Experimental studies of the dependence of the heterogeneity coefficient of the mixture on the technological parameters in the mixer with a variable working chamber

N M Lozovoi*, L V Radinskaya and S Y Lozovaya

Belgorod State Technological University named after V.G.Shukhov, 46 Kostyukova street, Belgorod, 308012, Russian Federation
*E-mail: lozwa@mail.ru

Abstract. Mixing bulk materials is widespread in various industries: construction, agro-industrial complex, chemical technology, energy industry and many others. At the same time, the task of preparing homogeneous mixtures is associated with a number of difficulties, such as a wide range of changes in the physicomechanical properties of the processed materials, requirements for the quality and composition of the product, productivity, energy and metal consumption, etc.

1. Introduction
In road construction, when they use quicklime or burnt lime waste as additives, cohesive soil, before mixing with lime, is moistened to the condition of 0.7–0.8 of the moistness at the soil yield line. If the process requires using mixed bulk additives, then they should be added before the soil is moistened. Before processing mixtures with an anionic emulsion, we should add a mixture of 1–2% lime-powder and 2–4% cement [1–3], which should be pre-mixed with each other.

Tools and methods of intensive mixing allow us to seriously revise the basic recipes of modified mixtures and their production technology, while increasing the impact of modifying additives on the physicomechanical and technological parameters of the prepared mixtures leads to significant savings in expensive components [4-5].

The task of increasing the efficiency of devices used in the preparation of bulk mixtures inclined to adhesion and agglomeration, segregation by the physicomechanical properties of particles (size and density), with a large volume ratio of components (1:10 or more), make it necessary to constantly improve the known types of mixing equipment and create new ones.

Today, the production of certain types of materials for construction purposes is impossible without the use of mixing equipment capable of providing the necessary level of homogeneity of the mixture. The system of additives is used in the compositions of dry construction mixtures to regulate their technological properties. A number of components are introduced in small quantities (0.05-0.5%), but their influence on the formation of the properties of mortar mixes and solutions is extremely large. They form their own structural network in the aqueous phase or interact with the dispersed phase and maintain
the stability of the system, enhance the anti-sedimentation effect, increase the plasticity of the system, provide the necessary level of tixotropic properties.

Nowadays, modifying additives having a complex composition are supplied for sale in a ready-for-use form. Therefore, a mixer capable of high-quality mixing and homogenizing powders from the initial components, differing from each other in particle size (from micron fractions to 5 mm) and density (from 0.1 g/cm³ to 4.0 g/cm³) is the main device of technological cycle of production of dry mixes and their components.

2. **Experimental installation of the mixer with a variable working chamber**

One of the possible ways to improve the mixing equipment for bulk materials is the use of mixer designs with the ability to control and regulate the movement of particles inside the mixing chamber, which will provide the necessary movement of particles, and the stable achievement of the required quality of the mixture [5-9]. Therefore, the ability to control the process of mixing, simplicity of design, quick and easy adjustment of the mixer to work with different bulk materials is an urgent issue. This can be implemented using the mechanism of deformation of thin-walled elements in mixers to increase degrees of freedom and to impact the material controlling the movement of the mixture and the corresponding mixing processes to obtain high-quality multicomponent mixtures with desired characteristics [6, 9].

We conducted the studies using an experimental test bench (Figure 1, a) and a laboratory setup (Figure 1, b). The experimental stand is based on the modular principle, i.e. the stand base remains unchanged, and individual modules are being replaced. This made it possible to simplify the formulation of experiments and to conduct them on a unified basis according to an invariable method.

The experimental stand allows us to change the diameter, length of the variable chamber over a wide range, adjusting the drive rotation frequency within the required limits, and thus allows investigating the process of mixing materials in the mixer with the variable working chamber using multifactorial experiment methods. The stand consists of a bed where all the main nodes are installed. The working chamber is fixed with one side to the rear support, which, depending on the length of the working chamber, can move along the frame. The movement to the deforming elements is transmitted from the actuator, providing stepless adjustment of movement.

![Figure 1. Equipment for experimental studies:](image)

a - assembled experimental stand: 1 – device under research; 2 - drive unit; 3 - tachometer; 4 - control and measurements unit; 5 –bunker for final product;<br>b - laboratory setup: 1 – camera; 2 – base; 3 – ring; 4 – pin; 5 – drive; 6 – bearing unit; 7 – loading hole; 8 – gate; 9 – shoulder blades; 10 - holes in the base for unloading material; 11 – gate for unloading.
The laboratory setup consists of a chamber 1 with a volume of 3 liters, fixed on the base 2 by a ring 3. The chamber 1 is fastened to the pin 4 with collars 4, through the drive 5 and the bearing unit 6, the rotation of the pin is transmitted from the spindle of the drilling machine. The loading is carried out through a hole 7, unloading through the gate 8. Blades 9 are attached to the pin 4, holes 10 are made in the base 2 for unloading the material. Their width is 6 mm and their size is justified by the fact that, if necessary, the chamber is filled with grinding bodies of size 6.5 mm and more and the device can work as a mill of superfine grinding.

The quality of mixing materials in devices with variable working chambers (the coefficient of heterogeneity of the mixture \( K_n \)) is influenced by the following factors:

\[
K_n = f ( \omega_c, L, D, d_{ch}, d_e, K_y, \Delta, t, K, R_t, j);
\]

where \( \omega_c \) – pin rotation speed around eccentric vertical axis, c\(^{-1} \); \( D \) - diameter of the base of the working chamber, m; \( d_{ch} \) - particle size of the base material, m; \( d_e \) – eccentricity of the pin rotation around the vertical axis, m; \( d_e \) – pin diameter, m; \( K_y \) - the fill coefficient of the chamber with mixed material; \( L \) – height of the working chamber, m; \( \Delta \) - deformation coefficient of the working chamber in height; \( t \) - mixing time of mixture components, sec; \( K \) – blend ratio, \%; \( R_t \) – radius of blades arrangement on the pin; \( j \) – number of blades.

We experimentally established that the mixing process takes place the more intensively, the greater the deformation coefficient of the variable chamber. It depends on the radius of the blades, since the blades should not be in contact with the walls of the chamber during the moving. The chamber has the shape of a half-bar, in which the height must be equal to the diameter of the base and the diameter of the pin is equal to 1/5 of the diameter of the base (by construction). The filling coefficient of the variable chamber with material, by analogy with existing mixers, was assumed to be 0.75% (2.25 l) of the chamber volume (3 l). Due to the problem of mixing the basic components of dry construction mixtures with different physical and mechanical characteristics, and due to the novelty of the mixing device, we chose sand as the main basic material with particle sizes of 1.25-2.5 mm, brand cement 350, to determine the device’s performance under the proposed conditions. The blend ratio of the mixture ranged from 90 / 10-60 / 40% [3-5].

Based on the estimating tests, the mixing time ranged from 1 minute to 7 minutes, the number of revolutions of the pin ranged from 100 to 300 rev/min (pin rotation frequency 10.5 - 31.5 c\(^{-1} \)). With a number of revolutions per minute less than 100 with a minimum mixing time, the heterogeneity coefficient was 60%, and with a speed of more than 300 rpm and a maximum mixing time of 7 min, the heterogeneity coefficient was 75.7%, which can be explained by the fact that the cement particle has higher dispersion than sand particle and under the action of centrifugal forces sand particles fly to the walls of the chamber. It causes a separation into fractions, which increases the coefficient of mixture’s heterogeneity. In this case, the eccentricity value was taken as maximum - 0.06 m.

At the experiments, we chose the following levels of variation to obtain a regression equation for the dependence of the mixture heterogeneity coefficient on the technological parameters (mixing time \( t \), the blend ratio \( K \), expressed in density \( \rho \) and drive speed \( n \)) (Table 1).

For \( K_n \) conversion formulas will be

\[
x = \frac{t - 240}{110}; y = \frac{K - 25}{9}; z = \frac{n - 200}{60}.
\]

In coded form, the regression equation for mixing sand and cement is

\[
Y = 12.01 - 1.3x_1 - 12.52x_2 + 2.3x_3 + 1.13x_1x_2 + 5.2x_1x_3 - 1.1x_2x_3 - 2.43x_1^2 + 7.24x_2^2 + 6.1x_3^2.
\]
Table 1. Intervals and levels of variation of independent variables.

|          | t, s | K, % | n, rpm |
|----------|------|------|--------|
| Main     | 240  | 0    | 0      |
|          | 110  | -1   | 60     |
| Variation intervals | 350  | +1   | 260    |
|          | 130  | -1   | 140    |
| Upper    | 420  | 1.682| 300    |
|          | 60   | -1.682| 100    |
| Lower    | 375  | 0    | 200    |
|          | 66   | +1   | 260    |
| Top point | 84   | -1   | 140    |
|          | 60   | -1.682| 100    |
| Bottom point | 90   | 1.682| 300    |

A negative sign at \( x_1 \) and \( x_2 \) shows that with an increase in mixing time and the proportion of filler in the mixture (sand), the heterogeneity coefficient decreases, with an increase in the number of revolutions of the pin, the heterogeneity coefficient increases.

Substituting the conversion formulas (2) into equation (3), we have:

\[
K_n = 306.2 - 0.2t - 5.5K - 1.2n + 0.001trK + 0.0008tn - 0.002Kn - 0.0002r^2 + 0.09K^2 + 0.002n^2.
\] (4)

Using the formulas, we determined the significance of factors \( t = 8\% \); \( K = 78\% \); \( n = 14\% \). The blend ratio in the mixture has the greatest influence on the value of the coefficient of heterogeneity of sand with a particle size of 1.2 - 2.5 mm with brand cement 350 in a mixer with a variable working chamber.

We built three-dimensional figures, showing the dependence of the heterogeneity coefficient on the main factors. Figure 3 shows the most typical shapes reflecting the values of the heterogeneity coefficient of the mixture from the main factors. Any point lying on a particular surface shows what values of time, blend ratios and the number of revolutions of the pin are required for the desired coefficient of heterogeneity of the mixture.
Analysis of three-dimensional figures (Figure 2, a, b) and graphs (Figure 3) shows that to obtain the heterogeneity coefficient of the mixture $K_n = 1\%$, we can use two modes of mixing:

- The presence of a double mode of mixing is typical in obtaining mixtures with an heterogeneity coefficient of up to 6\% (Figure 3, c, 5).

Figure 3, d, shows that the heterogeneity coefficient of the mixture is $K_n = 61\%$ with mixing time up to 240 seconds, pin speed from 100 to 140, blend ratio about 80/10. Moreover, this also applies to mixing modes with mixing time to 350 s, the number of revolutions of the pin from 250, the blend ratio of about 84/16. This can be explained by the fact that, firstly, sand and cement have a big difference in particle size and weight. In this case, the rotation frequency of the pin and the blend ratio are too small, so the cement falls in the voids between the sand particles. Secondly, in the case of a larger number of revolutions and mixing time, the cement particles are distributed closer to the chamber walls, which also reduces the homogeneity of the mixture.

**Figure 2.** Graphs of the dependence of the heterogeneity coefficient on the main factors:
- a - the surfaces displaying change of coefficient of heterogeneity;
- b - $K_n = 1\%$;
- c - $K_n = 6,8\%$;
- d - $K_n = 30\%$;
- e - $K_n = 60,9\%$.

**Figure 3.** Surfaces reflecting the dependence of $K_n = 1\%$ on technological parameters.
Here we can assume that in this device, with a smaller difference in the particle size of sand and cement, the smallest homogeneity coefficient can be obtained with a pin speed of up to 300 rpm, which is 5-10 times less than in known high-speed devices and with a shorter mixing time. The reason is that the particles of the material are mixed in the cross section by rotating the pin with the blades, and in the longitudinal section due to the deformation of the chamber, i.e. the number of degrees of freedom of mixing the material is maximum.

Figure 4 shows nomograms of the dependence of the mixture heterogeneity coefficient on two parameters with a fixed third. The areas highlighted in color show at which technological parameters the heterogeneity coefficient corresponds to: 1-5% (red); 5-10% (green); 10-15% (blue).

**Figure 4.** The change in the coefficient of heterogeneity of the mixture in the range from 1 to 25% depending:

1) on pin speed and density: a) $t=60s$; b) $t=130s$; c) $t=240s$; d) $t=350s$; e) $t=420s$;
2) on pin speed and time: a) $\rho=1150$ kg/m$^3$; b) $\rho=1180$ kg/m$^3$; c) $\rho=1225$ kg/m$^3$; d) $\rho=1270$ kg/m$^3$; e) $\rho=1300$ kg/m$^3$;
3) on time and density: a) $n=100$ rpm; b) $n=140$ rpm; c) $n=200$ rpm; d) $n=260$ rpm; e) $n=300$ rpm – $K_n=1$-5%; – $K_n=5$-10%; – $K_n=10$-15%; – $K_n=15$%; – $K_n=20$%; – $K_n=25$%.

3. **Conclusion**

The presence of a double blending mode is typical when obtaining blends with a heterogeneity factor of up to 6%: the first mode - when the number of revolutions of the pin is from 210 to 300 rpm, the mixing time is 60-100s and the percentage blend ratio is from 66/34 to 60/40 ($\rho = 1225 ... 1300$ kg / m$^3$); the second mode - when the number of revolutions of the pin is from 130 to 210 rpm, the mixing time is 380 - 420 s and the percentage blend ratio is from 66/34 to 60/40 ($\rho = 1225 ... 1300$ kg / m$^3$).
References

[1] Metodicheskie rekomendatsii po stroitelstvu osnovaniy dorozhnyh odezhd s ispolzovaniem svyaznyh gruntov, ukreplennyh mineralnymi ili organicheskimi vyazhushchimi s dobavkami PAV i promyshlennyh othodov/Soyuzdornii - 1985 39

[2] GOST R 52129-2003 Poroshok mineralnyh dlya asfaltobetonnyh i organomineralnyh smesey Tekhn usloviya - Izd ofits ; Vved 01 10 2003; Vved vpervye - M : Gosstroy Rossii, FGUP TSPP, 2004 - 33

[3] Laskorin B N 1984 Bezothodnaya tehnologiya pererabotki mineralnogo syrya - M : Nedra, - 334

[4] SHirina N V 2009 Stroitelnye rastvory Proshloe i nastoyashchee [Monografija - Belgorod: Izd-vo BGTU, – 219

[5] S Yu Lozovaya, N M Lozovoj and N V Shirina 2013 Influence of Processing Characteristics of Mixer with the Changing Camera on Quality of Heat-Insulating Plasters on the Basis of Modifying Agent and Anthropogenic Raw Materials/ World Applied Sciences Journal 24(10) 1404-10, ISSN 1818-4952 © IDOSI Publications, 2013 DOI: 10.5829/idosi wasj 2013 24 10 7021, Published: Sep 15 1404-10

[6] Lozovaya S YU, Lozovoy N M, Uvarov V A, Ryadinskaya L V, Sharapov R R, Ryadinskaya L V and Sharapov R R 2016 Studying changes in design and technological parameters of the grinding and mixing devices with cylindrical working chambers deformable in cross section International Journal of Pharmacy & Technology 8(4) 24733-24747 URL: http://www ijptonline com/wp-content/uploads/2017/02/24733-24747 pdf

[7] Tarshis, M YU 2008 K raschetu smesitelya sypuchih materialov so slozhnym dvizheniem elastichnoy rabochey kamery / M YU Tarshis // Izv VUZov, «Himiya i himicheskaya tehnologiya» 51(8) 75 -7

[8] Tarshis, M YU 2003 Novye apparaty s elastichnymi rabochimi elementami dlya smeshivaniya sypuchih sred Teoriya i raschet: YAGTU, – 84

[9] S Yu Lozovaya, N M Lozovoy, L V Ryadinskaya, I B Kostina, O N Satler, L V Logvinova and E I Ziborova 2018 Experimental studies of energy characteristics of mixer with deformable camera/ International Conference “Complex equipment of quality control laboratories” IOP Conf Series: Journal of Physics: Conf Series 1118(012024) IOP Publishing doi:10 1088/1742-6596/1118/1/012024