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

«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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«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

5 (461)

SEPTEMBER – OCTOBER 2023

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 5. Number 461 (2023), 89–99
https://doi.org/10.32014/2023.2518-170X.333

UDC 532.536

© D.A .Bolysbek[1,2*], A.B. Kuljabekov[1], G.I. Issayev[3], K.Sh. Uzbekaliyev[1], 2023
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EXPERIMENTAL STUDY OF DISSOLUTION OF CARBONATE SAMPLES USING X-RAY MICROCOMPUTED TOMOGRAPHY

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Abstract. The study of the interaction of hydrochloric acid with carbonate rock is important in the oil and gas industry. Carbonate rocks are common rock types, and half of all petroleum reserves worldwide are found in carbonate deposits. Understanding the mechanisms and characteristics of dissolution of carbonate rocks is of great practical importance in the production of hydrocarbons and the injection of carbon dioxide into formations. The purpose of this article is to study the dissolution processes of 5 carbonate samples in laboratory conditions using X-ray microcomputed tomography. The studies used 5 cylindrical carbonate samples, which were tested during the injection of hydrochloric acid solutions. The three-dimensional pore space of the samples was obtained using specialized software based on tomographic images. The study revealed that the physical properties of the samples, such as porosity and permeability, significantly influence the dissolution process. Samples with higher porosity exhibited higher permeability after acid injection. The created 3D models of the samples allowed

3D visualization of wormholes, including branched and dominant wormholes. 3D imaging provided valuable information about changes in the pore structure of the samples before and after acid injection. The results of this study highlight the importance of considering physical and structural properties when analyzing dissolution processes in carbonate samples. These data can have practical applications in the oil and gas industry, contributing to a more accurate understanding and optimization of the processes of interaction of acid solutions with carbonate samples.

Keywords: carbonate samples, dissolution, X-ray microcomputed tomography, porous structure, permeability

Acknowledgment. This study was funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan under the project AP09058419 "Prediction of porous media characteristics taking into account rock dissolution patterns at pore scale based on machine learning".

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EXPERIMENTAL STUDY OF DISSOLUTION OF CARBONATE SAMPLES USING X-RAY MICROCOMPUTED TOMOGRAPHY

Аннотация. Тұз қышқылының карбонатты жыныстармен әрекеттесуін зерттеудің мұнай-газ өнеркәсібінде маңызы зор. Карбонатты тау жыныстары кең таралған тау жыныстары болып табылады және дүние жүзіндегі барлық мұнай қорының жартысы карбонатты кен орындарында кездеседі. Көмірсутектерді өндіруде және қабаттарға көмірқышқыл газын айдау кезінде карбонатты жыныстардың еру механизмдері мен сипаттамаларын түсінудің практикалық маңызы зор. Бұл мақаланың мақсаты — рентгендік микрокомпьютерлік томографияны қолдану арқылы зертханалық жағдайда 5 карбонат үлгісінің еру процестерін зерттеу. Зерттеулерде 5 цилиндрлік карбонат үлгілері қолданылды, олар тұз қышқылы ерітінділерін айдау кезінде сыналған. Үлгілердің үш өлшемді кеуекті кеңістігі томографиялық кескіндерге негізделген арнайы бағдарламалық қамтамасыз етуді қолдану арқылы алынды. Зерттеу нәтижесінде үлгілердің кеуектілігі және өткізгіштігі сияқты физикалық қасиеттері еру процесіне айтарлықтай әсер ететіні анықталды. Кеуектілігі жоғары үлгілер қышқыл әсерінен кейін жоғары өткізгіштікке ие болды. Үлгілердің жасалған 3D модельдері еру фронттарын, соның ішінде тармақталған және басым еру фронттарын 3D кескіндеуге мүмкіндік берді. 3D кескін қышқыл әсерінен бұрын және одан кейінгі үлгілердің кеуек құрылымындағы өзгерістер туралы құнды ақпарат берді. Бұл зерттеудің нәтижелері карбонат үлгілеріндегі еріту процестерін талдау

кезінде физикалық және құрылымдық қасиеттерді ескерудің маңыздылығын көрсетеді. Бұл деректер қышқыл ерітінділерінің карбонат үлгілерімен әрекеттесу процестерін дәлірек түсінуге және оңтайландыруға ықпал ете отырып, мұнай-газ өнеркәсібінде практикалық қолданылуы мүмкін.

Түйін сөздер: карбонат үлгілері, еріту, рентгендік микрокомпьютерлік томография, кеуекті құрылым, өткізгіштік

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ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ РАСТВОРЕНИЯ КАРБОНАТНЫХ ОБРАЗЦОВ С ПРИМЕНЕНИЕМ РЕНТГЕНОВСКОЙ МИКРОКОМПЬЮТЕРНОЙ ТОМОГРАФИИ

Аннотация. Исследование взаимодействия соляной кислоты с карбонатными материалами имеет важное значение в нефтегазовой промышленности. Карбонатные породы являются распространенными типами горных пород, и половина всех запасов нефти по всему миру находится в карбонатных месторождениях. Понимание механизмов и особенностей растворения, карбонатных пород имеет важное практическое значение при добыче углеводородов и закачке углекислого газа в пласты. Целью настоящей статьи является изучение процессов растворения 5 карбонатных образцов в лабораторных условиях с применением рентгеновской микрокомпьютерной томографии. В изучениях были использованы 5 цилиндрических карбонатных образцов, которые были испытаны во время закачки растворов соляной кислоты. Трехмерное поровое пространство образцов было получено с помощью специализированного программного обеспечения на основе томографических изображений. Исследование выявило, что физические свойства образцов, такие как пористость и проницаемость, существенно влияют на процесс растворения. Образцы с более высокой пористостью демонстрировали более высокую проницаемость после воздействия кислотой. Созданные трехмерные модели образцов позволили трехмерно визуализировать червоточины, включая разветвленные и доминантные червоточин. 3D визуализация предоставила ценную информацию об изменениях поровой структуры образцов до и после воздействия кислоты. Результаты данного исследования подчеркивают важность учета физических и структурных свойств при анализе процессов растворения карбонатных образцов. Эти данные могут иметь практическое применение в нефтегазовой индустрии, способствуя более точному пониманию и оптимизацию процессов взаимодействия кислотных растворов с карбонатными образцами.

Ключевые слова: карбонатные образцы, растворение, рентгеновская микрокомпьютерная томография, пористая структура, проницаемость

Introduction

The study of dissolution processes in carbonate samples is important in geology and the oil and gas industry because it allows us to better understand changes in the pore structure of rocks and their impact on permeability. These processes play a key role in the context of the extraction and storage of hydrocarbon resources in underground formations, as well as in the processes of geological storage of carbon dioxide.

Carbonate samples such as calcite are common components of rocks and oil and gas reservoirs. Understanding their pore structure plays an important role in the processes of dissolution and transport of hydrocarbons, as well as in reactions with aggressive chemical environments such as hydrochloric acid.

Many studies have been devoted to dissolution processes in productive layers using reactive transport models (An et al., 2021; Luo et al., 2021; Maheshwari et al., 2014). Experiments were also conducted on the dissolution of carbonate rocks with various acid solutions (Luquot et al., 2014; Soltanbekova et al., 2021).

To create three-dimensional digital models of carbonate samples, X-ray microcomputed tomography has become widely used (Qajar et al., 2013; Qajar & Arns, 2016; Smith et al., 2013; Xie et al., 2022). Numerical simulations have been used to study the dissolution processes of porous structures (Turegeldieva et al., 2016; Zhou et al., 2020). At the same time, researchers also studied the influence of sample scales on changes in dissolution fronts (Turegeldieva et al., 2016).

The effect of different concentrations of hydrochloric acid on the porosity and permeability of carbonate rocks was analyzed (Al-Arji et al., 2021; Liu et al., 2023). In addition, studies have covered the influence of temperature on the dissolution processes of carbonate samples (SHE et al., 2016) and the mechanisms of dissolution in carbonate samples under high pressure conditions (He et al., 2017). Research also addressed the influence of the chemical composition of carbonate rocks on their solubility (Meng et al., 2022).

Researchers also paid attention to the influence of pore geometry on the efficiency of dissolution processes in carbonate samples (Bolysbek et al., 2023). The effects of exposure to carbonate rocks with different types of acid compositions at slow rates have been studied (Akasheva et al., 2023).

This paper studies the dissolution mechanisms of carbonate samples and their influence on their basic characteristics using X-ray microcomputed tomography. For this purpose, 5 cylindrical carbonate samples were used, onto which a 12 % solution of hydrochloric acid was pumped at a flow rate 0.5–32 ml/min.

Materials and methods

Sample characterization

To perform physical experiments related to the dissolution process, this work uses 5 cylindrical carbonate samples with a length and diameter of about 5 and 3 cm, respectively. These samples were extracted from a geological core extracted from a carbonate reservoir located in the coal system of one of the deposits in the Republic of Tatarstan (Fig. 1). In Fig. 1, the top row shows a photograph of the inlet and outlet slices of the samples, while the bottom row shows a photograph of the samples from the side.

Figure 1. Photos of considered samples

During standard analysis, the samples went through hydrocarbon extraction, salt removal and drying in Soxhlet apparatus. After that, filtration-capacitive and petrophysical properties were determined, including open porosity, bulk density and permeability of the samples.

The mineral composition of the samples was determined using a Bruker D2 X-ray diffractometer.

Experiments on injection of acid solution

Filtration studies of the acid solution were carried out using an electronic installation for studying rocks Wille Geotechnik Y1000 with the ability to physically simulate the thermobaric conditions of the formation. The installation allows you to evaluate the permeability of rock models before and after interaction with concentrated acid solutions in reservoir conditions.

A 12 % hydrochloric acid solution was used as an acid solution. The injection rate of the solution into the samples varied from 0.5 to 32 ml/min. During injection of the solution, a compression pressure of 3 MPa was created, and the temperature was maintained constant at 20°C.

The absolute permeability of samples to water is calculated according to Darcy's linear law:

$$K = \mu LQ/\Delta PF,$$

where K is absolute permeability, m^2; μ – dynamic viscosity, Pa·s; L – sample length, m; Q – volume flow, m^3/s; ΔP – pressure drop at the ends of the sample, Pa, F – cross-sectional area of the sample, m^2.

X-ray computed tomography

To obtain the digital pore space of the samples before and after dissolution, a General Electric phoenix v|tome|XS 240 X-ray microcomputed tomograph was used, with a resolution of about 18 μm.

The operating principle of the X-ray tomography method is to obtain a sequence of X-ray images of an object, which are then processed using software methods to create a three-dimensional image. In this technique, the key unit that determines the resolution of a three-dimensional model of an object is the voxel. Voxels are similar to pixels, but are applied in three-dimensional space. The result of 3D image reconstruction is a 3D array of voxels aligned along the XYZ coordinate axes. A single slice, one voxel thick, is usually called a slice. In the paper, the digital sample model contains about 1800x1800x3000 slices in three directions, respectively.

Processing and calculation of the characteristics of the volumetric model were

carried out in the specialized Avizo program, which allows you to create a 3D model of the samples and calculate microscopic and macroscopic properties.

Processing the resulting digital model of samples consists of several mandatory operations, such as cutting, noise removal and segmentation. The cutting was done to remove unwanted edge noise. Filtering of digital data was carried out to remove noise and artifacts directly within the sample. For filtering, the median filter was used, which was better suited. After filtration, segmentation of the pore space was performed. Segmentation was performed using the Interactive Thresholding module in Aviso, which determined the gray boundary threshold value to adequately separate the pore space from the solid skeleton.

Results and discussions

Results of physical experiments on sample dissolution

Before conducting experiments on pumping acid into samples, their filtration and petrophysical properties were determined (Table 1). The samples have similar sizes but differ in pore volume, porosity and permeability. If we compare the porosity and permeability values of the presented samples, it can be seen that samples with higher porosity have higher permeability values.

Table 1. Properties and mineral composition of samples

Sample	Length, cm	Diameter, cm	Porosity, %	Permeability, mD	Mineral composition, %		
					Calcite	Dolomite	Quartz
1	4,93	2,98	22,39	642,18	99	<1	1
2	4,92	2,96	23,05	920,64	100	-	<1
3	4,93	2,99	27,17	635,03	100	-	-
4	4,95	2,98	21,91	816,65	100	-	-
5	4,92	2,98	18,05	406,67	100	-	-

The mineral composition of the samples was also determined, which shows that all samples are almost entirely composed of calcite (Table 1). Only a few studied samples contained a small proportion of quartz, not exceeding 1 %. This indicates that all the studied samples are highly homogeneous in composition, which excludes the influence of this parameter when comparing the efficiencies of interaction of samples with acidic compounds.

After conducting standard studies, experiments were carried out on pumping acid into samples, the results of which are shown in Table. 2. In Fig. Figure 3 shows photographs of samples after injection of an acid solution. Photographs of the samples after injection of acid show that almost all samples had breakthroughs, except for sample 1. In sample 1, the process of rock dissolution at the inlet end was observed due to the low rate of injection of the acid solution; in the remaining experiments, wormholes were formed with a breakthrough of the sample.

A comparative analysis of injection rate and permeability changes indicates a direct relationship between them. An increase in injection rate was usually accompanied by an increase in permeability after acid exposure. For example, sample No. 5, which has the highest injection rate (32 ml/min), has the lowest initial permeability of 406.67

mD, but after exposure to an acid solution, the permeability increased significantly (up to 3009.90 mD) compared to the rest. However, the porosity of this sample increased from 18.05 % to 23.31 %, which is not quite high with the increases in other samples. Samples with relatively high increases in porosity showed an ambiguous relationship with changes in permeability, which may be associated with the peculiarities of changes in their structure.

Table 2. Results of experimental tests

Sample	Flow rate, ml/min	Porosity after dissolution, %	Permeability, mD		PV_{bt}
			before dissolution	after dissolution	
1	0,5	32,65	642,18	918,89	-
2	12	30,61	920,64	2391,17	5,81
3	16	32,46	635,03	3331,20	4,50
4	25	28,13	816,65	3889,23	6,31
5	32	23,31	406,67	3009,90	6,19

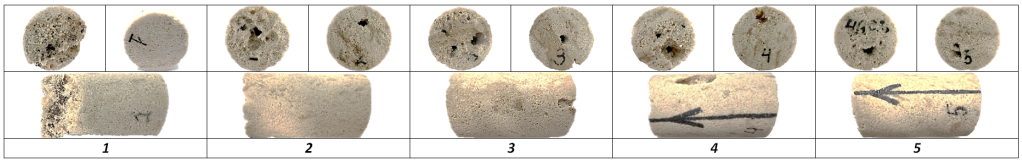

Figure 2. Photos of samples after injection of acid solution

Samples with higher injection rates also tended to have higher PV_{bt} values. No acid breakthrough was detected in sample 1, therefore, the PV_{bt} value for this sample was not determined.

3D digital model of samples

As a result of scanning the samples with an X-ray microcomputed tomograph, volumetric images of the samples were obtained. Each voxel in the sample images is assigned an X-ray density value, measured in conventional units of the linear attenuation scale relative to air. In this case, it varies in the range from 0 to 65535 units. Fig. 3 shows orthogonal sections of raw images of samples before and after dissolution with hydrochloric acid. The acid solution was pumped from bottom to top.

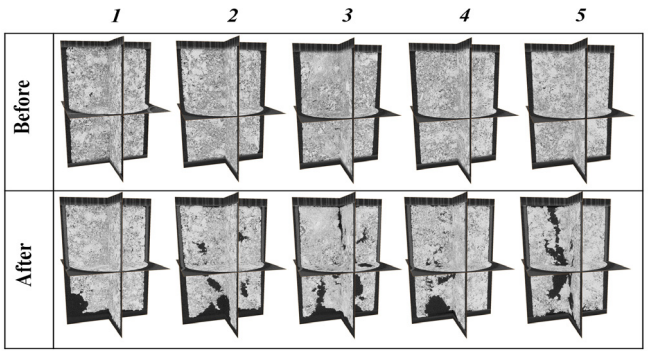

Figure 3. Raw images of samples before and after rock dissolution

Next, the sample images were processed by removing unwanted noise. Before applying the filters, the image boundaries were trimmed to the edges of the cylinder. As a result, the number of slices in three directions was reduced to 1600x1600x2600.

After this, sample images were filtered and segmented. A specific rectangular area was selected on one of the slices of sample 3 in order to demonstrate the results of filtering and segmentation visually (Fig. 4). In Fig. Figure 4 shows a comparison of the original image with the image after applying filtering, as well as their segmentation using sample 3 as an example. It should be noted that the distribution of gray color was adjusted to show the filtering results. As can be seen from the filtering results, the noise that was present in the original image was smoothed out. Depending on the structure, composition and scanning process, the boundaries of the X-ray absorption density distribution change differently, as well as their gray boundaries set for segmenting the pore space in the Interactive thresholding module. The upper threshold values for segmentation were determined by visual analysis of the slices, and they differed for each sample (Table 3).

In turn, based on the binary data of the samples, their porosity was calculated (Table 3). The calculated porosities from segmented images of the samples did not give bad results. Deviations from experimental porosity vary, but generally remain relatively low.

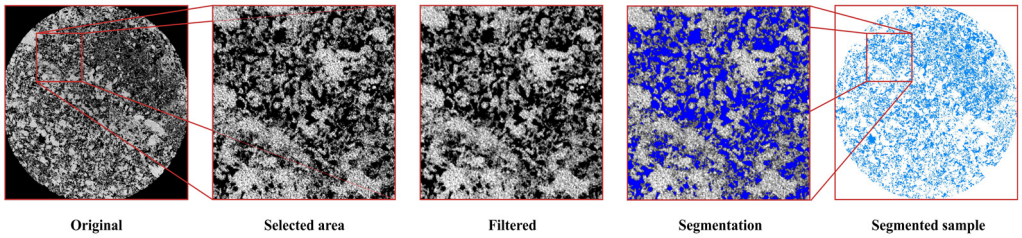

Figure 4. Results of filtering and segmentation of image of sample 3

Table 3. Results of porosity calculatiion from images

Sample		Image porosity, %	Experimental porosity, %	Deviation, %	Threshold
1	Before	20,21	22,39	9,75	25300
	After	29,63	32,65	9,24	30400
2	Before	21,01	23,05	8,84	21570
	After	28,07	30,61	8,31	24100
3	Before	24,73	27,17	8,97	26900
	After	29,81	32,46	8,15	28850
4	Before	19,80	21,91	9,63	11240
	After	25,54	28,13	9,22	27930
5	Before	16,33	18,05	9,51	24800
	After	21,30	23,31	8,61	24990

In Fig. Figure 5 shows the results of volumetric rendering of the segmented pore space of the samples before (a) and after (b) dissolution, as well as calculations of the average porosity along the length of the samples (c). The dark blue color shows the

pore space (Fig. 5 a, b). Injection direction in Fig. 6 occurs from left to right. Blue and orange lines show the porosity distribution before and after dissolution, respectively (Fig. 5c). It should be noted that, to visualize wormholes in 3D models of samples after dissolution, the transparency was increased (Fig. 5 b).

From the created 3D digital models of the samples, as well as from the distribution of porosity along the length of the samples, one can see the features of the dissolution mechanisms of the samples. The samples show evidence of several dissolution regimes. In sample 1, a surface dissolution mode was observed due to the low injection rate, and therefore no breakthrough of the acid solution through the sample was observed. In other samples, signs of branched and dominant (wormhole) dissolution regimes are noticeable. As the injection rate and the injected pore volume of acid increase, the thickness of the wormholes increases. Perhaps this explains the largest increase in permeability in sample 5 (Table 2). It can also show that in this sample the dissolution regime is reduced to a dominant wormhole, since porosity does not increase everywhere compared to samples 1 and 2 (Table 2).

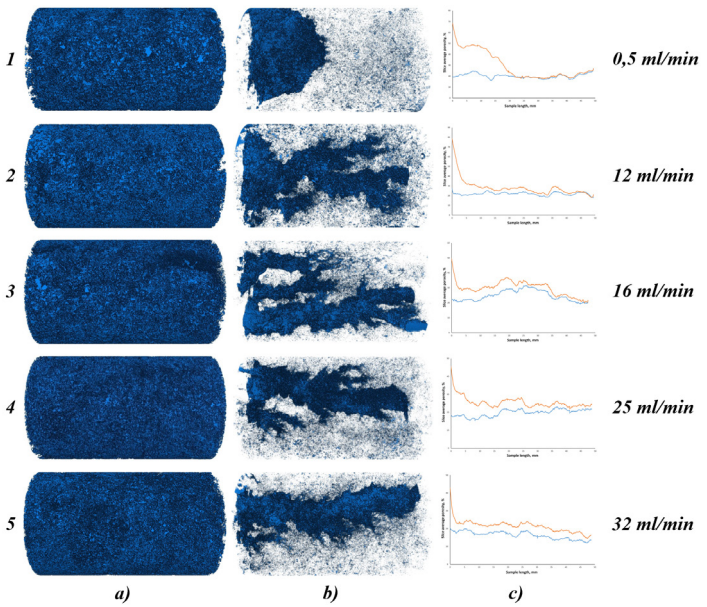

Figure 5. Pore spaces of samples before (a) and after (b) dissolution and porosity distribution along the length of samples (c) before and after dissolution

Conclusion

In this paper, the dissolution of carbonate rock samples was experimentally studied using X-ray microcomputed tomography with a spatial resolution of 18 μm. Microcomputed tomography provided important data on the interaction of the acid solution with 5 carbonate samples. Porosity and permeability were found to be significant factors affecting the dissolution process. Samples with higher initial porosity had higher increases in permeability as a result of acid injection. However, sample 5

showed a significant increase in permeability, despite a slight increase in porosity. This is confirmed by the fact that a dominant wormhole formed in this sample.

The constructed 3D digital models of the samples made it possible to clearly and in detail identify dissolution fronts. In samples 2-4, branched wormholes formed and developed, in which the solution injection rate was average, while in sample 5 one dominant wormhole formed and erupted. And in sample 1, surface dissolution of the rock was observed, which corresponds to a low solution injection rate. The results will demonstrate that microcomputed tomography is becoming one of the integral tools for studying the pore structure of rock samples with the creation of a database of digital cores, which is very useful in assessing the effectiveness of other types of intensification of fluid flow to the well, since the undamaged model of the samples is stored in the database.

Further research will be aimed at optimizing the conditions of exposure to acid solutions to achieve the most effective results, as well as studying changes in rock wettability as a result of dissolution.

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www:nauka-nanrk.kz
http://www.geolog-technical.kz/index.php/en/
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Подписано в печать 10.09.2023.
Формат 70x90$^{1}/_{16}$. Бумага офсетная. Печать – ризограф.
19,0 п.л. Тираж 300. Заказ 5.

РОО «Национальная академия наук РК»
050010, Алматы, ул. Шевченко, 28, т. 272-13-19