Research of the deformation of the shaping unit in an auger extruder caused by the extruding pressure in production of expanded clay

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Abstract. The technological process of forming expanded clay granules in an auger extruder is considered. Based on the analysis of well-known studies, considering the influence of conditions for shaping a ceramic mass on the quality of the produced porous aggregate, the following factor was identified: clogging of the shaping grid leads to an increase in pressure on it, its deformation and the impossibility of further operation. The authors note that there are practically no theoretical studies in the field of determining the most rational modes of functioning of the shaping equipment. The simulation model of an auger extruder shaping unit was developed in the SolidWorks software environment, computational experiments on the influence of design parameters on shaping pressure were carried out, and recommendations for further technical application were formulated. The use of the results obtained will improve both the reliability of extruders with a perforated grid, as well as the quality of the final product with the specified quality parameters (bulk density and strength).

1. Introduction
The production of expanded clay gravel is a continuous technological process, which includes several main stages: preparation of clay raw materials; shaping of raw granules and their preliminary drying; burning and expansion; cooling of expanded clay. Each of the above technological limits is characterized by intermediate indicators, which, ultimately, form the qualitative characteristics of the finished product (bulk density, strength, uniformity coefficient, etc.).

Currently, issues related to the study of the technological process of burning expanded clay gravel in rotary kilns 40x2.5m and the development of recommendations aimed at energy-efficient control of this equipment in order to obtain the final product with the specified quality indicators (bulk density and strength), have been well studied [1-3].

The analysis of the results of works [1,2] shows that the authors, when considering the technological process of burning expanded clay gravel, applied the decomposition method, assuming that the rheological and physicochemical characteristics of the semi-finished product supplied for burning remain constant. However, as practice shows, it is at the stage of manufacturing raw granules in an auger extruder that the preliminary strength and the uniformity coefficient of the final product are formed. The constant change in the physicochemical properties of the raw materials, the lack of control over the processes occurring in the shaping devices, in particular, the mass flow rate, extruding pressure and the use of shaping grids with an increased hole diameter lead to a significant spread in the uniformity
coefficient of the resulting product. The authors [4] revealed the constructive drawback of existing granulating auger extruders – the presence of "dead" spots in front of the shaping nozzle, which leads to an increase in the shaping pressure even when using shaping grids with an optimal hole diameter. As a result, some pronounced uneven pressure distribution over the surface takes place, which causes deformation and the impossibility of further operation of the shaping grid. The article proposes a technique for studying the auger extruder shaping unit, formulates recommendations for its modernization, aimed at increasing its technological reliability and more rational use of the technical characteristics of the equipment.

2. Materials and methods
The results of experimental studies conducted by V. F. Veber [5] showed that the modes of shaping (speed of shaping, pressure and length of the channel of the auger extruder shaping head) significantly affect the quality characteristics (bulk density and strength) of expanded clay gravel. When the clay mass flows through the shaping channel of the auger extruder head, an inhomogeneous stress field occurs in its cross section, which leads to variations in the speed of clay movement in different flow channels [6]. The physical and mechanical properties of the clay mass depend on the velocity gradient dz/dt; therefore, raw granules shaped at different speeds have different sensitivity to drying modes, which causes shrinkage cracks in the granules to appear. Burning granules with a layered structure, formed during shaping stage, leads to the occurrence of longitudinal cracks through which part of the gases escape and, as a consequence, the expansion of the granules worsens.

The analysis of the results of field experiments [6] showed that the pressure on the perforated grid depends on the perforation coefficient, the type of clay, the degree of its contamination and varies within 6-20 kg/cm². This is caused by the presence of solid inclusions 12-15 mm in size in the clay raw material, which leads to clogging of the shaping grids. Therefore, when about 25-50% of the grid holes are clogged, the extrusion pressure increases to the maximum attainable value of 20-22 kg/cm².

Thus, the goal of the study is to create a simulation model of the auger extruder shaping unit and to carry out computational experiments on the influence of design parameters (s is the thickness of the perforated grid; d is the diameter of the raw granules; C is the clogging of the shaping grid) on the shaping pressure in order to develop further technical recommendations.

The authors propose to use the SolidWorks software environment to solve the problem. When developing a model of the shaping unit, the results of field experiments [6-9], the main technological features and design characteristics of the extruder [10] were taken into account, namely: material - steel St 3; diameter – 500 mm; thickness – 16 mm; number of shaping channels (grid perforation coefficient) – 432 pcs; diameter of shaping channels – 10 mm; generated pressure – 6+22 kg/cm²; range of change in the degree of clogging of the shaping unit – 0±80%; clay raw materials of the Smyshlyaevskoe deposit.

3. Results and discussions
Comparative analysis of extrusion pressure diagrams obtained during field experiments [6] with the results performed on the model (figure 1, figure 2) showed the adequacy of the developed computational model of the shaping unit and the possibility of further application for the purpose of experiments.

The revealed design drawback of the granulating auger extruder, described above, namely, the presence of "dead" spots in front of the shaping head, leads to an increase in the shaping pressure and the speed of shaping, and as a consequence, negatively affects the homogeneity of ceramic gravel [6]. The authors propose to solve the problem by constructive modification of the existing shaping unit by producing tapered lead-in parts of peripheral shaping channels, forming a complex geometric surface along the border of "dead" spots, which consists of cylindrical and conical parts (figure 3).

Therefore, when carrying out research on the deformation of the auger extruder shaping unit from the shaping pressure, we will require the development and determination of the most effective design of the tapered lead-in parts of the peripheral shaping channels. As a result, perforated grids with different design parameters of the lead-in parts of the peripheral shaping channels were modeled, and experiments
were carried out on the influence of the maximum allowable pressure of 22 kg/cm² on the deformation of the shaping unit (figure 4).

![Figure 1](image1.png)

**Figure 1.** Pressure distribution in the auger extruder shaping unit at 0% clogging: a) inside; b) surface.

![Figure 2](image2.png)

**Figure 2.** Pressure distribution in the auger extruder shaping unit at 80% clogging: a) inside; b) on the surface.

![Figure 3](image3.png)

**Figure 3.** The tapered lead-in part of the peripheral shaping channel forming a complex geometric surface consisting of cylindrical and conical parts.
Figure 4. Diagram showing the change in the deformation of the shaping unit at a pressure of 22 kg/cm²: a) without tapering lead-ins of peripheral shaping channels; b) design parameters for the tapered part – $D=2$ mm, $A=45°$; c) design parameters for the tapered part – $D=2$ mm, $A=60°$

The studies revealed that the design parameters of $D=2$ mm and $A=60°$ (figure 4, c) are the most effective, but the resulting model does not reflect the law of pressure distribution inside the auger when the shaping nozzle is clogged and cannot be offered as a recommendation for further use. Therefore, additional studies of the developed model were carried out taking into account the clogging of the shaping nozzle with the effective design parameters of the lead-in parts ($D=2$ mm, $A=60°$) (figure 5, figure 6).

Figure 5. Pressure distribution inside the shaping unit with effective design parameters of the lead-in parts with clogged channels: a) 0%; b) 20%

Figure 6. Pressure distribution inside the shaping unit with effective design parameters of the lead-in parts with clogged channels: a) 50%; b) 80%
The analysis of the pressure distribution diagrams inside the shaping unit, presented in figure 5, figure 6 shows that the use of effective design parameters of the lead-in parts ($D = 2 \text{ mm}$, $A = 60^\circ$) will allow not only to reduce, but also to stabilize the total pressure inside the auger extruder, which will lead to a more even compaction of the raw material over the entire surface of the shaping unit.

4. Conclusions
The developed model and the computational experiments carried out to study the deformation of the auger extruder shaping unit from the shaping pressure, considered in the article, are aimed at solving an important practical problem – the analytical design of newly projected and operating equipment. Moreover, the obtained research results will help to improve the reliability of existing extruders, as well as create preconditions for the creation of automatic pressure stabilization systems in order to obtain the final product with the specified quality parameters (bulk density and strength).

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