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EFFICIENCY IMPROVEMENT OF CONCRETE MIX PREPARATION AND MORTAR DELIVERY PROCESSES IN CONSTRUCTION TECHNOLOGICAL COMPLEXES

Abstract. *The research relevance is determined by the need to improve construction production technological set operational efficiency ensuring concrete mix preparation and plastering mortar delivery under variable operating conditions. The study objective is to establish relationships between mixing equipment kinematic parameters, construction medium rheological characteristics, and conveying system geometric parameters and the technological set generalized efficiency indicator. The study uses mathematical modelling methods of construction mix mixing and transportation processes considering their structural-mechanical properties and equipment energy characteristics. An extremal dependence of the generalized efficiency indicator on mixer working body rotational speed was established, and the influence of mixture rheological parameters and pipeline system geometric characteristics on pressure loss and material delivery stability was determined. The obtained results enable substantiation of rational construction mix preparation and transportation technological set operating modes considering process energy and technological indicators.*

Keywords: *concrete mix, mortar, mixing equipment, 3D printing, transportation, pump, rheology, mathematical modelling, energy efficiency, pumping.*

Problem statement. Modern construction technological sets ensuring concrete mix preparation and plastering mortar delivery are characterized by a high mixing, conveying, and auxiliary equipment integration level within a unified functional system. Such system operational efficiency is determined not only by individual machine productivity but primarily by joint operation parameter coordination affecting material delivery stability, mixture homogeneity level, and technological process energy consumption.

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Traditional construction mix preparation and transportation process efficiency assessment approaches are mainly based on mixing equipment productivity, specific energy consumption, and mixture homogeneity indicator analysis. However, such approaches insufficiently consider relationships between mixer working body kinematic parameters, construction medium rheological characteristics, and subsequent delivery condition parameters to placement or application locations [1, 2].

Particular relevance is associated with concrete mix and plastering mortar delivery stability provision problems in construction technological sets operating under variable load conditions, material physical-mechanical property variation, and process energy consumption reduction requirements while maintaining specified technological process parameter. Insufficient construction mix preparation and delivery mode coordination leads to material transportation uniformity reduction, energy loss increase, and finished building structure and finishing coating operational characteristic deterioration [3, 4].

In this regard, the need arises for construction technological set concrete mix preparation and plastering mortar delivery process efficiency improvement approaches based on integrated mixing equipment kinematic parameter, construction medium rheological property, and conveying system energy characteristic consideration.

Analysis of recent studies and publications. Studies devoted to concrete mix mixing process investigation have established that homogeneous mixture structure formation efficiency is largely determined by mixer working body motion kinematic parameters, mixing chamber geometry, and component mixing mode characteristics. Considerable attention is given to mixing process intensification through mixer working body rotational speed optimization, structural parameter modification, and combined material motion mode application within the mixer working volume [5, 6].

A separate research direction is associated with pipeline transport and pumping unit concrete mix and plastering mortar delivery efficiency provision. These studies show that conveying system productivity is determined not only by pumping equipment structural parameters but also by construction medium rheological characteristics, particularly density, plastic viscosity, and yield shear stress. Material property variation during transportation was found to significantly affect delivery stability and equipment operational energy performance [7].

Modern construction process mechanization studies indicate the feasibility of a technological set operation analysis system approach involving mixing equipment and conveying machine parameter coordination considering construction mix rheological properties and material movement modes. Such an approach enables material delivery stability improvement, process energy consumption reduction, and required mixture homogeneity level provision during transportation to placement or application locations [8, 9].

Research objective is construction technological set concrete mix preparation and plastering mortar delivery process efficiency improvement through establishment of relationships between mixing equipment kinematic parameters, construction medium rheological characteristics, and conveying system energy performance indicators. To achieve this objective, substantiation of a mixing and material delivery process parameter coordination approach ensuring mixture transportation stability improvement and technological process specific energy consumption reduction is proposed.

Presentation of the main research material. Concrete mix preparation and plastering mortar delivery processes in modern construction production are implemented within technologically interconnected machine and mechanism systems whose operation is determined by mixing equipment working body motion parameters, material structure formation conditions, and material transportation modes to application locations. The interaction character of these processes significantly affects mixture flow rate stability, structure homogeneity level, and overall technological system energy performance indicators [10, 11].

A modern construction mix preparation and delivery technological set development direction is their application in additive construction element formation systems using layer-by-layer material deposition methods. In such technologies, concrete mix and construction mortar delivery processes are implemented through specialized extrusion nozzle systems ensuring continuous building element formation without traditional formwork application. Construction 3D-printing system technological equipment operational efficiency is determined by material flow rate stability, preparation and transportation mode coordination, and

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mixture rheological characteristic compliance with extrusion deposition process requirements [12].

A specific feature of construction mix delivery processes in 3D-printing technologies is increased material structure homogeneity requirement, rheological parameter stability requirement, and layer formation stage flow rate uniformity requirement. Mixing parameter mismatch with material transportation and deposition conditions leads to formed element geometric accuracy violation and building structure quality reduction. In this regard, construction technological set concrete mix preparation and plastering mortar delivery efficiency improvement becomes particularly relevant for automated material deposition system application in additive construction technologies [13].

Construction mix preparation and delivery technological sets include a mixing unit, receiving hopper, volumetric or screw-type conveying device, pipeline transportation system, and material delivery executive working body. Functional parameter interdependence of these elements is observed, since mixing unit operating characteristic variation leads to construction medium rheological property change, which subsequently determines transportation condition parameters.

Technological set productivity is determined by mixing and conveying equipment productivity ratio and can be expressed by the following relationship

$$Q = \min\left(Q_{зм}, Q_{тр}\right), \tag{1}$$

where Q – productivity of the technological set, m³/h;

$Q_{зм}$ – mixing equipment productivity, m³/h;

$Q_{тр}$ – material delivery system productivity, m³/h.

The given relationship reflects the need for mixing and conveying equipment operating mode coordination, since individual system element productivity exceedance does not ensure corresponding technological process overall productivity increase.

Construction mix delivery parameter characteristics are significantly influenced by component mixing stage formed rheological properties. The main parameters determining pipeline system material movement conditions include, belongs the density of the medium ρ, plastic viscosity μ and ultimate shear stress τ_0, on which the value of pressure losses during transportation depends

$$\Delta p = f\left(\rho, \mu, \tau_0, L, D, v\right), \quad (2)$$

where Δp – pressure loss during the transport of the mixture, Pa;

L – pipeline length, m;

D – inner diameter of the pipeline, m;

v – average velocity of the mixture, m/s.

Construction medium characteristic formation is determined by component mixing intensity, mixing duration, and mixing equipment working body motion kinematic parameters, which necessitates mixture structural and rheological property variation relationship consideration during preparation processes.

Concrete mix and plastering mortar preparation processes are accompanied by continuous component spatial distribution change within the mixer working volume, resulting in gradual formation of homogeneous material structure with specified physical-mechanical and rheological characteristics. This process intensity is determined by mixing equipment working body motion kinematic parameters, working chamber geometry, and material mixing duration [14].

Mixing process efficiency evaluation is advisable based on mixture homogeneity coefficient characterizing component distribution uniformity degree within the mixer working volume and can be expressed by the following relationship

$$k_{o\partial} = 1 - \frac{\sigma}{\sigma_0}, \quad (3)$$

where $k_{o\partial}$ – mixture homogeneity coefficient;

σ – post mixing controlled component concentration standard deviation;

σ_0 – initial mixture component concentration standard deviation.

Mixture homogeneity coefficient variation during mixing has an exponential character and can be described by the following relationship

$$k_{o\partial} = 1 - \exp(-\beta t), \quad (4)$$

where β – mixing intensity factor, s^{-1};

t – mixing duration, s.

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Mixing intensity coefficient depends on mixer working body rotational speed, mixing device structural parameters, and construction medium properties and can be represented by the following functional relationship

$$\beta = f(n, R, \rho, \mu), \tag{5}$$

where n – mixer working body rotational speed, s^{-1};

R – characteristic material particle displacement radius in the mixer, m;

ρ – mixture density, kg/m³;

μ – viscosity of the medium, Pa·s.

With increasing mixing duration, construction mixture homogeneity degree increases, resulting in rheological characteristic stabilization and conveying system material delivery nonuniformity reduction. At the same time, required mixture structural parameter formation is accompanied by yield shear stress and effective medium viscosity variation determining subsequent pipeline or volumetric pump working body transportation conditions.

Considering these factors, pipeline system mixture mean flow velocity can be represented by the following relationship

$$v = \frac{Q}{A}, \tag{6}$$

where v – average velocity of the mixture, m/s;

Q – material consumption, m³/s;

A – cross-sectional area of the pipeline, m²,

which enables transition to construction mix delivery process energy parameter analysis considering mixing-process-formed medium rheological characteristics.

Concrete mix and plastering mortar motion in pipeline delivery systems is accompanied by hydraulic resistance occurrence determined by medium rheological properties, pipeline geometric parameters, and material transportation velocity. For construction mixtures characterized by yield shear stress presence, pressure drop–material flow velocity relationships are advisable to describe based on generalized viscoplastic medium rheological models [15].

In this case, the pressure drop during the transportation of the mixture through a pipeline with a length of L can be represented by addiction

$$\Delta p = \frac{4L}{D}\left(\tau_0 + \mu\frac{8v}{D}\right), \tag{7}$$

where Δp – differential pressure along the pipeline, Pa;

L – pipeline length, m;

D – inner diameter of the pipeline, m;

τ_0 – maximum shear stress of the mixture, Pa.

Yield shear stress or plastic viscosity increase leads to pipeline system pressure loss increase and corresponding material transportation energy consumption increase, which necessitates mixing process parameter consideration when determining rational construction mix delivery operating modes.

Power required for pipeline system material transportation can be determined by the following relationship

$$N = \frac{\Delta p Q}{\eta}, \tag{8}$$

where N – drive power of the conveying system, W;

η – conveying unit efficiency coefficient.

For delivery systems using screw working bodies, conveying equipment productivity is determined by screw pair geometric parameters and rotational speed and can be represented by the following relationship

$$Q_{mp} = k \cdot n, \tag{9}$$

where k – delivery coefficient depending on working body geometric parameters and material properties;

n – rotor rotational speed, s^{-1}.

Construction mixture rheological characteristic variation after the mixing process leads to screw pump delivery coefficient change directly affecting material flow rate stability and transportation process energy performance indicators. In this regard, mixing equipment parameter coordination with conveying system operating modes ensures material delivery stability and overall technological set operational efficiency improvement.

Considering mixing and construction mix transportation process parameter interrelationships, technological set operational efficiency representation as an

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integrated indicator considering system productivity, material delivery stability, and process energy consumption is advisable.

Considering mixing and construction mix transportation process parameter interrelationships, technological set operational efficiency representation as an integrated indicator considering system productivity, post-mixing material homogeneity degree, and delivery process energy consumption is advisable. Such an approach enables quantitative evaluation of mixing and conveying equipment operating mode effects on technological process resulting parameters.

Technological set overall operational efficiency indicator can be represented by the following relationship

$$K_{еф} = \frac{Q_{тр}\, k_{од}}{N}, \tag{10}$$

where $K_{еф}$ – generalized indicator of the technological set efficiency;

N – drive power of the conveying system, W.

The proposed indicator enables simultaneous mixing and transportation parameter influence consideration on technological set operational performance and provides the possibility of different operating mode comparison based on an integral criterion.

Considering conveying system power determination by pipeline pressure drop and material flow rate, the integrated efficiency indicator can be represented by the following relationship

$$K_{еф} = \frac{k_{од}\, \eta}{\Delta p}. \tag{11}$$

The obtained relationship reflects mixing-process-formed material rheological characteristic influence on subsequent pipeline delivery system transportation energy parameters. At the same time, yield shear stress and effective medium viscosity reduction contributes to pressure loss reduction and technological set operational efficiency improvement.

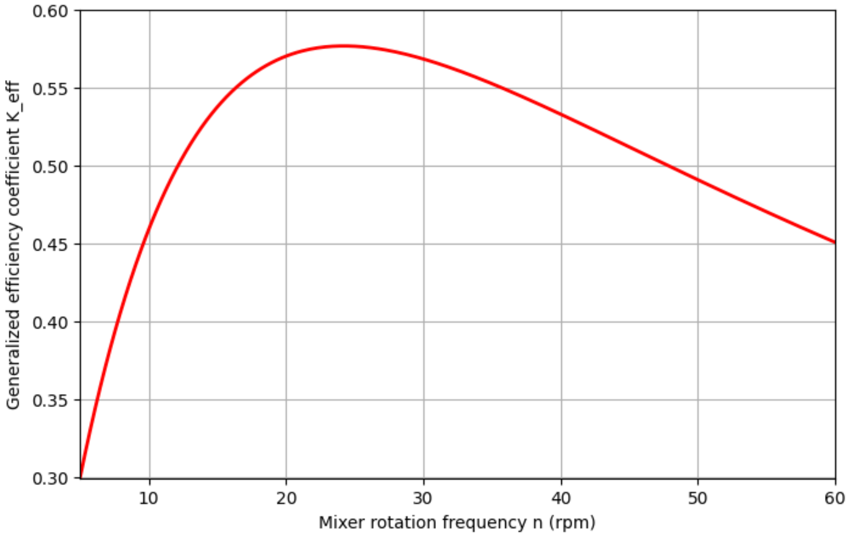

Figure 1 – Technological set integrated efficiency indicator dependence on mixer working body rotational speed

Based on the obtained analytical relationship, a technological set integrated efficiency indicator variation versus mixer working body rotational speed graph was constructed. Graphical relationship analysis shows that rotational speed increases up to a certain value results in technological set operational efficiency improvement due to mixture component mixing intensity increase and mixture homogeneity improvement. Further rotational speed increase is accompanied by mixing process energy consumption growth leading to integrated efficiency indicator reduction. The obtained relationship enables determination of a rational mixer working body rotational speed range ensuring maximum construction mix preparation and delivery process efficiency.

Considering mixture homogeneity coefficient dependence on mixing duration and mixer working body motion kinematic parameters, the integrated efficiency indicator can be represented by the following functional relationship

$$K_{e\phi} = f(n, t, \rho, \mu, \tau_0, L, D). \quad (12)$$

Technological set operational efficiency representation as a function of these parameters enables determination of rational mixing and conveying equipment operating modes considering construction medium properties and material delivery conditions.

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Technological set operational efficiency representation as a functional dependence on mixing equipment kinematic parameters, construction medium rheological characteristics, and conveying system geometric parameters enables establishment of construction mix and plastering mortar preparation and delivery process performance variation relationships under real equipment operating conditions. The determining parameters influencing the integrated efficiency indicator value include mixer working body rotational speed, material mixing duration, mixture yield shear stress, effective viscosity, and delivery pipeline system geometric characteristics.

Mixture yield shear stress and plastic viscosity significantly influence technological set operational efficiency, since their reduction contributes to delivery pipeline system pressure loss reduction and material transportation stability improvement. Delivery pipeline length increase leads to proportional pressure loss growth, whereas pipeline diameter increase reduces mixture flow hydraulic resistance.

Conclusions. As a result of the conducted study, technological set concrete mix preparation and plastering mortar delivery operational efficiency variation relationships depending on mixing equipment kinematic parameters, construction medium rheological characteristics, and material transportation system geometric parameters were established. It is shown that the technological set integrated efficiency indicator has an extremal dependence on mixer working body rotational speed, enabling determination of rational operating modes considering required mixture homogeneity degree provision and process energy consumption minimization.

It was established that construction mixture rheological characteristics, particularly yield shear stress and effective viscosity, significantly affect delivery pipeline system pressure loss magnitude and material transportation stability. Conveying system geometric parameter influence on delivery process energy performance indicators was substantiated, enabling determination of rational pipeline parameters depending on mixture physical-mechanical properties and equipment operating conditions.

The obtained results create theoretical prerequisites for construction production technological set operational efficiency improvement through mixing and conveying equipment operating mode coordination with material rheological characteristics and delivery system structural parameters, ensuring construction mix preparation and transportation process productivity increase with simultaneous specific energy consumption reduction.

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ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ПРОЦЕСІВ ПРИГОТУВАННЯ ТА ПОДАЧІ БЕТОННИХ СУМІШЕЙ І ШТУКАТУРНИХ РОЗЧИНІВ У ТЕХНОЛОГІЧНИХ КОМПЛЕКСАХ БУДІВНИЦТВА

Анотація. *У статті досліджено вплив кінематичних параметрів змішувального обладнання, реологічних характеристик бетонних сумішей і штукатурних розчинів та геометричних параметрів систем подачі на ефективність функціонування технологічних комплектів будівництва. Особливу увагу приділено встановленню взаємозв’язку між параметрами процесів змішування матеріалу та умовами його подальшого транспортування до місця укладання або нанесення.*

Запропоновано узагальнений показник ефективності технологічного комплекту, який враховує продуктивність процесу приготування суміші, ступінь її однорідності після змішування та енергетичні витрати під час транспортування трубопровідними системами подачі. На основі використання аналітичних залежностей встановлено закономірності зміни показників ефективності залежно від режимів роботи змішувального і транспортуючого обладнання.

Встановлено екстремальний характер залежності узагальненого показника ефективності від частоти обертання робочого органа змішувача та визначено вплив параметрів трубопровідної системи на втрати тиску під час подачі матеріалу. Отримані результати дозволяють обґрунтувати раціональні режими функціонування змішувального і транспортуючого обладнання та підвищити стабільність подачі будівельних сумішей у технологічних комплектах сучасного будівництва.

Ключові слова: *бетонна суміш, розчин, змішувальне обладнання, 3D-друк, транспортування, насос, реологія, математичне моделювання, енергоефективність, перекачування.*

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