > 1 \).

5. Conclusion

Most of the existing criteria for assessing the quality mixing of loose materials [10] are probabilistic in nature and predict quality mixing indicators with rather low probability, as applied to the actual production.

The article developed a new criterion for quality mixing assessment, which is a two-parameter function of the metering devices accuracy and the parameter of the final effective mixture use. The first parameter is intermediate and takes into account the functional characteristics of the unit-produced effective mixture dose with a given volume or mass, and the second parameter reflects the results of the ultimate goal to use the product as a whole. Thus, the probability of compliance with the predicted and obtained quality mixing indicators increases significantly, and with a certain engineering approach this probability can be set, ensuring the guaranteed and controlled quality of the mixtures obtained.

Moreover, the secondary parameter can be determined and associated with other parameters in the system empirically by experimental destructive control methods in a multiparameter model, if it is economically justified. Multiparameter step quality control may be unique, provided that the number of parameters considered for the function of the final result \( R_c \) is more than one or even a few dozen.

The integral quality indicator, in this case, ceases to be representative. Experimental verification of parameters part for a common function can minimize their number and reduce most of them to one, as well as the most difficult ones to be taken into account can also be reduced to one, but the most adequate parameter describing real processes.

In this regard, it is obviously necessary to solve the problem of optimizing algorithms, methods and experimental plans, both final and intermediate quality control, in order to reduce the overall economic burden on the production of products using a mixture of small component batches. But it is also obvious that this task is very specific, has an interdisciplinary focus and is solved for a specific production and technological chain, which will also give the maximum effect from its results.

As examples of this technique application, the following can be cited: in the food industry it is preparing a flour mixture for a specific type of bakery products and quality indicators of their final production; in pharmacology it is the parameter of the exact proportion in the mixture of medicinal drugs and the result of their complex use in treatment; in the instrumental industry it is the qualitative characteristics of the preparation of the metal charge and the parameters of the tool [2]; in chemical technologies there are many different parameters of formation uniformity of loose material mixtures and final use options, etc [1,5,10]. This technique is proposed for the first time and its relevance is due to the increasingly high demands placed on consumers to mixed products and products with its use.

The author plans to systematize and present developments on the multiparameter control and quality management of products with a mixture of loose components in the following articles, including a criterial justification for the calculated and empirical parameters.

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