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MODELLİNG OF CONSTRUCTİON SAND PREPARATİON TECHNOLOGY

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ABSTRACT

of the dissertation for the degree of Doctor of Philosophy

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İMZANI TƏSDİQ

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GENERAL CHARACTERISTICS OF THE WORK

Relevance of the topic and degree of development. One of the main tasks facing every state in modern times is to further raise the standard of living of the country's citizens, expand housing construction, develop culture, education, and healthcare. For this, it is required to strengthen the material and technical base of the construction industry by taking advantage of the achievements of scientific and technical progress. Currently, the use of local building materials in reconstruction works in the construction sector is prioritized. It is this factor that leads to the development of the construction materials industry when building and installation works are carried out in the regions. Thus, inert materials (sand, gravel, crushed stone, etc.) which are considered important in construction works are the basis of consideration of the composition of construction materials, products and constructions. Thus, sand is widely used in the creation of various construction mixtures (concrete, asphalt, plaster, various decorative coatings, etc.), reinforced concrete structures, and also in sandblasting and filling works, as a component for the production of glass, silicate and classic clay bricks. Various methods of sand washing exist and are now widely used in sand producing quarries.

When cleaning sand with traditional methods, repeated washing is required to completely clean the clay particles in the sand. At this time, productivity decreases and excess energy is spent on operating the devices. Despite the development of numerous scientific studies, application methods and methodologies in this field, the problem remains relevant. Eliminating the indicated deficiencies is an important scientific-practical issue.

The presented dissertation is devoted to the solution of this problem, researches were conducted to improve the quality of sand, and the obtained results were based on mathematical and simulation modeling. A new approach was proposed to overcome the problem - sand washing methods and existing technologies were studied, a new method was proposed and tested as a more effective method. Thus, a new sand washing device was proposed and tested in order to achieve a higher level of cleaning of dust, clay and silt particles by washing the sand produced by the proposed method. A new sand washing technology designed for the production of all types of sand has been introduced in the industry by means of a sand washing device with the conventional name "JJ Clean Sand" (JJCS). The application of the mentioned technology and equipment will lead to an increase in the quality indicators, a decrease in the cost of sand, and a significant reduction in production costs in the cleaning of small and large-grained sand extracted from quarries by washing them from dust, silt and clay mixtures .

The object and subject of the research. The research object of the dissertation work is the technological process of sand washing. Its subject is the methods and means of the scientific-theoretical study of the design of these devices and technological processes, and the parameters determining their technical and operational characteristics. The apparatus and its technological process perform hydraulic processing of construction sand applied in civil and industrial construction facilities.

The purpose and tasks of the study. The purpose of the research is the application of new methods that ensure the improvement of the quality of construction sand, the creation of devices, the development of an automated management system that ensures the improvement of the quality of sand. The main tasks of the research consist of the complex solution of the following issues:

- conducting a comparative analysis of the technological experience of recent years related to construction sand processing;
- development of a new method for separating construction sand from harmful mixtures, taking into account the parameters of natural resources (inert materials);
- development of a new sand washing device that cleans construction sand from harmful mixtures, taking into account the parameters of natural resources;
- development of simulation modeling of a new unit that cleans construction sand from harmful mixtures by means of Proteus software;
- development of the Arduino system for a new device that cleans construction sand from harmful compounds with simple coding through programming;
- analysis of the experimental results of the elimination of defects in the preparation of construction mortars, concrete products and structures using the proposed sandblasting device.

Scientific-practical significance and application of research. A new sand washing method, control system, and device were developed and used in the cleaning of inert construction materials (gravel, sand and crushed stone), especially harmful mixtures contained in construction sand. Also, based on the experimental results, the washing and cleaning of clay, silt and dust mixtures contained in construction sand with different size modules was determined. Hardening processes for various samples of construction mortar and concrete mix based on pure construction sand produced by the newly modeled sand washing plant were studied, and the assurance of high quality was substantiated by mathematical and simulation modeling. The prepared small-sized sand washing device was tested in the "Construction materials scientific research and testing" laboratory of the Azerbaijan University of Architecture and Construction and applied in the test site of the concrete production plant of "CC Concrete" LLC.

Research methods. During the researches, scientific-theoretical methods of creation and operation of construction materials processing technology and apparatus, automatic regulation technique, schematic engineering, engineering experiments were studied. Based on the research method, a new method different from the traditional technologies was checked, experiments and tests were conducted in laboratory and industrial conditions, and an automated and modeled modern sand washing method and device were studied, such as cleaning small and large-grained sand extracted from quarries by washing them from dust, silt and clay mixtures. Calculations are based on computer modeling in the Matlab software environment.

Main clauses defended. The results of research conducted for modeling and improving the quality of construction sand production technology:

- development of a new method that separates construction sand from harmful mixtures, taking into account the parameters of natural resources (inert materials);
- study of the automatic adjustment of the main parameters of the new unit that washes construction sand from harmful mixtures, taking into account the parameters of natural resources (inert materials), study of the automated technological process;
- development of simulation modeling of a new unit that cleans construction sand from harmful mixtures using Proteus software;
- development of the Arduino system with simple coding through programming for a new device that cleans construction sand from harmful compounds;

- study of the elimination of defects in the preparation of construction solutions, concrete products and structures using a new sandblasting device.

Scientific novelty of the research:

- the study of the sand washing facility as a management object, the determination of the quantities characterizing it;
- drawing up the dynamic equations of the functional elements of the sand washing device and the dynamic equation of the control system based on them;
- simulation study of the control of the sand washing machine using the Proteus program and development of the software for the Arduino controller;
- Development of a three-circuit automatic cascade regulation system of a new washing machine proposed by the plaintiff;
- determination of the stability areas of the control system through the simulation program of the three-loop automatic cascade regulation system in the Matlab environment and, based on it, determination of the reliable operating mode of the device.

Theoretical and practical significance of research. Taking into account the parameters of natural resources (inert materials), a new method was invented that separates construction sand from harmful mixtures. Thus, the construction sand washing method combines the delivery of primary sand from the quarry to the chamber from above with shares, the dispersion of the primary sand in the chamber with high-pressure turbulent water-air nozzles, and the separation of cleaned sand and water-clay slurry. Dispersion of primary sand is carried out by facing nozzles coming out from the grid placed at the bottom of the chamber under 3-4 atmospheric pressure, which creates a boiling medium in the chamber, but the boiling medium (aqueous-airy-sandy-clay) is fixed in the upper part of the chamber, kinematic as a result of the interaction with the hanging bending elements, it further disperses the boiling medium. Taking into account the parameters of natural resources, a new type of automated and modeled modern device was invented, which washes construction sand from harmful impurities. Thus, the construction sand washing device combines a charging bunker, a working chamber, a water-air mixture delivery system, an outlet for removing washed sand from the chamber, and an outlet for water-clay sludge from the chamber. The working chamber is divided into two unequal parts by a metal grating placed at an angle of 30^{0} in its lower part . The small lower part of the chamber is supplied with water and air under a pressure of 3-4 atmospheres from two sides towards each other. The resulting mixture passes through a slotted metal grate to the upper part of the chamber, where it mixes with the primary sand to create a boiling medium, dividing the primary material into sandy and clayey fractions and dispersing it. Metal chains are attached to the upper surface of the chamber, in which the boiling multicomponent medium interacts with each other, and as a result, this medium undergoes additional dispersion. In addition, the outlet for washed sand is located in the area of the lower point of the metal grid at the top of the chamber. The outlet of the water-clay slurry is located in the upper part of the chamber. The object of the invention is to increase the leaching rate of natural sands in clay mixtures. The main scientific-practical importance of the dissertation work is the development and application of the theoretical-practical method of creating new sand washing devices, which are relatively superior to their analogues in terms of quality indicators, the development of improved forms of the methods of adjusting the main parameters, and the calculation of mathematical algorithms.

Approval and application. The main results of the dissertation were discussed and presented at the following international conferences and seminars.

- The 7th International Conference on Control and Optimization with Industrial Applications. August 26-28, 2020. Baku, Azerbaijan, COIA2020;
- Online scientific conference of young researchers and doctoral students dedicated to the 100th anniversary of Azerbaijan State Oil and Industry University, May 7-8, 2020, GTDOEK 2020;
- XXXVI International Scientific and Practical Conference "Advances in Science and Technology" . Moscow, April 30, 2021;
- XXIV Republican scientific conference of doctoral students and young researchers, 2021;
- Information Systems and Technologies: Achievements and Prospects, Conference materials, SSU, December 08-09, 2022;
- III International scientific forum on computer and energy sciences (WFCES 2022). Apple Father. AIP Conference proceedings ISSN: 1551-7616. https://ide-rus.ru/wfces2022 .

The name of the organization where the dissertation work was carried out - Azerbaijan State Oil and Industry University, "Electronics and automatics" department.

The total volume of the dissertation is indicated by noting the volume of the structural sections of the dissertation separately . The dissertation consists of 185 pages: introduction, 4 chapters, main results, 133 references, including 39 figures and 13 tables. Dissertation consists of 187808 characters.

CONTENTS OF WORK

In the introduction, the relevance of the topic, the purpose of the work, the scientific novelty of the research, the applied importance, the defended provisions and the approval level of the dissertation work are given.

The first chapter is dedicated to the literature review, in the results of the conducted researches, existing methods and devices are compared, analyzed and researched, the shortcomings are revealed and presented as an actual problem in the dissertation, the directions for solving the issues of improving the productivity and efficiency of construction sand production technology, and improving its quality are substantiated. Also, the physico-chemical properties of the main components affecting the quality of construction sand and their main characteristics were investigated. It was determined that, compared to the current situation, in new facilities that can provide better quality and more productive and efficient sand obtaining, existing technologies should be used complexly, but at the same time, they should also have a relatively simple construction scheme.

In the second chapter , the object and methods of research, as well as the dynamics of development and improvement of construction sand preparation technology, are directly determined by the ever-tightening requirements for processing productivity and the quality of the finished product, and it seems that this development direction and trend is characterized by the rise of the level of dispersion of the sand-clay mixture. In this sense, the research of newly created technological machines with appropriate purpose, mathematical modeling of mechanical dispersion process, static and dynamic characteristics is quite important and relevant issue. Thus, it is possible to study the stability of the process based on the analysis of the results of numerical calculations and computer simulations performed on mathematical and computer models that will be created based on it, to calculate and determine the required values of the dimensions that determine the constructive solution of the apparatus, and also to predict the unwanted effects and their complications. It is clear that when each technological machine is selected for processing operations, its purpose, universality and productivity, quality and economy, automatic control method and level of automation, flexible adaptation to changing product, etc. like this, comprehensive factors justifying the correctness of the choice and its expediency are taken as a basis. In addition, the following factors, which are directly related to the specific properties and indicators of each device, have a significant impact: the type of the body, its location in space; the shape of the cross-sectional area; type of mixer; type of mixing device guides; the presence of a heat carrier, if any, the shape of its cover, etc. As an analysis of the results of the conducted studies, it was shown that one of the important parameters that determines the efficiency of the mixing devices is the pumping effect:

$$V_p = Cnd_m^3 \tag{1}$$

where Vp is volume consumption of the liquid created by the mixer - m^3/s; C - a fixed coefficient determined depending on the type of mixer; n - rotation frequency of the mixer - cycle/min; d_m - diameter of the mixer-m. Numerical values of C-coefficient are known for different types of mixers: for open type turbine mixers - C=0.25-1.2 (in most cases 0.5-0.8); for propeller mixers-C=0.3-1 (mostly, 0.4-0.8). The second, important factor parameter is the time for the rotating sand-clay mixed liquid to reach the inner surface of the container:

$$\tau_C = \frac{\pi}{4Cn} \tag{2}$$

The importance of the statement (2) is explained by the fact that, it determines the period of obtaining a two-phase system with a liquid-solid medium in a rotary sandblaster, which is one of the main factors affecting the solution of the productivity issue.

Also in this chapter, as a logical continuation of the research, Khodakov's rheological model , which is widely used in the relevant field of science, is taken as basis for the purpose of static research for two-phase, liquid-solid particle environment. Here, several additional parameters reflecting the regularities of the viscosity of the dispersed system are used: - the coefficient of dispersion medium; - the relative volume of the dispersed system is determined by the capacity of the solid particles in it. The dynamic viscosity of the dispersed system considered in this form:

$$\mu = \frac{\mu_0 k(\varphi_0)}{1 - \left[1.5(1-\varphi_0)^{1.5} + 1 + V(\varphi_0)\right]\varphi_0} \tag{3}$$

is calculated with the expression Here, μ_0 is the specific dynamic viscosity of the dispersed medium; φ_0 - the relative volume of the dispersed environment; $k(\varphi_0)$ the value of the dispersion medium. The unit of measurement of viscosity in the International System of Units is *Pa ·sec* (Pascal-second); In the System of Absolute Units - puaz (pz) (1 pz = 0.1 Pa ·sec). From a purely theoretical point of view, the value of the dynamic resistance of water at 20°C ·is 1,002 mPa sec, but in practical cases, it can be taken equal to the unit.

The relative volume of the dispersed medium in expression (3) is defined by the expression

$$\varphi_0 = \frac{\rho_J + \rho_T S_M \delta}{\rho_J + \rho_T (S_M \delta + \varphi_M - 1)} \tag{4}$$

Here, φ_M is the mass fraction of the solid phase;

ρ_J -; ρ_T - respectively, the true densities of liquid and solid phases, kg /m ^{3} S_M - specific surface of the solid phase, m ^{2} ; δ - the thickness of the dispersion medium layer, determined only by the size of the solid particles, m. The following relations are true for the considered parameters:

$$\begin{cases} 1 \le k(\varphi_0) \le 5 \\ \varphi_0 \le 0{,}15;\ k(\varphi_0) = 1 \\ \varphi_0 \ge 0{,}5;\ k(\varphi_0) = 5 \end{cases} \tag{5}$$

The parameters included in relations (5) together with other parameters included in expressions (3) characterize the processing quality of construction sand. The expression for determining the power spent on dispersion was determined by means of the parameters determining the dispersion medium:

$$\mathrm{N_{disp}} = 3.7 \cdot 10^{-5} 3\pi^3 k_N \rho_{dm} \omega^3 d_M^3 \tag{6}$$

ρ -density of the heterodyne medium - kg/m ^{3} ; ω - angular speed of rotation of the liquid flow with dispersion medium-rad/sec.; d_M -diameter of rotating object-m; k_N – an empirical coefficient determined depending on the type and geometrical coefficients of the mixer.

$$\mathrm{N_{disp}} = \frac{30}{\pi} M_{bf} n \tag{7}$$

Two-phase fluid flow torque:

$$M = 3.7 \cdot 10^{-5} 3\pi^3 k_N \rho_{dm} \omega^2 d_M^5 \,. \tag{8}$$

From the literature devoted to modern washing machines, important parameters for the research performed here are that the plasticity of the clay in the dispersion, the coefficient of washing, and the productivity of the washing process have been determined.

The plasticity index of clay is a positive number (plasticity number) and determined by the difference between the threshold values that determine the upper and lower levels of plasticity of clay with moisture:

$$P = Wu - Wl \,. \tag{9}$$

Here, *P* is the plasticity number; *Wu* the threshold value that determines the upper level of plasticity (determined by the transition of clay from a plastic state to a liquid state, known by the flow of wet elephant), (%); Wl, is the threshold value that determines the low level of plasticity (determined by the loss of plasticity of clay, known by its dispersion under normal pressure), (%).

Clay with a plasticity number of up to 7 is considered a low-plastic clay, and it mixes relatively easily with sand. On the contrary, as the number of plasticity increases, it becomes difficult to integrate with sand. Similarly, for the disintegration process, the negative effect of the plasticity number in the direction of increase should be taken into account. The ability to wash is characterized by the appropriate coefficient (flushing coefficient):

$$k_{\mathrm{fc}} = 0.5 t_0 I_0 + (t_0 I_0)^2 \tag{10}$$

Here, I_0 is the maximum value of the flow rate of clay from mixtures containing clay; t_0 the time of obtaining the maximum value of the effluent (characteristic washing time). To calculate the productivity of the washing machine (t/h), the amount of electricity used to wash 1 t of sand is used:

$$\mathrm{Q} = \frac{\mathrm{N}\eta}{\mathrm{q}} \tag{11}$$

where *N* is the power consumed by the driving mechanism (electrical, hydraulic, pneumatic, turbine, etc.), *kW* ; – power utilization coefficient (useful work coefficient) (= 0.7-0.8); q is the power required to wash the material taken in a unit volume of electricity, it is called specific power (kWh/m ^{3}). Relating the specific value of electricity to the washability coefficient is one of the influencing factors. The essence of the relationship is that the washability of the material is correlated with the specific electrical energy per unit mass spent on the disintegration (separation of clay from sand) process:

- up to 0.25 kWh/t for easily washable mixtures;
- for mixtures with medium washing difficulty - 0.25 - 0.5 kWh/t
- more than 0.5 kWh/t for hard-to-wash mixtures.

The corresponding values are shown in table 1

Table 1

Indicators of sand washing

Flush level	electric energy kW·s/t	Washing time in running water , minutes	Clay/Sand ratio	Molecular partial moisture, %	Washing time in stagnant water min.	Washout - coefficient
Easy to wash blends	0.25	50	1: 50	7	-	1
Medium difficulty washable	0.25-0.5	70-80	1: 20-40	7-15	1-1.5	1-1.5
Hard to wash Mixtures	0.5-0.75	120	1: 8-10	15-20	4.0	2

Thus, based on table 1, the expression of the washability coefficient can be formulated. For example, for a clay-sand ratio of 1:50, we can write:

$$k_{fc} = 0.5(0.83x_t)I_0 + ((0.83x_t)I_0)^2 = 1 \tag{12}$$

$$Q = \frac{N\eta}{q} = \frac{N\eta}{0,25} \cdot \tag{13}$$

Expressions similar to (12) and (12), as well as clay-sand ratio 1:40; 1:20, 1:10; It can also be written for construction sands in the ratio of 1-8. Thus, using the relations shown in this table, it is possible to determine the maximum speed of clay flow from the in the form liquid mixture - I $_0$ based on equation (10). For this purpose, first the expression should be written (10):

$$k_{fc} = 0.5T_{fc}x_T I_0 + (T_{fc}x_T I_0)^2, \tag{14}$$

Here, T_{fc} -sand washing time, hours; x_T - the relative value of the duration of obtaining the maximum value of the flow rate of clay from mixtures containing clay (relative value of characteristic washing time). The general expression for solving equation (14) with respect to the maximum value of clay flow velocity - I $_0$ is as follows:

$$I_0 = \frac{1}{Tx_t} 0.5 + \sqrt{0.25 + 4k_{fc}} \ . \tag{15}$$

For easy-to-wash mixtures ($k_{fc} = 1;\ T = 50.$ min .):

$$I_0 = \frac{0.5 + \sqrt{4.25}}{0,83x_t} \tag{16}$$

for mixtures with medium washing difficulty ($k_{fc} = 1,5;\ T = 80$ min .):

$$I_0 = \frac{0.5 + \sqrt{6.25}}{1,33x_t} \tag{17}$$

finally, for difficult-to-wash mixtures ($k_{fc} = 2;\ T = 120$ min)

$$I_0 = \frac{0.5 + \sqrt{8.25}}{2x_t} \ . \tag{18}$$

If to take into account the washing time instead of the time t, which is the expression (7) and reflects the time the internal volume of the working chamber is filled with a liquid mixture: t=T:

$$n = \frac{\pi h D^2}{4CTd_m^3} \tag{19}$$

expression is obtained. After that, if to move to the relative values of the geometric dimensions, first, in order to make the calculations relatively easier, the diameter of the liquid mixture stream, which rotates during the filling of the working capacity with a liquid mixture, should be equal to the inner diameter of the working capacity of the technological machine: $D = d_m$; and the height of the working capacity as a ratio of its diameter: $h = aD$ it is reasonable to accept. Then:

$$n = \frac{\pi a}{4CT} \tag{20}$$

In expression (6) - $\mathrm{N}_{disp} = k_N \rho_{dm} n^3 d_M^3$, the above conditions: $D = d_m$; $h = aD$, thereby - $d_M^3 = (h/a)^3$ for the price of the desired power spent on sand washing, if it is taken into account that:

$$\mathrm{N}_{disp} = k_N \rho_{dm} n^3 d_M^3 \tag{21}$$

expression is obtained. After that, if the expression (20) is also taken into account, depending on the mutual ratio of the geometric dimensions, the value of the power spent on washing is obtained as follows:

$$\mathrm{N}_{disp} = k_N \rho_{dm} \left(\frac{\pi h}{4CT} \right)^3 \tag{22}$$

Figure 1 shows the static model for the liquid-solid particles two-phase environment, compiled in the Matlab Simulink program environment, and Figures 2 - 4 show the oscillograms obtained from the simulation of the model. These oscillograms show the graphs of changes in the rotation speed of the water-clay sand mixture, the speed of the clay removal flow, and the power spent on washing. Expressions (5)-(11), (15) - (18), (19) and (22) were used to create the model, and the numerical values of the parameters are from table 1 ($k_{fc}=2;\ T=120$min , $k_{fc}=1{,}5;\ T=80$min.; $k_{fc}=1;\ T=50$min) and C=0, 25-1,2, $k_N=1;\ \rho_{dm}=1920\,\frac{kg}{m^3}$ taken as. According to the results obtained from the second chapter, the change of the speed of the clay separation flow and the relative values of the washing power is nonlinear, while the change of the rotation speed of the water-clay sand mixture is linear.

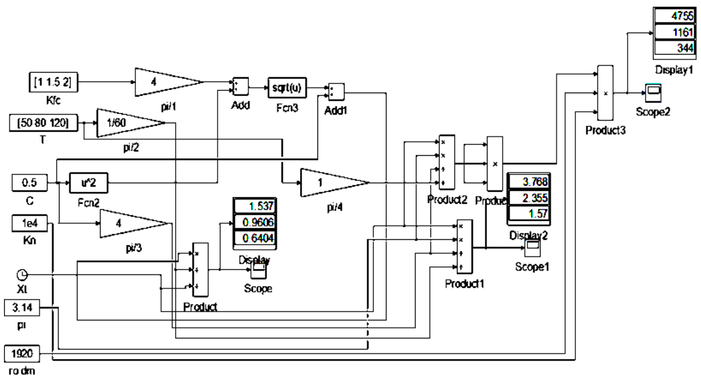

Figure 1. A static model developed for a liquid-solid particle bilayer environment

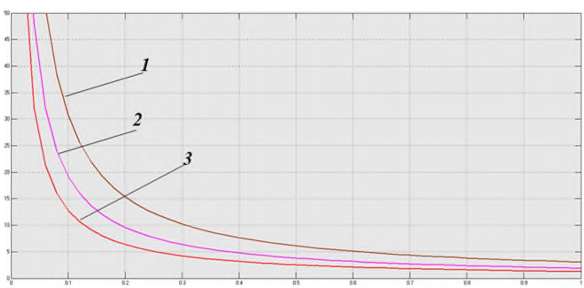

Figure 2. Oscillograms obtained from the simulation: graphs of the change in the velocity of the flow of clay: $I_0=f(x_T)$.

1- $k_{fc}=1;\ T=50$ min; 2 $k_{fc}=1{,}5;\ T=80$. minutes; 3 $k_{fc}=2;\ T=120$ min.

The linearity of the rotation speed of the water-clay sand mixture in the untreated state is ensured when the container is filled with a liquid-solid particle mixture, and the diameter of the circular flow created by the rotation movement is equal to the inner diameter of the working container.

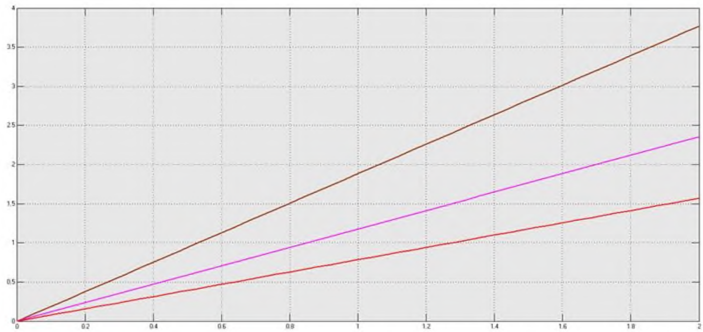

Figure 3. n=f(a) 1- $k_{fc}=1;\ T=50$ min;

2 $k_{fc}=1{,}5;\ T=80$. minutes; 3 $k_{fc}=2;\ T=120$ min.

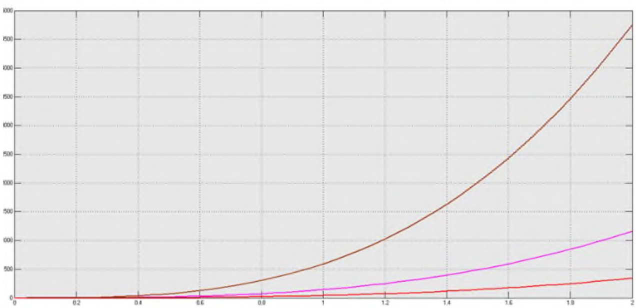

Figure 4. Oscillograms obtained from simulations: graphs of changes in power spent on washing: N=f(h) 1- $k_{fc}=1;\ T=50$ min;

2 $k_{fc}=1{,}5;\ T=80$. minutes; 3 $k_{fc}=2;\ T=120$ min.

In the third chapter, the issue of mathematical and simulation modeling of the proposed "JJ Clean Sand" (JJCS) construction sand washing method and equipment was considered. The scheme of the device is shown in Figure 3.1.1. The main new feature of the proposed device is related to the fact that the initial sand dispersion is carried out by a front of facing nozzles coming out of the grid placed at the bottom of the chamber under a pressure of 3-4 atmospheres, which creates a boiling environment in the chamber and makes it possible the proposed technical solution to obtain new characteristics. However, in the parameters of the indicated water-air environment, intensive micro-bumps are created, which collide with the mutual flow of the initial sand and create chaotic turbulence in the closed space of the chamber.

Thus, as a result of its multi-component hydrodynamics and the interaction of primary sand with clay admixture and with the "boiling" water-air environment, intensive dispersion of primary sand (i.e. separation of sandy particles from small dispersed particles of clay) is possible.

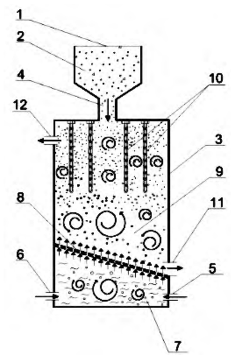

Figure 5. Construction sand washing method

1 – bunker; 2 – primary sand; 3 – camera body; 4 – entrance hole to the camera; 5 – door to let water into the chamber; 6 – the door for supplying air under high pressure to the chamber; 7 – the lower part of the chamber; 8 – a metal grate with a small groove (metal grid); 9 – upper part of the chamber; 10 – metal chains; 11 – door for releasing washed sand; 12 – output of water-clay slurry.

The second new feature of the proposed device is related to the fact that only as a result of the interaction of the boiling medium (aqueous-airy-sandy-clay) with the kinematic swinging bending elements attached to the upper part of the chamber, it further disperses the boiling medium, the proposed technical solution allows to get a new feature. The flexural kinematic elements shown in the turbulent, boiling four-phase environment provide vibration, dynamic drag, which allows sand particles to disperse further from the rest of the clay admixture, as well as dispersing individual clay floating aggregates. The indicated new features and characteristics are not available in known technical solutions. It allows the proposed technical solution to be effective and at the same time creates conditions for increasing the washing rate of natural sands from clay admixtures. From the quarry, the bunker 1 is filled with 2 portions of the specified initial sand, which enters the chamber 2 through the inlet hole 4 from above. Water is supplied to the hole 5, and in the hole 6, they mix with the turbulence in the lower part of the chamber 7 under pressure and create a water-air turbulent environment under a pressure of 3-4 atmospheres. The water-air turbulent medium passes from the lower part of the chamber 7 through a small slotted grate (mesh) 8 and enters the upper part 3 of the chamber 9 in the form of thin high-pressure water-air jets, where it mixes with the flow of the primary sand 2 and comes into contact with the suspended kinematic bending elements 10 and create a multi-component boiling environment. Dispersing in this boiling medium, the primary sand is cleaned of clay impurities and removed from the chamber 3 in a cleaned (washed) state through the hole 11 located on the grates (metal grid), and the water-clay slurry is removed from the chamber 3 through the hole 12 located in the upper part of the chamber. The developed new method of washing construction sand is carried out by a special device, the construction of which is laid out in a separate claim document according to the invention and has the same priority as the proposed method. From bunker 1 to chamber with 3 holes of 4 set from above, the share of initial sand taken from the quarry is transferred. 5 out of 7 holes supply water to the lower part of the chamber. In accordance with the scheme shown in Figure 6, a sample of a small-sized device was tested in the building materials laboratory of the Azerbaijan University of Architecture and Construction and on the test site at the concrete production plant of "CC Concrete" LLC. The working principle of the device was checked in experimental conditions. The prepared small-sized device made it possible to completely wash 8-10 kg of dirty construction sand.

The sand washing machine called "JJ Clean Sand" (JJCS) is designed for all types of sand production in the industry. The new sand washing technology is currently thought of as a replacement for sand washing devices that are widespread in the world, including in our Republic. It was considered that the existing sand washing facilities do not look promising for the sand washing technology due to the following reasons. The proposed sand washing device consists of the development of a completely new type of sand washing technology, that’s why it can be attributed to the category of automated and modeled modern sand washing technology, such as cleaning small and large-grained sand extracted from quarries by washing them from dust, silt and clay mixtures. Since this device is mainly developed based on automated and modeled modern sandblasting technologies, it has a number of advantages listed below: it completely meets the need for sandblasting; since it can be made in any size, with a simple design, it opens up great prospects for the construction and field industry from the point of view of construction and architects; does not require large capital investment ;technologically simple; the cost is not high; productivity is high; It has the ability to work 24 hours a day; service life is long; has a pure sandblasting feature; no crop loss; it has easy service. In order to model the device, a schematic was first drawn in the Proteus program. This system, which we developed using the Proteus program, was simulated on Arduino, load cell, hx 711 (Figure 6).

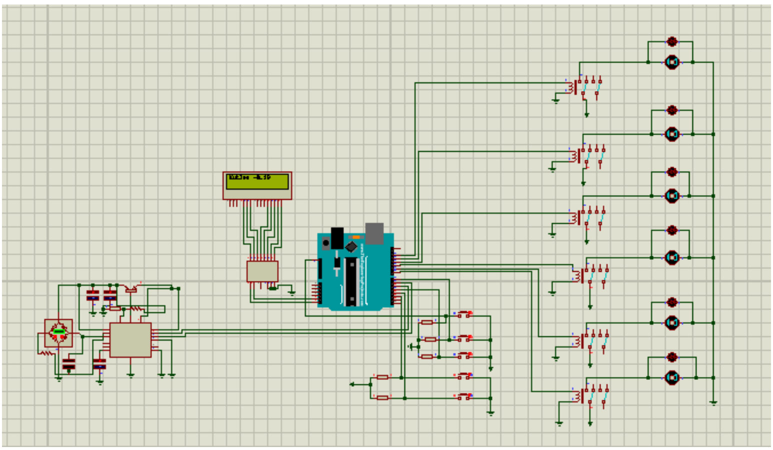
Figure 6. System control scheme with Arduino

Taking into account the characteristics of the created apparatus, the block diagram of the automatic control of the two-component washing machine is proposed as follows. Input parameters of the facility: X_1 - pressure water flow consumption; X_2 - sand-clay mixed raw materials. Output parameters of the facility: Y1- cleaned, solid sand product; Y2- flow of liquid clay. Y3- sand washing quality (Figure 7).

The main parameters of exciting effects: F_1 -turbulent motion factor; F_2 - the factor of sudden change in the ratio of liquid-raw materials; F_3 - the factor of instantaneous change of liquid pressure; F_4 - the factor of causing vibrations in the body of the device. TPMD-technological process management device; PLFC-pressure liquid flow channel; RSWC-raw sand washing channel; Feedback according to PWLF-pressurized water line; Feedback according to the RSLF-raw sand line; SBT - sandblasting tank . Of course, the water flow, its volume and level are performed by an electromagnetic valve activated by a pressure transmitter (Figure 7).

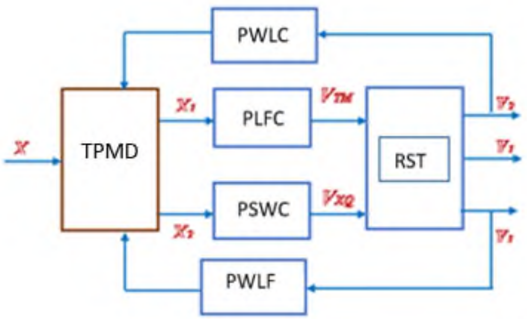

Figure 7. Block diagram of the automatic control of the two-component washing machine and the functional diagram of the automatic control system of the valve

The transmission functions and transmission numbers of the clauses in the structural scheme are as follows: W_{1t} - is the transmission function of the pressure regulator; W_{2t} - is the transfer function of the level regulator; $W_{3t}(s)$ is the transfer function of the sand amount regulator; $W_{im}(s)$ - is the transmission function of the three-phase asynchronous motor of the pump; $W_n(s)$ - is the transmission function of the liquid pump (Figure 8).

$W_q(s)$ is the transmission function of the cover of the sand supply to the dispersion chamber; $W_{qs}(s)$- is the transfer function of the sediment chamber; k_{01}, k_{02}, $W_{03}(s)$- respectively, the transmission numbers of the level and pressure transmitters are a function of the transmission according to the amount of sand. Before writing the transfer functions of the structural scheme, it was replaced by an equivalent scheme in order to make some corrections. The places of the collector element and the manga of the equivalent circuit $W_{qs}(s)$ have been changed.

Based on the previously known data, the following expressions can be written.

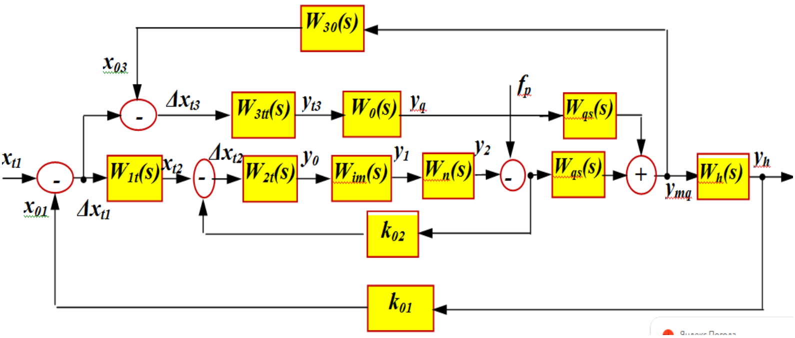

Figure 8. Structural diagram of the sand washing machine according to the amount of sand and liquid-clay flow

The transfer function for the open state of the pressure regulation system according to the order of sequential combination of elements:

$$W_2(s) = W_{2t}(s)W_m(s)W_n(s) = k_{2t}\frac{k_m}{T_m s+1}\frac{k_n}{T_n s+1},$$

$$W_2(s) = \frac{k_{2t}k_m k_n}{T_n T_m s^2 + (T_n T_m)s + 1} \quad (23)$$

and for the closed case:

$$\Phi_2(s) = \frac{K_2}{a_0 s^2 + a_1 s + 1} \quad (24)$$

Here:

$$K_2 = \frac{k_{2t}k_m k_n}{1 + k_{2t}k_m k_n k_{02}};\ a_0 = \frac{T_n T_m}{1 + k_{2t}k_m k_n k_{02}};\ a_1 = \frac{T_n + T_m}{1 + k_{2t}k_m k_n k_{02}} \quad (25)$$

The overall transfer function of the water yield contour:

$$W_s(s) = \frac{k_{1t}K_2 k_{qs}}{T_{qs}a_0 s^3 + \left(a_0 + T_{qs}a_1\right)s^2 + \left(T_{qs} + a_1\right)s + 1} \quad (26)$$

The overall transfer function of the sand yield contour is:

$$W_q(s) = \frac{k_{3t}k_0 k_{qs}}{T_0 T_{qs}s^2 + (T_0 + T_{qs})s + 1}$$

The transfer function of the dispersion process:

$$W_d(s) = W_s(s) + W_q(s)$$

$$W_d(s) = \frac{K_d}{d_0 s^5 + d_1 s^4 + d_2 s^3 + d_3 s^2 + d_4 s + 1} \quad (27)$$

$k_d = k_{3t}k_0 k_{qs};\ d_0 = T_0 T_{qs}^2 a_0;\ d_1 = (a_0 + T_{qs}a_1)T_0 T_{qs} + T_{qs}a_0(a_0 + T_{qs});$ Transmissio

$d_2 = (T_{qs}a_0 + T_0 T_{qs}(a_1 + T_{qs}) + (T_0 + T_{qs})(a_0 + T_{qs}a_1);$

$d_3 = T_0 T_{qs} + a_0 + T_{qs}a_1 + (T_0 + T_{qs})(a_1 + T_{qs});$

$d_4 = a_1 + T_0 + 2T_{qs}$

n of the closed adjustment contour of the dispersion process function:

$$\Phi_d(s) = \frac{W_d(s)}{1 + k_{03}W_d(s)}$$

$$\Phi_d(s) = \frac{W_d(s)}{1 + k_{03}W_d(s)} = \frac{C_d}{c_0 s^5 + c_1 s^4 + c_2 s^3 + c_3 s^2 + c_4 s + 1} \quad (28)$$

Here

$$C_d = \frac{K_d}{1 + K_d k_{03}};\ c_0 = \frac{d_0}{1 + K_d k_{03}};\ c_1 = \frac{d_1}{1 + K_d k_{03}}; \quad (29)$$

$$c_2 = \frac{d_2}{1 + K_d k_{03}};\ c_3 = \frac{d_0}{1 + K_d k_{03}};\ c_4 = \frac{d_4}{1 + K_d k_{03}}$$

The transfer function of the closed regulation system according to the level of the system:

$$\Phi_h(s) = \frac{K_h}{n_0 s^5 + n_1 s^4 + n_2 s^3 + n_3 s^2 + n_4 s + 1} \quad (30)$$

Here

$$K_h(s) = \frac{C_d}{1 + C_d k_{01}};\; n_0 = \frac{c_0}{1 + C_d k_{01}};\; n_1 = \frac{c_1}{1 + C_d k_{01}}; \quad (31),$$

$$n_2 = \frac{c_2}{1 + C_d k_{01}};\; n_3 = \frac{c_3}{1 + C_d k_{01}};\; n_4 = \frac{c_4}{1 + C_d k_{01}}$$

The characteristic equation of the transfer function of the elements of the Hurvis matrix from the algebraic stability criteria:

$$n_0 s^5 + n_1 s^4 + n_2 s^3 + n_3 s^2 + n_4 s + 1 \quad (32)$$

coefficients are determined as follows:

$$\begin{vmatrix} n_1 & n_3 & 1 & 0 & 0 \\ n_0 & n_2 & n_4 & 0 & 0 \\ 0 & n_1 & n_3 & 1 & 0 \\ 0 & n_0 & n_2 & n_4 & 0 \\ 0 & 0 & n_1 & n_3 & 1 \end{vmatrix} \quad (33)$$

$$\begin{vmatrix} n_1 & n_3 \\ n_0 & n_2 \end{vmatrix} = n_1 n_2 - n_0 n_3, \begin{vmatrix} n_1 & n_3 & 1 \\ n_0 & n_2 & n_4 \\ 0 & n_1 & n_3 \end{vmatrix} = n_1 n_2 n_3 + n_0 n_1 - n_3 n_3 n_0 - n_1 n_1 n_4$$

Initial data for numerical calculations:

$$k_m = 1.43;\; T_m = 0.043;\; k_{01} = 0.02; k_n = 1.6;\; T_n = 0.05;\; k_{02} = 0.168;$$
$$k_0 = 1.26;\; T_0 = 0.19;\; k_{01} = 0.45;\; k_{qs} = 2.86; T_{qs} = 0.043;$$

Depending on the time constants of the transmission numbers of the regulators, change dependencies were established using the Matlab Simulink software package (Figure 11). After that, based on the numerical results and preliminary data, the structural scheme of the automatic pressure and level adjustment system of the sand washer was constructed and simulated (Figures 9-11). The value of the electromagnetic time constant of the valve specifies the real nature of the adjustment periods.

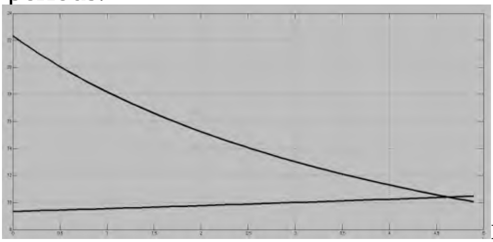

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Figure 9. Graphs of dependence on the time constants of the mathematical apparatus developed for calculating the transmission numbers k_{t1} and k_{t2} of the regulators : $k_{t1} = f(T_{1qk})$ and $k_{21} = f(T_{2qk})$

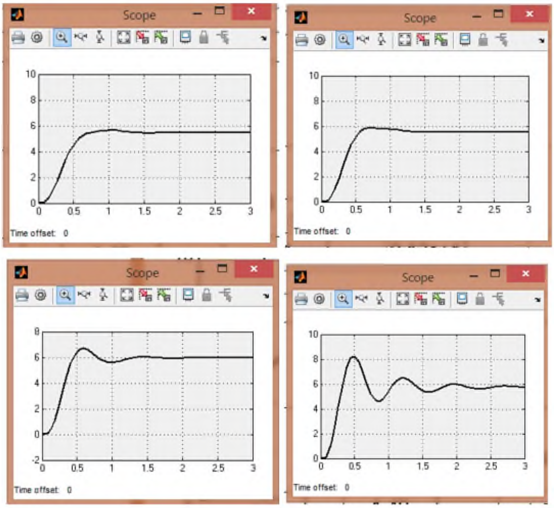

Figure 10. Transition processes of the washed sand output obtained in the simulation of the automatic control system of the sand washing machine according to the pressure, level and raw material consumption: a) $k_{t2}/k_{t3} = 2...3$; b) $k_{t2}/k_{t3} = 3.5...4.5$; c) $k_{t1}/k_{t3} = 5...6$; c) $k_{t1}/k_{t3} = 7....8$

In each regulation circuit, the regulation time is calculated depending on the valve's connection time; The structural scheme of the proposed regulatory system determines that regulatory processes are aperiodic; When the ratio of the transmission numbers of the level regulator and the raw sand mixture quantity regulator is approximately 2.5-3.1 while the transmission number of the pressure regulator remains constant, obtaining aperiodic processes with extreme regulation is ensured, not exceeding 1%; When operating the automated control system of the sand washing unit, the input parameters of the unit - the entry of sand, water and compressed air into the unit - are performed from the control center.

The fourth chapter is devoted to the experimental study of the proposed device in the process of sand washing. From the results of construction and technical properties of sand, it can be seen that sand naturally contains up to 20% of clay, silt and dust mixtures. These mixtures should not exceed 3% of the norm. Therefore, it is required to separate clay, silt and dust mixtures from sand by different methods. In our research work, this problem was solved at a high level by means of the method and device invented.

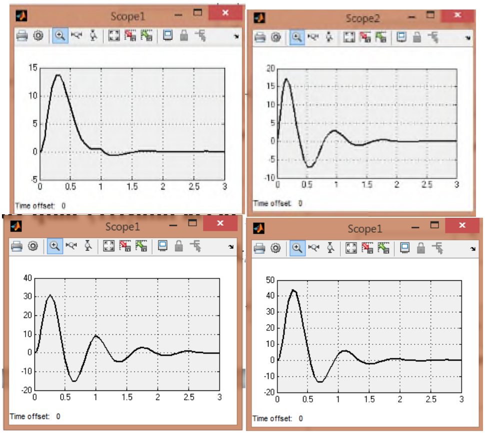

Figure 11. Transient processes of liquid clay flow output obtained from the computer model simulation of the automatic control system of the sand washing machine according to the pressure, level and raw material consumption: a) $k_{t2}/k_{t3}=2...3$; ..b) $k_{t2}/k_{t3}=3.5...4.5$; c) $k_{t1}/k_{t3}=5...6$; c) $k_{t1}/k_{t3}=7....8$

According to the requirements of the standard, the tested sand belongs to the small-grained sand group. The effect of clay on the bulk modulus of sand was studied and shown in the graph below. As it can be seen from the graph, if to consider that the clay mixture in the sand varies from 0-20%, it turns out that as the amount of clay mixture in the sand increases, the bulk modulus of the sand decreases.

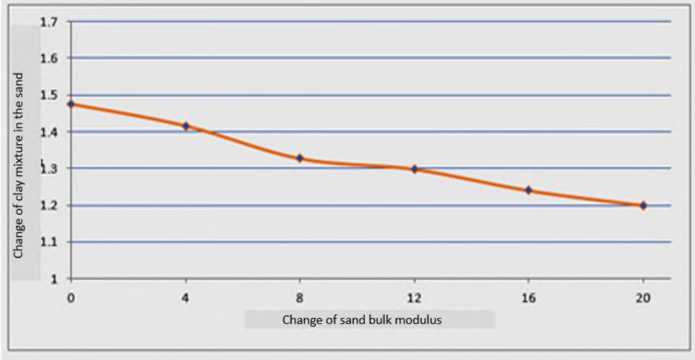

Figure 12. Graph of the dependence of the bulk modulus of natural construction sand on the change in the amount of clay

As can be seen from the experimental results, as the amount of clay mixture in the sand increases, the bulk modulus of the sand decreases and its dirtiness increases, limiting the use of the sand and making it unsuitable. During the research, it was found that since clay particles are much smaller than sand grains, as the amount of clay in the sand increases, the bulk modulus of the sand decreases. The effect of clay on the true density of sand has been studied and shown in the graph below. The effect of clay on the void (porosity) of sand has been studied and shown in the graph below.

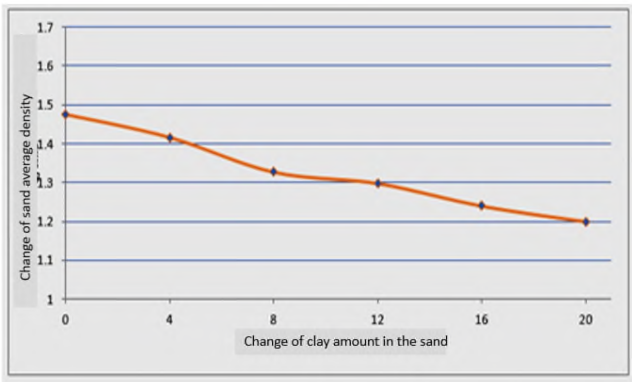

Figure 13 . Graph of the dependence of the average casting density of natural construction sand on the change in the amount of clay

A comparison table of the technical and economic indicators of the proposed "JJ Clean Sand" (JJCS) sand washer with the technical and economic indicators of traditional sand washers is given below.

The following results were obtained for chapter IV: during the research conducted on natural sand, for the first time, the influence of the clay mixture contained in the sand on the main construction technical properties of the sand was calculated; during the experiment, the ratio of different percentages of clay to sand in naturally taken sand was determined by mathematical calculations; The granular composition, bulk modulus, real density, casting average density, void (porosity), moisture content, the amount of clay-silt-dust particles, and the amount of organic compounds were determined by mathematical calculation.

Table 2

Comparative analysis results of "JJ Clean Sand" (JJCS) sand washer

Time	Hydro-cyclone washing system	Hydro-mechanized- sand processing	Drum type sand washer	Sand washer with holes	Wheel and bucket type sand washer	Spiral-type washer	Offered - "JJ Clean Sand" device
0	0	0	0	0	0	0	0
10	41	50	28	17.5	10	7.5	1.4
20	90	94	54	37	17	13	2.8
25	100	100	68	48	20	15	3
30	100	100	70	50	20	15	3
0	0	0	0	0	0	0	0
10	41	50	28	17.5	10	7.5	1.4

RESULTS

1. The traditional methods were analyzed, the results of the conducted research and the devices available in this field were compared and critical studies were conducted.
2. During the research conducted on natural sand, for the first time, the influence of the clay mixture contained in the sand on the main construction technical properties of the sand was studied, and a complex approach for cleaning the sand from mixtures - a new

method and device - was proposed. A simulation of the proposed device has been performed. Taking into account that the simulation process gave a positive result, a prototype of the device was developed.

3. The functional scheme of the sand washing unit was drawn up, the dynamic equations of the elements included in the functional scheme were drawn up, and they were purposefully processed according to certain superior conditions with technical and operational indicators.
4. Based on developed dynamic equations, the transfer functions were designed. On the basis of the structural scheme of the sandblasting unit, dynamic models were drawn up based on the general transfer functions for its individual adjustment contours.
5. The regulators of the automatic control system with three regulation channels for pressure, level and raw material consumption of the sand washer were synthesized and modeled in the Matlab software environment.
6. The code considered for the process is converted into *.hex code, in order to language considered Arduino can be understandable, and uploaded to the Arduino, to make the system operational. Since the Arduino system is an open source system, it was possible to operate this system with simple coding through programming, and the importance of the proposed method was justified.
7. As a result of numerous studies and experiments, the suitability of the device for industrial use has been justified. An International patent has been obtained for the proposed method and device.

The main provisions of the dissertation are reflected in the publications published by the author himself and co-authors:

1. Aghayev F.H., Mehdiyeva A.M., Allahverdiyeva N.M. Control algorithm based on corrective filter for measuring channel errors. The 7th International Conference on Control and Optimization with Industrial Applications. August 26-28, 2020. Baku. pp. 35-37.
2. Allahverdiyeva N.M. Method of controlling quality indicators and eliminating deviations. Online scientific conference of young researchers and doctoral students dedicated to the 100th anniversary of Azerbaijan State Oil and Industry University, May 7-8, 2020, GTDOEK 2020, p. 289.

3. Allahverdiyeva N.M. Determination and diagnosis of construction material quality control problems. Висник Priazovskoho State Technical University: Science work Vip. 41. – Mariupol: ДВНЗ «Priazov. country technical un-t», Ukraine, 2020. pp 130-135.
4. Allahverdiyeva N.M. Factors affecting the quality of construction materials. Scientific almanac. 2020. N 9-2(71). Russia, Tambov. v. 11-14
5. Mehdiyeva A.M. Jamalov J.A. Allahverdiyeva N.M. Research of ways of increasing the reliability and durability of reinforced concrete constructions of operating buildings. Sciences of Europe. Vol 1, No 68. 2021. Praha, Czech Republic. pp. 46-50.
6. Allahverdiyeva N.M. Improvement of quality indicators of building materials. XXXVI International Scientific and Practical Conference "Advances in Science and Technology". Moscow, April 30, 2021, pp 122-123.
7. Allahverdiyeva N.M. Modeling the technological process of construction materials preparation. Online Scientific Conference of young researchers and doctoral students dedicated to the 98th anniversary of the birth of national leader Heydar Aliyev, May 21, 2021, p. 453
8. Allahverdiyeva N.M. Analysis of collected data on construction sand. XXIV Republican scientific conference of doctoral students and young researchers, 2021 p. 57-59.
9. Jamalov J.A, Allahverdiyeva N.M. Research of ways to increase the reliability and longevity of reinforced concrete structures. AzIMETI N2.2021, pp 10-17.
10. Allahverdiyeva N.M. Features of qualitative indicators in construction and research of tasks increasing their accuracy of measurements. "News of Azerbaijan Higher Technical Schools", ASOIU. Volume 23, Issue 3(131) 2021, pp 51-60.
11. Mehdiyeva A.M., Allahverdiyeva N.M. Method of improving construction materials quality indicators. "News of Azerbaijan Higher Technical Schools". Volume 23 Issue 2(130) 2021, pp 68-73.
12. Mehdiyeva A.M., Allahverdiyeva N.M., Guliyeva S.V. Development of a control system for cleaning construction sand from harmful mixtures. Information Systems and Technologies: Achievements and Prospects, SSU, December 08-09, 2022, pp 134-137.
13. Mehdiyeva A.M., Jamalov J.A, Allahverdiyeva N.M. Development of a modeled and automated management system of construction sand preparation technology. News of ASOIU, Azerbaijan Higher Technical Schools. Baku. 2022. Volume 21. Issue 10. pp. 13-19

14. Mehdiyeva A.M., Allahverdiyeva N.M., Neymetov V.A. Static model for the drain rate of clay extraction and power consumption for sand washing. Journal of Energy Research and Reviews. Volume 14, Issue 1, pp 1-8, 2023; Article no. JENRR.98860.
15. Mehdiyeva A.M., Allahverdiyeva N.M., Alekberli S.Y. Modeling of construction sand washing technological process. III International Scientific Forum on Computer and Energy Sciences (WFCES). August 01 2023. AIP Conference Proceedings.
16. Jamalov J.A., Habibov F.G., Rashidov K.D., Allahverdiyeva N.M. The method of washing construction sand. EAPV registered number: 202200107, Eurasian patent organization (EAPO). 10.08.2022.
17. Jamalov J.A., Habibov F.G., Rashidov K.D., Allahverdiyeva NM Device for washing construction sand. EAPV registered number: 202200108, Eurasian patent organization (EAPO) 10.08.2022.

Candidate's personal contribution:

Works [2, 3, 4, 6, 7, 8, 10] were performedby the author in works [1, 5, 9, 11, 12, 13, 14, 15] participation in setting the issue, conducting research and summarizing the results,

[16, 17] participation in setting the issue, making reports, analyzing the results, conducting laboratory tests and summarizing the results.

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