ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

ҚАЙЫРЫМДЫЛЫҚ ҚОРЫ
HALYK
CHARITY FOUNDATION

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ
«ХАЛЫҚ» ЖҚ

ХАБАРЛАРЫ

ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
АКАДЕМИИ НАУК РЕСПУБЛИКИ
КАЗАХСТАН»
ЧФ «Халық»

N E W S

OF THE ACADEMY OF SCIENCES
OF THE REPUBLIC OF
KAZAKHSTAN
«Halyk» Private Foundation

SERIES
OF GEOLOGY AND TECHNICAL SCIENCES

3 (465)

MAY – JUNE 2024

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, NAS RK

NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

ЧФ «ХАЛЫҚ»

В 2016 году для развития и улучшения качества жизни казахстанцев был создан частный Благотворительный фонд «Халык». За годы своей деятельности на реализацию благотворительных проектов в областях образования и науки, социальной защиты, культуры, здравоохранения и спорта, Фонд выделил более 45 миллиардов тенге.

Особое внимание Благотворительный фонд «Халык» уделяет образовательным программам, считая это направление одним из ключевых в своей деятельности. Оказывая поддержку отечественному образованию, Фонд вносит свой посильный вклад в развитие качественного образования в Казахстане. Тем самым способствуя росту числа людей, способных менять жизнь в стране к лучшему – профессионалов в различных сферах, потенциальных лидеров и «великих умов». Одной из значимых инициатив фонда «Халык» в образовательной сфере стал проект Ozgeris powered by Halyk Fund – первый в стране бизнес-инкубатор для учащихся 9-11 классов, который помогает развивать необходимые в современном мире предпринимательские навыки. Так, на содействие малому бизнесу школьников было выделено более 200 грантов. Для поддержки талантливых и мотивированных детей Фонд неоднократно выделял гранты на обучение в Международной школе «Мирас» и в Astana IT University, а также помог казахстанским школьникам принять участие в престижном конкурсе «USTEM Robotics» в США. Авторские работы в рамках проекта «Тәлімгер», которому Фонд оказал поддержку, легли в основу учебной программы, учебников и учебно-методических книг по предмету «Основы предпринимательства и бизнеса», преподаваемого в 10-11 классах казахстанских школ и колледжей.

Помимо помощи школьникам, учащимся колледжей и студентам Фонд считает важным внести свой вклад в повышение квалификации педагогов, совершенствование их знаний и навыков, поскольку именно они являются проводниками знаний будущих поколений казахстанцев. При поддержке Фонда «Халык» в южной столице был организован ежегодный городской конкурс педагогов «Almaty Digital Ustaz.

Важной инициативой стал реализуемый проект по обучению основам финансовой грамотности преподавателей из восьми областей Казахстана, что должно оказать существенное влияние на воспитание финансовой грамотности и предпринимательского мышления у нового поколения граждан страны.

Необходимую помощь Фонд «Халык» оказывает и тем, кто особенно остро в ней нуждается. В рамках социальной защиты населения активно проводится работа по поддержке детей, оставшихся без родителей, детей и взрослых из социально уязвимых слоев населения, людей с ограниченными возможностями, а также обеспечению нуждающихся социальным жильем, строительству социально важных объектов, таких как детские сады, детские площадки и физкультурно-оздоровительные комплексы.

В копилку добрых дел Фонда «Халык» можно добавить оказание помощи детскому спорту, куда относится поддержка в развитии детского футбола и карате в нашей стране. Жизненно важную помощь Благотворительный фонд «Халык» оказал нашим соотечественникам во время недавней пандемии COVID-19. Тогда, в разгар тяжелой борьбы с коронавирусной инфекцией Фонд выделил свыше 11 миллиардов тенге на приобретение необходимого медицинского оборудования и дорогостоящих медицинских препаратов, автомобилей скорой медицинской помощи и средств защиты, адресную материальную помощь социально уязвимым слоям населения и денежные выплаты медицинским работникам.

В 2023 году наряду с другими проектами, нацеленными на повышение благосостояния казахстанских граждан Фонд решил уделить особое внимание науке, поскольку она является частью общественной культуры, а уровень ее развития определяет уровень развития государства.

Поддержка Фондом выпуска журналов Национальной Академии наук Республики Казахстан, которые входят в международные фонды Scopus и Wos и в которых публикуются статьи отечественных ученых, докторантов и магистрантов, а также научных сотрудников высших учебных заведений и научно-исследовательских институтов нашей страны является не менее значимым вкладом Фонда в развитие казахстанского общества.

С уважением,
Благотворительный Фонд «Халык»!

«ҚР ҰҒА» РҚБ Хабарлары. Геология және техникалық ғылымдар сериясы».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Меншіктеуші: «Қазақстан Республикасының Ұлттық ғылым академиясы» РҚБ (Алматы қ.).
Қазақстан Республикасының Ақпарат және қоғамдық даму министрлігінің Ақпарат комитетінде 29.07.2020 ж. берілген **№ KZ39VPY00025420** мерзімдік басылым тіркеуіне қойылу туралы куәлік.
Тақырыптық бағыты: *геология, мұнай және газды өңдеудің химиялық технологиялары, мұнай химиясы, металдарды алу және олардың қосындыларының технологиясы.*
Мерзімділігі: жылына 6 рет.
Тиражы: 300 дана.
Редакцияның мекен-жайы: 050010, Алматы қ., Шевченко көш., 28, 219 бөл., тел.: 272-13-19
http://www.geolog-technical.kz/index.php/en/

«Известия РОО «НАН РК». Серия геологии и технических наук».
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Собственник: Республиканское общественное объединение «Национальная академия наук Республики Казахстан» (г. Алматы).

Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и общественного развития Республики Казахстан **№ KZ39VPY00025420,** выданное 29.07.2020 г.

Тематическая направленность: *геология, химические технологии переработки нефти и газа, нефтехимия, технологии извлечения металлов и их соеденений.*

Периодичность: 6 раз в год.

Тираж: 300 экземпляров.

Адрес редакции: 050010, г. Алматы, ул. Шевченко, 28, оф. 219, тел.: 272-13-19

http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: RPA «National Academy of Sciences of the Republic of Kazakhstan» (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Social Development of the Republic of Kazakhstan **No. KZ39VPY00025420,** issued 29.07.2020.
Thematic scope: *geology, chemical technologies for oil and gas processing, petrochemistry, technologies for extracting metals and their connections.*
Periodicity: 6 times a year.
Circulation: 300 copies.
Editorial address: 28, Shevchenko str., of. 219, Almaty, 050010, tel. 272-13-19
http://www.geolog-technical.kz/index.php/en/

NEWS of the National Academy of Sciences of the Republic of Kazakhstan
SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 3. Number 465 (2024), 107–118
https://doi.org/10.32014/2024.2518-170X.413

UDC 622.271

© A.V. Mitrofanov, G.G. Abdullina*, G.K. Ahmedyanova, D.G. Aigozhina, D.N. Kabylkaiyr, 2024

Toraighyrov University, Pavlodar, Republic of Kazakhstan.

E-mail: gulnara_1277@mail.ru

STOCHASTIC MODEL OF HYDROTRANSPORTATION OF DISPERSED ORE MATERIALS IN VERTICAL PIPELINES

Mitrofanov Andrey Vasilevich — Doctor of Technical Sciences, Visiting Professor, Department of «Mechanics and Oil and Gas Business», Toraighyrov University, Pavlodar, Kazakhstan
E-mail: and2mit@mail.ru, ORCID 0000-0002-4651-7473;
Abdullina Gulnar Gosmanovna — Candidate of Technical Sciences, Associate Professor, Department of «Mechanics andOil and Gas Business», Toraighyrov University, Pavlodar, Kazakhstan
E-mail: gulnara_1277@mail.ru, ORCID 0000-0002-4651-7473;
Akhmedyanova Galiya Kazbekovna — Lecturer, Department of «Mechanics andOil and Gas Business», Toraighyrov University, Pavlodar, Kazakhstan
E-mail: galliya77@yandex.ru, ORCID 0000-0002-0218-8567;
Aigozhina Dinara Gabdulgazasovna — Lecturer, Department of «Mechanics andOil and Gas Business», Toraighyrov University, Pavlodar, Kazakhstan
E-mail: dina7041976@mail.ru, ORCID 0000-0002-5712-5280+77774609251;
Kabylkaiyr Dauren Nurlanuly — Lecturer, Department of «Mechanics andOil and Gas Business», Toraighyrov University, Pavlodar, Kazakhstan
E-mail: Kabylkairov91@mail.ru, ORCID 0000-0002-7897-7714.

Abstract. A hydraulic borehole mining is widely used for the extraction of mineral resources and the organization of underground workings. Hydrotransportation of the bulk medium in the vertical direction is one of the key stages of this process. Therefore the development of predictive analytics methods for this process seems to be an urgent task. The paper proposes a fundamentally new computational model for the processes of hydraulic extraction of minerals to describe the vertical transport of a liquid-solid mixture, based on the mathematical apparatus of the theory of Markov chains. The used approach makes it possible to describe the pipeline as an object with distributed and non-stationary characteristics, while avoiding the decomposition of the working volume of the pipeline into conditionally infinitesimal volumes. The latter makes it possible to remove formal contradictions between the presence of macroparticles in the pipeline and its decomposition into infinitesimal representative volumes, which inevitably arise when using methods of differential integral calculus. The results of numerical experiments with the developed mathematical model made it possible to describe at a qualitative level the transient process in a vertical pipeline during the periodic extraction of bulk medium grains from the well. The obtained results allow us to consider the proposed mathematical model as a reliable scientific basis for further improvement of methods for calculating the functioning of vertical pipelines for hydraulic transportation of granular media.

Keywords: minerals extraction, Markov chains, state vector, matrix of transition probabilities, hydraulic borehole mining

Acknowledgments. *The authors are grateful to K.Abishev, K.Assylova for preparing this publication.*

© А.В. Митрофанов, Г.Г. Абдуллина*, Г.К. Ахмедьянова, Д.Г. Айгожина, Д.Н. Қабылқайыр, 2024

Торайғыров университеті, Павлодар, Қазахстан.

E-mail: gulnara_1277@mail.ru

ТІКҚҰБЫРЛАР АРҚЫЛЫ ДИСПЕРСТІ КЕН МАТЕРИАЛДАРЫН ТАСЫМАЛДАУДЫҢ СТОХАСТИКАЛЫҚ МОДЕЛІ

Митрофанов Андрей Васильевич — т.ғ.к, Торайгыров университеті, «Механика және мұнайгаз ісі» кафедрасының профессоры, *Павлодар*, Қазақстан
E-mail: and2mit@mail.ru. ORCID 0000-0002-4651-7473;
Abdullina Gulnar Gosmanovna — х.ғ.к, Торайгыров университеті, «Механика және мұнайгаз ісі» кафедрасының қауымдастырылған профессоры, *Павлодар, Қазақстан*
E-mail: gulnara_1277@mail.ru. ORCID 0000-0002-4651-7473;
Akhmedyanova Galiya Kazbekovna — Торайгыров университеті, «Механика және мұнайгаз ісі» кафедрасының аға оқытушысы, *Павлодар, Қазақстан*
E-mail: galliya77@yandex.ru. ORCID 0000-0002-0218-8567;
Aigozhina Dinara Gabdulgazasovna — Торайгыров университеті, «Механика және мұнайгаз ісі» кафедрасының аға оқытушысы, *Павлодар, Қазақстан*
E-mail: dina7041976@mail.ru. ORCID 0000-0002-5712-5280;
Kabylkaiyr Dauren Nurlanuly — Торайгыров университеті, «Механика және мұнайгаз ісі» кафедрасының аға оқытушысы, *Павлодар, Қазақстан*
E-mail: Kabylkairov91@mail.ru ORCID 0000-0002-7897-7714.

Аннотация. Ұңғыма гидротехникасы минералды ресурстарды өндіру және жерасты қазбаларын ұйымдастыру үшін кеңінен қолданылады. Сусымалы ортаны тік бағытта тасымалдау осы процестің негізгі кезеңдерінің бірі болып табылады. Сондықтан бұл процесс үшін болжамды аналитика әдістерін дамыту өзекті мәселе болып көрінеді. Жұмыста Марков тізбектер теориясының математикалық аппаратына негізделген гидроқосылғылардың тік тасымалын сипаттау үшін пайдалы қазбаларды гидроөндіру процестері үшін түбегейлі жаңа есептеу моделі ұсынылған. Бұл тәсіл құбырдың жұмыс көлемін шартты түрде шексіз аз көлемге бөлуді болдырмай, құбырды таратылған және стационарлық емес сипаттамалары бар объектретінде сипаттауға мүмкіндік береді.

Соңғысы құбырдағы макробөлшектердің болуы мен оны дифференциалды интегралды есептеу әдістерін қолдану кезінде сөзсіз пайда болатын шексіз аз өкілдік көлемдерге ыдырату арасындағы ресми қайшылықтарды жоюға мүмкіндік береді. Әзірленген математикалықмодельменжүргізілгенсандықэксперименттердіңнәтижелеріұңғымадан сусымалы ортаның дәндерін алу кезінде тікқұбырдағы өтпелі процесті сапалы деңгейде сипаттауға мүмкіндік берді. Алынған нәтижелер ұсынылған математикалық модельді түйіршікті ортаныг идравликалық тасымалдау үшін тікқұбырлардың жұмысын есептеу әдістерін одан әрі жетілдірудің сенімді ғылыми негізі ретінде қарастыруға мүмкіндік береді.

Түйін сөздер: тау-кенөндірісі, Марков тізбегі, күйвекторы, өтпелі ықтималдық матрицасы, ұңғымалық су өндіру

Торайгыров университет, Павлодар, Казахстан.

E-mail: gulnara_1277@mail.ru

СТОХАСТИЧЕСКАЯ МОДЕЛЬ ГИДРОТРАНСПОРТА ДИСПЕРСНЫХ РУДНЫХ МАТЕРИАЛОВ ПО ВЕРТИКАЛЬНЫМ ТРУБОПРОВОДАМ

Митрофанов Андрей Васильевич— к.т.н, профессор кафедры «Механика и нефтегазовое дело», Торайгыров университет, *Павлодар, Казахстан*
E-mail: and2mit@mail.ru. ORCID 0000-0002-4651-7473;
Abdullina Gulnar Gosmanovna — к.х.н., ассоциированный профессор кафедры «Механика и нефтегазовое дело», Торайгыров университет, *Павлодар, Казахстан*
E-mail: gulnara_1277@mail.ru. ORCID 0000-0002-4651-7473;
Akhmedyanova Galiya Kazbekovna — старший преподаватель кафедры «Механика и нефтегазовое дело», Торайгыров университета, *Павлодар, Казахстан*
E-mail: galliya77@yandex.ru. ORCID 0000-0002-0218-8567;
Aigozhina Dinara Gabdulgazasovna — старший преподаватель кафедры «Механика и нефтегазовое дело», Торайгыров университета, *Павлодар, Казахстан*
E-mail: dina7041976@mail.ru. ORCID 0000-0002-5712-5280;
Kabylkaiyr Dauren Nurlanuly — старший преподаватель кафедры «Механика и нефтегазовое дело», Торайгыров университета, *Павлодар, Казахстан*
E-mail: Kabylkairov91@mail.ru. ORCID 0000-0002-7897-7714.

Аннотация. Скважинная гидродобыча широко используется для добычи минеральных ресурсов и организации подземных выработок. Гидротранспортирование сыпучей среды в вертикальном направлении представляет собой одну из ключевых стадий этого процесса. Поэтому развитие методов предсказательной аналитики для этого процесса представляется актуальной задачей. В работе предложена принципиально новая для процессов гидродобычи полезных ископаемых вычислительная модель для описания вертикального транспорта гидросмеси, основанная на математическом аппарате теории цепей Маркова. Указанный подход позволяет описывать трубопровод как объект с распределенными и нестационарными характеристиками, избежав при этом декомпозиции рабочего объема трубопровода на условно бесконечно малые объемы. Последнее позволяет снять формальные противоречия между наличием макрочастиц в трубопроводе и декомпозицией его на бесконечно малые представительные объемы, которые неизбежно возникают при использовании методов дифференциально-интегрального исчисления. Результаты численных экспериментов с разработанной математической моделью позволили на качественном уровне описать переходный процесс в вертикальном трубопроводе при периодическом заборе зерен сыпучей среды из скважины. Полученные результаты позволяют рассмотреть предложенную математическую модель в качестве достоверной научной основы для дальнейшего совершенствования методов расчета функционирования вертикальных трубопроводов для гидравлического транспортирования зернистых сред.

Ключевые слова: добыча полезных ископаемых, цепи Маркова, вектор состояния, матрица переходных вероятностей, скважинная гидродобыча

Introduction

A pay zone development (minerals extraction) should be considered as a key stages of a process of hydraulic borehole mining (HBM) as a whole. In turn, mining involves several stages and should be analyzed as a complex system. The key technological processes are realized during the process of minerals extraction are: rock fracturing by a jet of pressurized water, suction and arising of the liquid-solid suspension to the surface, delivery of the suspension to the slurry pump (Bondarchuk et al., 2015: 24–27). The description of such complex objects requires the use of a systematic approach (Kafarov et al., 2020: 19–26; Orazbekova et al., 2018: 208–217). Technically bottlenecks often arise precisely at the junctions of individual subsystems (Kafarov et al., 2020: 19–26). Thus, in (Mizonov et al., 2018: 20–28) it was shown that the positioning of the return to the rising column is able to reveal the performance reserves of systems with particle recycling.

Nevertheless, it is obvious that laying out a model of the functioning of the whole system is advisable when a predicatively effective mathematical description is available for each subsystem. With regard to minerals extraction development processes, these requirement can hardly be considered fulfilled (Melnik et al., 2000: 15–18; Rochev et al., 2018: 6).

It seems a reasonable solution to take into account all the forces acting on the particle when it moves along with the liquid in the pipe. This approach most fully implements the discrete element method (DEM) (Qiu, et al., 2017: 37–43). This approach is consistent from a physical point of view, but in practice it is extremely unlikely to quantify all these forces. One of the consequences of this is that the models developed within the framework of the approach are subject to simplification (Kondrat'ev et al., 2008: 96–101; Kondrat'ev et al., 2007: 216–220). However, from the authors' point of view, the most important consequence is that the opportunity opens up for the development of competitive calculation methods based on other approaches.

In this study, an attempt is made to lay the foundations of a method for calculating the transport of particles in a vertical flow based on the application of the theory of Markov chains.

This approach, as far as we know, does not find application for simulation of the minerals extraction processes, although has been productively used to modeling of particulate processes in chemical engineering (Mizonov et al., 2020: 2163–3932; Catak et al., 2010: 403–409; Harris et al., 2002: 4779–4796).

It is important to note that in the context of the work, there are no plans to develop an engineering calculation method that will allow predicting the real parameters of the operation of hydraulic transport devices. Endowing the proposed model with predictive abilities is considered us as a goal of future stages of the research associated with parametric identification of the model. At this stage of the research, the work is rather conceptual in nature. This article is aimed to demonstrate the possibility of simulation hydraulic transport systems for the extraction of raw materials based on probabilistic methods.

Materials and methods

In order to describe the particle content distribution over the length of an arising column, the cell model proposed in our previous work (Mitrofanov et al., 2018: 244–253) is used. According to it the volume of the column is separated into n perfectly mixed cells of the length $\Delta x=L/n$ where L is the length of the working part of the vertical column or pipeline.

The particle content distribution is presented as the column state vector $\mathbf{S_p}=\{S_{pi}\}$, i=1,2,…n from the bed bottom. Under the action of the fluid flow the ensemble of particles are moved up along the pipeline. It is quite natural that the particles inside the pipe do not move in the ideal displacement mode (only upwards). The particles are carried away by the fluid flow and gradually move upward, however, along with this upward movement, the particles can move up and down in the random walk mode.

Thus, the proposed model at this stage is based on the following basic assumptions (Figures 1):

1. the model describes a section of the pipeline in unsteady-state operation, which is sufficiently remote from the supply and unloading of material particles (assembling a model of the entire production line is the task of future research);
2. the model describes the gradual progress of the suspension from the bottom up;
3. the model takes into account random walks of suspension particles up and down (diffusion process).

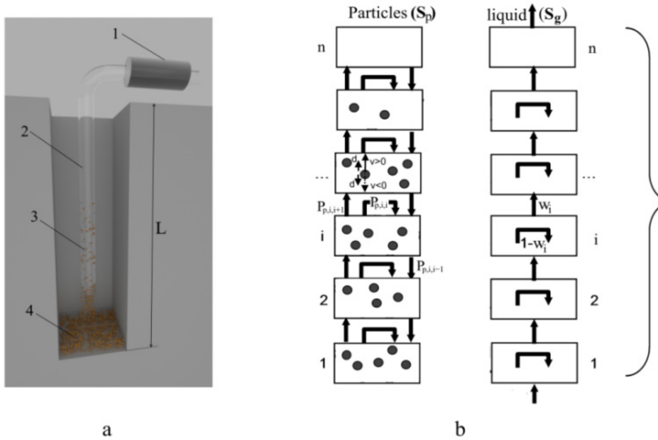

Figure 1 – (a): the scheme of the described process: 1 – dredger, 2 – vertical pipeline, 3 – movable bulk medium, 4 – destroyed dispersed rock; (b): calculation scheme of a cellular mathematical model

The processes of migration of particles, their «creation» (feeding) and «death» (unloading) are described by the matrix recurrent equality:

$$\mathbf{S_p}^{k+1}=\mathbf{P_p}^k\mathbf{S_p}^k+\mathbf{S_f}-\mathbf{S_d}, \qquad (1)$$

where k is the number of time transition of duration Δτ, $\mathbf{P_p}$ is the matrix of transition probabilities that control the process of particles migration within the mathematical model, $\mathbf{S_f}$ is$\mathbf{S_d}$ are the feeding and unloading vectors.

Each of the vectors $\mathbf{S_f}$ and $\mathbf{S_d}$ contains one non-zero element. The first element of the vector $\mathbf{S_f}$ contains the number of particles that are fed into the first cell of the vector $\mathbf{S_p}^k$ during the time duration Δτ. The last element of the vector $\mathbf{S_d}$ contains the number of particles that are subtracted from the last (upper) cell of the vector $\mathbf{S_p}^k$ during the time duration Δτ. These vectors are assumed to be independent of the time step (this is one of the assumptions of the models, which should be corrected when assembling the model of the entire system in the future studies). This matrix $\mathbf{P_p}$is a tri-diagonal matrix, elements of which are calculated as:

probability of downward transitions for the particles in i-th cell

$$P_{p,i-1,i}=d+v_i^k\cdot(1-e),\ i=\overline{1,n-1}, \qquad (2)$$

probability of upward transitions for the particles in i-th cell

$$P^k_{p,i+1,i}=d+v_i^k\cdot e,\ i=\overline{1,n-1}, \qquad (3)$$

probability to stay for the particles in i-th cell

$$P^k_{p,i,i}=1-P^k_{p,i+1,i}-P_{p,i,i+1},\ i=\overline{1,n}, \qquad (4)$$

where d is the probability of pure stochastic (diffusion) transitions, v_i^k is the probability of convection transition caused by the gas upstream flow, if $v_i^k>0$ e=1 and if $v_i^k<0$ e=0.

The probability of pure stochastic (diffusion) transitions can be calculated as:

$$d=D\Delta t/\Delta x^2, \qquad (5)$$

where D is the dispersion coefficient.

The convection transition probability can be calculated from the following equation:

$$v_i^k=(W_i^k-V_{sj}^k)\,\Delta t/\Delta x^2, \qquad (6)$$

where W_i^k is the local velocity of flow around particle, V_{sj}^k is the particle settling velocity.

The longwise evolution of the state of the chain for gas can be described by the following recurrent matrix:

$$\mathbf{S_g}^{k+1}=\mathbf{P_g}^k\mathbf{S_g}^k+\mathbf{S_{gf}}, \qquad (7)$$

where$\mathbf{P}_g$is the matrix of transition probabilities for gas, $\mathbf{S}_g$is the vector of gas volume in the cells, $\mathbf{S}_{gf}$ is the vector of gas source. If the backward transitions of gas can be neglected, the elements of the matrix $\mathbf{P}_g^{\ k}$ can be calculated as follows:

probability of upward transitions

$$P^k_{g,i+1,i}=v_i^k, \quad i=\overline{1,n-1}, \tag{8}$$

probability to stay

$$P^k_{g,i,i}=1-v_i^k, \quad i=\overline{1,n}, \tag{9}$$

Where $v_i^k=W_i^k\Delta t/\Delta^2$ is the convection transition probability in the chain for gas.

The gas source vector $\mathbf{S}_{gf}$ contains only one non-zero element if the gas is supplied through a bottom, i.e.

$$S_{gfi}=G_g\Delta t \ \text{if} i=1 \text{ and } S_{gfi}=0 \ \text{ if } i=\overline{2,n} \tag{10}$$

Thus, in the proposed model, it is necessary to identify only two parameters, which distinguishes it favorably from the «detailed» models specified earlier. Calculation of the both needs special discussion, which will be given below. Here we immediately note two features that are important from the point of view of this discussion. Firstly, the relationship of these model parameters with the physical characteristics of the motion of media is not functional in nature, rather regression. In other words, although we match some physical quantities to the parameters of the model, this relationship is not fully defined and in the future, it is likely that adjustment of these parameters will be required. The next feature is that the model describes the rising columns as an object with distributed characteristics. In this regard, the model parameters are also calculated not for the entire column, but separately for local volumes (cells).

The settling velocity of an individual particle Vs is the most deterministic parameter of the particle motion. This velocity is related to the weight P of the particle as (Mitrofanov et al., 2018: 244–253):

$$P=C_d\, f_p \ {}_g \frac{V_{si}^2}{2}, \tag{11}$$

where C_d is the particle drag force coefficient; $f_p$is the area of the largest cross-section of the particle perpendicular to the velocity vector; $\rho_g$is the density of the medium flowing around the particle.

The drag force coefficient of a single particle depends on the mode of motion of the flowingmedium, that is, ultimately, it is a function of the media velocity in the cell w_i, the value of which is calculated taking into account the solution of the problem of constrained flow around the particle. In this study, the same assumptions are made as in. Thus, the local air velocity is determined by the ratio (Mitrofanov et al., 2018: 244–253):

$$w_i = \frac{W_0}{\eth - \left(\tilde{N}_i \big/ 8 \cdot C_{max} \right)^{2/3}}, \tag{12}$$

where C и C_{max} are the current and maximum possible (for a fixed bed) values of the volume concentration of particles in the cell.

The drag force coefficient is calculated according to the empirical ratio (Khan et al., 1987: 135–150). as follows:

$$C_d = \left(2{,}25 \cdot Re^{-0{,}31} + 0{,}36 \cdot Re^{0{,}06} \right)^{0{,}45}, \tag{13}$$

where Re is the Reynolds number by particle diameter and gas-solids slip veloci-

ty.

Of course, there are many other empirical ratios known for the drag force coefficient, which may be more or less suitable for different materials (a detailed analysis of the relationships can be found in the work (Mikhailov et al., 2013: 432–435)).

The symmetric components of the transfer probabilities d are related to the macrodiffusion coefficient of the particles suspension (ratio (5)), which is an empirical parameter and can be calculated as (Esin et al., 1984: 241–244):

$$D = 0{,}051 \cdot (w/w_{in}) \cdot (w - w_{in})^{1{,}471}, \tag{14}$$

Where w_{in} is fluidization start rate.

Results and discussion

Figures 2–4 show the results of numerical experiments with the proposed model. Since the tip of the suction device moves, each of its new positions gives rise to a new intensity of sand supply to the pipeline. In this regard, it was interesting to investigate the transition process in the pipeline. The numerical experiments were are also performed in order to demonstrate the response of the model to the variation of key parameters.

These parameters are the superficial fluid velocity W_0 and the macrodiffusion coefficient D. During numerical experiments, the superficial velocity of the liquid remained constant W_0 =0,4 m/s (the velocity of the constrained fluid movement, of course, was higher and was calculated by Eq. (12)). Thus, the nature of the process is determined by the presence (D>0) or absence (D=0) of diffusion mixing of the solid phase.The cell with the number 25 is the last cell of the chain (the total of 25 cells (with Δx=2 m) describe the entire length of the pipeline).

Figures 2 shows the evolution of the movement of particles along the pipeline at D=0. It is obvious that at any given time the flow is close to the ideal displacement mode. The higher concentration of particles in the first (lower) cell is explained by the fact that the material enters there (Figures 2–3). The discrepancy in the concentration in the upper cells is explained by the fact that the settling velocity of the particles is lower than the superficial velocity of the carrier phase.

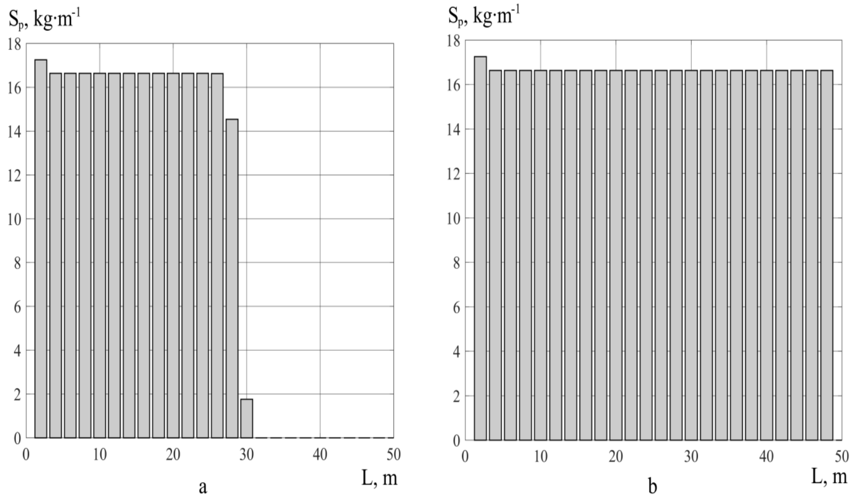

Figure 2 – mass particle distribution along the pipeline for different time points
(a – by the time of 0,5 min, b – by the time of 1,5 min) at w_0=0,4 m/s and D=0 m^2/s

Figures 3 shows the evolution of the movement of particles along the pipeline at D>0. Here, the distribution of particles along the pipeline is significantly more uneven due to their diffusion casting into different sections.

The last cell of the chain corresponds to the unloading of the material (its contents are recorded in a separate array). The value of the number of particles in the vector $\mathbf{S_p}$ is then reset to zero. Figure 4 shows the value of the recorded discharge intensity depending on the process time. It is obvious that there is no discharge of the material until the particles reach the upper section of the pipeline (the 25th cell). The momentary intensity of unloading for a steady state is equal to the rate of receipt (constant value).In the absence of longitudinal mixing (D=0), the transition from the zero level of unloading to the steady level looks very sharp (Fig. 4a). At the presence of longitudinal mixing (D>0), the transition from the zero discharge level to the steady-state level looks more blurred (Fig. 4b)

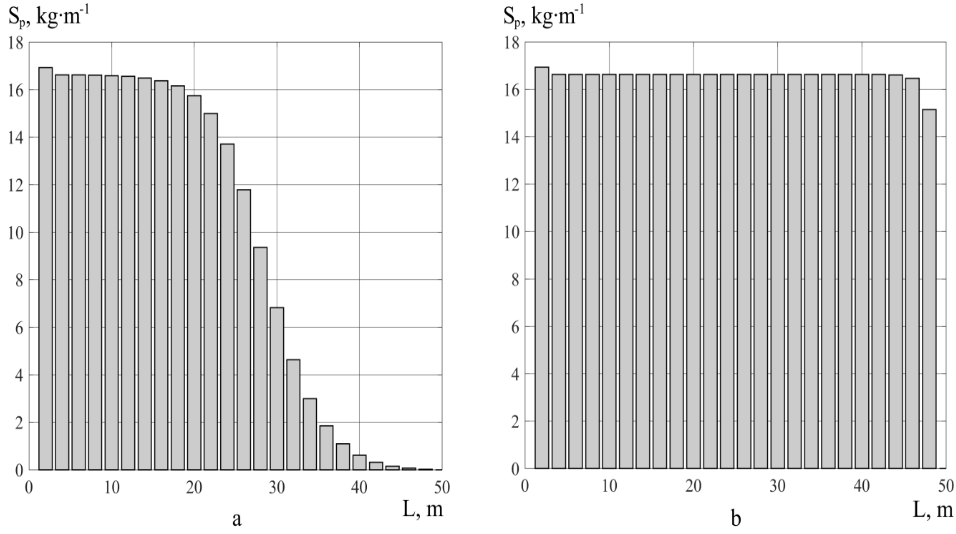

Figure 3 – mass particle distribution along the pipeline for different time points (a – by the time of 0,5 min, b –by the time of 1,5 min) w_0=0,4 m/s and D determined by the Eq. (14)

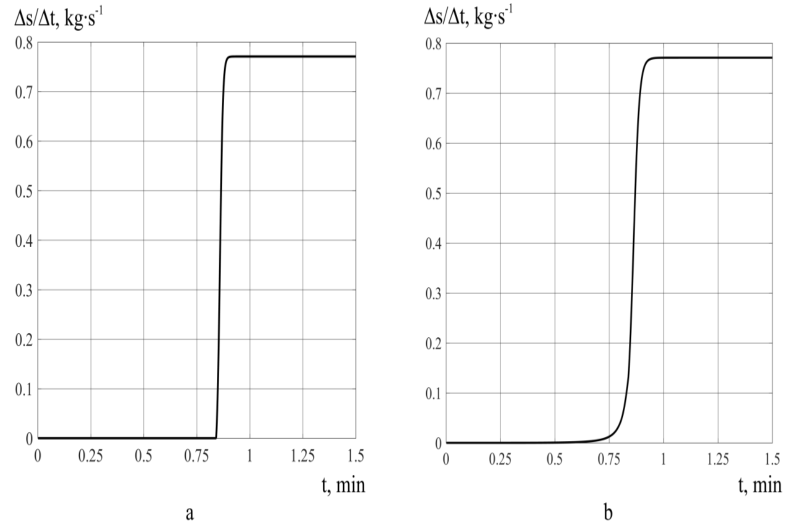

Figure 4 – mass output of particles at various moments of the transition process

(a – by the time of 0,5 min, b –by the time of 1,5 min)

Conclusions

The paper proposes a fundamentally new computational model for the processes of hydraulic extraction of particulate minerals to describe the vertical transport of a liquid-particle mixture based on the mathematical approach of the Markov chain theory.The used approach makes it possible to describe the pipeline as an object with distributed and non-stationary characteristics, while avoiding the decomposition of the working volume of the pipeline into conditionally infinitesimal volumes.The latter makes it possible to remove formal contradictions between the presence of macroparticles in the pipeline and its decomposition into infinitesimal representative volumes, which inevitably arise when using methods of differential integral calculus.In addition, in a certain sense, the approach used makes it possible to reduce the computational cumbersomeness of calculation procedures.

The obtained results of numerical simulation of periodic hydraulic lifting of the bulk medium on are qualitatively consistent. The proposed model can be regarded as a reliable scientific basis for the future development of methods for predicting the operation of vertical pipelines for the transportation of bulk media.

REFERENCES

Bondarchuk I.B., Shenderova I.V. (2015). Classification of hydraulic borehole mining technological processes during pay zone development. IOP Conference Series: Earth and Environmental Science. — Tomsk: Institute of Physics Publishing, Russia. — DOI: https://doi.org/10.1088/1755-1315/24/1/012004.(in Eng.).

Kafarov V.V., Meshalkin V.P. Analysis and synthesis of chemical and technological systems: Textbook for universities. — Moscow: Chemistry. (in Rus.).

Orazbekova G.B. (2018). Application of systems approach to prognostication of ore fields in local auriferous nidalstructures (On the example of Vera-Char-Baladzhalnidal structure in West-Kalbinsk gold-bearing area of East Kazakhstan) // — *News of the National Academy of Sciences of the Republic of Kazakhstan,* Series of Geology and Technical Sciences. — Vol. 3. — № 429. — Pp. 208–217. (in Eng.).

Mizonov V., Mitrofanov A., Camelo A., Ovchinnikov L. (2018). Theoretical study of particulate flows formation in circulating fluidized bed // Recent Innovations in Chemical Engineering. — Vol. 11. — № 1. — Pp. 20–28. — DOI: https://doi.org/10.2174/2405520410666170620105102. (in Eng.).

Melnik V.V., Malukhin N.G. (2000). Features of pulp lifting by various devices with borehole technology of coal mining // Mining information and analytical bulletin. — № 2. — Pp. 15–18. (in Rus.).

Rochev V. (2018). Hydraulic borehole mining method possible application at Middle Larba alluvial gold field // E3S Web of Conferences. – Vol. 56. – DOI: https://doi.org/10.1051/e3sconf/20185601025 (in Eng.).

Kondrat'ev A.S., Naumova E.A. (2008). Calculation of the settling velocity of particles for the hindered sedimentation of polydisperse mixtures of arbitrarily shaped solid particles in a Newtonian liquid //Theoretical Foundations of Chemical Engineering. — Vol. 42. — Pp. 96–101. — DOI: https://doi.org/10.1134/S0040579508010120 (in Eng.).

Kondrat'ev A.S., Naumova E.A. (2007). Calculation of the hindered settling velocity of a bimodal mixture of solid particles of arbitrary shape in a Newtonian fluid // Theoretical Foundations of Chemical Engineering. — Vol. 41. — Pp. 216–220. — DOI: https://doi.org/10.1134/S0040579507020170 (in Eng.).

Qiu X. (2017). DEM Simulations in Mining and Mineral Processing. // Proceedings of the 7th International Conference on Discrete Element Methods. DEM 2016. Springer Proceedings in Physics. —Vol 188. — Springer, Singapore. — DOI: https://doi.org/10.1007/978-981-10-1926-5_5. (in Eng.).

Mizonov V., Mitrofanov. A. (2020). Application of the Theory of Markov Chains to Model Different Processes in Particle Technology. Nova Science Publishers. — New-York, USA. — ISBN: 978-1-53617-003-0 (ebook). — ISSN: 2163–3932 (book); — ISBN: 978-1-53617-002-3 (chapter) (in Eng.).

Catak M., Bas N., Cronin K. (2010). Markov chainmodelling of fluidized bed granulation //Chemical Engineering Journal. — Vol. 164. — *P*p. 403–409 (in Eng.).

Harris A.T., Thorpe R.B., Davidson J.F. (2002). Stochastic modelling of the particle residence time distribution in circulating fluidised bed risers //ChemEng Science. — Vol. 57. — **P**p. 4779–4796 (in Eng.).

Mitrofanov A.V., Mizonov V.E., Tannous K., Ovchinnikov L.N. (2018). A Markov ChainModel to Describe Fluidization of Particles with Time-Varying Properties //Particulate Science and Technology. — Vol. 36. — Pp.

244–253. — DOI: https://doi.org/10.1080/02726351.2016.1243180(in Eng.).

Khan A.R., Richardson J.F. (1987). The Resistance to Motion of a Solid Sphere in a Fluid // Chemical Engineering Communications. — Vol. 62. — Pp. 135–150. — DOI: https://doi.org/10.1080/00986448708912056 (in Eng.).

Mikhailov M.D., Silva Freire A.P. (2013). The drag coefficient of a sphere: An approximation using Shanks transform // Powder Technology. — Vol. 237. — *P*p. 432–435. — DOI: https://doi.org/10.1016/j.powtec.2012.12.033 (in Eng.).

Esin A., Altun M. (1984). Correlation of axial mixing of solids in fluidized beds by a dispersion coefficient // Powder technology. — Vol. 39. — Pp. 241–244. — DOI: https://doi.org/10.1016/0032-5910(84)85041-X (in Eng.).

CONTENT

Publication Ethics and Publication Malpractice in the journals of the National Academy of Sciences of the Republic of Kazakhstan

For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Submission of an article to the National Academy of Sciences of the Republic of Kazakhstan implies that the work described has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier.com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The National Academy of Sciences of the Republic of Kazakhstan follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http://publicationethics.org/files/u2/New_Code.pdf). To verify originality, your article may be checked by the originality detection service Cross Check http://www.elsevier.com/editors/plagdetect.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will onh accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the National Academy of sciences of the Republic of Kazakhstan.

The Editorial Board of the National Academy of sciences of the Republic of Kazakhstan will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайте:

www:nauka-nanrk.kz

ISSN 2518-1483 (Online), ISSN 2224-5227 (Print)

http://geolog-technical.kz/en/archive/

Подписано в печать 15.06.2024.

Формат 60x88$^{1}/_{8}$. Бумага офсетная. Печать - ризограф.

15,0 п.л. Тираж 300. Заказ 3.

РОО «Национальная академия наук РК» 050010,

Алматы, ул. Шевченко, 28, т. 272-13-19