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ХАБАРШЫСЫ

HERALD

OF THE KAZAKH-BRITISH TECHNICAL UNIVERSITY

ВЕСТНИК

КАЗАХСТАНСКО-БРИТАНСКОГО ТЕХНИЧЕСКОГО УНИВЕРСИТЕТА

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Duisek B.E*, Sarsembin D.D, Abdurazak K.A.

Kazakh-British Technical University, 050000, Almaty, Kazakhstan
*E-mail: be_duisek@kbtu.kz

COMPARISON AND ANALYSIS OF DIFFERENT MACHINE LEARNING METHODS ON ASTEROID DIAMETER PREDICTIONS BASED ON THE NASA SMALL CELESTIAL BODIES DATABASE

Abstract. The database of small celestial bodies NASA is provided by the Jet Propulsion Laboratory and represents the collected information about asteroids and comets, describing their parameters available for observation and determination, including physical ones, as well as their classification and data on the number and duration of observation. Many of these celestial techs have an incomplete description of their properties, which makes it difficult to predict their behavior and potential interaction with other objects in space, including man-made ones. This study proposes a solution to a certain part of the problems of asteroid exploration by finding a prediction of the diameter of asteroids based on information from the NASA database and the results of machine learning methods on processed data from the source. For this research, some of the most commonly used algorithms for implementing such prediction models have been selected, such as KNN, linear regression, random forest, decision trees, and gradient boosting. Applied machine learning algorithms were evaluated based on the results of diameter prediction accuracy, speed of training and prediction process, and square mean error rates. The study will help to choose the most optimal approach for predicting this feature of asteroids, describe the process of data pre-processing, while achieving the best performance of the model, and analyze the correlations between the properties of these celestial bodies.

Key words: machine learning, asteroid, prediction model, KNN, linear regression, random forest, decision tree, gradient boosting.

Introduction

The Solar System and space beyond are inhabited by plenty of small body objects that float in different directions and collide with other objects, which may result in the creation of potentially hazardous situations for our planet[7]. Hence numerous researchers track and collect data about asteroids to identify those objects that are the most threatening to the Earth. In 2009, the University of Glasgow proposed a paper “Multicriteria Comparison Among Several Mitigation Strategies for Dangerous Near-Earth Objects” with properties of objects that may help to evaluate and assess effective methods of identifying such. This paper contains about 90 variables that are taken into account to predict and define mathematics models for identifying dangerous near-Earth objects[16]. None of the proposed strategies used machine learning algorithms. In another article “Parameter estimation for optimal asteroid transfer trajectories using supervised machine learning” the authors used supervised machine learning techniques such as differential evolution algorithm, gaussian process regression to evaluate the trajectories of asteroids[17].

Our research is based on the current database of small celestial bodies presented by the Jet Propulsion Laboratory of California Institute of Technology consists of hundreds of thousands of asteroids and comets, and while some of them are well studied, some objects miss many valuable parameters, which can describe their future interactions with other bodies, while also assisting in prediction possible behavioral patterns[11]. Correlation with several attributes, such as categorical values of Potentially Hazardous Asteroids (PHA)[3] or semi-major axis, may help researchers to predict possible threats of previously unknown or under-researched asteroids or generally identify characteristics of their orbits[20]. However, it is worth considering that an asteroid's diameter also has a direct correlation with its mass. Mass is not one of the features we are taking into account in our study, but the distribution of masses of asteroids is a more complex topic due to the nature of mass measurement techniques, but the various mass distribution prediction methods have been applied for closely located asteroids for many decades now[9].

Table 1 – The embeddings for each column

name	Name of asteroid
a	Semi-major axis, in AU
e	Eccentricity
i	Inclination, in degrees
om	Longitude of the ascending node, in degrees
w	Argument of perihelion, in degrees
q	Perihelion distance, in AU
ad	Aphelion distance, in AU
per_y	Orbital period, in years
data_arc	Number of days spanned by the data arc, in days
condition_code	Orbit condition code
n_obs_used	Number of observations used
H	Absolute magnitude parameter
neo	Near-Earth Object flag, yes or no
pha	Potentially Hazardous Asteroid flag, yes or no
diameter	Object diameter, in kilometers
extent	Object tri-axial ellipsoid dimensions, in kilometers
albedo	Albedo
rot_per	Rotation period, in hours
GM	Product of the mass (M) multiplied by the gravitational constant (G)
BV	Color index B-V magnitude difference
UB	Color index U-B magnitude difference
IR	Color index I-R magnitude difference
spec_B	Spectral taxonomic type (SMASSII)
spec_T	Spectral taxonomic type (Tholen)
G	Magnitude slope parameter
moid	Earth minimum orbit intersection distance, in AU
class	Orbit class
n	Mean motion, in degrees/days
per	Orbital period, in days
ma	Mean anomaly, in degrees

Literature review

Basu(2019) used the Multilayer Perceptron algorithm to predict the diameter of asteroids[21]. It analyzed its performance, utilizing other machine learning methods on the same dataset, as in this paper. It appears that the methods that were used for comparison differ from the methods that will be used in this paper.

Recently Hossain & Zabed(2023) produced a comparison of machine learning algorithms for the classification and diameter prediction of asteroids[22]. For the task of diameter, predictions used the same machine-learning algorithms. However, only parameters of absolute magnitude H and albedo were used as inputs and it seems that no proper process of finding data correlation between parameters was conducted, for the task of diameter prediction.

It is clear that a thorough analysis of the dataset features correlation is needed for a more accurate forecast of asteroid diameter and comparison of the performance of machine learning algorithms. Moreover, studies involving this particular NASA dataset and forecasting models for diameter prediction are not that frequent and mostly set their objectives in other areas.

Main provisions

The main goal of the analysis of this particular dataset consists of data preprocessing [1] and feature identification through the profound examination of the correlation between the diameter and each of the columns.

Figure 1 – Relationship between data_arc and diameter

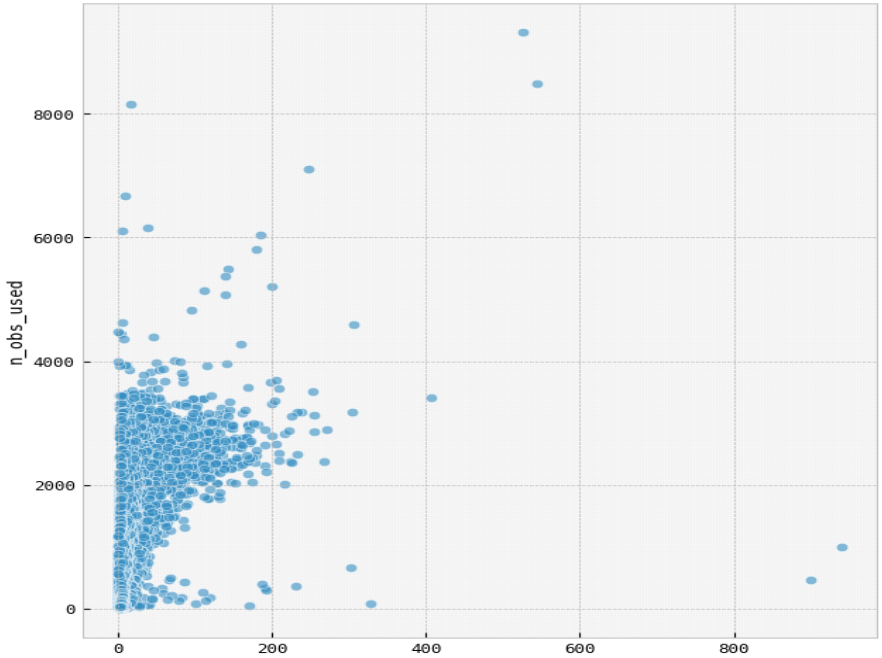

Figure 2 – Relationship between n_obs_used and diameter

Data

The dataset has 839736 entries and 27 columns. Out of all columns and their descriptions, which are depicted in Table 1., initially we dropped only 3 features: *name*, *data_arc*, and *n_obs_used* because all these fields will either result in overly biased results, in the case of *data_arc* or *n_obs_used* or just be useless in prediction since they are manually assigned names, in case of *name*. *n_obs_used* column represents the total number of observations of the distinct asteroid. At the same time, the *data_arc* feature refers to the total amount of days between the first and the last observation of an asteroid. Even though both fields have a high correlation with diameter, shown in Figure 1. for *data_arc*, and in Figure 2. for *n_obs_used*, they represent historical human activity. They will not contribute to predictions for newly discovered celestial objects.

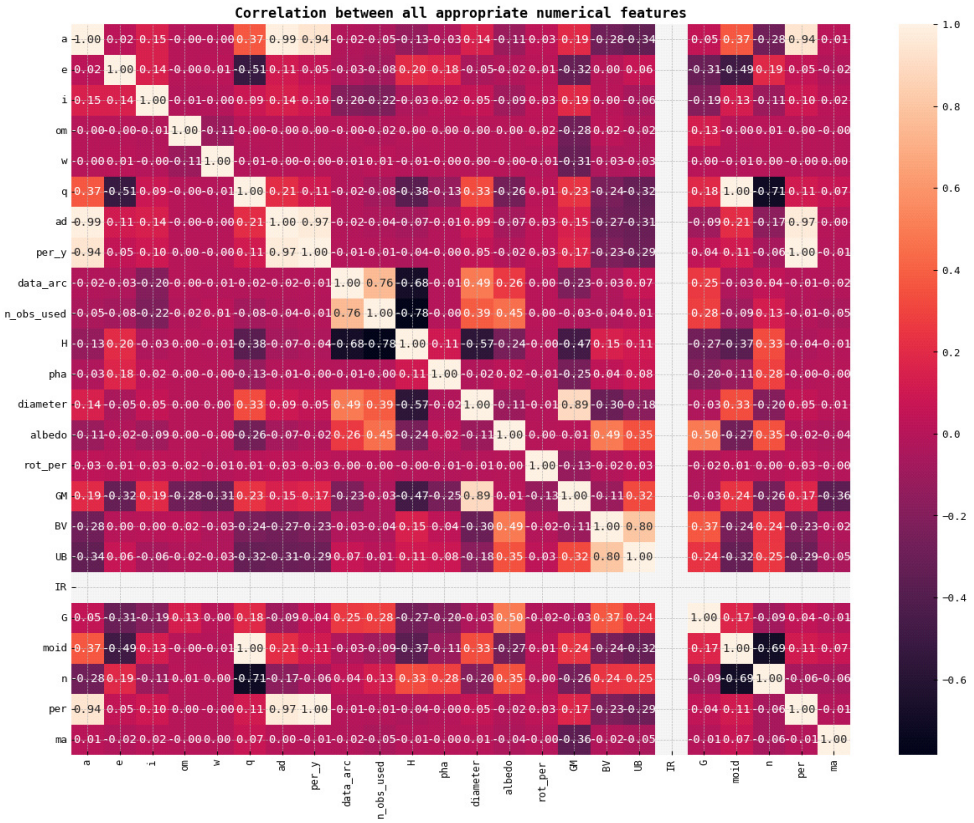

Figure 3 – Correlation heatmap for all numerical and categorical features

After this step, we began analyzing other numerical and categorical attributes by plotting the correlation heatmap for all features in order to find the most appropriate features for diameter prediction, depicted in Figure 3. To plot the correlation heatmap we used Pandas built-in .corr method which can use Pearson(standard) correlation coefficient [12], Kendall Tau correlation coefficient [15], and Spearman rank correlation [8]. According to this data, 11 out of 24 columns have a pairwise correlation between -0.1 and 0.1, which demonstrates their insignificance for the forecasting process, thus they were dropped alongside. Those fields are *e (Eccentricity)*, *ad (Aphelion distance)*, *i (Inclination)*, *om (Longitude of the ascending node)*, *w (Argument of perihelion)*, *per_y (Orbital period)*, *rot_per (Rotation period)*, *G (Magnitude slope parameter)*, *per (Orbital period)*, *pha (Potentially Hazardous Asteroid)* and *ma (Mean anomaly)*. Low correlation values for the aforementioned attributes may be related to the nature of asteroid formation or events that occurred before measurements were taken. Nonetheless, those features were excluded from further testing, improving overall prediction accuracy. Furthermore, we dropped all items with unidentified diameters, since in this research we are trying to train models with predefined desired prediction parameters for testing, resulting in dropping 702100 rows from the initial dataset, leaving 137636 items in the final iteration of a dataset.

Table 2 – Number of asteroids with missing values for given attributes

Column	***Rows with NaN value***
a	0
q	0
H	747
UB	136671
BV	136631
GM	137622
moid	0

diameter	0
albedo	1230
n	0
IR	137635

During the next phase of preprocessing, we counted all the asteroids with missing values for all remaining features. As demonstrated in Table 2., *UB (Color index U-B magnitude difference), BV (Color index B-V magnitude difference), GM (Product of the mass (M) multiplied by a gravitational constant (G)),* and *IR (Color index I-R magnitude difference)* fields have only 965, 1005, 14, and 1 non-missing values presented, correspondingly. While we may fill empty *UB*, *GM*, and *BV* cells with mean values of these columns since they have at least some amount of rows filled with data, it will negatively impact the mean square error during prediction, which is shown in Table 3. Thus, we are removing these columns from further processing and testing, alongside rows, which contain NaN values in remaining attributes, which means out of 11 columns, the resulting dataset only includes 7. After the deletion of all items with missing values, the total number of removed rows reached 1230, which is a maximum between *H* and *albedo*.

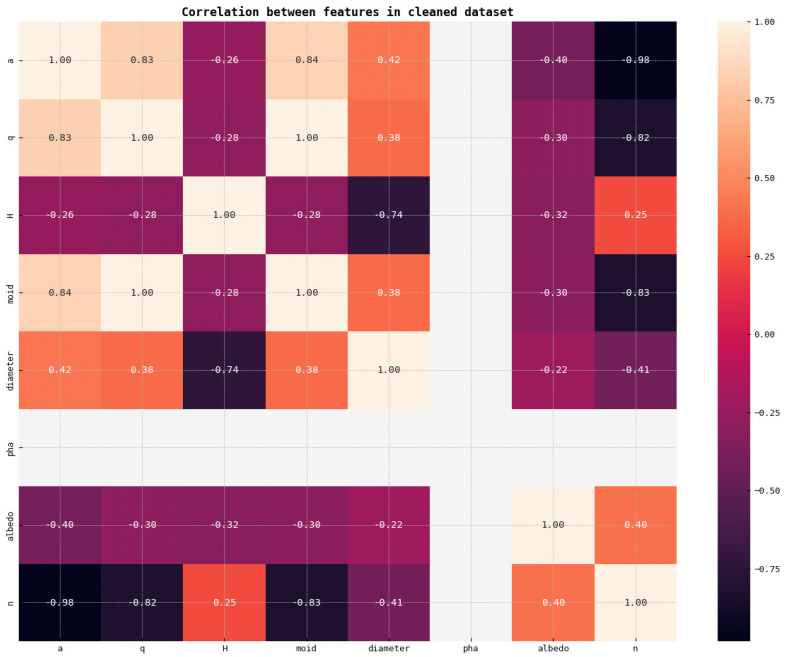

Figure 4 – Correlation heatmap for all numerical and categorical features after optimization

Outliers deletion is the final step in data standardization to achieve the most optimal accuracy rates for all the models this research uses as prediction models for the diameter of asteroids. Outliers were identified by calculating *Z-score* for every value inside the features and using list-wise deletion [10] with an absolute *Z-score* exceeding the value of 3, which equals 5333 deleted rows, and 130800 left after this step. Number 3 was taken as an arbitrary value, often used by models to find unusual entries in datasets. Z-score can be described as a statistical measurement, which depicts the connection between a value and a set of values mean [2]. Standard deviations from the mean are used to measure Z-score. Score formula:

$$Z = (x - \mu) / \sigma, \qquad (1)$$

where is the standard score, is the observed value, is the mean of the sample, is the standard deviation of the sample. In this case, the mean of the sample represents the average data on the column, while the standard deviation of the sample is the root-mean square of the difference between the given observation and the sample mean [14].

The new correlation heatmap depicted in Figure 4. shows far greater pairwise correlation values for diameter, implying our preprocessing had a significant effect on the prediction capabilities of our model.

Methods

During the training and prediction phases of this study, we were able to test several popular machine learning techniques as regressors, such as K-nearest neighbors (KNN) [4], linear regression [13], decision tree [5], random forests [6], and gradient boosting [18].

KNN: the KNN algorithm is a supervised learning classifier that utilizes proximity by producing classifications or predictions about how a particular data point will be grouped. It is non-parametric.

Linear regression: as for linear regression, and its application as the classifier, it can be characterized as a method, in which a variable's value can be predicted using linear regression analysis based on the value of another variable. The dependent variable is the one you want to be able to forecast. The independent variable is the one you're using to predict the value of the other variable.

Decision Tree: by constructing a decision tree, the decision tree classifier [19] develops the classification model. A test on an attribute is specified by each node in the tree, and each branch descending from that node represents one of the possible values for that property.

Random forests: as an ensemble learning technique for classification and regression, random forests build a large number of decision trees during the training phase. The class that the majority of the trees choose is the output of the random forest for classification problems. The mean or average forecast of each tree is returned for regression tasks. The tendency of decision trees to overfit their training set is corrected by random decision forests.

Gradient boosting: this estimator allows for the optimization of any differentiable loss function and constructs an additive model in a forward stage-wise manner. A regression tree is fitted on the negative gradient of the provided loss function at each level.

Table 3 – R2 score, Root MSE (Mean Square Error), and execution time for each method (UB, GM, and BV)

Method (Regressor)	R2 score	R2 score, outliers removed	Root MSE	Root MSE, outliers removed	Execution time, in ms	Execution time, outliers removed, in ms
Linear regression	0.55	0.78	6.90	1.39	6.30	4.06
Decision tree	0.92	0.93	2.91	0.77	127.65	105.53
KNN	0.77	0.95	4.98	0.63	1357.18	72.94
Random forest	0.94	0.96	2.53	0.57	9528.88	7997.67
Gradient boosting	0.93	0.96	2.58	0.57	3057.80	2934.02

Table 4 – R2 score, Root MSE (Mean Square Error), and execution time for each method

Method (Regressor)	R2 score	Root Mean Square Error	Execution time, in ms
Linear regression	0.78	1.39	4.06
Decision tree	0.93	0.77	105.53
KNN	0.95	0.63	72.94
Random forest	0.96	0.57	7997.67
Gradient boosting	0.96	0.57	2934.02

Results and Discussion

In order to achieve a better understanding of per-model performance we conducted 3 separate sets of testing, in which predictions were made based on datasets with both *UB*, *GM*, and *BV* features removed and remained, then there was a removal of any outliers with Z-index score higher than 3. In this study, the authors use the R2 score as an indicator of accuracy. Authors can observe the difference between forecasting results of data before and after outlier removal with *UB*, *GM*, and *BV* attributes in Tables 3 and 4. Outliers had a significant impact on R2 score, which is calculated as the R2 score, which is a coefficient of determination, used as a regression score function, for some methods, such as linear regression and KNN, while other techniques only had improvement in root mean square error. Also, we have a major improvement in execution times. The most noticeable execution time inequality is represented by the difference in KNN execution times before and after outlier removal, from 1357.18 ms to 72.94 ms, which can be explained by a significant reduction in the total

number of rows. Overall, as shown in Table 3, with given initial input data, the decision tree and KNN have the best R2 score per execution time ratio, while gradient boosting and random forest both demonstrate very high R2 score and execution time, but lower root square mean error in comparison with other algorithms.

On the other hand, as Table 4. depicts, removing *UB*, *GM*, and *BV* columns, which almost fully consist of mean sample data values of the initial few items, resulted in a comparable performance, but a significantly better root mean square error indicator. Comparing all the methods in our final testing, all the methods except linear regression had a great R2 score in forecasting asteroid diameters. Linear regression, while being the least accurate one, still has the acceptable root mean square error value, and substantially lower execution time. KNN achieved the best overall performance, reaching a value of 0.95 for R2 score, which is 0.01 lower in comparison with random forest and gradient boosting, and had a reasonable execution time of 72.94, while the aforementioned random forest and gradient boosting exceed 2500 ms each.

Conclusion

This paper presented a profound description of building a model for forecasting asteroid diameters based on NASA's small body database. The main idea of the research was to identify pairwise correlations between dataset features and diameter and analyze several approaches to diameter prediction with the help of various machine learning algorithms.

With the given results, we may potentially forecast the diameters of many currently understudied asteroids and newly discovered ones. Applications to such predicted data can improve the identification of potentially hazardous asteroids, and generally enhance our understanding of the behavior of many small bodies we can not study due to technological limitations.

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Information about authors

Duisek Bermagambet Erikuly (corresponding author)
Master student, School of Information Technology and Engineering, Kazakh-British Technical University, 59, Tole bi street, Almaty, 050000, Kazakhstan.
ORCID ID: 0009-0007-3508-8718
E-mail: be_duisek@kbtu.kz

Sarsembin Dauren Diyasovich
Master student, School of Information Technology and Engineering, Kazakh-British Technical University, 59, Tole bi street, Almaty, 050000, Kazakhstan.
ORCID ID: 0009-0008-7229-2985
E-mail: da_sarsembin@kbtu.kz

Abdurazak Kuanyshbek Abdurazakovich
Master student, School of Information Technology and Engineering, Kazakh-British Technical University, 59, Tole bi street, Almaty, 050000, Kazakhstan.
ORCID ID: 0000-0001-5743-5572
E-mail: ku_abdurazak@kbtu.kz

Авторлар туралы мәліметтер

Дуйсек Бермагамбет Ерикулы (корреспонденция авторы)
Магистрант, Ақпараттық технологиялар және инженерия мектебі, Қазақстан-Британ техникалық университеті, Төле би көш., 59, 050000, Алматы қ., Қазақстан.
ORCID ID: 0009-0007-3508-8718
E-mail: be_duisek@kbtu.kz

Сарсембин Даурен Диясович
Магистрант, Ақпараттық технологиялар және инженерия мектебі, Қазақстан-Британ техникалық университеті, Төле би көш., 59, 050000, Алматы қ., Қазақстан.
ORCID ID: 0009-0008-7229-2985
E-mail: da_sarsembin@kbtu.kz

Абдуразак Куанышбек Абдуразакович
Магистрант, Ақпараттық технологиялар және инженерия мектебі, Қазақстан-Британ техникалық университеті, Төле би көш., 59, 050000, Алматы қ., Қазақстан.
ORCID ID: 0000-0001-5743-5572
E-mail: ku_abdurazak@kbtu.kz

Информация об авторах

Дуйсек Бермагамбет Ерикулы (автор для корреспонденции)
Магистрант, Школа информационных технологий и инженерии, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, г. Алматы, Казахстан
ORCID ID: 0009-0007-3508-8718
E-mail: be_duisek@kbtu.kz

Сарсембин Даурен Диясович
Магистрант, Школа информационных технологий и инженерии, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, г. Алматы, Казахстан.

ORCID ID: 0009-0008-7229-2985
E-mail: da_sarsembin@kbtu.kz

Абдуразак Куанышбек Абдуразакович
Магистрант, Школа информационных технологий и инженерии, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, г. Алматы, Казахстан
ORCID ID: 0000-0001-5743-5572
E-mail: ku_abdurazak@kbtu.kz

Дүйсек Б.Е.*, Сарсембин Д.Д., Абдуразак К.А.

Қазақстан-Британ техникалық университеті, 050000, Алматы қ., Қазақстан
*E-mail: be_duisek@kbtu.kz

КІШІ АСПАН ДЕНЕЛЕРІ ТУРАЛЫ NASA ДЕРЕККӨРЫ НЕГІЗІНДЕ АСТЕРОИДТАРДЫҢ ДИАМЕТРІН БОЛЖАУ ҮШІН ӘРТҮРЛІ МАШИНАЛЫҚ ОҚЫТУ ӘДІСТЕРІН САЛЫСТЫРУ ЖӘНЕ ТАЛДАУ

Аңдатпа. NASA кіші аспан денелерінің дерекқорын Jet Propulsion Laboratory ұсынады және ол астероидтар мен кометалар туралы жиналған ақпаратты, оларды бақылау және анықтау үшін қол жетімді параметрлерді, соның ішінде физикалық параметрлерді, сондай-ақ олардың жіктелуі, бақылау саны мен ұзақтығы туралы деректерді қамтиды. Бұл аспан денелерінің басым көпшілігінің қасиеттері толық сипатталмаған, бұл олардың мінез-құлқын және ғарыштағы басқа объектілермен, соның ішінде қолдан жасалған заттармен өзара әрекеттесуін болжауды қиындатады. Бұл зерттеу астероидтарды зерттеу мәселелерінің белгілі бір бөлігін NASA дерекқорынан алынған ақпарат пен бастапқы көзден өңделген деректерді пайдалана отырып, машиналық оқыту әдістерінің нәтижелері негізінде астероидтардың диаметрінің болжамын табу арқылы шешуді ұсынады. Бұл жұмыста осындай болжау модельдерін жүзеге асыру үшін ең жиі қолданылатын KNN, linear regression, random forest, decision tree және gradient boosting сияқты алгоритмдер таңдалды. Пайдаланылған машиналық оқыту алгоритмдері диаметрді болжау дәлдігінің, жұмыс жылдамдығының және орташа квадраттық қателік көрсеткіштерінің нәтижелері бойынша бағаланды. Зерттеу астероидтардың берілген көрсеткішін болжаудың ең оңтайлы тәсілін таңдауға көмектеседі, модельдің ең жақсы көрсеткіштеріне қол жеткізу үшін деректерді алдын ала өңдеу процесін сипаттайды және осы аспан денелерінің қасиеттері арасындағы корреляцияны талдайды.

Тірек сөздер: машиналық оқыту, астероид, болжау моделі, KNN, linear regression, random forest, decision tree, gradient boosting.

Дүйсек Б.Е.*, Сарсембин Д.Д., Абдуразак К.А.

Казахстанско-Британский технический университет, 050000, г. Алматы, Казахстан
*E-mail: be_duisek@kbtu.kz

СРАВНЕНИЕ И АНАЛИЗ РАЗЛИЧНЫХ МЕТОДОВ МАШИННОГО ОБУЧЕНИЯ НА ПРЕДСКАЗАНИЯХ ДИАМЕТРОВ АСТЕРОИДОВ НА ОСНОВЕ БАЗЫ ДАННЫХ МАЛЫХ НЕБЕСНЫХ ТЕЛ NASA

Аннотация. База данных малых небесных тел NASA предоставляется Jet Propulsion Laboratory и представляет собой собранную информацию об астероидах и кометах, описывая их доступные для наблюдения и определения параметры, в том числе физические, также их классификацию и данные по количеству и длительности наблюдений. Множество этих небесных тех имеют неполное описание их свойств, что делает затруднительным предсказание их поведения и потенциальное взаимодействие с другими объектами в космосе, в том числе и рукотворными. Данное исследование предлагает решение определенной части проблем по исследованию астероидов путем нахождения предсказания диаметра астероидов, основываясь на информации из базы данных NASA и результатах работы методов машинного обучения по обработанным данным из изначального источника. Для этой работы

были выбраны некоторые из наиболее часто используемых алгоритмов для реализации подобных моделей предсказания, такие как: KNN, linear regression, random forest, decision tree и gradient boosting. Использованные алгоритмы машинного обучения были оценены по результатам точности предсказании диаметра, скорости работы и показателям среднеквадратичных ошибок. Исследование поможет выбрать наиболее оптимальный подход для предсказания данного показателя астероидов, опишет процесс предварительной обработки данных для достижения лучших показателей модели и проанализирует корреляции между свойствами этих небесных тел.

Ключевые слова: машинное обучение, астероид, модель предсказания, линейная регрессия, случайный лес, дерево решений, повышение градиента.

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Sencer Yeralan*[1], Laura Ancona Lee[2]

[1]ADA University Baku, Azerbaijan
[2] Internationalization Office, UNIP, Sao Paolo, Brazil
*E-mail: sencer.yeralan@gmail.com

GENERATIVE AI: CHALLENGES TO ACADEMIC QUALITY

Abstract. This study explores the intricate relationship between Generative Artificial Intelligence and Academic Quality, two domains that have robust technical and historical underpinnings. Originating from divergent research fields, an understanding of the impact of one on the other necessitates a foundational familiarity with both. We offer a comprehensive review that serves as a bedrock for future scholarly dialogue. We articulate key insights into how emerging generative technologies are anticipated to influence academic quality. Concurrently, we note that these technological advancements are emerging at a time of significant transformation and diversification within higher education. While it is premature to proffer definitive predictions, we argue that the impact of these technologies will be institution-specific, contingent upon the unique mission and vision of each educational entity. Our analysis and reflection suggests that institutions emphasizing critical thinking and innovation stand to gain more from the integration of Generative Artificial Intelligence technologies than those primarily focused on career preparation for students.

Key words: AI, Generative AI, academic quality, Higher education, ChatGPT

Introduction

Generative Artificial Intelligence (GAI) has rapidly expanded its presence within edu- cational institutions, finding acceptance among students, faculty, and staff alike. This technology exhibits the capability to engage in sustained interactive dialogues and pro- duce reasonably meaningful written content. Unsurprisingly, it is now a routine tool for faculty to generate questions and assignments, for students to submit assignments and facilitate self-directed learning, and for administration to craft manuals, memoranda, and policy documents. With its potential to drive significant social innovation, teetering on the brink of becoming a disruptive force, it appears highly improbable that it will fade into obscurity without becoming deeply integrated into nearly all facets of academic and pedagogical activities. While it is premature to precisely determine the role of this technology in education, we offer insights to assist in deliberations and provide a con- cise overview of the opportunities and challenges it presents. Our primary focus is on examining the impact of GAI on academic quality.

The concept of academic quality is inherently multifaceted, with various interpretations and ambiguities. Furthermore, definitions of academic quality are formulated differently by different institutions, each shaped by their distinct philosophies regarding higher education. These institutional philosophies can span a wide spectrum, ranging from traditions rooted in Humboldtian ideals to those of vocational schools, from an emphasis on job-oriented STEM disciplines to nurturing the social and emotional development of students.

Main provisions: AI Technology in Brief

Among all others, Artificial Neural Networks (ANN) serve as the foundational framework for contemporary commercially widespread use of AI. They originated in the mid-20th century with the aim of emulating the intricate structure of the human brain. The human brain comprises numerous interconnected neurons linked by synapses, facilitating the transmission of electrical signals. This observation gave rise to the notion that a similar network could generate electrical activity capable of manifesting various aspects of intelligence, including perception, cognitive processes, consciousness, self-awareness, and intellect.

In their nascent stages, these circuits featured as a building block a single neuron with multiple inputs and a single output. This was easily build upon the existing technology of analog computers in which input and output

voltages at each terminal represented the value of a system variable. All input signals underwent modification through their input function, often as simple as a multiplicative weight, before reaching a *summer* (Yeralan, 2023). The summer then aggregated the weighted voltages to yield a solitary output that passes through an activation function. Here, the neuron fires or not based on the strength of the output. Note that while some inputs strengthen the output, some may act as inhibitors, weakening the output. A single neuron constructed as such was referred to as a *perceptron*. While individual neuron units were developed as building blocks, they could be interconnected to create more intricate networks, encompassing a multitude of inputs and outputs. Typically, neurons are grouped into layers, representing stages. Then, a successive series of layers form a network. In this topology, while the inputs of the initial layer and the outputs of the final layer are available to communicate with the outside world, multiple hidden layers improves performance and accuracy. Such inside layers are referred to as "hidden layers" and networks employing potentially may hidden layers are called *deep neural networks*. From a mathematical viewpoint, each signal weight and each threshold function adds to the degrees of freedom of the system. The number of such parameters grows with the number of neurons. It is conjectured that the perceived intelligence of the entire network increases superlinearly with the total degrees of freedom, or the total number of independent parameters.

To employ the neural network, one must represent the input for the application as a vector containing specific values that encode its features. Consider, for instance, a facial recognition application that distinguishes cats and dogs. Initially, a set of features are extracted from a provided image, through image processing techniques. These features may include measurements like the normalized distance between the eyes, between the eyes and nose, and so forth. These feature values are then fed into the neural network, each as an input to a neuron. Each output of the network represents a different type of animal (dog, cat, other). The network's task is to identify the closest match and present its selection as the output.

The proper functioning of a neural network hinges on two key factors: the determination of input weights and the activation function. This determination process bears a resem- blance to curve fitting through the application of the least-squares method (Holland, 1992). It involves estimating parameter values to establish the most effective relation- ship between the network's output and input. Typically, the activation function form is set *a priori* while its parameters are free to change. With a large number of neurons, the number of parameters grows quite rapidly. It is not uncommon to have the size of the parameter space to exceed hundreds of millions of parameters. It is reported that (Open AI, 2023) ChatGPT versions 2, 3, and 4 had 1.5 billion, 175 billion, and 1.7 trillion parameters respectively.Determining the best values of system parameters poses a formidable challenge. How- ever, this task can be accomplished through an iterative procedure involving the pre- sentation of inputs and observing the corresponding outputs within the neural network. Internal to the network, a mathematical search process is employed to identify the system parameters that best establish a relationship between the provided inputs and outputs. This essential procedure is known as "training the neural network," and at its core, it resembles a curve-fitting endeavor whose mathematics are hidden within.

The logic underpinning ANNs is inherently straightforward. Individual neurons are not imbued with intelligence. Rather, intelligence is conceived as an emergent property arising from the interactions of a multitude of neurons. This perspective recognizes that each perceptron does not embody intelligence but contributes to the emergence of it. Notable thought experiments, such as the 1960s Game (Dneprov, 1961) and the 1980s Chinese Room (Searle, 1980), illustrate this concept brilliantly.

We conclude this brief overview reiterating the key point: AI in its most commonly imple- mented form relies on emergent behavior acquired through a vast parameter space. The practicality of its mathematical parametrization is done indirectly through input-output pairs (training), thereby removing the burden of directly solving for model parameters. The vast number of parameters provide extensive flexibility, allowing the network to be trained in any application. Notwithstanding the theoretical and philosophical implica- tions of the mathematical structure, we simply accept the technology to *almost* pass the Turing test (Turing, 1950).

GAI relies heavily on Natural Language Processing (NLP). It involves the deployment of a relatively extensive neural network featuring an extensive array of hidden layers. Until a short while ago, there was uncertainty regarding whether such a network could successfully emulate human language skills or facilitate authentic interactions through natural language inputs and outputs (Solaiman et al., 2019). The training process for contemporary NLP networks, particularly the Large Language Models (LLM) that have become commonplace, demands substantial computational resources, a considerable neural network size, and a multitude of hidden layers. Nevertheless, the fundamental logic behind this endeavor remains quite straightforward.

OpenAI's ChatGPT (Open AI, 2023), as detailed on their website, represents an ambi- tious endeavor involving the development of an LLM through extensive human trainer collaboration. GPT, an acronym for Generative Pre-trained Transformer, characterizes a neural network that evaluates words to select the most suitable continuation for an incomplete sentence. This description, though simplified, highlights the complexity in- herent in this process. Notably, it must navigate diverse potential conclusions for an initial sub-sentence, necessitating a decision on how to complete the sentence. Further- more, the system scrutinizes each word within a sentence for overall coherence with the entire statement. Despite this intricacy, the system chooses words and phrases to generate textual output. In a manner akin to conventional grammar and spell check- ers, this neural network is equipped with rules and the capacity to ensure grammatical correctness and proper punctuation of its output.

Another noteworthy and advantageous feature that sets ChatGPT apart from conven- tional search engines is its utilization of the "*Open Session*" concept, which incorporates previous interactions into its generation of new text. Consequently, ChatGPT is not limited to a mere query-and-response process, as is typical with search engines. Instead, it can be employed iteratively, involving a cycle of requesting information, submitting queries, reviewing responses, and refining queries. For instance, one might initially re- quest ChatGPT to provide a recipe for a dish and subsequently refine the request byasking for a more spicy version. This interactive episodic search experience creates the impression of communicating with a human being, heightening the perception of Chat- GPT as a collaborator or co-pilot.

Materials and Methods

Academic Quality

The study of the effects of GAI on academic quality holds as a prerequisite a clarification of the notion of academic quality itself.

The Merriam-Webster Dictionary defines the adjective "quality" to refer to "high qual- ity", i.e., having a large degree of "quality". As a noun, the dictionary provides several entries. Of those, we list the ones that are most relevant to academic quality (Table 1).

Table 1 – Academic quality

1	Nature, Property	peculiar and essential character, e.g., "a disturbing quality of on-line education"
2	Characteristic, Timber, Vividness	distinguishing attribute, e.g., "the tonal quality con- tributed to the overall success of the band"
3	Grade, Rank	degree of excellence, superiority in kind, e.g., "the quality of the cafeteria food was a determining factor"

A common source of confusion and miscommunication in academia is due to the various different definitions of "quality". At the simplest level, do we speak of "characteristics" or of "rank"? That is, are we focused more on "what attributes are appropriate for education" or "the level of our excellence"? Moreover, if the latter, to what do we compare our level? Is it our past performance, or that of other institutions? Given that there are different determinants of "excellence" and that no single institution is a non-dominated superior in all such factors, which factors do we prioritize, and why? Presumably, the "why" must be related back to the national and regional needs of the community the institution is serving, which in itself is a demanding task.

The confusion is highlighted in an OECD study (H´enard & Leprince-Ringuet, 2008) regarding teaching quality.

But quality teaching lacks a clear definition, because quality can be regarded as an outcome or a property, or even a process, and because conceptions of teaching quality happen to be stakeholder relative.

At the onset, we must also note that there are interrelated concepts, often associated and sometimes confused with quality, such as *faculty performance* or *student achievement*.

As we contemplate "academic quality", we are mindful of existing literature. Typically, the literature classifies academic quality issues under a few domains.

- Course design, development, and deployment
- Course resources (laboratories, library, etc.)
- Faculty competency and well-being
- Student support

- Institutional and administrative support
- Evaluation and assessment

This is by no means an exhaustive set, but rather what one encounters the most in the literature. Nonetheless, these aspects are useful in developing an operational definition of the concept.

Moreover, the flurry of activity during the past few decades has led to the notion of the "quality culture". As it applies to higher education, much have been debated as to how and why such a culture must be established, and what factors have positive or negative effects on such an institutional culture of quality. A good summary is from Bendermacher et al. (Bendermacher et al., 2017). A radicalization of the notion of "quality culture" is also present in the literature. For instance, DeMarco and Lister use the term the "cult of quality" (DeMarco & Lister, 1999).

Bendermacher et al. (Bendermacher et al., 2017) submit that the quality culture, while may have the intention and potential to promote clear policies, people-oriented shared values, a climate of trust and shared understanding, and the clarification of responsibili- ties, it also may result in a hierarchical divided structure, top-down management, a rigid control-oriented culture, act as communication gatekeepers, and discourage sharing best practices among competing divisions. An immediate derivative of this view is that the benefits of the quality culture are more easily achieved in a liberal and inclusive envi- ronment compared to a more rigid-control oriented one predisposed to more autocratic practices.

A Definition of "Academic Quality"

There may be a myriad of definitions of academic quality. Of the few definitions enter- tained, perhaps the best is represented by that from the University of Glasgow. The University of Glasgow ("Academic Quality Framework", 2021) defines academic quality as

Academic quality is a way of describing how well the learning opportunities available to students help them to achieve their award. It is about making sure that appropriate and effective teaching, support, assessment and learning opportunities are provided for them.

This definition proposes that the academic environment is responsible for the establish- ment of favorable conditions for learning. The onus of learning is on the students. If some students succeed in learning then the academic environment should be declared as being of sufficient quality. An immediate corollary of this definition is that any measure- ment of quality is not contingent on the success of all students. It is entirely possible that the institution is of sufficient quality (i.e., is providing a fertile environment for learning) but the students chose not learn. After all, the student has the legal right to take a class and fail if she so desires[1].

This notion is often openly declared, for instance, as illustrated by the Atlanta Metropoli- tan State College (AMSC, 2023) website, which gives students advise on academic success.

Remember that you alone are responsible for your academic achievement. Your instructor is your guide and your classmates may help you to under- stand your assignments; however, you are responsible for your own success.

Some posit that quality improvement starts with the students. This notion has even prompted discussion on how to empower students as agents of change (Kay et al., 2010).

It is clear from even a cursory review of the literature that the concept of academic quality lacks a sufficiently universal definition that would allow a rigorous evaluation of any potential effects of GAI on quality. Such a quest may proceed by selecting a set of definitions and developing an understanding based on that contingency. However, it may be best to view such lack of a common understanding as an indication and invitation to further scrutinize pertinent components of the phenomena with hopes to develop alternative contemporary conceptualizations of education and academic quality as a larger system.

Indicators of "Academic Quality"

Academic quality is almost always measured by a set of performance measures or in- dicators. These are typically quantitative measures, whose values are easily treated as statistics. One could perform many arithmetic operations, such as computing averages, standard deviations, ranges, modes, medians, etc. The numerics also allow for the values to be compared to past performances, to extract trends, and to set flags when thresholds are breached.

On a more general survey (Strang et al., 2016) regarding the factors that influence academic excellence, a pre-pandemic study lists about two dozen indicators grouped under three categories: student experience,

teacher performance, and institution. Most indicators seem to be weak in their predictive power. Only a few seem to have a moderate value in determining and assessing teaching quality. This is quite troublesome, as quality is often quantified and measured so that its improvement could be tracked and reported. While all indicators fare rather poorly, the somewhat marginally relevant indicators fall under the category "institution". This may be a revealing result, as it seems to point to the notion that the primary function of a university is the physical infrastructure that allows students and teachers to interact. This may seem as a departure from the notion that students as interested agents and teachers as mentors constitute the primary component of education. Any such a departure may also be evaluated by entertaining the notion that education in general has been experiencing a shift in focus, modalities, purpose, and outcome.

The Changing Landscape of Higher Education

One must also be mindful of the changes in higher education. These are affected by technological developments as well as social, political and economic processes.

The universities and professors are no longer seen as the only reservoir of information. One can learn from many sources. A response to this fact has manifested itself in the concept of the *flipped classroom*. However, it could be argued that the ample availability of knowledge outside the university would have to be addressed by more substantial modalities than a simple flipping.If students do not come to the university for knowledge, then what exactly is the attrac- tor? Below is an incomplete list.

- Social skills
- Future professional networking
- Facilities, e.g., laboratories
- Team work, interdisciplinary work
- Belonging to an exclusive society
- A diploma
- Access to industry/professional institutions

If indeed the function of the university is in flux, then so must the approach to academic quality. In fact, one could argue that the determination of the specific function or functions of the university is a prerequisite for the way academic quality matters are to be structured.

A strong case is made in the literature regarding the effects of neo-liberal pressures on higher education (Brown, 2015; Marginson, 2016; Slaughter & Rhoades, 2004). While there is much criticism regarding the perceived overreach of neo-liberalism into education (Readings, 1996), others see the influence as a component of the change to knowledge- based economies (Olssen & Peters, 2005).

The end of the Cold War served as a pivotal moment, not just in geopolitics, but also in the conceptual framing of higher education's role and structure (Harvey, 2007). Neo- conservatives interpreted the collapse of the Soviet Union and the end of the ideological battle between capitalism and communism as a definitive victory for free-market capital- ism. This interpretation led to the belief that the principles underlying competitive, open markets were universally applicable and should be adopted by all institutions, including higher education (H. Giroux, 2002).

This ideological shift further accelerated the corporatization of higher education. The logic of the market was increasingly imposed on academic institutions, reinforcing the view that they should operate like corporate businesses to be efficient, profitable, and ostensibly, more effective. The neoliberal and neo-conservative ideologies converged in their influence, intensifying the focus on vocational training, commercialization, brand- ing, and market orientation. This exacerbated the existing trends of privatization and fundamentally altered the ethos of higher educational institutions, diverting them further from their original missions of broad-based, liberal education and critical inquiry.

The triumphalist interpretation of capitalism's "victory" over communism or even all other forms of social structures (Fukuyama, 2006; Barber, 1996) not only impacted eco- nomic and political spheres but also had a profound and lasting influence on the many industries including the academic world. The evolving corporate philosophies and oper- ational strategies during the late 20th century in Western economies can be interpreted as a strategic response to the emergence of new economic powers, primarily in Asia, during the 1970s. Existing management frameworks such as Total Quality Management (TQM) (Deming, 2018), ISO 9000 standards (Hoyle, 2009), Lean Manufacturing (Wom- ack et al., 2007), and Six Sigma (Singh & Rathi, 2019) appear to have facilitated a seamless transition for Western corporations into the neoliberal economic model, which

gained prominence during this period (Harvey, 2007). With this background, neolib- eral views justified and intensified the application of market principles to educational institutions, cementing the shift towards a more commercialized, market-driven model of higher education (Slaughter & Rhoades, 2004; Marginson, 2011).

Typical claims include students seeing themselves as a customer and their diploma as a commodity (H. A. Giroux, 2014; Bok, 2009). This fits well with the view that university education is for the purpose of acquiring the skills and knowledge for the workforce. As a departure from the Humboldtian principles of enlightenment, this view emphasizes the "vocational school" aspect of education. These developments have been received by much dismay among much of the established academic community (Readings, 1996; Nussbaum, 2016).

Results and Discussion

Uses of AI in Higher Education

The utilization of AI in the realm of higher education is not a recent occurrence (Amershi et al., 2014; Belda-Medina & Calvo-Ferrer, 2022; Kuhail et al., 2023). It has given rise to certain apprehensions, primarily centered on the concern that students may exploit AI-driven tools to complete their academic assignments with minimal genuine effort. Additionally, educators might employ such tools to generate multiple-choice quizzes or presentations for their courses. Such a scenario may spiral down to the instructors' AI communicating with the students' AI, nullifying the exercise from any trace of learning or intellectual growth.

While AI-powered tools can prove valuable in the initial stages of brainstorming and drafting, there exists a valid worry regarding the potential for academic dishonesty. Plagiarism detection systems have grown increasingly sophisticated in identifying content generated by AI systems. Nevertheless, it remains conceivable to submit AI-generated output as original work. As is customary, the progression of technology for creation and detection evolves in tandem, with each feeding off and influencing the development of the other.

On one hand, the potential for the misuse of GAI exist, potentially short-circuiting the pedagogical process by allowing students to produce output without intellectual growth. On the other side of the debate lies the fact that GAI can serve as a valuable asset in streamlining many of the cognitive processes, the least of which is writing. One can request GAI to produce alternative responses and multiple iterations of an initial draft, thereby enhancing and simplifying the initial brainstorming phase and enriching the thinking process. Therefore, the proposition that universities summarily should ban the use of GAI must be carefully reviewed not to result in an erroneous reflex response.

AI in Future Higher Education

With the complex historical tapestry of pertinent technological, social, political, and economic constructs, it is clear that any future use of AI in higher education will be a heterogeneous, case-dependent proposition. Accordingly, any ethical or normative considerations will be varied. In short, the implementation of AI as well as the wide range of educational modes and structures will inevitably lead to a very wide range of dissimilar uses, implementations, regulations, and views.

A case in point, an educational institution that has centered itself as a resource to prepare students for their careers and jobs may discourage the use of GAI by its students. The justification is clear: these schools focus on skills that must be learned and exercised by graduates. Using AI tools to pass check-points that verify that such skills are acquired clearly undermines the mission of the school. Here, one may expect a shift towards the use of oral examinations or presentations in front of a panel of instructors to pass such check-points.

On the other hand, schools that have taken upon themselves the mission to provide the fertile grounds for students to reach further enlightenment through their individual path choices, schools that prioritize creative and innovative thinking beyond job-skill acquisition, are likely to find GAI a useful too that promotes brainstorming while reduces some of the tedium in the process by undertaking the routine aspects of the work.

The discourse surrounding the impact of AI on employment is complex and multi-faceted, often framed by polarized narratives. One assertion posits that AI will not directly displace workers but will empower a single individual to accomplish tasks traditionally requiring multiple persons. Implicit within this is the concern that this singularly enabled individual becomes the agent of job displacement for others.

This viewpoint aligns with the concept of "skill-biased technological change," which sug- gests that technological advancements often disproportionately benefit skilled workers while making unskilled workers redundant (Autor et al., 2003). By amplifying the capa- bilities of a skilled individual, AI serves as a force multiplier that enables that individual to execute functions previously requiring a team, thereby rendering others in the team expendable.

The notion that one person, amplified by AI, will be the agent of job displacement also resonates with theories related to economic inequality. For instance, the "winner-takes- all" market phenomenon (Frank & Cook, 2013) can be seen as extended into the realm of employment by AI, where the 'winner' is the individual most adept at leveraging AI technologies to their advantage.

However, it is crucial to also consider counterarguments. The "complementary" nature of human-machine interaction suggests that while certain tasks may be automated, new roles that require human creativity, emotional intelligence, or domain-specific expertise may emerge (Agrawal et al., 2018). After all, this pattern has been repeated over the last millennium as new disruptive technologies emerged, from steam to electricity, to information, etc.

GAI is unlikely to act as a monolithic force that invokes a uniform response from academia. We do submit, thought, that those universities whose mission better aligns with skill transfer will tend to suppress the use of AI and GAI, while those institu- tions that align more with innovation and enlightenment will tend to find a useful place in their work, potentially leveraging the new technology to develop new modalities of instruction.

Conclusion

The effects of AI on higher education on academic quality is subject to still evolving phenomena whose diagnosis requires the preponderance of many technological, social, political, and economic factors. Defining and improving "quality", whatever that may entail for the specific institution, is a good place to start the soul-searching effort towards institutional identity, character, culture, purpose, and effectiveness. In this respect, the institution may benefit from intensive and continuous discussions on the subject matter.While this brief report leaves much to be desired, at the least, institutions may recognize that the field is yet to be fully developed and established to provide grounds to seek a robust long-term worldview. The recognition that the phenomena is multi-faceted and far from a monolithic proposition will be of benefit in any quest.

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Information on the authors

Sencer Yeralan PE (corresponding author)
PhD Professor, ADA University Baku, Azerbaijan,
ORCHID: 0000-0002-8689-5268
E-mail: sencer.yeralan@gmail.com

Laura Ancona Lee
PhD, Dean of Academic Internationalization UNIP, S˜ao Paulo, Brazil
E-mail: internacionalizacaoacademica2@unip.br
ORCHID: 0000-0002-9930-6119

Авторлар туралы мәліметтер

Сенджербей Ералан (корреспонденция авторы)
Профессор, АДА университеті, Баку қ., Әзірбайжан,
ORCHID: 0000-0002-8689-5268
E-mail: sencer.yeralan@gmail.com

Лаура Анкона Ли
PhD, Интернационалдандыру кеңсесінің деканы, UNIP, Сан-Паулу қ., Бразилия
E-mail: internacionalizacaoacademica2@unip.br
ORCHID: 0000-0002-9930-6119

Сведения об авторах

Сенджербей Ералан (автор для корреспонденции)
Профессор, Университет АДА, Баку, Азербайджан
ORCHID: 0000-0002-8689-5268
E-mail: sencer.yeralan@gmail.com

Лаура Анкона Ли
PhD, декан офиса интернационализации, UNIP, Сан Паоло, Бразилия
E-mail: internacionalizacaoacademica2@unip.br
ORCHID: 0000-0002-9930-6119

Сенджер Ералан*[1], Лаура Анкона Ли[2]

[1]ADA университеті, Баку қ., Әзірбайжан
[2] UNIP интернационалдандыру кеңсесі, Сан-Паулу қ., Бразилия
*E-mail: sencer.yeralan@gmail.com

ГЕНЕРАТИВТІ ЖИ: АКАДЕМИЯЛЫҚ САПА МӘСЕЛЕЛЕРІ

Аңдатпа. Бұл зерттеу генеративті жасанды интеллект пен академиялық сапа қиылысына тоқталады. Бұл екі сала да техникалық және тарихи әдебиеттерде кеңінен ұсынылған. Зерттеу салалары әртүрлі болғандықтан, бірінің екіншісіне әсер етуіне мағыналы жауап беру үшін кез келген ізденіс кем дегенде әрқайсысына әсер етуді қамтуы керек. Біз қосымша талқылауларды жеңілдету және жаңа технологияның академиялық сапаға әсері туралы тиісті ойларды ұсыну үшін осы салаларға қысқаша шолуды ұсынамыз. Сондай-ақ мақалада генеративті ЖИ-дің жоғары білімге оң ықпалы талқыланады және болашақ коммуникацияда, ұжымдық жұмыста ЖИ-ді қолданудың болашақ бағыттары көрсетіледі.

Тірек сөздер: ЖИ, генеративті ЖИ, академиялық сапа, жоғары білім, ChatGPT.

Сенджер Ералан*[1], Лаура Анкона Ли

[1]Университет ADA, г. Баку, Азербайджан
[2] Офис интернационализации UNIP, г. Сан-Паулу, Бразилия
*E-mail: sencer.yeralan@gmail.com

ГЕНЕРАТИВНЫЙ ИИ: ПРОБЛЕМЫ АКАДЕМИЧЕСКОГО КАЧЕСТВА

Аннотация. Данное исследование посвящено пересечению генеративного искусственного интеллекта и академического качества. Обе эти области широко представлены в технической и исторической литературе. Поскольку области исследований разнородны, любой поиск значимого ответа на влияние одной на другую должен включать как минимум воздействие каждой из них. Мы даем краткий обзор этих областей, чтобы облегчить дальнейшее обсуждение и представить соответствующие мысли об ожидаемом влиянии новой технологии на академическое качество. В документе также обсуждается положительное влияние генеративного ИИ на высшее образование и демонстрируются будущие направления использования ИИ в будущем общении и коллективной работе.

Ключевые слова: ИИ, генеративный ИИ, академическое качество, высшее образование, ChatGPT.

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Исахов А.А.*[1,2], Байбатырова К.Е.[1]

[1]Казахстанско-Британский технический университет, 050000, г. Алматы, Казахстан
[2]Казахский национальный университет имени аль-Фараби, 050040, г. Алматы, Казахстан
*E-mail: al.isakhov@kbtu.kz

ВЛИЯНИЕ ТЕПЛОФИЗИЧЕСКИХ СВОЙСТВ ЖИДКОСТЕЙ НА КОНВЕКТИВНЫЙ ТЕПЛОПЕРЕНОС В ЭЛЕКТРОННЫХ УСТРОЙСТВАХ

Аннотация. Влияние соотношения сторон корпуса и различных теплофизических свойств жидкостей на теплопередачу было исследовано в прямоугольном корпусе с массивом микросхем размером 3x3, установленных заподлицо, размещенных на передней вертикальной стенке с постоянной температурой и охлаждаемых противоположной стенкой. Для изучения теплопередачи внутри корпуса было проведено моделирование для четырех соотношений сторон корпуса (A=1.0, 5.0, 7.5, 20.0) и пяти различных сред (воздух, вода, FC-40, FC-72, FC-88). Численные результаты показывают, что самые высокие скорости наблюдаются в воздухе, в то время как низкие скорости были замечены в воде и в трех диэлектрических жидкостях FC-40, FC-72, FC-88. Максимальные скорости воздуха для компонента W получены на высоте Z= 5.5. Замечено, что при уменьшении соотношения сторон корпуса скорость потока жидкости увеличивается. Максимальное число Nu было обнаружено, когда корпус был заполнен диэлектрическими жидкостями FC-72 и FC-88, а минимальное – в воздухе. Чтобы убедиться в том, что выбранные численные методы, компьютерная программа были реализованы корректно, была выполнена тестовая задача. Между результатами обнаружено хорошее соответствие.

Ключевые слова: теплопередача, микросхемы, соотношение сторон, теплофизические свойства жидкостей, диэлектрические жидкости.

Введение

В современном мире, где многие процессы автоматизированы, технологии стали неотъемлемой частью нашей жизни. Во многих устройствах, которые нас окружают, используется интегральная схема. При длительной и высокопроизводительной работе в микросхемах повышается температура и выделяется тепловой поток. Однако нужно отметить, что безопасный предел температуры в микросхемах – 85 °C [1]. Соответственно, вопрос об эффективном охлаждении в электронных устройствах остается актуальным и сегодня, так как есть возможность повысить долговременную надежность соединения на 50% при каждом снижении температуры на 20 °C [2]. Пристальное внимание уделяется естественной конвекции в корпусах из-за того, что она находит применение в охлаждении электронных устройств. Из-за практической значимости данной темы было рассмотрено множество экспериментальных, численных и теоретических исследований.

Chu et al. [3] провел двумерное исследование в горизонтальном канале, где на вертикальной стене расположен источник тепла, а противоположная стена охлаждалась. В ходе исследования изучалось влияние изменений расположения, размера, соотношения сторон источника тепла. Chadwick et al. [4] в вертикальном корпусе исследовали естественную конвекцию с одним и несколькими двумерными источниками тепла, установленными заподлицо. В своем исследовании они брали во внимание такие параметры, как соотношение сторон, диапазон чисел Грасгофа и расположение источников тепла. Ahmed Refai and Yovanovich [5] рассмотрели заполненный воздухом квадратный корпус, где между нижней и верхними частями вертикальной границы изменяется расположение источника тепла. Варьируя местоположение нагревателей и граничные условия, они изучили влияние на скорость теплопередачи в диапазоне Ra от 0 до 10^6. В квадратной полости Shuja et al. [6] провели исследование с различными соотношениями сторон от 0.25 до 4 в выступающем источнике тепла. Было выяснено, что соотношения сторон в выступающем источнике тепла имеют внушительное влияние на характеристики теплопереноса.

Ogut [7] исследовал в двумерном наклонном квадратном корпусе с источником тепла, локализированном в центре на левой вертикальной стороне, и охлаждающейся правой стороной с использованием пяти наножидкостей на основе воды. С учетом горизонтальной и вертикальной ориентации пластины Kang and Jaluria [8] экспериментально изучили влияние разных факторов на коэффициент конвективной теплопередачи и тепловое поле. Fujii et al. [9] рассмотрели в вертикальных параллельных пластинах с выступающими источниками тепла естественную конвекционную теплопередачу. С несколькими выступающими нагревателями в прямоугольном корпусе с охлаждающейся верхней стенкой Desai et al. [10] смоделировали численно естественную конвекцию. Afrid and Zebib [11] в своей работе использовали двумерную сопряженную модель ламинарного течения и численно смоделировали воздушное охлаждение одиночных и нескольких равномерно нагретых устройств, расположенных на вертикальной стене, с использованием естественной конвекции.

Исследование с пятью выступающими нагревателями, расположенными вертикально на вертикальной стенке в прямоугольной полости, провели Keyhani et al. [12]. Оценивалось влияние на естественную конвекцию различных соотношений сторон полости. Chuang et al. [13] выполнил исследование, где анализировалось изменение температуры в трех чипах при пяти различных позициях в трехмерном ламинарном потоке естественной конвекции. В прямоугольном корпусе, заполненном диэлектрической жидкостью FC-75, Wroblewski and Joshi [14] рассмотрели влияние различных размеров выступающих чипов и корпуса на максимальную температуру чипа. Была изучена естественная конвекция Sezai and Mohamad [15] в горизонтальном корпусе с одним источником тепла, который был расположен в нижней части корпуса и охлаждался сверху. Liu et al. провели несколько исследований с применением сопряженной теплопроводности-конвекции на подложке в корпусе [16], в цилиндре [17], в подземном прямоугольном воздуховоде [18]. Изменяя расположение трех источников тепла, Liu et al. [16] провели моделирование сопряженной теплопроводности-конвекции. Высокая температура была обнаружена на верхнем чипе при вертикальном и шахматном расположении трех чипов. В горизонтальном канале с массивом 6x3 нагревателями, расположенными на вертикальной стене, Gavara and Kanna [19] численно изучили трехмерную естественную конвекцию.

Существует ряд работ, касающихся моделирования естественной конвекции в корпусах с массивом дискретных источников тепла 3x3. Такое моделирование было проведено Joshi et.al. [20] в корпусе с прямоугольными выступами, где они изучили экспериментально естественное конвекционное охлаждение с использованием диэлектрической жидкости FC-75. Mukutmoni, Joshi, Kelleher [21] (1995) для массива выступов размером 3x3, которые охлаждались погружением в жидкость FC-75, исследовали влияние теплопроводности подложки на естественную конвекцию. Tou et.al. [22], используя похожее расположение источников тепла, изучили естественную конвекцию в прямоугольном корпусе, заполненном различными жидкостями (вода, FC-72, FC-77, этиленгликоль). Tou and Zhang [23], применили ту же геометрию, что и в работе [22], они поворачивали корпус, заполненный жидкостью, вокруг горизонтальной оси X, чтобы оценить влияние наклона на процессы теплопереноса. Tso et al. [24] провели похожее исследование в наклонной прямоугольной полости с нагревателями 3x3, где анализируют сложные взаимодействия тепловых полей и полей внутреннего потока жидкости. С целью исследовать охлаждение электронного оборудования с использованием наножидкостей Purusothaman [25] выбрали трехмерный прямоугольный корпус с естественной конвекцией и источниками тепла, расположенными 3x3 на одной из стенок.

Основные положения

Для проведения численного моделирования были использованы уравнения Навье-Стокса:

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\vartheta\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\vartheta\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\beta g(T-T_0)$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho}\frac{\partial p}{\partial z}+\vartheta\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)$$

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right)$$

Материалы и методы

В данной работе исследуется теплоперенос в прямоугольном корпусе с использованием различных жидкостей. Для моделирования естественной конвекции в прямоугольном корпусе с изменением соотношений сторон и при различных жидкостях была выбрана схема, основанная на изменении давления в связи с ламинарным потоком. Гравитационное ускорение было направлено отрицательное по z-направлению. Анализ сетки был выполнен для повышения точности вычислений, на основе этого анализа было обнаружено, что размер элемента 0.4 мм подходит лучше всего. Выше указаны граничные условия, которые применялись. Теплофизические свойства жидкостей, которые были использованы при вычислениях, указаны в таблице 2.

Геометрия исследуемой области изображена на рисунке 1. Параметры и размеры геометрии были использованы те же, что и в работе Tou et.al. [22]. На вертикальной передней стенке расположен массив 3x3 чипов. Размер всех чипов одинаковый, и они имеют квадратную форму (12.7x12.7 мм). В данном исследовании температура стоит именно на чипах, которые расположены на передней стенке, так как именно они нагреваются. Противоположная стенка является холодной. Остальные стенки остаются адиабатическими. Во время моделирования изменялась только ширина корпуса, все остальные параметры геометрии оставались неизменными.

Для решения трехмерных уравнений Навье-Стокса был выбран алгоритм SIMPLE. Для переменных конвективно-диффузионного переноса используется схема степенного закона. Была применена стандартная инициализация. Расчеты велись с шагом по времени 0.1 и выполнено 10 000 интераций. Чтобы быть уверенным в правильности выбранных численных методов и убедиться, что компьютерная программа была реализована правильно, сначала была решена тестовая задача, результаты которой сравнивались с результатами Tou et.al.[22].

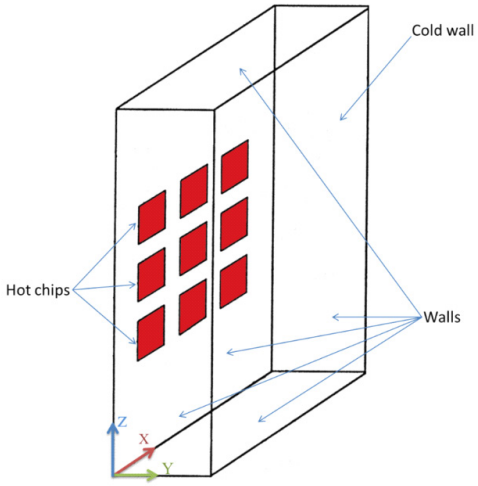

Рисунок 1 – Геометрия исследуемой области

Таблица 1 – Размеры геометрии корпуса

Ширина (мм)	Высота (мм)	Длина (мм)	Соотношение сторон (мм)
95.25	95.25	57.2	1.0
19.05	95.25	57.2	5.0
12.7	95.25	57.2	7.5
4.7625	95.25	57.2	20.0

Таблица 2 –Теплофизические свойства

Свойства	Воздух	Вода	FC-40	FC-72	FC-88
p(kq/m³)	1.225	998.2	1870	1680	1640

Продолжение таблицы 2

c_p*(J/kqK)*	1007	4184	1050	1050	1050
k (W/m K)	0.02476	0.5674	0.067	0.059	0.056
v(kq/ms)	1.802e-05	0.00123	0.0041	0.00064	0.0005
β (K^{-1})	0.0035	0.0001523	0.0012	0.0016	0.0016

Граничные условия:
На чипах: $\theta = 358.15K, u = v = w = 0$
На холодной стенке: $\theta = 288.15K, u = v = w = 0$
На стенках: $\frac{\partial \theta}{\partial x} = 0, u = v = w = 0$

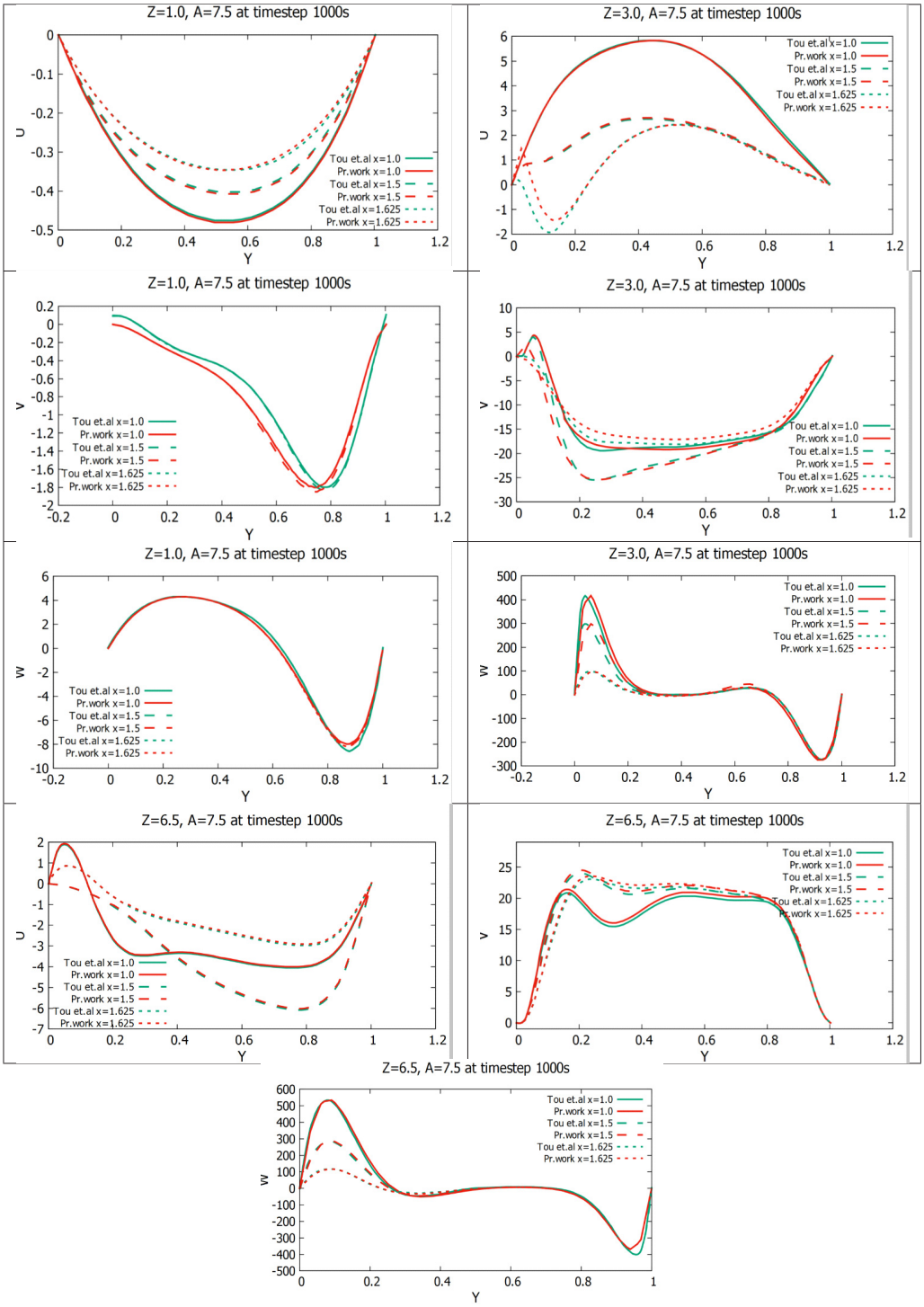

Рисунок 2 – Профили скоростей *U,V,W* на Z=1.0, Z=3.0, Z=6.5

Результаты и обсуждение

На рисунке 3 представлены результаты влияния свойств жидкости на поведение потока жидкостей. Полученные результаты показали, что среди U, V, W компонентов скоростей во всех соотношениях и при различных жидкостях именно компоненты по W имеют высокие скорости. Поэтому было решено рассматривать результаты только по W-компоненту. На рисунке 3 изображены скорости по W-компоненту в разных средах при соотношениях сторон A=1.0, 5.0, 7.5, 20.0 и взятые на различных высотах Z=1.0, Z=3.0, Z=5.5, Z=6.5. Сравнивая значение скоростей по W во всех соотношениях сторон и высот, было обнаружено, что именно в воздухе самые максимальные показатели скорости, нежели в других жидкостях. В воде, FC-40, FC-72, FC-88 наблюдаются низкие скорости. Это можно объяснить тем, что вязкость жидкостей больше, чем вязкость воздуха. Так как это ламинарное течение, где в движении жидкости преобладают силы вязкости, то с увеличением вязкости жидкости увеличивается ее сопротивление потоку, а это приводит к снижению скорости жидкости. Также низкая плотность воздуха обеспечивает легкость течения, а значит, увеличивается скорость.

Однако не на всех высотах скорости по W-компоненту высокие. Например, на высоте Z=1.0 скорости низкие по сравнению с показателями на высотах Z=3.0, Z=5.5, Z=6.5. Максимальные показатели скорости воздуха по W-компоненту получены именно по высоте Z=5.5, но при приближении к потолку корпуса (Z=6.5) скорости начинают снижаться. Это означает, что, приближаясь к холодной стене, поднимающийся поток флюидов начинает замедляться.

С увеличением соотношения сторон корпуса можем наблюдать (рисунок 3), как показатели скорости W снижаются даже в воздухе, так как уменьшается толщина корпуса, в связи с чем происходит ограничение потока стенкой и у жидкости меньше пространства, чтобы перемещаться. С уменьшением соотношения сторон корпуса скорость жидкости увеличивается. Следовательно, можно сделать вывод, что увеличение ширины корпуса приводит к тому, что движение жидкости становится более сложным и образовываются многовихревые структуры. Также увеличение ширины в прямоугольном корпусе способствует уменьшению пограничного слоя, и тепловые шлейфы становятся более узкими и концентрированными, это приводит к высоким скоростям жидкости вблизи центра корпуса, где тепловые потоки наиболее интенсивные.

Результаты (рисунок 4) показывают, что соотношение сторон и теплофизические свойства сред имеют большое влияние на теплоперенос внутри корпуса. Например, на рисунке 4 (a) видно, что при соотношении сторон A=1.0 число Нуссельта минимально, но с увеличением соотношений сторон можно заметить, как число Нуссельта тоже увеличивается, при A=20.0 (рисунок 4(d)) наибольшее число Нуссельта по сравнению с другими соотношениями сторон. Это позволяет сделать вывод, что с увеличением соотношения сторон можем наблюдать увеличение числа Нуссельта. Это объясняется тем, что при увеличении соотношения сторон уменьшается ширина корпуса, это, в свою очередь, приводит к уменьшению площади поверхности, тепло, исходящее от микросхем, распространяется активнее в меньшей площади поверхности, чем в большей площади. Когда соотношение сторон уменьшается, происходит наоборот: стенка, на которой расположены чипы, и холодная стенка становятся все дальше и дальше друг от друга, соответственно, тепло, исходящее от микросхем, распространяется не так активно.

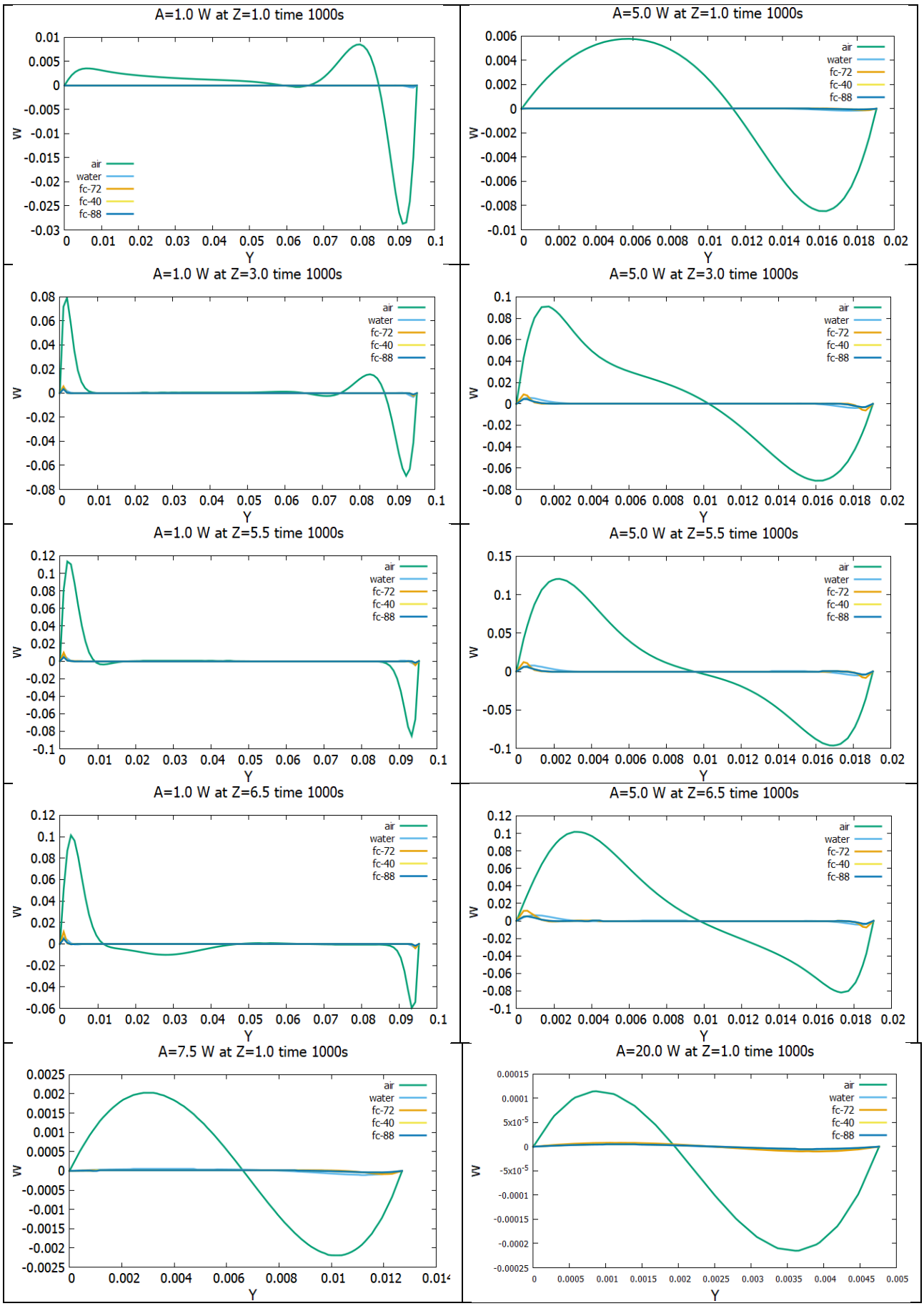

Рисунок 3 – Профили скоростей по W на разных Z, когда X=1.0: (a) A=1.0; (b) A=5.0; (c) A=7.5; (d) A=20.0

Продолжение рисунка 3

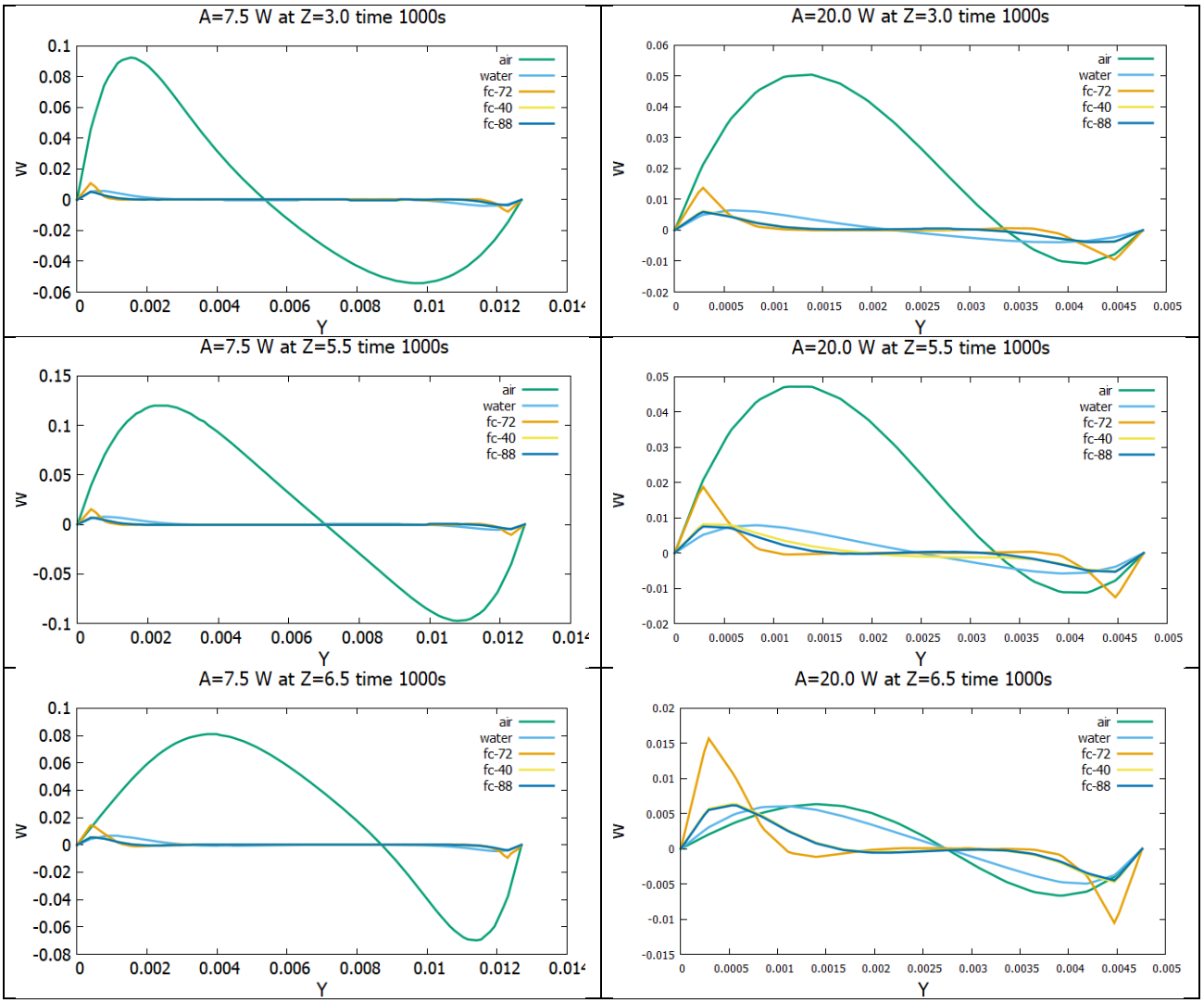

Рисунок 3 – Профили скоростей по W на разных Z, когда X=1.0: (a) A=1.0; (b) A=5.0; (c) A=7.5; (d) A=20.0

На рисунке 4 (a) при соотношении сторон A=1.0 максимальное число Нуссельта наблюдается при использовании диэлектрической жидкости FC-72, а минимальное – в воздухе. При остальных соотношениях сторон ситуация аналогичная. Отсюда следует вывод, что теплофизические свойства жидкости оказывают большое влияние на число Нуссельта. Маленькое число Нуссельта в воздухе указывает на то, что в воздухе плохая конвекция. Небольшое число Нуссельта в воздухе по сравнению с другими жидкостями связано с низкой теплопроводностью и низкой плотностью воздуха, что, в свою очередь, приводит к снижению скорости теплопередачи за счет естественной конвекции. Также в воздухе выталкивающие силы слабее, чем в жидкостях, поэтому это приводит к менее эффективной конвективной теплопередаче. Самые высокие значения числа Нуссельта наблюдаются в диэлектрических жидкостях FC-72 и FC-88, это связано с особыми теплофизическими свойствами этих жидкостей. Из этого следует, что эти две жидкости способствуют эффективной конвективной теплопередаче.

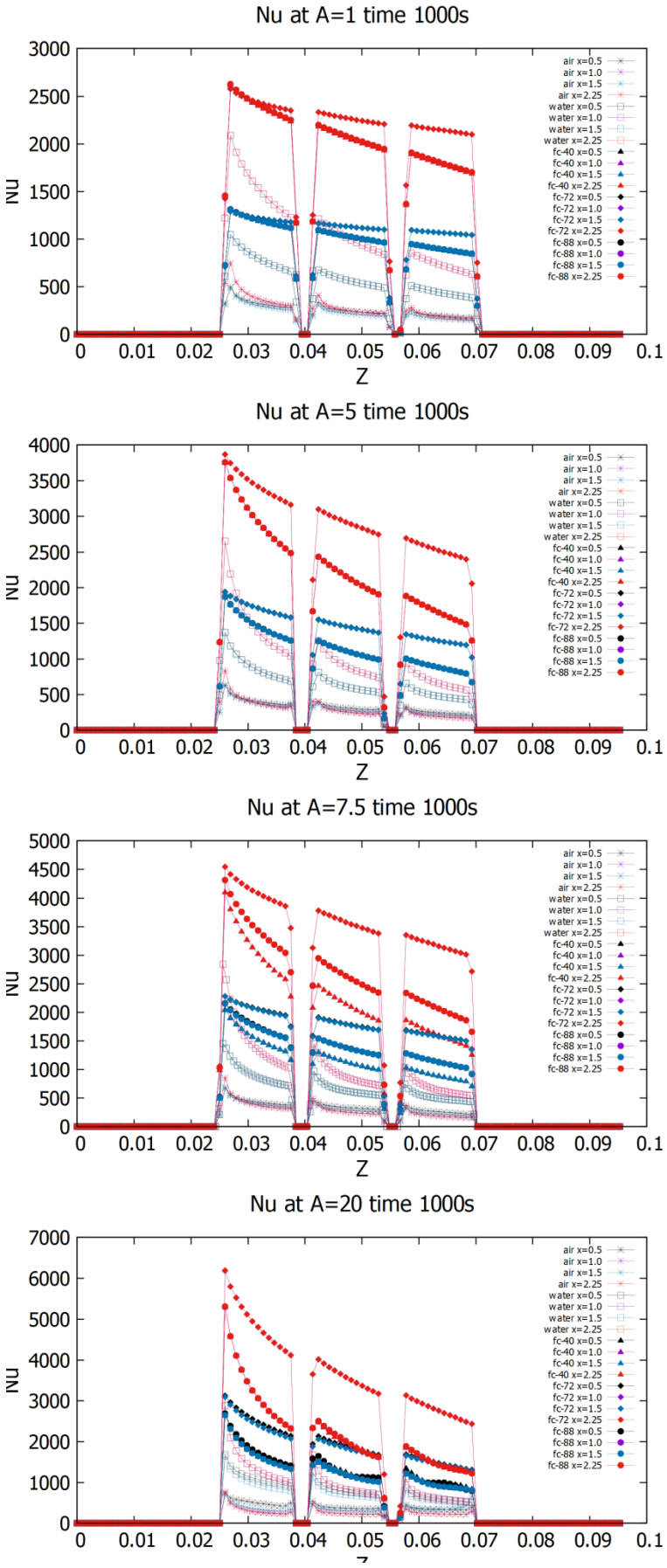

Рисунок 4 – Число Nu в разных соотношениях сторон: (a) A=1.0; (b) A=5.0; (c) A=7.5; (d) A=20.0

Заключение

Целью исследования было выяснить, какое влияние оказывают такие факторы, как соотношение сторон корпуса и жидкости с различными теплофизическими свойствами, на теплопередачу, когда температура чипов достигает пика. Для этого исследования была выбрана геометрия с массивом микросхем размером 3x3, размещенных на передней вертикальной стенке, и охлаждающейся противоположной стеной. Для исследования теплопередачи внутри корпуса было проведено моделирование для четырех соотношений сторон корпуса (A=1.0, 5.0, 7.5, 20.0) и пяти жидкостей (воздух, вода, FC-40, FC-72, FC-88). В качестве тестового задания рассматривалась работа Tou et al. [22]. Обнаружено хорошее соответствие между численными результатами в работе [22] и настоящим исследованием (рисунок 2). Анализ численных результатов показал, что:

- теплофизические свойства жидкостей оказывают значительное влияние на скорость движения жидкостей внутри корпуса; чем ниже вязкость жидкости, тем выше скорость движения жидкости; воздух обладает самой низкой вязкостью и плотностью, благодаря этому наблюдались самые высокие скорости; высокая вязкость приводит к высокому сопротивлению потока и снижению скорости;

- чем больше соотношение сторон корпуса, тем ниже значения скорости текучих сред; увеличение соотношения сторон корпуса означает, что ширина становится меньше и происходит ограничение потока стенкой, у потока остается меньше пространства для перемещения; из этого следует, что соотношение сторон оказывает существенное влияние на скорость жидкости;

- было обнаружено значительное влияние соотношения сторон корпуса на теплопередачу; чем больше соотношение сторон корпуса, тем больше число Nu; эффект объясняется уменьшением ширины, что означает уменьшение расстояния между стенкой с горячими чипами и холодной стенкой; тепло от чипов при небольшой ширине корпуса распространяется быстрее, чем при отдалении стенок друг от друга;

- во всех моделированиях самые высокие значения числа Нуссельта наблюдались в диэлектрических жидкостях FC-72 и FC-88, а минимальные были обнаружены в воздухе; специфические теплофизические свойства диэлектрических жидкостей оказывают большое влияние на теплопередачу.

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Информация об авторах

Исахов Алибек Абдиашимович (автор для корреспонденции)

Доктор PhD, профессор Школы прикладной математики, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, г. Алматы, Казахстан

ORCID ID: 0000-0002-1937-8615

E-mail: al.isakhov@kbtu.kz

Байбатырова Камилла Ермековна

Магистрант, Школа прикладной математики, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, г. Алматы, Казахстан

ORCID ID: 0009-0006-3522-8656

E-mail: k_baibatyrova@kbtu.kz

Авторлар туралы мәліметтер

Исахов Алибек Абдиашимович (корреспонденция авторы)
PhD докторы, Қолданбалы математика мектебінің профессоры, Қазақстан-Британ техникалық университеті, Төле би көш., 59, 050000, Алматы қ., Қазақстан
ORCID ID: 0000-0002-1937-8615
E-mail: al.isakhov@kbtu.kz

Байбатырова Камилла Ермековна
Магистрант, Қолданбалы математика мектебі, Қазақстан-Британ техникалық университеті, Төле би көш., 59, 050000, Алматы қ., Қазақстан
ORCID ID: 0009-0006-3522-8656
E-mail: k_baibatyrova@kbtu.kz

Information on the authors

Issakhov Alibek Abdiashimovich (corresponding author)
Doctor PhD, Professor of of School of Applied Mathematics, Kazakh-British Technical University, 59, Tole bi street, Almaty, 050000, Kazakhstan
ORCID ID: 0000-0002-1937-8615
E-mail: al.isakhov@kbtu.kz

Baibatyrova Kamilla Ermekovna
Master Student, School of Applied Mathematics, Kazakh-British Technical University, 59, Tole bi street, Almaty, 050000, Kazakhstan
ORCID ID: 0009-0006-3522-8656
E-mail: k_baibatyrova@kbtu.kz

Исахов А.А.[*1,2], Байбатырова К.Е.[1]

[1]Қазақстан-Британ техникалық университеті, 050000, Алматы қ., Қазақстан
[2]әл-Фараби атындағы Қазақ ұлттық университеті, 050040, Алматы қ., Қазақстан
*E-mail: al.isakhov@kbtu.kz

СҰЙЫҚТЫҚТАРДЫҢ ЖЫЛУФИЗИКАЛЫҚ ҚАСИЕТТЕРІНІҢ ЭЛЕКТРОНДЫҚ ҚҰРЫЛҒЫЛАРДАҒЫ КОНВЕКТИВТІ ЖЫЛУТАСЫМАЛДАУҒА ӘСЕРІ

Аңдатпа. Корпустың арақатынасы мен сұйықтықтардың әртүрлі жылуфизикалық қасиеттерінің жылутасымалдауға әсері алдыңғы тік қабырғасына тұрақты температурада 3x3 өлшемді микросұлбалар массиві орнатылған және қарама-қарсы қабырғамен салқындатылатын тікбұрышты корпуста зерттелді. Корпус ішіндегі жылудың берілуін зерттеу үшін қоршаудың төрт арақатынасы (A=1,0, 5,0, 7,5, 20,0) мен бес түрлі ортаға (ауа, су, FC-40, FC-72, FC-88) модельдеу жүргізілді. Сандық нәтижелерге сәйкес ең жоғары жылдамдықтар ауада, ал төмен жылдамдықтар суда және үш диэлектрлік сұйықтықтарда FC-40, FC-72, FC-88 байқалады. W жылдамдық компонентінің максималды жылдамдығы ауада Z=5.5 биіктігінде анықталды. Корпустың арақатынасы азайған сайын сұйықтық ағынының жылдамдығы артатыны байқалады. Корпустың Nu максималды саны корпус FC-72 және FC-88 диэлектрлік сұйықтықтармен толтырылған кезде, ал минимум ауада болған кезде анықталды. Таңдалған сандық әдістердің, компьютерлік бағдарламаның дұрыс орындалғанына көз жеткізу үшін тест тапсырмасы орындалды. Нәтижелер арасында жақсы сәйкестік анықталды.

Тірек сөздер: жылутасымалдау, микросұлба, жақтардың арақатынасы, сұйықтықтардың жылуфизикалық қасиеттері, диэлектрлік сұйықтықтар.

Issakhov A.A.[*1,2]**, Baibatyrova K.E.**[1]

[1]Kazakh-British Technical University, 050000, Almaty, Kazakhstan
[2]Al-Farabi Kazakh National University, 050040, Almaty, Kazakhstan
*E-mail: al.isakhov@kbtu.kz

THE EFFECT OF THERMOPHYSIZAL PROPERTIES OF FLUIDS ON CONVECTIVE HEAT TRANSFER IN ELECTRONIC DEVICES

Abstract. The impact of enclosure aspect ratio and different thermophysical properties of fluids on heat transfer were investigated in rectangular enclosure with 3x3 array of flush-mounted chips placed on the front vertical wall with constant temperature and cooled by the opposite wall. To study heat transfer inside the enclosure simulations were done for four enclosure aspect ratios(A=1.0, 5.0, 7.5, 20.0) and five fluids(air, water, FC-40, FC-72, FC-88). Numerical results show that the highest velocities are in the air while low velocities have been noticed in the water, FC-40, FC-72, FC-88. The maximum air velocities for the W component are obtained precisely at a height of Z= 5.5. It is observed that when enclosure aspect ratio decreases, the fluid velocity increases. Maximum Nu number was when enclosure was filled with dielectric fluids FC-72 and FC-88, and minimal was found in the air. To ensure that chosen numerical methods, computer program was implemented correctly test task were completed. Good agreement is found between the results.

Key words: convective heat transfer, IC chips, enclosure aspect ratio, thermophysical properties of fluids, dielectric liquids.

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Beisenbay A. A.

Institute of Mathematics and Mathematical Modeling, 050010, Almaty, Kazakhstan
Al-Farabi Kazakh National University 050040, Almaty, Kazakhstan
E-mail: beisenbay@math.kz

ON AN ANALOGUES OF VAN DER CORPUT LEMMAS

Abstract. The article deals with analogues of the van der Corput lemmas involving Mittag-Leffler functions. In fact, the classical estimates for the oscillatory integrals was obtained by the Dutch mathematician Johannes Gaultherus van der Corput and named in his honour. Various generalisations of the van der Corput lemmas have been investigated over the years. The general statement is that we replace the exponential function with the Mittag-Leffler-type function, to study oscillatory integrals appearing in the analysis of time-fractional partial differential equations. For a particular purpose, the present paper focuses on the integral of the form

$$I_{\alpha,\beta}(\lambda) = \int_R E_{\alpha,\beta}\big(\zeta\lambda\phi(x)\big)\psi(x)dx,$$

in the case β = α, for the range 0 < α < 2. This make wider the variety of estimates obtained in the work [1], where integrals with functions $E_{\alpha,\beta}\big(i^{\alpha}\lambda\phi(x)\big)$ have been studied. In this paper we interested in the behavior of the integral $I_{\alpha,\beta}(\lambda)$ when λ is large. We realize that the decay rates of the integral which, we have been considered, depend on the ranges of parameters α and β. Further studying Van der Corput lemmas will reveal new insights and applications in mathematics and beyond.

Key words: Van Der Corput lemmas, Mittag-Leffler function, inductive hypothesis, estimate, smooth function, oscillatory integral

Introduction

In this paper we will expand the study of oscillatory-type integrals involving Mittag-Leffler functions $E_{\alpha,\beta}$ initiated in [1]. In the case of $\alpha = \beta = 1$, we have $E_{1,1}(z) = e^z$, thus reducing the integral to the classical question of decay of oscillatory integrals. Indeed, the estimate obtained by the Dutch mathematician Johannes Gaultherus van der Corput [2] and named in his honour, following Stein [3], can be stated as follows:

Van der Corput lemma. Suppose ϕ is a real-valued and smooth function in [a;b]: If ψ is a smooth function and $\phi^{(k)}(x)\ \vee\geq 1, k \geq 1$ for all $x \in (a,b)$, then

$$\left|\int_a^b e^{-i\lambda\phi(x)}\psi(x)dx\right| \leq C\lambda^{-1/k}, \lambda \longrightarrow \infty, \qquad (1.1)$$

for k = 1 and ϕ' is monotonic, or k ≥ 2. Here C does not depend on λ.

Various generalisations of the van der Corput lemmas have been investigated over the years [3], [4-10]. Multidimensional analogues of the van der Corput lemmas were studied in [11-17], while in [18] the multi-dimensional van der Corput lemma was obtained with constants independent of the phase and amplitude.

We consider the generalized oscillatory integral defined by

$$I_{\alpha,\beta}(\lambda) = \int_R E_{\alpha,\beta}\big(\zeta\lambda\phi(x)\big)\psi(x)dx, \qquad (1.2)$$

where $0 < \alpha < 2, \beta > 0, \zeta \in C, \phi$ is a phase and ψ is an amplitude, and λ –is a positive real number that can vary. Here $E_{\alpha,\beta}\big(\zeta\lambda\phi(x)\big)$ is the Mittag-Leffler function defined as (see e.g. [19], [20])

$$E_{\alpha,\beta}(\zeta\lambda\phi(x)) = \sum_{k=0}^{\infty} \frac{(\zeta\lambda\phi(x))^k}{\Gamma(\alpha k+\beta)}, \alpha > 0, \beta \in R,$$

with the property that

$$E_{1,1}(\zeta\lambda\phi(x)) = e^{\zeta\lambda\phi(x)}. \quad (1.3)$$

Since the function $E_{\alpha,\beta}(\zeta\lambda\phi(x))$ has a set of real zeros [20], the integral (1.2) is oscillating.

The main goal of the present paper is to obtain van der Corput-type estimates for the oscillatory integral (1.2) in the form

$$\left|\int_a^b E_{\alpha,\alpha}(\zeta\lambda\phi(x))\psi(x)dx\right| \le C\lambda^{\frac{-1}{k}}, \lambda \longrightarrow \infty. \quad (1.4)$$

It is one extension of (1.1) in view of (1.3), namely, an extension (in Theorem 3.5) to the range $0 < \alpha < 2$, , for $k = 1$ and ϕ' is monotonic, or $k \ge 2$.

This present paper is a generalization of [1], where a variety of van der Corput type lemmas were obtained for the integral defined by

$$\mathcal{T}_{\alpha,\beta}(\lambda) = \int_R E_{\alpha,\beta}(i^\alpha\lambda\phi(x))\psi(x)dx. \quad (1.5)$$

As we see above, the integral (1.5) is different from the integral (1.2), since in (1.5) there is a purely imaginary number i^α before the phase function, and in (1.2) the complex number, i.e. ζ. As in the case of (1.5) studied in [1], we find that the decay rates of (1.2) when, $\beta = \alpha$, as $\lambda \longrightarrow \infty$ depend on the ranges of parameters and . We also obtain more results in the case of in finite intervals.

Main provisions. Material and methods

Proposition 2.1 ([Pod99]). If $0 < \alpha < 2$, β is an arbitrary real number, μ is such that $\pi\alpha/2 < \mu < min\{\pi, \pi\alpha\}$, then there is $C_1, C_2 > 0$, such that we have

$$\left|E_{\alpha,\beta}(\zeta\lambda\phi(x))\right| \le C_1(1+|\zeta\lambda\phi(x)|)^{(1-\beta)/\alpha} exp\left(\Re\left((\zeta\lambda\phi(x))^{1/\alpha}\right)\right) + \frac{C_2}{1+|\zeta\lambda\phi(x)|}, \quad (1.6)$$

where, $\zeta \in C$, $\left|arg(\zeta\lambda\phi(x))\right| \le \mu$.

We are interested in particular in the behavior of $I_{\alpha,\beta}(\lambda)$ when λ is large, as for small λ the integral is just bounded.

Results and discussions

In this section we consider integral (1.2) in the finite interval $[a,b] \subset R$, $-\infty < a < b < +\infty$, as well as we are interested in a particular case of the integral (1.2), when $0 < \alpha < 2, \beta = \alpha$, i.e.

$$I_{\alpha,\alpha}(\lambda) = \int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))\psi(x)dx. \quad (2.1)$$

Since $I_{\alpha,\alpha}(\lambda)$ is bounded for small λ, further we can assume that $\lambda \ge 1$.

Theorem 2.1. Let $-\infty < a < b < +\infty$ and $I = [a,b] \subset R$. Let $0 < \alpha < 2$ and let ϕ be a real-valued function such that $\phi \in C^k(I), k \ge 1$. Let $\phi^k(x) \vee\ge 1$ for all $x \in I$, and $\zeta \in C, \vee\zeta\vee\neq 0$, then

$$\left|\int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \le M_k\lambda^{\frac{-1}{k}}, \lambda \ge 1 \quad (2.2)$$

for k = 1 and ϕ' is monotonic, or k ≥ 2. Here M_k does not depend on λ.

We note that the classical van der Corput lemma (1.1) is covered by (2.2) with α = 1.

Proof. First we will prove the case k = 1. Let $0 < \alpha < 2$, $\lambda \ge 1$ and let ϕ has one zero $c \in [a,b]$. Let us consider the integral

$$\int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx.$$

Then integrating by parts gives

$$\int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx = \frac{\alpha}{\zeta\lambda}\int_I \frac{d}{d\phi(x)}\left(E_{\alpha,1}(\zeta\phi(x))\right)dx$$

$$\frac{\alpha}{\zeta\lambda}\int_I \frac{1}{\phi'(x)}\frac{d}{dx}\left(E_{\alpha,1}(\zeta\lambda\phi(x))\right)dx$$

$$\frac{\alpha}{\zeta\lambda}E_{\alpha,1}(\zeta\lambda\phi(b))\frac{1}{\phi'(b)} - \frac{\alpha}{\zeta\lambda}E_{\alpha,1}(\zeta\lambda\phi(a))\frac{1}{\phi'(a)}$$

$$\frac{-\alpha}{\zeta\lambda}\int_I E_{\alpha,1}(\zeta\lambda\phi(x))\frac{d}{dx}\left(\frac{1}{\phi'(x)}\right)dx,$$

thanks to property $\frac{d}{dz}E_{\alpha,1}(z) = \frac{1}{\alpha}E_{\alpha,\alpha}(z)$ and Then we get

$$\left|\int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))\,dx\right| \le \frac{\alpha}{\lambda}\int_I |E_{\alpha,1}(\zeta\lambda\phi(x))|\left|\frac{d}{dx}\left(\frac{1}{\phi'(x)}\right)\right|dx$$

$$\frac{+\alpha}{\lambda}|E_{\alpha,1}(\zeta\lambda\phi(x))|\frac{1}{|\phi'(b)|}$$

$$\frac{+\alpha}{\lambda}|E_{\alpha,1}(\zeta\lambda\phi(a))|\frac{1}{|\phi'(a)|}. \qquad (2.3)$$

As ϕ' is monotonic and $\phi'(x) \ge 1$ for all $x \in [a,b]$, then $\frac{1}{\phi'}$ is also monotonic, and $\frac{d}{dx}\frac{1}{\phi'(x)}$ has a fixed sign.

Hence estimate (1.6) and $\phi(c) = 0, c \in [a,b]$ gives

$$\left|\int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \le \frac{C\alpha}{\lambda}\int_I (1+\lambda|\phi(x)|)^{\frac{1-\alpha}{\alpha}}$$

$$\frac{+C\alpha}{\lambda}(1+\lambda|\phi(b)|)^{\frac{1-\alpha}{\alpha}} + \frac{C\alpha}{\lambda}(1+\lambda|\phi(a)|)^{\frac{1-\alpha}{\alpha}}$$

$$\le^{|\phi(x)|\ge 0}\frac{C\alpha}{\lambda}\int_I \left|\frac{d}{dx}\left(\frac{1}{\phi'(x)}\right)\right|dx + \frac{2C\alpha}{\lambda}$$

$$\le \frac{C\alpha}{\lambda}\int_I \left|\frac{d}{dx}\left(\frac{1}{\phi'(x)}\right)\right|dx + \frac{2C\alpha}{\lambda}$$

$$\le \frac{C\alpha}{\lambda}\left[2 + \frac{1}{|\phi'(b)|} + \frac{1}{|\phi'(b)|}\right] \le \frac{M_1}{\lambda},$$

thanks to fixed sign $\frac{d}{dx}\frac{1}{\phi'(x)}$. Here M_1 does not depend on

We prove (2.1) for k = 2. Let for $d \in [a,b]$ satisfies $|\phi'(d)| \le |\phi'(x)|$ for all $x \in [a,b]$. Then $|\phi'(x)| \ge \varepsilon$ on $[a,b]d-\varepsilon, d+\varepsilon$. Hence

$$\int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx = \left(\int_\alpha^{d-\varepsilon} + \int_{d-\varepsilon}^{d+\varepsilon} + \int_{d+\varepsilon}^{b}\right)E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx.$$

Then $|\phi'(x)| \ge \varepsilon$ on $[a,b]d-\varepsilon, d+\varepsilon$, we obtain estimates

$$\left|\int_\alpha^{d-\varepsilon} E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \le M_1(\varepsilon\lambda)^{-1},$$

$$\left|\int_{d+\varepsilon}^{b} E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \le M_1(\varepsilon\lambda)^{-1}.$$

As

$$\left|\int_{d-\varepsilon}^{d+\varepsilon} E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \le 2\varepsilon,$$

it is evident that

$$\left|\int_\alpha^b E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \le 2M_1(\varepsilon\lambda)^{-1} + 2\varepsilon.$$

Taking $\varepsilon = \lambda^{\frac{-1}{2}}$ we obtain the estimate (2.1) for k=2.

We prove the case k ≥ 2 by induction method. Let (2.1) is true for k, and suppose $|\phi^{(k+1)}(x)| \geq 1$, for all $x \in [a,b]$, we prove (2.1) for k + 1.

Let for $d \in [a,b]$ satisfies $|\phi^k(d)| \leq |\phi^k(x)|$ for all $x \in [a,b]$.

Then on $|\phi^k(x)| \geq \varepsilon$ on $[a,b]c-\varepsilon, c+\varepsilon$. Therefore

As

$$\int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx =$$

By inductive hypothesis, we infer that

$$\left|\int_\alpha^{d-\varepsilon} E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \leq M_k(\varepsilon\lambda)^{\frac{-1}{k}},$$

and

$$\left|\int_\alpha^{d-\varepsilon} E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \leq M_k(\varepsilon\lambda)^{\frac{-1}{k}},$$

As

$$\left|\int_{d-\varepsilon}^{d+\varepsilon} E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \leq 2\varepsilon,$$

we have

$$\left|\int_\alpha^b E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \leq 2M_k(\varepsilon\lambda)^{\frac{-1}{k}} + 2\varepsilon.$$

Taking $\varepsilon = \lambda^{\frac{-1}{k+1}}$ we obtain the estimate (2.1) for k+1.

Below we show that if ϕ' is not monotonic, then to obtain estimate (2.1) when k = 1, it is necessary to increase the smoothness of function ϕ.

Theorem 2.2. Let $-\infty < a < b < +\infty$ and $I = [a;b] \subset R$. Let $0 < \alpha < 2$ and let ϕ be a real-valued function such that $\phi \in C^2(I)$. Let $|\phi'(x)| \geq 1$ for all $x \in I$, and $\zeta \in C$, then

$$\left|\int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \leq M\lambda^{-1}, \lambda \geq 1,$$

where M does not depend on λ.

Proof. Suppose that $\phi \in C^2(I)$ and $|\phi'(x)| \geq 1$ for all $x \in I$, then from (2.3) we have

$$\left|\int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \leq \frac{\alpha}{\lambda}\int_I |E_{\alpha,1}(\zeta\lambda\phi(x))|\left|\frac{d}{dx}\left(\frac{1}{\phi'(x)}\right)\right|dx$$

$$\frac{+\alpha}{\lambda}|E_{\alpha,1}(\zeta\lambda\phi(b))|$$

$$\frac{+\alpha}{\lambda}|E_{\alpha,1}(\zeta\lambda\phi(a))|.$$

Since $\phi \in C^2(I)$ and $|\phi'(x)| \geq 1$ for all $x \in I$, then the function will be continuous and bounded, and therefore by (1.6) we have

$$\left|\int_I E_{\alpha,\alpha}(\zeta\lambda\phi(x))dx\right| \leq \frac{C\alpha}{\lambda}\left[\int_I \left|\frac{d}{dx}\left(\frac{1}{\phi'(x)}\right)\right|dx + 2\right]$$

$$\leq \frac{C\alpha}{\lambda},$$

where $M_1 = \left\|\frac{d}{dx}\left(\frac{1}{\phi'(x)}\right)\right\|_{L^\infty(I)}$, $C \geq |E_{\alpha,1}(z)|$, and M is a constant independent of λ.

Conclusion

We could show the behavior of $I_{\alpha,\beta}(\lambda)$ when λ is large, and we obtain variety of van der Corput type lemmas for the integral (2.1).

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Information about author

Beisenbay Aray Amanzholkyzy

Master, PhD student of al-Farabi Kazakh National University, Junior researcher of the Institute of Mathematics and Mathematical Modeling,125 Pushkin str., 050010, Almaty, Kazakhstan

ORCID ID: 0000-0001-5032-2428

E-mail: beisenbay@math.kz

Автор туралы мәлімет

Бейсенбай Арай Аманжолқызы

Магистр, әл-Фараби атындағы ҚазҰУ докторанты, Математика және математикалық модельдеу институтының кіші ғылыми қызметкері, 050010, Алматы қ., Пушкин көш., 125, Қазақстан

ORCID ID: 0000-0001-5032-2428
E-mail: beisenbay@math.kz

Информация об авторе

Бейсенбай Арай Аманжолкызы
Магистр, докторант КазНУ им. аль-Фараби, младший научный сотрудник Института математики и математического моделирования, 050010, г. Алматы, ул. Пушкина, 125, Казахстан
ORCID ID: 0000-0001-5032-2428
E-mail: beisenbay@math.kz

Бейсенбай А.А.

Математика және математикалық модельдеу институты, 050010, Алматы қ., Қазақстан
әл-Фараби атындағы ҚазҰУ, 050040, Алматы қ., Қазақстан
E-mail: beisenbay@math.kz

ВАН ДЕР КОРПУТ ЛЕММАЛАРЫНЫҢ АНАЛОГТАРЫ ТУРАЛЫ

Аңдатпа. Бұл мақалада Миттаг-Леффлер функцияларымен Ван дер Корпут леммаларының аналогтары қарастырылады. Шын мәнінде, бұл бағалау ең алғаш рет голланд математигі Йоханнес Хольтерус ван дер Корпутпен алынды және оның құрметіне Ван дер Корпут леммасы деп аталды. Ван дер Корпут леммаларының түрлі жалпыламалары бірнеше жыл бойы зерттеліп келеді. Жалпы мақсатымыз бен жұмыс барысын сипаттайтын болсақ: біз Ван дер Корпут леммасындағы экспоненциалды функцияны Миттаг-Леффлер типті функциямен ауыстырамыз, яғни уақыттан тәуелсіз дифференциалдық теңдеулерді талдау кезінде пайда болатын тербелмелі интегралдарды зерттейміз. Арнайы осы мақсат үшін бұл мақалада диапазоны $0 < \alpha < 2$ болатын

$$I_{\alpha,\beta}(\lambda) = \int_R E_{\alpha,\beta}\big(\zeta\lambda\phi(x)\big)\psi(x)dx,$$

интегралдың $\beta = \alpha$ жағдайына назар аударылады. Бұл $E_{\alpha,\beta}\big(i^{\alpha}\lambda\phi(x)\big)$ функциялары қатысқан тербелмелі интегралдар [1] жұмысында зерттеліп алынған бағалаулардың әртүрлілігін кеңейтеді. Бұл мақалада бізді λ шамасы үлкен болған жайғдайдағы $I_{\alpha,\beta}(\lambda)$ тербелмелі интегралдың өзгеру әрекеті қызықтырады. Біз қарастырған тербелмелі интегралдың кему жылдамдықтары β және α параметрлерінің диапазондарына байланысты екенін түсінеміз. Ван дер Корпут леммаларын одан әрі тереңнен зерттеу математикада және одан өзге салаларда жаңа түсініктер мен қолданбалардың ашылуына мүмкіндік береді.

Тірек сөздер: Ван дер Корпут леммалары, Миттаг-Леффлер функциясы, индуктивті гипотеза, бағалау, тегіс функция, тербелмелі интегралдар.

Бейсенбай А.А
Институт математики и математического моделирования, 050010, г. Алматы, Казахстан
КазНУ им. Аль-Фараби, 050040, г. Алматы, Казахстан
E-mail: beisenbay@math.kz

ОБ АНАЛОГАХ ЛЕММ ВАН ДЕР КОРПУТА

Аннотация. В данной статье рассматриваются аналоги лемм Ван дер Корпута с функциями Миттаг-Леффлера. На самом деле эта оценка была впервые получена голландским математиком Йоханнесом Хольтерусом ван дер Корпутом и названа в его честь леммой Ван дер Корпута. На протяжении многих лет изучались различные

обобщения лемм Ван дер Корпута. Если описать нашу общую цель и ход работы: мы заменяем экспоненциальную функцию в лемме ван дер Корпута функцией типа Миттаг-Леффлера, то есть изучаем осциллирующие интегралы, возникающие при анализе дифференциальных уравнений, не зависящих от времени. Специально для этой цели в настоящей статье основное внимание уделяется интегралу формы

$$I_{\alpha,\beta}(\lambda) = \int_R E_{\alpha,\beta}\big(\zeta\lambda\phi(x)\big)\psi(x)dx,$$

для диапазона $0 < \alpha < 2$, в случае $\beta = \alpha$. Это расширяет разнообразие оценок, полученных в работе [1], где изучались интегралы с функциями $E_{\alpha,\beta}\big(i^{\alpha}\lambda\phi(x)\big)$. В этой статье нас интересует поведение интеграла $I_{\alpha,\beta}(\lambda)$ при больших λ. Мы понимаем, что скорости убывания рассмотренного нами интеграла зависят от диапазонов параметров α и β. Дальнейшее изучение лемм Ван дер Корпута откроет новые идеи и приложения в математике и за ее пределами.

Ключевые слова: леммы Ван дер Корпута, функция Миттаг-Леффлера, гипотеза индукции, оценка, гладкая функция, осциллирующие интегралы.

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Вербовский В.В.*[1], Ершигешова А.Д.[2]

[1]Казахский национальный исследовательский технический университет
им. К.И. Сатпаева, 050013, г. Алматы
[2]Университет им. Сулеймана Демиреля, 040900, г. Каскелен
*E-mail: v.verbovskiy@satbayev.university

ПРИМЕРЫ ЛИНЕЙНЫХ ПОРЯДКОВ С ОПРЕДЕЛИМОЙ ОДНОМЕСТНОЙ ФУНКЦИЕЙ И СВОЙСТВО НЕЗАВИСИМОСТИ

Аннотация. После появления понятия о-минимальности, которое было введено Л. ван ден Дриесом для обогащений упорядоченного поля вещественных чисел и обобщено на произвольные линейные порядки А. Пиллаем и Ч. Стайнхорном, линейно упорядоченные структуры прочно вошли в круг интересов специалистов по теории моделей. В работах разных авторов появились многочисленные обобщения понятия о-минимальности, такие как слабая о-минимальность, квази-о-минимальность, слабая квази-о-минимальность, дп-минимальность и упорядоченная стабильность. Б.С. Байжановым и В.В. Вербовским было доказано, что упорядоченная стабильность обобщает все вышеперечисленные понятия для линейно упорядоченных структур и что упорядоченная стабильность влечет отсутствие свойства независимости. Также ими было доказано, что любой линейный порядок имеет упорядоченно суперстабильную теорию. В.В. Вербовским были исследованы упорядоченно стабильные упорядоченные группы, в частности, им было доказано, что они являются коммутативными. В данной работе мы начинаем исследование вопроса, насколько сложной может быть теория линейного порядка с одной одноместной функцией. Мы строим пример обогащения линейно упорядоченной структуры одной одноместной функцией, который обладает свойством независимости.

Ключевые слова: линейно упорядоченное множество, свойство независимости, унар, упорядоченная стабильность, о-минимальность.

Введение

Обобщая понятие тотально трансцендентной теории, С. Шелах в работе [10] ввел понятие стабильной теории, которое оказало колоссальное влияние на дальнейшее развитие теории моделей. В 1984 г. А. Пиллай и Ч. Стайнхорн обобщили понятие о-минимального обогащения упорядоченного поля вещественных чисел, которое ввел Л. ван ден Дриес. Они ввели понятие о-минимальной структуры [7]. Это понятие оказалось не менее интересным, чем понятие стабильной теории, и стало поворотным в дальнейшем развитии теории моделей, теперь специалисты по теории моделей обратили свое пристальное внимание на классы теорий логики предикатов первого порядка, в сигнатуре которых имеется символ , который интерпретируется как линейный порядок, то есть эти теории включают в себя аксиомы линейного порядка. Понятие о-минимальности не могло не повлечь за собой появление самых различных обобщений. Первое из них – понятие слабой о-минимальности, которое было введено в работе Д. Макферсона, Д. Маркера и Ч. Стайнхорна [6]. Дальнейшее развитие теории слабой о-минимальности получило среди специалистов по теории моделей из Казахстана, мы не будем перечислять все работы, отметим лишь некоторые: работу Б.С. Байжанова [4], в которой он решал проблему Г. Черлина, и работы Б.Ш. Кулпешова [8, 9]. Дальше появилось понятие квази-о-минимальности, дп-минимальности, на которых мы подробно останавливаться не будем. Понятие квази-о-минимальности для упорядоченных групп оказалось эквивалентным понятию косет-минимальности. Среди работ по косет-минимальным группам можно отметить статью [5]. Некоторым итогом этих обобщений классов теорий упорядоченных структур стало понятие упорядоченной стабильности, введенное в работе [1]. Класс упорядоченно стабильных теорий включает в себя и о-минимальные теории, и слабо о-минимальные, квази-о-

минимальные и слабо квази-о-минимальные [1], а также дп-минимальные теории с определимым линейным порядком [2]. Дальнейшее свое развитие теория упорядоченной стабильности получила в работах [11–16]. В статье [1] Б.С. Байжановым и В.В. Вербовским было доказано, что элементарная теория любого чистого линейного порядка является упорядоченно суперстабильной. Поэтому перед специалистами в теории моделей встает естественный вопрос: а что можно добавить в сигнатуру чистого линейного порядка, чтобы полученные алгебраические структуры были бы достаточно хорошими? Самым естественным было добавить символ двуместной операции, который удовлетворял бы аксиомам группы. Более того, естественно было положить, что такая группа является упорядоченной. В работе [3] было доказано, что упорядоченно стабильная упорядоченная группа является коммутативной, кроме того, были получены и другие интересные свойства упорядоченно стабильных упорядоченных групп.

Теперь мы решили рассмотреть, что будет, если к языку чистого линейного порядка добавить одну одноместную функцию – унар. В данной работе мы построим пример линейно упорядоченной структуры с одной одноместной функцией, которая обладает свойством независимости, таким образом, получаем, что элементарная теория этой структуры не является упорядоченно стабильной.

Целью данной работы является продвижение к проблеме нахождения условий, как необходимых, так и достаточных, которые бы обеспечивали упорядоченную стабильность обогащения чистого линейного порядка одной одноместной функцией.

На данном этапе мы доказали, что эти условия не могут быть тривиальными, поскольку существует пример такого обогащения, чья элементарная теория не является упорядоченно стабильной. Более того, этот пример обладает свойством независимости.

Основная часть

В работе начато исследование теоретико-модельных свойств алгебраических линейно упорядоченных структур с одной одноместной функцией. Если чистые линейные порядки и линейные порядки с произвольным числом одноместных предикатов достаточно хорошо изучены, из теоремы Рубина следует полное описание 1-типов над моделью, то свойства линейных порядков с одной одноместной функцией еще не были исследованы. Таким образом, в некотором смысле тематика является новой. Что же касается исследований линейно упорядоченных структур с точки зрения упорядоченной стабильности, то их совсем немного, практически все результаты по этой тематике содержатся в работах [1–3, 11, 13, 16]. Основным результатом статьи является построение примера линейно упорядоченной структуры с одной одноместной функцией, которая обладает свойством независимости.

Материалы и методы

В работе использовались известные методы теорий моделей полных теорий логики предикатов первого порядка, в частности касающиеся свойства независимости и построения формульных подмножеств данной алгебраической структуры.

Результаты исследования и их обсуждение

Пусть s – некоторый частичный n - тип, A – множество, Δ – семейство формул от n свободных переменных, где свободные переменные, вместо которых будут поставлены параметры, в счет не идут. Тогда

$$S^n_{\Delta,s}(A) \stackrel{\text{def}}{=} \{p \in S^n_\Delta(A): p \cup s\text{совместно}\}$$

Если Δ = L, то будем опускать этот индекс и писать просто S^n_s. Заметим, что s не обязательно является частичным типом над множеством A. Если же $\Delta = \{\varphi\}$, то будем писать $S_\varphi(A)$ вместо $S_{\{\varphi\}}(A)$.

Определение 1. Пусть M – некоторая структура, $A \subseteq M$. Пусть Δ и ∇ – семейства формул вида $\varphi(x;\overline{y})$.

1. Структура M называется стабильной с точностью до Δ в (λ, ∇), если для любого подмножества $A \subseteq M$, такого что $A \vee\leq \lambda$, для любого Δ-типа p над M существует самое большее λ∇-типов над A, которые совместны с p, то есть $S^1_{\nabla,p}(A) \vee\leq \lambda$.

2. Теория T называется стабильной с точностью до Δ в (λ, ∇), если каждая ее модель такова. В некоторых случаях будем писать, что теория T (λ, ∇)-стабильна с точностью до Δ.

3. Если ∇ = L, то будем опускать этот индекс и писать, что теория T стабильна в λ, или -стабильна с точностью до Δ.

4. Теория T называется стабильной с точностью до Δ, если существует бесконечный кардинал λ, в котором теория T стабильна с точностью до Δ. Будем писать, что теория T стабильна с точностью до φ, подразумевая, что она стабильна с точностью до $\Delta = \{\varphi\}$.

5. Теория называется суперстабильной с точностью до Δ, если существует кардинал λ, такой, что теория T стабильна с точностью до Δ во всех $\mu \geq \lambda$.

6. Пусть $\varphi(x;y) \stackrel{\text{def}}{=} x < y$, а теория T содержит аксиомы линейного порядка для предиката. Если теория T стабильна с точностью до φ, то T называется упорядоченно стабильной.

Определение 2. Будем говорить, что формула $\varphi(\overline{x};\overline{y})$ обладает свойством независимости, если для каждого натурального положительного числа существуют кортежи $\overline{a}_1, \ldots, \overline{a}_n$ и кортежи $\overline{b}_\tau$, где τ пробегает множество всех функций из $\{1, \ldots, n\}$ в $\{0,1\}$, такие, что для каждого индекса является истинной формула

$$i = 1n\varphi^{\tau(i)}\left(\overline{b}_\tau; \overline{a}_i\right)$$

Здесь мы используем стандартную запись, что φ^1 обозначает φ, а φ^0 обозначает $\neg\varphi$.

В работе [1] было доказано, что упорядоченно стабильные теории не обладают свойством независимости.

Построение примера

Мы будем использовать тот факт, что множество натуральных чисел вместе с отношением делимости обладает свойством независимости. Здесь $b \vee a$ интерпретируется как число α делит b число без остатка. Действительно, будем брать в качестве α простые числа $p_1 = 2, p_2 = 3, p_3 = 5, \ldots, p_n, \ldots$ Зафиксируем число n > 1 и функцию τ. В качестве числа b_τ мы возьмем следующее число:

$$\prod_{i=1}^{n} p_i^{\tau(i)}$$

Пусть φ (b, α) будет $b \vee a$. Очевидно, что для любого τ является истинной формула

$$i = 1n\varphi^{\tau(i)}(b_\tau, p_i)$$

Действительно, произведение чисел $\prod_{i=1}^{n} p_i^{\tau(i)}$ делится на число p_j тогда и только тогда, когда показатель степени $\tau(j)$ множителя p_j в рассматриваемом произведении больше нуля.

В качестве носителя нашей алгебраической структуры мы рассмотрим множество рациональных чисел Q. То есть мы рассмотрим структуру $Q = (Q, <, f)$, где V – естественный порядок на множестве рациональных чисел, а функцию f мы определим ниже.

Если $q \in Q$ больше нуля и является целым числом, то $f(q) = 1$.

Если $q \in Q$ больше нуля, но не является целым числом, то $f(q) = 0$.

Пусть множество A_i содержит все положительные числа, которые делятся на простое число p_i. Полуинтервал (-1,0], как подмножество множества рациональных чисел, является счетным множеством, точно так же, как и множество A_1 положительных целых чисел, которые делятся на $p_1 = 2$ (то есть четных чисел). Значит, существует биекция $g_1: (-1,0] \to A_1$. Определим функцию f на множестве (-1,0] тождественно равной функции g_1.

Аналогично полуинтервал $(-n, -n+1]$, как подмножество множества рациональных чисел, является счетным множеством, точно так же, как и множество A_n положительных целых чисел, которые делятся на n-тое простое число p_n. Следовательно, существует биекция $g_n: (-n, -n+1] \to A_n$. Определим функцию f на множестве $(-n, -n+1]$ тождественно равной функции g_n.

Таким образом, функция f является всюду определенной.

Покажем теперь, что множество A_n формульно в структуре $Q = (Q, <, f)$. Действительно, $x \in A_n$ тогда и только тогда, когда

$$\exists y\left(-n < y \leq -n+1 \wedge x = f(y)\right)$$

Обозначим последнюю формулу как $\psi(x; -n, -n+1)$. Очевидно, что по построению множество всех реализаций формулы $\psi(x, -n, -n+1)$ в структуре Q совпадает с множеством A_n, которое, в свою очередь, совпадает с множеством всех реализаций формулы $\varphi(x, p_n)$ в структуре, если рассматривать N как подмножество множества Q.

Отсюда очевидно, что формула $\psi(x; y, z)$ обладает свойством независимости. Следовательно, элементарная теория алгебраической структуры Q не является упорядоченно стабильной.

Заключение

Обогащения линейных порядков одноместной функцией могут иметь достаточно сложную теорию, в частности они могут обладать свойством независимости. Цель дальнейших исследований – найти условия, которые бы обеспечивали упорядоченную стабильность подобных обогащений.

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Информация об авторах

Виктор Вербовский (автор для корреспонденции)
Доктор физико-математических наук, доцент, профессор Satbayev University, ул. Сатпаева, 22, 050013, г. Алматы, Казахстан
ORCID ID 0000-0001-5177-8523
E-mail: v.verbovskiy@satbayev.university

Айша Ершигешова
Магистр математики, старший преподаватель Университета им. Сулеймана Демиреля, ул. Абылай хана, 1/1, 040900, г. Каскелен, Казахстан
ORCID ID 0000-0001-6732-1077
E-mail: aisha.yershigeshova@sdu.edu.kz

Авторлар туралы мәліметтер

Виктор Вербовский (корреспонденция авторы)
Физика-математика ғылымдарының докторы, доцент, Satbayev University профессоры, Сәтбаев көш., 22, 050013, Алматы қ., Қазақстан
ORCID ID 0000-0001-5177-8523
E-mail: v.verbovskiy@satbayev.university

Айша Ершигешова
Математика магистрі, Сулейман Демирель атындағы университеттің аға оқытушысы, Абылай хан көш., 1/1, 040900, Қаскелең қ., Қазақстан
ORCID ID 0000-0001-6732-1077
E-mail: aisha.yershigeshova@sdu.edu.kz

Information about authors

Viktor Verbovskiy (corresponding author)
Doctor of physical and mathematical sciences, docent, professor of Satbayev University, 22a Satpaev str., 050013, Almaty, Kazakhstan
ORCID ID 0000-0001-5177-8523
E-mail: v.verbovskiy@satbayev.university

Aisha Yershigeshova
Master of mathematics, Senior Lecture of Suleyman Demirel University, 1/1 Abylai Khan st., 040900, Kaskelen, Kazakhstan
ORCID ID 0000-0001-6732-1077
E-mail: aisha.yershigeshova@sdu.edu.kz

Вербовский В.В.*[1], Ершигешова А.Д.[2]

[1]Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті, 050013, Алматы қ.
[2]Сулейман Демирель атындағы университет, 040900, Қаскелең қ.,
*E-mail: v.verbovskiy@satbayev.university

АНЫҚТАЛАТЫН БІР ОРЫНДЫҚ ФУНКЦИЯСЫ БАР СЫЗЫҚТЫҚ РЕТТЕРДІҢ МЫСАЛДАРЫ ЖӘНЕ ТӘУЕЛСІЗДІК ҚАСИЕТІ

Аңдатпа. Нақты сандардың реттелген өрісін байыту үшін Л. ван ден Дриес енгізген және А. Пиллай мен Ч. Стайнхорнның ерікті сызықтық реттерге жалпыланған о-минималдылық тұжырымдамасы пайда болғаннан кейін сызықтық реттелген құрылымдар модельдер теориясы мамандарының қызығушылықтар шеңберінде берік орнықты. Әртүрлі авторлардың еңбектерінде әлсіз о-минималдық, квази-о-минималдық, әлсіз квази-о-минималдық, дп-минималдық және реттелген тұрақтылық сияқты о-минималдық ұғымының көптеген жалпылаулары пайда болды. Б.С. Байжанов пен В.В. Вербовский реттелген тұрақтылық сызықтық реттелген құрылымдар үшін жоғарыда аталған барлық ұғымдарды жалпылайтынын және реттелген тұрақтылық тәуелсіздік қасиетінің жоқтығынан туындайтынын дәлелдеді. Олар сондай-ақ кез келген сызықтық реттің реттелген супертұрақты теориясы бар екенін дәлелдеді. В.В. Вербовский реттелген тұрақты ретті топтарды зерттеді, атап айтқанда, олардың коммутативті екенін дәлелдеді. Бұл жұмыста біз бір орынды функциямен сызықтық тәртіп теориясы қаншалықты күрделі болуы мүмкін деген сұрақты зерттеуді бастаймыз. Сызықтық реттелген құрылымды тәуелсіздік қасиеті бар бір орынды функциямен байыту мысалын құрастырамыз.

Тірек сөздер: сызықтық реттелген жиын, тәуелсіздік қасиеті, унар, реттелген тұрақтылық, о-минималдық.

Verbovskiy V.V.*[1], Ershigeshova A.D.[2]

[1]Satbayev University, 050013, Almaty
[2]Suleyman Demirel University, 040900, Kaskelen
*E-mail: v.verbovskiy@satbayev.university

EXAMPLES OF LINEAR ORDERS WITH A DEFINABLE UNARY FUNCTION AND THE INDEPENDENCE PROPERTY

Abstract. After the appearance of the concept of o-minimality, which was introduced by L. van den Dries for expansions of the ordered field of real numbers and generalized to arbitrary linear orders by A. Pillay and C. Steinhorn, linearly ordered structures became firmly established in the circle of interests of specialists in model theory. Numerous generalizations of the concept of o-minimality have appeared in the works of various authors, such as weak o-minimality, quasi-o-minimality, weak quasi-o-minimality, dp-minimality, and o-stability. B. S. Baizhanov and V. V. Verbovskiy proved that o-stability generalizes all the above concepts for linearly ordered structures and that o-stability entails the absence of the independence property. They also proved that any linear order has an o-superstable theory. V. V. Verbovskiy studied o-stable ordered groups, in particular, he proved that they are commutative. In this paper, we begin the study of the question of how complex the theory of a linear order with one unary function can be. We construct an example of an expansion of a linearly ordered structure with one unary function, which has the independence property.

Key words: linearly ordered set, independence property, unar, o-stability, o-minimality.

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Sinitsa A.V.*[1], Tskhay Y.A.[1], Ukassova A.K.[1], Antonio Capsoni[2]

[1]Kazakh-British Technical University, 050050, Almaty, Kazakhstan
[2]Polytechnic University of Milan, 20133, Milan, Italy
*E-mail: a.sinitsa@kbtu.kz

MATHEMATICAL MODELING OF ACOUSTIC PROPOGATION THROUGH AURALIZATION TECHNIQUES INSIDE ENCLOSERS WITH VARIATION OF BOUNDARY CONDITIONS

Abstract. Registration of acoustic properties and auralization of enclosed spaces is becoming increasingly important. In today's world, when designing or renovating historic buildings such as opera houses, churches and concert halls, it is important to simulate sound propagation in order to preserve the original acoustic properties. In our article, we consider the process of propagation of a sound wave in an internal three-dimensional non-stationary area, namely, the modeling of acoustics in a concert hall. To do this, according to the given input parameters, initial and boundary conditions, the distribution function of sound pressure in a given area over a period of time was determined. In the course of calculations, we use a computing platform to implement the finite element method, as well as the finite difference method using an explicit scheme as an example. On the basis of numerical results, we draw conclusions about the effectiveness of closed space auralization methods, and also describe aspects of optimization and use of methods.

Key words: Mathematical model, acoustic propagation, boundary conditions, environment simulation, numerical analysis.

Introduction

Auralization is a powerful technique that allows us to experience and understand sound in a simulated or virtual environment. Similar to visualization, which creates visual representations of data or scenarios, auralization focuses on creating accurate auditory representations. By leveraging advanced acoustic modeling and signal processing techniques, auralization provides a means to perceive and analyze sound in various contexts.

The applicability of auralization spans across multiple domains, offering valuable insights and benefits in several fields. One of its primary applications is in architectural and environmental acoustics. Architects and designers can utilize auralization to predict and evaluate the acoustic properties of buildings, rooms, or public spaces before they are constructed. By simulating sound propagation, reflections, and absorption, auralization enables professionals to optimize the acoustic design, minimize noise pollution, and create immersive auditory experiences.

In the field of audio engineering and sound production, auralization plays a vital role. Sound engineers can use auralization techniques to simulate the acoustics of different recording spaces, such as concert halls or studios. This enables them to make informed decisions during the production process, including microphone placement, audio mixing, and effects design. Auralization also facilitates the evaluation of audio processing algorithms and audio equipment by providing a realistic auditory representation of their performance.

Auralization finds significance in the realm of virtual and augmented reality (VR/AR) as well. By accurately modeling sound propagation and spatial audio cues, auralization enhances the immersive experience in virtual environments. It enables users to perceive sounds as if they were present in a particular location or scenario, contributing to a more realistic and engaging VR/AR experience. This technology has applications in gaming, training simulations, architectural walkthroughs, and other interactive virtual experiences.

Furthermore, auralization plays a crucial role in noise control and environmental planning. It aids in assessing the impact of noise sources, such as transportation systems or industrial facilities, on surrounding areas. By simulating and analyzing the propagation of noise, auralization helps policymakers and urban planners to develop effective noise reduction strategies, optimize urban layouts, and create more livable environments.

In summary, auralization offers a powerful tool for simulating and analyzing sound in diverse contexts. Its applicability ranges from architectural and environmental acoustics to audio engineering, virtual reality, and noise control. By leveraging auralization techniques, professionals can make informed decisions, optimize designs, and create more immersive and pleasant auditory experiences in various fields.

Various phenomena are studied throughout the cross-relation of research areas. For instance, the authors in [1] investigated the aural comfort which is negatively affected during a train's passage through various tunnel environments. In their study a middle ear finite element model was constructed in order to simulate the dynamic responses with the pressure transients, and three indicators were analyzed to assess the severity of aural sensations. Meanwhile, the authors in [2] discussed a new technique to produce fast and reliable auralization methods with a computer code for room acoustics simulation using binaural room impulse responses generation classic method. Authors successfully demonstrated a new technique using radial basis functions type of artificial neural networks. Another recent study [3] presents a method derivation for delivering a binaural auralization technique of the noise generated by a moving vehicle to response of arbitrarily located moving listener (pedestrian). Authors integrated in a novel way a dynamic auralization engine, enabling real-time update approach of the acoustic cues in the binaural signal delivered via headphones, assuring that the reproduction of the synthesized signal is perceptually similar to one occurring on pedestrian/vehicle interactions during situations of street crossing. Auralization methods continue to improve, becoming one of the main elements for predicting the propagation of sound in space [4]. To simplify calculations and improve visualization, acoustic modeling programs are developed and used, which contain algorithms for auralization methods [5, 6]. Another work [7] provides insights into the fundamental concepts and techniques of auralization. It discusses various auralization methods, such as geometric acoustics, wave-based methods, and statistical models. The paper also highlights the applications of auralization in architectural acoustics, virtual reality, and soundscape design. Some interesting insights could be found in [8], study that delves into the theoretical and practical aspects of auralization. It covers the fundamentals of acoustics, sound propagation models, simulation techniques, and algorithms used in auralization. The authors explore the applications of auralization in architectural and environmental acoustics, room acoustics design, and audio engineering. At the same time, authors of [9] presented a virtual sound environment system that combines measured and simulated room impulse responses for auralization. The authors demonstrate the effectiveness of the system in creating realistic auditory experiences in virtual environments. The paper discusses the integration of auralization techniques in architectural and soundscape design. Focusing on urban sound planning and soundscape design, the research paper [10] explores the use of auralization in analyzing and improving the acoustic environment of urban areas. The authors discuss the integration of auralization with soundscape mapping and perception studies to develop effective noise control strategies and create pleasant urban soundscapes. Some useful results could be found in [11], where authors investigate the auralization of wind turbine noise to assess its impact on the soundscape. The authors develop auralization models that accurately simulate the complex acoustic behavior of wind turbines. The research highlights the importance of auralization in soundscape assessment and its potential for informing noise mitigation strategies. Some findings that authors presented in [12] also could be useful on the application of auralization in room acoustics design. Authors explore the integration of auralization with virtual reality (VR) technology. The authors also propose a VR-based auralization system that allows designers to experience and evaluate different room acoustic scenarios in an immersive virtual environment. The study demonstrates the effectiveness of auralization in optimizing room acoustics.

Main provisions

3D modeling is used to create high quality models for cinema, video games, architectural visualizations, design, and many other areas. Building 3D models can be done using various programs and tools such as SketchUp, Blender, 3Ds Max, Autodesk Revit, and others. The 3Ds Max platform was chosen for our work. It has a wide range of modeling tools such as primitive creation, polygon, mesh and surface manipulation, object modification tools and others. In our case, simple objects were used to create a model to save computational resources and simplify the process of building a computational grid. The model is shown in figure 1.

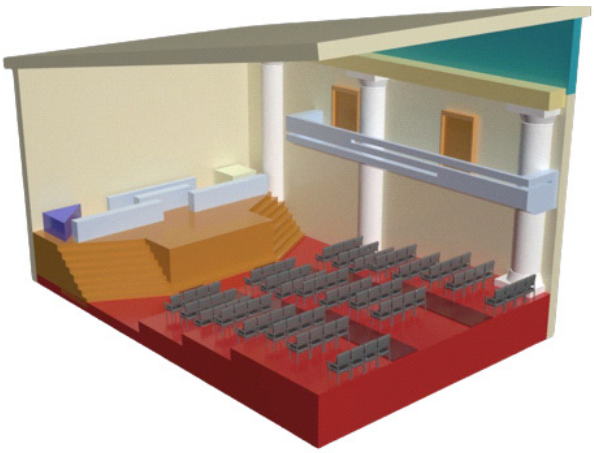

Figure 1 – Visualisation of concert hall model

We have optimized our model shown in figure 1 for this computing platform in drawing format. The final result of the model, to which the finite element method was applied, is shown in figure 2.

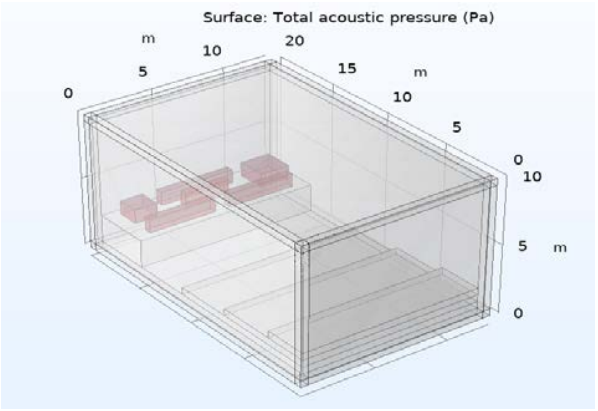

Figure 2 – Model for the finite element method at the initial time

The direct problem consists of determining the pressure field in domain $\Omega = [0, L_x] \times [0, L_y] \times [0, L_z] \times$ $\times [0, T_{max}]$. Further for setting up a mathematical model, we are implementing the equation of the plane wave through the parametrized radius vector r(t):

$$P(\vec{r}, t) = P_0 cos(\omega t - (\vec{k}, \vec{r}) + \varphi_0). \quad (1)$$

Further we use the differentiation and take the partial derivatives with respect to all spatial variables, obtaining the following mathematical model:

$$\frac{\partial^2 P(\vec{r},t)}{\partial t^2} = -\omega^2 P_0 cos(\omega t - (\vec{k}, \vec{r}) + \varphi_0) = -\omega^2 P(\vec{r}, t). \quad (2)$$

$$\frac{\partial^2 P(\vec{r},t)}{\partial x^2} = -k_x^2 P_0 cos(\omega t - (\vec{k}, \vec{r}) + \varphi_0) = -k_x^2 P(\vec{r}, t). \quad (3)$$

$$\frac{\partial^2 P(\vec{r},t)}{\partial y^2} = -k_y^2 P_0 cos(\omega t - (\vec{k}, \vec{r}) + \varphi_0) = -k_y^2 P(\vec{r}, t). \quad (4)$$

$$\frac{\partial^2 P(\vec{r},t)}{\partial z^2} = -k_z^2 P_0 cos(\omega t - (\vec{k}, \vec{r}) + \varphi_0) = -k_z^2 P(\vec{r}, t). \quad (5)$$

We combine the equations (3), (4) and (5) obtained by the system into the following form:

$$\frac{\partial^2 P(\vec{r},t)}{\partial x^2} + \frac{\partial^2 P(\vec{r},t)}{\partial y^2} + \frac{\partial^2 P(\vec{r},t)}{\partial z^2} = -\left(k_x^2 + k_y^2 + k_z^2\right)P(\vec{r},t) = -\left(\vec{k}\right)^2 \cdot P(\vec{r},t). \quad (6)$$

From the equation (2) we note that:

$$\frac{-1}{\omega^2} \cdot \frac{\partial^2 P(\vec{r},t)}{\partial t^2} = P(\vec{r},t). \quad (7)$$

By substitution the equation (7) to the resulting sum (6)
and replacing $\frac{\omega}{k} = c$, we get:

$$\frac{\partial^2 P(\vec{r},t)}{\partial x^2} + \frac{\partial^2 P(\vec{r},t)}{\partial y^2} + \frac{\partial^2 P(\vec{r},t)}{\partial z^2} = \frac{1}{c^2} \cdot \frac{\partial^2 P(\vec{r},t)}{\partial t^2}. \quad (8)$$

The following interpretation of the equation allows us to determine the value of the sound pressure at the point (x, y, z) of the selected area at time t:

$$\frac{\partial^2 p}{\partial t^2} = c^2 \left(\frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^2}\right), (x, y, z) \in \Omega. \quad (9)$$

Here $p(x, y, z, t)$ – the sound pressure, c – speed of the sound.

Sound pressure is the force acting per unit area, arising in an elastic area in which an acoustic wave propagates. It is measured in pascals (Pa).

The speed of sound is a constant value that determines the propagation speed of elastic waves in a certain environment. The unit of measurement is the meter divided by a second (m/s). Thus Equation 9 is the final equation for the model under consideration.

Next, we describe the initial conditions.For the pressure amplitude, we take the maximum value of sound pressure that an orchestra can create. This value is calculated as follows:

$$L = 20log_{10}\left(\frac{P_0}{P_{spl}}\right). \quad (10)$$

Where: L = 100 dB is the maximum volume of the orchestra, Pspl = 20 μPa is the sound pressure level, which advises the hearing threshold of a sinusoidal sound wave. Solving this equation with respect to P_0, we obtain the value of the amplitude for the initial condition:

$$P_0 = P_{spl} \cdot 10^{\frac{L}{20}} = 2Pa. \quad (11)$$

The angular frequency can be expressed in terms of the frequency of the sound of musical instruments (ν) using the formula:

$$\omega = 2\pi\nu. \quad (12)$$

For our model, we used the balanced value of the frequency range of each instrument, which is presented in Table 1, as the frequency. The phase shift for the wave oscillation equation is zero. Thus, the general form of the initial conditions at these points are described by the following formulas at considered for various frequencies according to the further Table 1:

$$P(x, y, z, t) \quad |_{t=0} = 2sin(2\pi\nu t) \quad |_{t=0}. \quad (13)$$

$$\frac{\partial P(x,y,z,t)}{\partial t} \quad |_{t=0} = -4\pi\nu cos(2\pi\nu t) \quad |_{t=0}. \quad (14)$$

Table 1 – Initial conditions for instruments.

Instrument	Frequency (Hz)	$P(x,y,z,0)$	$\frac{\partial P(x,y,z,0)}{\partial t}$
Violin	1505	0	-6020π
Cello	1722,5	0	-6890π
Flute	1270	0	-5080π
Tube	1825	0	-7300π
Piano	2136	0	-8544π
Xylophone	2000	0	-8000π

As noted earlier, the initial conditions are one of the main parts of the mathematical model since the calculation starts from these values.

Materials and Methods

Boundary conditions can be represented in three different ways. Conditions of the first kind are represented in the form of the Dirichlet problem, which determines the solution on the boundary of the domain, the second, in the form of the Neumann problem, which determines the derivative of the solution at the boundary points, and the third kind, Robin, which specifies the relationship between the desired function and its derivative.

In our case, using the absorption coefficients of building materials, we can determine what part of the sound will be reflected from the boundary and remain in the system, and what part will be absorbed. Gypsum plaster on walls absorbs 24% of sound, a concrete ceiling only 2%, and a carpeted concrete floor 27% [13].

In general, boundary conditions play an important role in mathematical models and make it possible to take into account the influence of the boundary on the solution of the problem. Approximating our mathematical model using an explicit scheme of finite difference method, we obtain the following expression:

$$\frac{P_{ijk}^{n+1} - 2P_{ijk}^{n} + P_{ijk}^{n-1}}{\Delta t^2} = c^2\left(\frac{P_{i+1jk}^{n} - 2P_{ijk}^{n} + P_{i-1jk}^{n}}{\Delta x^2} + \frac{P_{ij+1k}^{n} - 2P_{ijk}^{n} + P_{ij-1k}^{n}}{\Delta y^2} + \frac{P_{ijk+1}^{n} - 2P_{ijk}^{n} + P_{ijk-1}^{n}}{\Delta z^2}\right). \quad (15)$$

The indices "i, j, k" denote the coordinates of the grid nodes, and "n" represents the time step. After transferring all unknown components to the right side of the equation, it becomes:

$$P_{ijk}^{n+1} = 2P_{ijk}^{n} - P_{ijk}^{n-1} + \Delta t^2 c^2\left(\frac{P_{i+1jk}^{n} - 2P_{ijk}^{n} + P_{i-1jk}^{n}}{\Delta x^2} + \frac{P_{ij+1k}^{n} - 2P_{ijk}^{n} + P_{ij-1k}^{n}}{\Delta y^2} + \frac{+P_{ijk+1}^{n} - 2P_{ijk}^{n} + P_{ijk-1}^{n}}{\Delta z^2}\right), n = 0. \quad (16)$$

The procedure described above is carried out until the following condition became true:

$$\left|P_{ijk}^{n+1} - P_{ijk}^{n}\right| \leq \varepsilon. \quad (17)$$

Stability condition:

$$\frac{c^2\Delta t^2}{\Delta x^2} + \frac{c^2\Delta t^2}{\Delta y^2} + \frac{c^2\Delta t^2}{\Delta z^2} \leq 1. \quad (18)$$

Truncation error:

$$O(\Delta t^2, \Delta x^2, \Delta y^2, \Delta z^2). \quad (19)$$

For finite element modeling, we set a mathematical model that describes wave processes in the area where sound propagates. Various parameters were considered, such as air temperature, sound speed, absorption coefficients, as well as parameters of sound sources. For example, the amplitude and frequency of sound vibrations. With this module, you can simulate a wide range of problems related to sound: sound propagation, acoustic isolation, noise isolation, and so on.

Thus, the use of a computing platform can be an effective tool for the analysis, optimization of structures and systems related to acoustics, and visualization of sound propagation in three-dimensional space.

Results and Discussion

A small time step allows you to get results with greater accuracy. The initial conditions were set on the sixth layer in height (stage height) and depended on the location of the instruments. Figure 3 shows the sixth vertical slice at the initial time t=0. The scheme reached stability in 923 iterations (t=0.4615s). This method does not take into account that the auditorium is an amphitheater. Also, the materials of the scene were not considered, respectively, in the direction of the stage, the sound propagates with the same velocity as through the air. In figure 4, you can see a graph showing the sound pressure at the end time in the sixth layer in height.

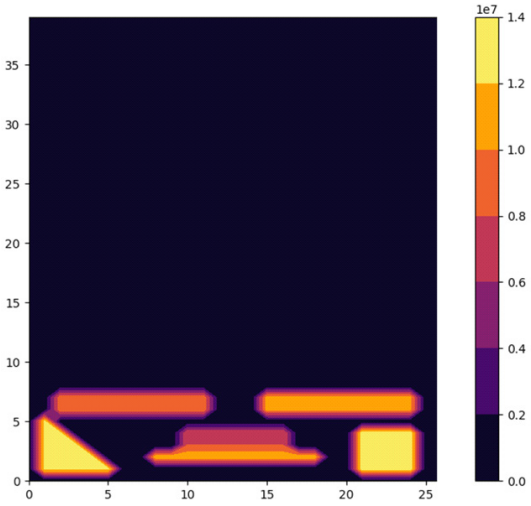

Figure 3 – Sixth layer in height at t=0 s

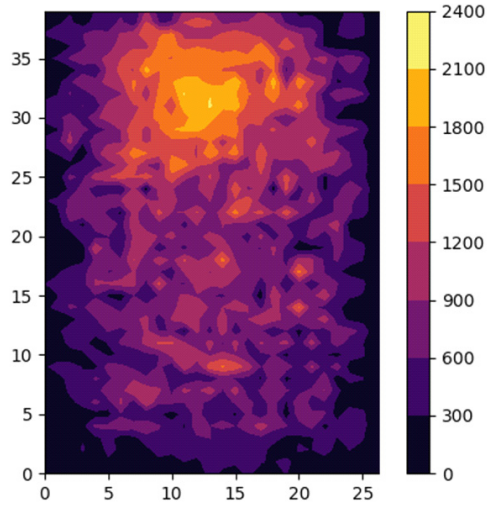

Figure 4 – Sixth layer in height at t=0.4615 s

As can be seen in these figures, at the initial moment of time, the instruments that are sources of sound concentrate the sound pressure in themselves. Then the instruments stop playing, the sound propagates from the stage to the end of the hall, where condensation can be observed due to the fact that there is a reflection of the sound, given by the boundary conditions. The graphs show pressure results in micro pascals [μPa].

The finite element method is a powerful tool for solving acoustic problems. The advantage of this method is that it allows solving problems of complex geometry and inhomogeneous media. In addition, it allows one to take into account various factors, such as reflection and refraction of sound waves at the interfaces between areas. Let's consider the further propagation of sound in different periods of time until the moment when the sound reaches the opposite stage boundary, shown in figures 5, 6.

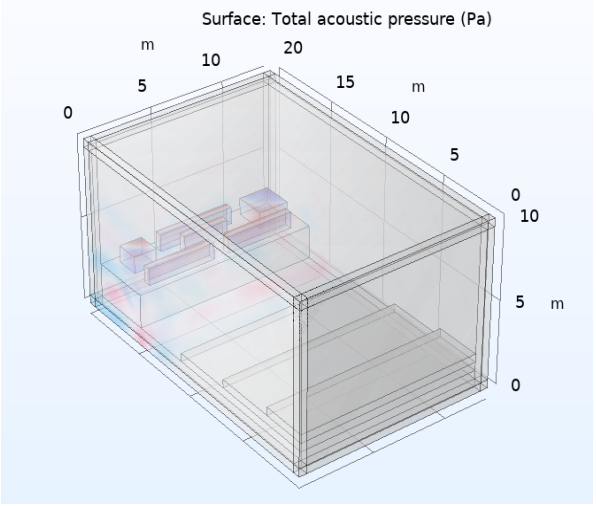

Figure 5 – Sound pressure at 0.02 seconds

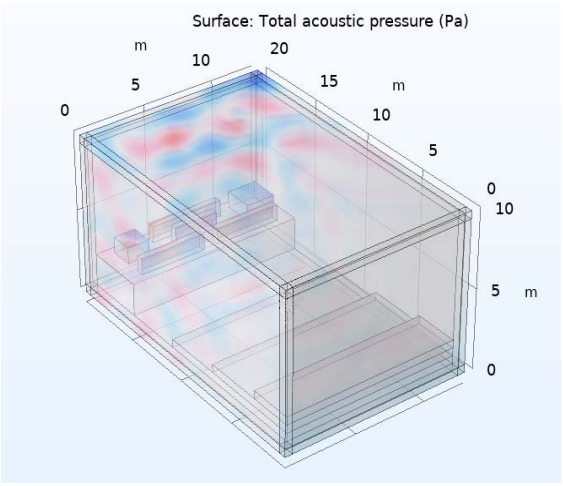

Figure 6 – Sound pressure at 0.06 seconds

The figures show the wave-like nature of the sound, which is demonstrated by the color map. The blue areas show the propagation of sound against the considered axis, and the red ones, on the contrary, in the direction. After the waves reach the boundary, part of the sound is reflected, the pressure gradually spreads over the entire area under study. In this case, the waves act on each other, forming areas with higher and lower pressure. This is reflected by the intensity of the color in certain areas. Fragments with a brighter color reflect the highest values, and dim - low values of acoustic pressure, as shown in figures 7, 8.

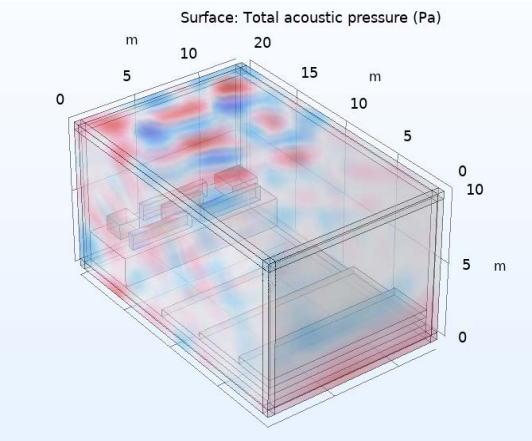

Figure 7 – Sound pressure at 0.07 seconds

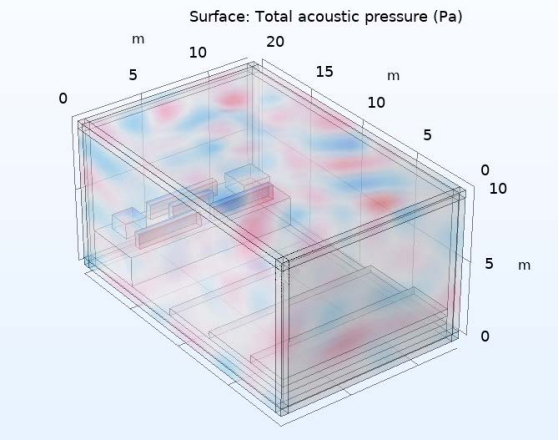

Figure 8 – Sound pressure at 0.12 seconds

These mathematical methods can be widely used for auralization, allowing you to select materials for construction, the location of sound sources and take into account all the interactions of waves with surfaces. Judging by the graphs, we can say that the results of the methods are similar, but the finite element method considers the direction of sound at a certain point, and the finite difference method considers only the sound pressure value at this point. Numerical values in both cases give close results, which allows us to conclude that both of these methods are accurate enough to be used as auralization methods and study the wave equation. Based on the features of the approaches, we conclude that the finite element method allows taking into account more factors, but at the same time spends more computational resources, while the finite difference method is less accurate in terms of aspects that affect the behavior of acoustic waves, but it spends significantly less time. The choice of one of these two methods depends on the objectives of the work to be achieved.

Conclusion

The use of mathematical and computer methods in the auralization of acoustic modeling of enclosers is an effective and promising direction in the field of sound design and acoustic engineering. In the work, various methods of auralization were considered, such as the finite element method, finite difference method. The advantages and disadvantages of each method are described, as well as examples of their application in the auralization of a closed space. It has been shown that the use of computer methods can significantly increase the accuracy and speed of auralization techniques implementation, as well as reduce computational costs.

Based on the data obtained, we conclude that the simplest implementation is one of the finite difference methods - an explicit scheme. This method allows you to get sufficiently accurate results applicable to sound modeling, with minimal time. The finite element method is also a good tool for acoustic problems, but it requires more time and computational resources.

In this work, only a part of the mathematical methods was studied, and the results obtained require further study and practical application. Thus, it can be concluded that mathematical and computer methods are an integral part of the auralization of closed spaces, and their implementation allows achieving high accuracy and efficiency in solving problems of sound design and acoustic engineering.

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Information about authors

Sinitsa Artem Vitalievich (corresponding author)
PhD, Senior-lecturer, Kazakh-British Technical University, Vice Dean of School of Applied Mathematics, Tole-bi 59, Almaty, Kazakhstan
ORCID ID 0000-0002-5828-7820
E-mail: a.sinitsa@kbtu.kz

Tskhay Yuliya Andreevna
Bachelor of Sciences, Kazakh-British Technical University, School of Applied Mathematics, Tole-bi 59, Almaty, Kazakhstan
ORCID ID: 0009-0003-0772-4319
E-mail: y_tskhai@kbtu.kz

Ukassova Aisulu Karimovna
Bachelor of Sciences, Kazakh-British Technical University, School of Applied Mathematics, Tole-bi 59, Almaty, Kazakhstan
ORCID ID: 0009-0003-0402-4720
E-mail: a_ukasova@kbtu.kz

Antonio Capsoni
PhD, Professor, Polytechnical University of Milan, Architecture and Civil Engineering of the Built Environment, Piazza Leonardo da Vinci, 32, Milan, Italy
ORCID ID 0000-0002-2056-495X
E-mail: antonio.capsoni@polimi.it

Авторлар туралы мәліметтер

Синица Артём Витальевич (корреспонденция авторы)
PhD, Сениор-лектор, Қазақстан-Британ техникалық университеті, Қолданбалы математика мектебі деканының орынбасары, Төле би көш., 59, 050000, Алматы қ., Қазақстан
ORCID ID: 0000-0002-5828-7820
E-mail: a.sinitsa@kbtu.kz

Цхай Юлия Андреевна
Жаратылыстану ғылымдарының бакалавры, Қазақстан-Британ техникалық университеті, Қолданбалы математика мектебі, Төле би көш., 59, 050000, Алматы қ., Қазақстан
ORCID ID: 0009-0003-0772-4319
E-mail: y_tskhai@kbtu.kz

Укасова Айсулу Каримовна
Жаратылыстану ғылымдарының бакалавры, Қазақ-Британ техникалық университеті, Қолданбалы математика мектебі, Төле би көш., 59, 050000, Алматы қ., Қазақстан
ORCID ID: 0009-0003-0402-4720
E-mail: a_ukasova@kbtu.kz

Антонио Капсони
PhD, профессор, Милан политехникалық университеті, сәулет және жобалау, Леонардо да Винчи алаңы, 32, Милан қ., Италия
ORCID ID: 0000-0002-2056-495X
E-mail: antonio.capsoni@polimi.it

Информация об авторах

Синица Артём Витальевич (автор для корреспонденции)
PhD, Сениор-лектор, Казахстанско-Британский технический университет, заместитель декана Школы прикладной математики, ул. Толе би, 59, 050000, г. Алматы, Казахстан
ORCID ID 0000-0002-5828-7820
E-mail: a.sinitsa@kbtu.kz

Цхай Юлия Андреевна
Бакалавр Естественных наук, Казахстанско-Британский технический университет, Школа прикладной математики, ул. Толе би, 59, 050000, г. Алматы, Казахстан
ORCID ID: 0009-0003-0772-4319
E-mail: y_tskhai@kbtu.kz

Укасова Айсулу Каримовна
Бакалавр Естественных наук, Казахстанско-Британский технический университет, Школа прикладной математики, ул. Толе би, 59, 050000, г. Алматы, Казахстан
ORCID ID: 0009-0003-0402-4720
E-mail: a_ukasova@kbtu.kz

Антонио Капсони
PhD, профессор, Политехнический университет Милана, архитектура и проектирование, площадь Леонардо да Винчи, 32, г. Милан, Италия
ORCID ID 0000-0002-2056-495X
E-mail: antonio.capsoni@polimi.it

Синица А.В.[*1], Цхай Ю.А.[1], Укасова А.К.[1], Антонио Капсони[2]

[1]Қазақстан-Британ техникалық университеті, 050000, Алматы қ., Қазақстан
[2]Милан политехникалық университеті, Милан, Италия
*E-mail: a.sinitsa@kbtu.kz

ШЕКАРАЛЫҚ ШАРТТАРДЫҢ ӨЗГЕРУІМЕН ШЕКТЕУ ІШІНДЕГІ ДЫБЫСТЫҢ ТАРАЛУЫН АУРАЛИЗАЦИЯ ҚҰРАЛДАРЫ АРҚЫЛЫ МАТЕМАТИКАЛЫҚ МОДЕЛЬДЕУ

Аңдатпа. Акустикалық қасиеттерді тіркеу және жабық орынжайларды аурализациялау маңызды бола түсуде. Қазіргі кезде опера театрлары, шіркеулер және концерт залдары сияқты тарихи ғимараттарды жобалау немесе қайта құру кезінде бастапқы акустикалық қасиеттерді сақтау үшін дыбыстың таралуын модельдеу маңызды. Біздің мақалада біз дыбыс толқынының ішкі үш өлшемді стационарлық емес аймақта таралу процесін, нақтырақ айтқанда концерт залындағы акустиканы модельдеуді қарастырамыз. Ол үшін берілген кіріс параметрлері бойынша бастапқы және шекаралық шарттарды пайдалана отырып, белгілі бір уақыт аралығында берілген аймақтағы дыбыстық қысымның таралу функциясы анықталды. Есептеулер барысында біз ақырлы элементтер әдісін жүзеге асыру үшін есептеу платформасын, сондай-ақ айқын схема мысалында ақырлы айырымдылық әдісін қолданамыз. Сандық нәтижелерге сүйене отырып, біз жабық кеңістікті аурализациялау әдістерінің тиімділігі туралы қорытынды жасаймыз, сонымен қатар әдістерді оңтайландыру мен қолдану аспектілерін сипаттаймыз.

Тірек сөздер: Математикалық модель, акустикалық таралу, шекаралық шарттар, қоршаған ортаны модельдеу, сандық талдау.

Синица А.В.[*1], Цхай Ю.А.[1], Укасова А.К.[1], Антонио Капсони[2]

[1]Казахстанско-Британский технический университет, 050000, г. Алматы, Казахстан
[2] Политехнический университет Милана, Милан, Италия
*E-mail: a.sinitsa@kbtu.kz

МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ РАСПРОСТРАНЕНИЯ ЗВУКА С ПОМОЩЬЮ СРЕДСТВ АУРАЛИЗАЦИИ ВНУТРИ ОГРАНИЧЕНИЯ С ВАРИАЦИЯМИ ГРАНИЧНЫХ УСЛОВИЙ

Аннотация. Регистрация акустических свойств и аурализация закрытых помещений приобретают все большее значение. В современном мире при проектировании или реконструкции исторических зданий, таких как оперные театры, церкви и концертные залы, важно смоделировать распространение звука, чтобы сохранить первоначальные акустические свойства. В нашей статье мы рассматриваем процесс распространения звуковой волны во внутренней трехмерной нестационарной области, а именно моделирование акустики в концертном зале. Для этого по заданным входным параметрам, начальным и граничным условиям была определена функция распределения звукового давления в заданной области за период времени. В ходе расчетов мы используем вычислительную платформу для реализации метода конечных элементов, а также метод конечных разностей на примере явной схемы. На основе численных результатов мы делаем выводы об эффективности методов аурализации замкнутых пространств, а также описываем аспекты оптимизации и использования методов.

Ключевые слова: математическая модель, акустическое распространение, граничные условия, моделирование окружающей среды, численный анализ.

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Жақатай А.Б.*, Койшиев Т.Қ.

әл-Фараби атындағы Қазақ ұлттық университеті, 050040, Алматы қ., Қазақстан
*E-mail: aizhan_1705@mail.ru

ШЕЛЕК ҚОСАЛҚЫ СТАНЦИЯСЫНЫҢ ДЕРБЕС ТҰТЫНУШЫЛАРЫН ЭНЕРГИЯМЕН ҚАМТАМАСЫЗ ЕТУГЕ АРНАЛҒАН ҚҰРАМАЛЫ КҮН-ЖЕЛ ҚОНДЫРҒЫЛАРЫНЫҢ ЖҰМЫС РЕЖИМІН БАҒАЛАУ ЖӘНЕ БАҚЫЛАУ

Аңдатпа: Параболоцилиндрлік күн концентраторы және горизонтальды жел генераторы секілді әртүрлі түрлерін біріктіретін құрамалы жаңғыртылатын энергия жүйелерін пайдалану арқылы қуаттылықты арттыру, жүйенің тұрақтылығын жақсарту және сенімділікті арттыру тұрғысынан көптеген артықшылықтарды қамтамасыз ете алады. Күн мен жел ресурстарының бірін-бірі толықтыратын сипатын пайдалана отырып, мұндай құрамалы жүйелері арқылы тұрақты және сенімді қуат көзін қамтамасыз ете алатынымыз анықталады, бұл дегеніміз тұрақты энергетикалық болашаққа ықпал етеді. Әлем энергия өндірісінде неғұрлым тұрақты және жасыл энергия көзқарасына көшкен сайын, құрамалы күн-жел қондырғылары дербес тұтынушылардың энергетикалық қажеттіліктерін қанағаттандыру үшін инновациялық шешімге айналды. Құрамалы күн-жел қондырғылары дәстүрлі энергия көздеріне қолжетімділік шектеулі немесе сенімсіз болуы мүмкін автономды немесе шалғай аудандар үшін өте қолайлы. Автономды энергетикалық жүйелерді электр энергиясымен қамтамасыз ету үшін олардың бірегей ерекшеліктерін, артықшылықтарын және әлеуетті қолданбаларын зерттей отырып, дербес тұтынушылар үшін арнайы әзірленген құрамалы күн-жел қондырғыларының тұжырымдамасы қарастырылды.

Тірек сөздер: құрамалы жаңғыртылатын энергия көздері, параболацилиндрлік күн концентраторы, горизонтальды жел генераторы

Кіріспе

Жаңғыртылатын энергия көздеріне сұраныс жылдан жылға артып келе жатқандықтан, құрамалы күн-жел қондырғылары автономды тұтынушылардың энергетикалық қажеттіліктерін қанағаттандыру үшін перспективалы шешім негізінде қабылданды. Қажетті қондырғыларда параболоцилиндрлік күн концентраторларымен жиналған күн энергиясының қуатын көлденең жел генераторлары шығаратын кинетикалық энергиямен біріктіреді, нәтижесінде екі көзді электрмен жабдықтау жүйесі тиімді және сенімді болады.

Құрамалы күн-жел қондырғыларының бірқатар артықшылықтары бар, соның ішінде энергия өндіруді арттыру, жүйенің тұрақтылығын арттыру және дәстүрлі энергия көздеріне тәуелділікті азайту. Параболоцилиндрлік күн концентраторлары мен көлденең жел генераторларының бірегей ерекшеліктеріне, сондай-ақ олардың автономды немесе шалғай аудандарды электрмен қамтамасыз ету үшін әлеуетті қолданылуына назар аудара отырып, автономды тұтынушыларды энергиямен қамтамасыз етуге арналған құрамалы күн-жел қондырғыларының тұжырымдамасы қарастырылады.

Жаңғыртылатын энергия көздері секторының өсуі мен дамуының негізгі мінездемелері:

• жаңғыртылатын энергия өндірісі физикалық және табиғи ортаға аз әсер етеді, әртүрлі ландшафтқа бейімделеді және көмір электр станцияларымен салыстырғанда инфрақұрылымға төмен талаптар қояды;

• орталықсыздандырылған жаңғыртылатын энергия өндірісі сенімді және экологиялық тұрақты түрде шөлді және таулы аймақтарды, табиғи қорықтарды және ерекше қорғалатын аумақтарды қоса алғанда, шалғай және аз қоныстанған аудандардағы ауылдық және шағын кәсіпорындардың энергияға деген қажеттіліктерін қанағаттандыруға көмектеседі;

• жаңғыртылатын энергия саласындағы жобаларды іске асыру әлеуметтік және аумақтық дамуға әсер етеді, әсіресе ауылдық жерлерде жұмыс орындарын құруға, басқа да экономикалық пайда әкелуі мүмкін;

• жаңғыртылатын энергия өндіретін нысандар дәстүрлі энергия генераторларымен салыстырғанда техникалық қызмет көрсету шығындарын аз талап етеді.

Зерттеудің мақсаты. Құрамалы күн-жел қондырғылары арқылы дербес тұтынушыларды энергиямен қамтамасыз ету, Nasa Power Data Access Viewer бағдарламасы аясында зерттеу

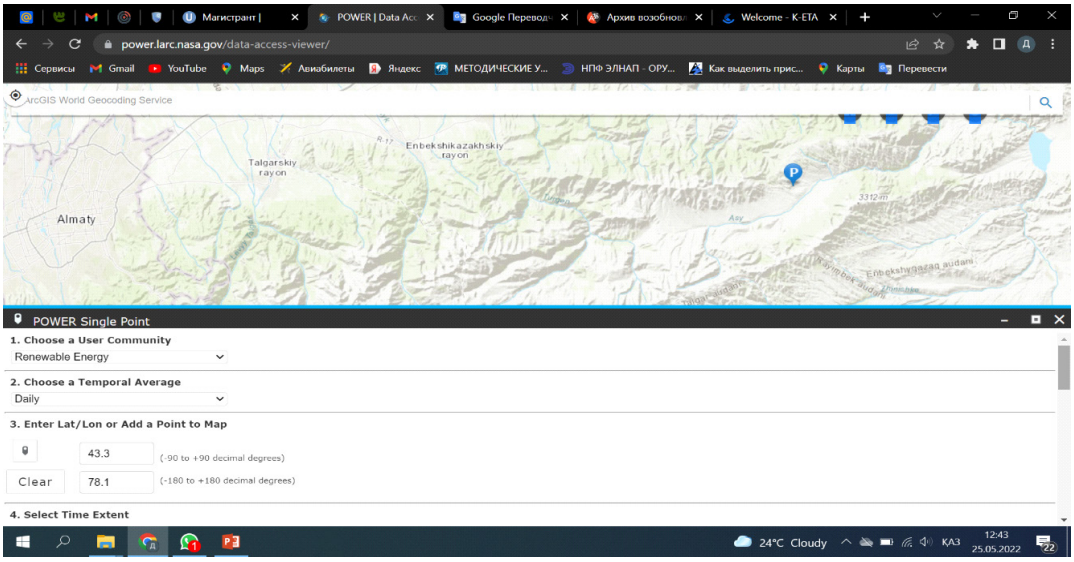
Зерттеудің нысаны. Шелек қосалқы станциясының дербес тұтынушылары.

Зерттеудің теориялық құрылымы. Шелек аймағындағы дербес тұтынушыларды энергиямен қамтамасыз ету үшін жел және күн энергиясын өндірудің әлеуеті, қолданудың техникалық мүмкіндіктері қарастырылды.

Материалдар және әдістер

NASA-ның Жер туралы ғылым саласындағы мақсаты – жер жүйесін байқау, түсіну және модельдеу, оның қалай өзгеретінін білу, өзгерістерді жақсы болжау және жер бетіндегі тіршіліктің салдарын түсіну.

«Әлемдік энергетикалық ресурстардың болжамы» (POWER) жобасы жаңғыртылатын энергия көздері бойынша ағымдағы деректер жиынтығын жақсарту және жаңа спутниктік жүйелерден жаңа деректер жиынтығын құру үшін бастамашылық жасалған. POWER жобасы үш пайдаланушы қауымдастығына бағытталған: (1) жаңғыртылатын энергия көздері, (2) тұрақты ғимараттар және (3) агроклиматология (1-сурет).



Сурет 1 – Шелек аймағын Nasa Power Data Access Viewer бағдарламасында зерттеу

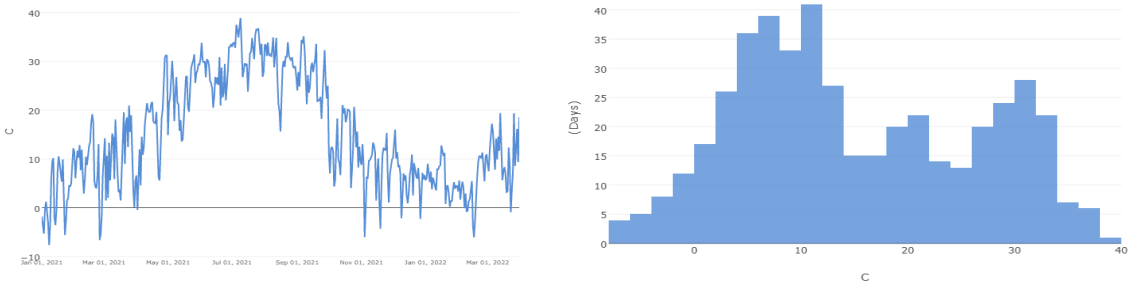
Nasa Power Data Access Viewer (DAV) веб-карта қолданбасында жаңғыртылатын энергия жүйелерін бағалау және жобалау үшін тұжырымдалған күн энергиясына, метеорологияға және бұлттарға қатысты геокеңістіктік параметрлер бар. Power деректер мұрағаты веб-карта қолданбасынан тыс кеңейтілетін және ажырамас бірқатар қызметтер арқылы қолжетімді болады. POWER әр түрлі мәтіндік, кестелік, геокеңістіктік деректер жиынтығын және пайдаланушылар одан әрі өңдеу, талдау және визуализация үшін пайдаланушы бағдарламалық жасақтамасы мен қосымшаларына жүктей және біріктіре алатын файлдарды ұсынады.

Осы аталған бағдарламада алынған нәтижелер MathCAD ортасында да өңделеді.

Нәтижелер мен талқылау

Nasa Power Data Access Viewer бағдарламасы арқылы Шелек аймағының күн және жел электр станциялары бойынша өзімізге қажетті мәліметтерге графиктер (2–3-суреттер) және кестелер алынды. Сонымен қатар Шелек аймағына салыстырмалы түрде Кентау аймағы (Түркістан облысы) мен Жалаңаш аймағы (Қызылорда облысы) мәліметтерін салыстыру 1, 2-кестелер негізінде көрсетілді.

2 метр қашықтықтағы максимум температура



Сурет 2 – Шелек аймағы үшін алынған мәліметтер

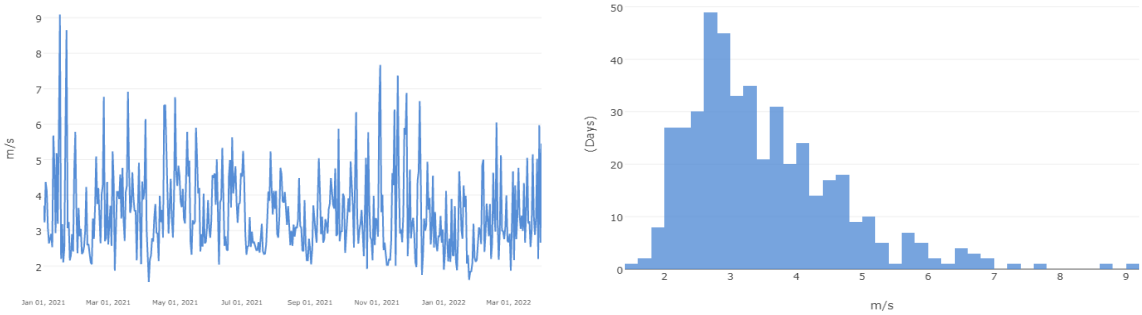
Кесте 1 – Аймақтар бойынша орташа мәндері

Айдың орташа күндері	15.01.21	15.02.21	15.03.21	15.04.21	15.05.21	15.06.21	15.07.21	15.08.21
Шелек аймағы								
Орташа мәні (кВтсағ/м²/күн)	-0,36	12,66	3,15	21,27	13,96	26,8	29,54	19,75
Кентау аймағы								
Орташа мәні (кВтсағ/м²/күн)	-2,51	12,79	-7,13	19,4	23,73	29,82	27,72	25,19
Жалағаш аймағы								
Орташа мәні (кВтсағ/м²/күн)	-3,01	1,08	-1,16	19,61	29,29	35,04	28,86	28,48

Кесте 1 (жалғасы) – Аймақтар бойынша орташа мәндері

Айдың орташа күндері	15.09.21	15.10.21	15.11.21	15.12.21	15.01.22	15.02.22	15.03.22
Шелек аймағы							
Орташа мәні (кВтсағ/м²/күн)	29,73	19,3	1,46	0,89	8,66	-3,71	5,65
Кентау аймағы							
Орташа мәні (кВтсағ/м²/күн)	30,73	17,14	1,8	2,2	4,2	-3,84	7,53
Жалағаш аймағы							
Орташа мәні (кВтсағ/м²/күн)	30,58	18,31	-0,12	-0,47	-1,09	-1,63	2,74

10 метр қашықтықтағы жел жылдамдығы



Сурет 3 – Шелек аймағы үшін алынған мәліметтер

Кесте 2 – Аймақтар бойынша орташа мәндері

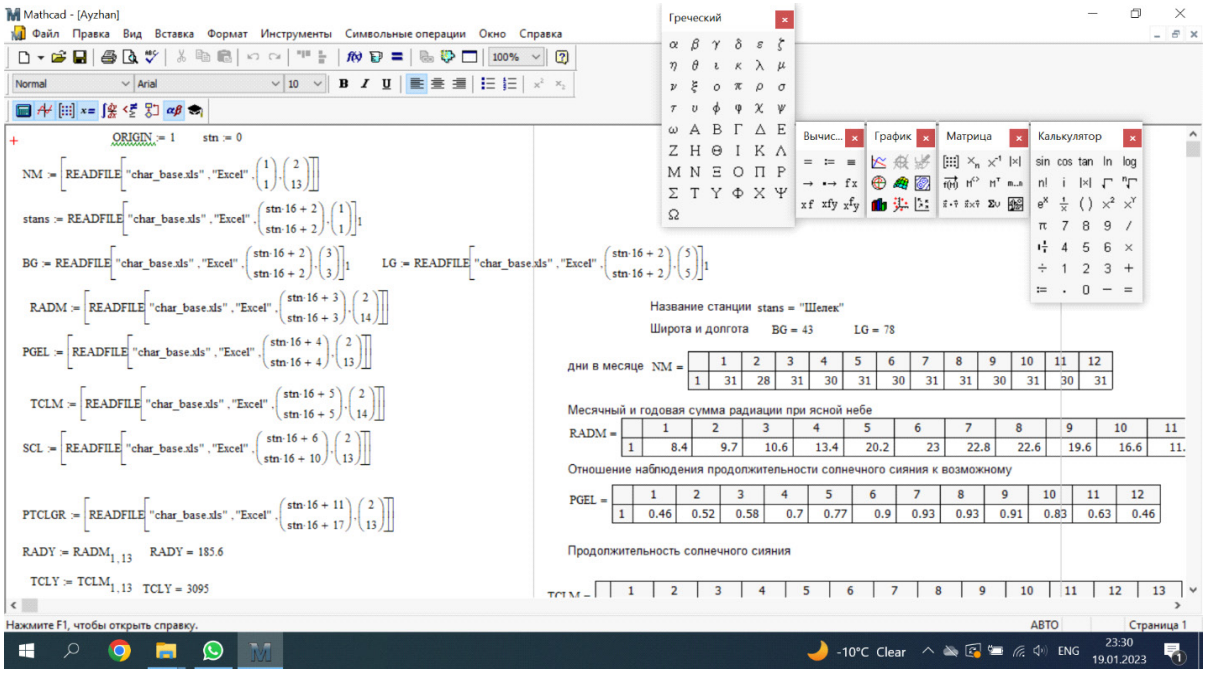
Айдың орташа күндері	15.01.21	15.02.21	15.03.21	15.04.21	15.05.21	15.06.21	15.07.21	15.08.21
Шелек аймағы								
Орташа мәні (кВтсағ/м²/күн)	5,81	3,34	3,28	2,91	2,69	2,57	2,45	2,99
Кентау аймағы								
Орташа мәні (кВтсағ/м²/күн)	11,26	2,32	5,19	5,14	12,44	10,51	4,75	7,6
Жалағаш аймағы								
Орташа мәні (кВтсағ/м²/күн)	9,54	3,51	3,02	7,05	7,27	5,52	2,73	5,05

Кесте 2 (жалғасы) – Аймақтар бойынша орташа мәндері

Айдың орташа күндері	15.09.21	15.10.21	15.11.21	15.12.21	15.01.22	15.02.22	15.03.22
Шелек аймағы							
Орташа мәні (кВтсағ/м²/күн)	3,32	2,63	4,62	3,0	4,67	4,63	4,34
Кентау аймағы							
Орташа мәні (кВтсағ/м²/күн)	3,26	7,11	4,55	4,2	5,91	3,14	4,85
Жалағаш аймағы							
Орташа мәні (кВтсағ/м²/күн)	2,93	5,75	3,32	3,16	5,77	3,48	3,82

Бағдарлама арқылы салыстыру нәтижесі жүзеге асырылды.

NASA POWER ACCESS бағдарламасы арқылы алынған деректер бойынша MathCAD ортасында 4-суретте есептеу жұмыстары жүргізілді.



Сурет 4 – MathCAD ортасында есептеу барысы

Нәтижелер бойынша NASA POWER ACCESS бағдарламасы арқылы алынған деректер MathCAD ортасында алынған деректермен сәйкес келді.

Қорытынды

Зерттеу жұмысы барысында электр энергетикасындағы қазіргі уақыттағы негізгі мәселелердің бірі – жаңғыртылатын энергия көздері арқылы электр энергиясын тиімді өндіру, сонымен қатар дербес тұтынушыларды энергиямен қамтамасыз етуге арналған құрамалы күн-жел қондырғыларының жұмыс режимін бағалау зерттелді.

Құрамалы күн-жел электр станциялары электр энергиясын өндірудің сенімді және тұрақты жүйесін қамтамасыз ететін бірнеше көздерден алынатын жаңғыртылатын энергияны пайдаланудың перспективалы шешімі болып табылады. Күн мен жел энергиясының қосындысы бір-бірін толықтыра алады, энергия өндірісін барынша арттырады.

Бірінші заманауи жаңғыртылатын энергия көздеріне шолу және сонымен қатар Шелек аймағындағы дербес тұтынушыларды энергиямен қамтамасыз ету үшін жел және күн энергиясын өндірудің әлеуеті, қолданудың техникалық мүмкіндіктері қарастырылды. Nasa Power Data Access Viewer бағдарламасы аясында Шелек аймағының күн және жел бойынша энергия өндіруге қажетті мәліметтері алынды. Бағдарлама негізінде Қазақстанның 3 аймағын салыстыру негізінде күн ағындары және оған байланысты барлық параметрлер, әртүрлі биіктіктегі күн температуралары және т.б. деректер өңделді. Алынған деректер бойынша MathCAD ортасында есептеу жұмыстары жүргізілді.

Қорытындылай келе, құрамалы күн-жел электр станциялары қуат коэффициентінің жоғарылауы, желінің интеграциясының жақсаруы және қоршаған ортаға аз әсер етуі сияқты артықшылықтарды ұсына алады.

Күн мен жел технологияларының үздіксіз инновациялары мен интеграциясы гибридті жүйелердің дамуына және олардың әлеуетіне таза және тұрақты энергия өндіруге ықпал ете отырып, болашақ энергия қажеттіліктерін қанағаттандыруда маңызды рөл атқара алады.

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Авторлар туралы мәліметтер

Жақатай Айжан (корреспонденция авторы)
әл-Фараби атындағы Қазақ ұлттық университеті, әл-Фараби көш., 71, Алматы қ., 050040, Қазақстан
ORCID ID 0009-0003-3710-7645
E-mail: aizhan_1705@mail.ru

Койшиев Темірхан
әл-Фараби атындағы Қазақ ұлттық университеті, әл-Фараби көш., 71, Алматы қ., 050040, Қазақстан
ORCID ID 0009-0005-7990-6036
E-mail: phystech.final2022@mail.ru

Информация об авторах

Жақатай Айжан (автор для корреспонденции)
Казахский национальный университет им. Аль-Фараби, ул. Аль-Фараби, 71, г. Алматы, 050040, Казахстан
ORCID ID 0009-0003-3710-7645
E-mail: aizhan_1705@mail.ru

Койшиев Темірхан
Казахский национальный университет им. Аль-Фараби, ул. Аль-Фараби, 71, г. Алматы, 050040, Казахстан
ORCID ID 0009-0005-7990-6036
E-mail: phystech.final2022@mail.ru

Information about authors

Zhakatai Aizhan (corresponding author)
Al-Farabi Kazakh National University, St. Al-Farabi, 71, Almaty, 050040, Kazakhstan
ORCID ID 0009-0003-3710-7645
E-mail: aizhan_1705@mail.ru

Koishiev Temirkhan
Al-Farabi Kazakh National University, St. Al-Farabi, 71, Almaty, 050040, Kazakhstan
ORCID ID 0009-0005-7990-6036
E-mail: phystech.final2022@mail.ru

Zhakatai A.B.*, Koishiev T.K.

Al-Farabi Kazakh National University, 050040, Almaty, Kazakhstan
*E-mail: aizhan_1705@mail.ru

ASSESSMENT AND MONITORING OF THE WORKING MODE OF COMBINED SUN-WIND UNITS FOR SUPPLYING INDEPENDENT CONSUMERS WITH ENERGY OF THE CHELEK SUBSTATION

Abstract: The use of hybrid renewable energy systems combining various types of renewable energy technologies, such as a parabolocylindrical solar concentrator and a horizontal wind generator, can provide many advantages in terms of increasing power, increasing the stability of the system and increasing reliability. By leveraging the complementary nature

of solar and wind resources, we discover that we can provide a stable and reliable source of energy with such combined systems, which means that we are contributing to a sustainable energy future.

As the world has moved towards a more sustainable and environmentally friendly approach to energy production, combined solar and wind installations have become an innovative solution to meet the energy needs of autonomous consumers. Combined solar wind turbines are ideal for autonomous or remote areas where access to traditional energy sources may be limited or unreliable. Having studied their unique features, advantages and potential applications for providing electricity to autonomous energy systems, the concept of combined solar and wind installations developed specifically for individual consumers was considered.

Key words: hybrid renewable energy sources, parabolacylindrical solar concentrator, horizontal wind generator.

Жақатай А.Б.*, Койшиев Т.Қ.

Казахский национальный Университет имени аль-Фараби, 050040, г. Алматы, Казахстан
*E-mail: aizhan_1705@mail.ru

ОЦЕНКА И КОНТРОЛЬ РЕЖИМА РАБОТЫ ГИБРИДНЫХ СОЛНЕЧНО-ВЕТРОВЫХ УСТАНОВОК, ПРЕДНАЗНАЧЕННЫХ ДЛЯ ЭНЕРГООБЕСПЕЧЕНИЯ АВТОНОМНЫХ ПОТРЕБИТЕЛЕЙ ШЕЛЕКСКОЙ ПОДСТАНЦИИ

Аннотация. Использование гибридных возобновляемых энергетических систем, сочетающих в себе различные типы технологий возобновляемой энергии, таких как параболоцилиндрический солнечный концентратор и горизонтальный ветрогенератор, может обеспечить множество преимуществ с точки зрения увеличения мощности, повышения устойчивости системы и повышения надежности. Используя взаимодополняющий характер солнечных и ветровых ресурсов, мы обнаруживаем, что можем обеспечить стабильный и надежный источник энергии с помощью таких комбинированных систем, это означает, что мы способствуем устойчивому энергетическому будущему.

По мере того, как мир перешел к более устойчивому и экологичному подходу к производству энергии, комбинированные солнечные и ветровые установки стали инновационным решением для удовлетворения энергетических потребностей автономных потребителей. Комбинированные солнечные ветряные турбины идеально подходят для автономных или удаленных районов, где доступ к традиционным источникам энергии может быть ограниченным или ненадежным. Изучив их уникальные особенности, преимущества и потенциальное применение для обеспечения электроэнергией автономных энергетических систем, была рассмотрена концепция комбинированных солнечно-ветровых установок, разработанная специально для индивидуальных потребителей.

Ключевые слова: гибридные возобновляемые источники энергии, параболацилиндрический солнечный концентратор, горизонтальный ветрогенератор.

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Khaniyev B.A.[1], Meirambekuly N.[*1], Khaniyeva A.K.[1], Ashirkulov K.[2], Beisen A.N.[3]

[1] Department of Physics and Technology, Al-Farabi Kazakh National University, 050040, Almaty, Kazakhstan
[2] Graduate school of social sciences, Mugla Sitki Kocman University, Kötekli, Kötekli Mevkii, 48000, Muğla, Türkiye
[3]International Taraz Innovative Institute named after Sherkhan Murtaza, Taraz 080000, Kazakhstan
*E-mail: nurs.kaznu@gmail.com

THE SENSING PERFORMANCE OF SURFACE-MODIFIED POROUS SILICON GAS SENSORS FOR NON-POLAR GAS DETECTION

Abstract. Gas sensors are important devices in various industrial and environmental monitoring applications. Toluene and chloroform are harmful non-polar gases that are produced in various combustion processes and are associated with air pollution and respiratory diseases. Porous silicon (PS) has shown promising results as a material for ammonia and ethanol gas sensing applications. However, there is potential for further improvement by optimizing their surface properties for non-polar gas sensing applications. Chemical treatment has been widely utilized to modify the surface characteristics of materials, including semiconductors, for various applications. We have deposited nickel (Ni) layer on PS surface using chemical treatment. In comparison to the PS sample, it was discovered that the Ni-deposited PS sample was more sensitive to 0.1 ppm concentrations of non-polar toluene and chloroform vapours, increasing from 1% to 39% and 32.6%, respectively. This study provides valuable insights into the surface modification techniques for enhancing the performance of gas sensors, which can have a significant impact on the development of advanced sensing technologies for environmental and industrial applications.

Key words: gas sensor, porous silicon, nickel, chemical treatment, sensitivity.

Inroduction

Nowadays, the development of industrial technologies and automation of processes, increasing requirements for human health and environmental protection have led to a significant increase in the demand for gas sensors [1]. Control and monitoring systems used to analyze the composition of air in the environment and to accurately determine the concentration of a certain type of gas mainly consist of a gas sensor, an analog-to-digital converter, a microprocessor used for digital processing of information on the composition of air, and an electronic display. In addition, if necessary, such systems can be equipped with wireless communication systems for remote control and monitoring. The main areas of application of these devices include industrial enterprises, factories, mines, industrial security services and crowded places [2].

The primary measuring element of the electronic gas sensor is the sensitive element. As the primary sensitive component of gas sensors, metal-oxide semiconductors like ZnO, SnO2, TiO2, In2O3, and MoS2 are frequently utilised. [3]. In addition, many works have been published to study the possibilities of gas sensors based on organic compounds, optical sensors, materials based on carbon nanotubes and conductive nanostructures as various gas sensors. However, gas sensors based on metal-oxide semiconductors, which are widely used in practice, usually operate at high temperatures between 150-300°C, and therefore require high energy consumption and low selectivity and sensitivity to some types of gases [4]. In addition, poor compatibility with contemporary silicon-based electronic gadgets and increasingly complex manufacturing techniques. Thus, it can be considered a difficult task to monitor harmful gases using gas sensors based on metal oxide semiconductors at room temperature [5].

The large surface area due to the fractal structure, the chemical activity of the material surface, the uncomplicated production technology, as well as the unique optical, electrical and structural properties make porous silicon (PS) a promising material for use as a sensitive element in gas sensor technology [6].

In addition, another advantage of using silicon nanostructures as a gas sensor is compatibility with modern electronics. Although PS is highly sensitive to certain types of gases, it is less stable due to rapid acidification of its surface. Therefore, the sensitivity and selectivity characteristics of electronic gas sensors for difficult-to-detect gas species can be increased by using a surface-modified PS for solid-state electronics manufacturing applications [7]. The results of the experimental study showed that the tested samples can detect harmful gases at a concentration of 0.1 ppm at room temperature. These results demonstrate the possibility of developing highly sensitive and cost-effective electronic sensors for various harmful and hazardous gases. High-tech tools and processes of radio engineering and electronics were used to obtain sensitive elements and study their electrical, morphological and optical characteristics.

In this work, we investigate the impact of chemical treatment on the morphology of PS as well as on the gas sensing performance of surface modified PS-based gas sensors towards non-polar gases such as toluene and chloroform in order to enhance the device performance.

Main provisions

For the first time, surface-modified porous silicon with a nickel layer was used to detect non-polar gases with concentrations up to 0.1 ppm.

Materials and Methods

During the experiment, nanoscale PS samples were used as the research subject. By electrochemically etching p-type silicon wafers with a resistance of 10 Ohm/cm and a crystal orientation of 100, PS samples were produced. Fig. 1 shows a schematic illustration of the electrochemical etching procedure [8].

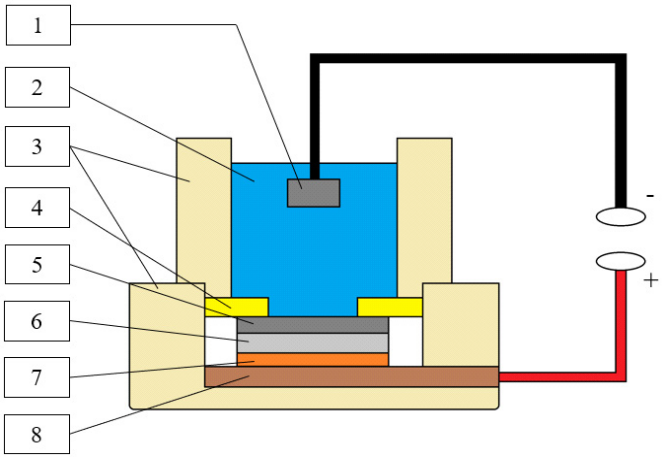

Figure 1 – Electrochemical etching procedure: 1 – platinum cathode; 2 – electrolyte; 3 – Teflon-like fluoroplastic cell; 4 – sealing ring; 5 – porous silicon; 6 – silicon; 7 – metal layer; 8 – anode [8].

In the beginning, thin films of PS were created by electrochemical etching in a 1:1 HF:C2H5OH solution electrolyte. Before being rinsed with deionized water, silicon wafers were first cleaned in HF solution. A metal layer needs to be deposited on the silicon wafer's bottom surface before it can be placed in the cell used for the electrochemical etching procedure. For this, a silicon wafer must be kept pre-covered in a nickel solution that has been heated to between 50 and 60 oC for five to seven minutes. The silicon wafer is placed in a cell constructed of fluoroplastic Teflon and an electrolyte is poured over it after the metal layer has been applied to the bottom surface. On the silicon's bottom surface, a sealing ring is put in place to prevent the electrolyte from passing through. Because platinum is one of the metals that does not change when exposed to the HF solvent acid, platinum is employed as the cathode. Anode is attached to the silicon surface where nickel has been deposited. Such a structure has an edge over other technologies due to its ease of use and affordable cost. At a current density of 5 mA/cm2, the electrochemical etching process was conducted for 40 minutes.

The gravimetric method was used to determine the porosity of the obtained PS sample in accordance with the expression (1) below. [9]:

$$P = \frac{m_1 - m_2}{m_1 - m_3} \times 100\%, \qquad (2.1)$$

where m_1 – mass of the sample before the PS layer is fabricated, m_2 – mass of the sample after the PS layer has been fabricated, m_3 – mass of the sample after the PS layer has been stripped off.

PS samples generated by electrochemical etching were placed in a nickel solution heated to a temperature of 50–60 °C for 5-7 minutes in order to deposit a nickel layer on the surface.

A scanning electron microscope, the Quanta 200i 3D, was used to examine the morphology of the materials. A 473 nm laser was used to excite the photoluminescence, which was examined using the NT-MDT Solver Spectrum system. In order to obtain electrical properties, two ohmic contacts of InGa alloy in a coplanar configuration were thermally installed on the surface of the samples. The samples' sensitivity to vapours of toluene and chloroform was determined using the formula in [10].

Results and Discussion

The PS substrate had a porosity of 72.7%.

Fig. 2 shows the cross section and top view SEM images of the obtained Ni/PS material. As shown in the figure, the Ni layer is deposited on the PS surface as a porous structure and a metal-conductor contact is formed.

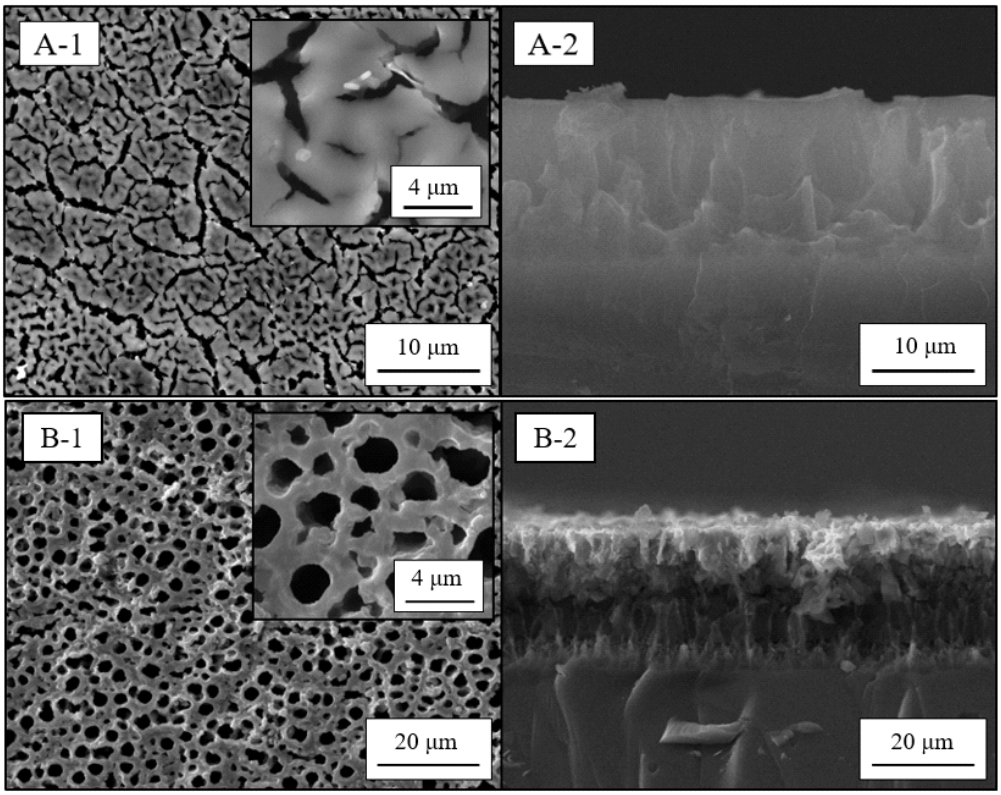

Figure 2 – SEM images of PS (A) and Ni/PS (B): 1 – top view; 2 – cross-section view.

Figure 3 shows that, as compared to PS, the Ni/PS sample's normalised photoluminescence (PL) intensity is displaced to the green area of the spectrum at wavelengths of 520 nm and 535 nm, respectively (photon energies are 2.38 eV and 2.32 eV).

Photoluminescence signals of semiconductor materials are generated by photoinduced recombination of charge carriers [10]. It is seen that the spectrum of the given material has the ability to radiate from the blue to the red region.

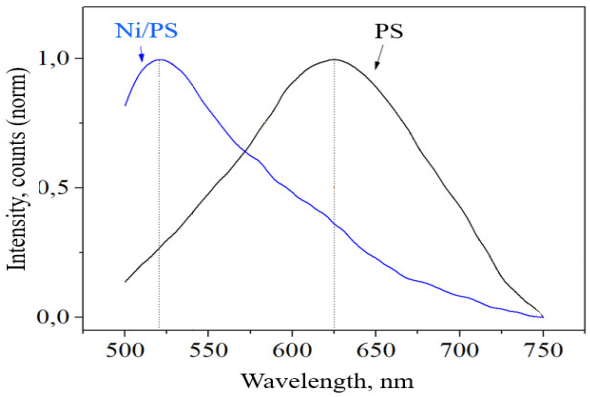

Figure 3 – Photoluminescence spectra of PS and Ni/PS samples

The defect states created from oxygen vacancies are responsible for the material's emission at various wavelengths. As the efficiency of electron transport at the border between the adsorbed molecule and the material's surface rises, such oxygen vacancies enable materials to be more sensitive.

Let's now think about the electrical properties of the Ni/PS sample under various gas exposures. The current-voltage characteristics of the PS sample with a Ni layer modification are shown in Fig. 4. The figure illustrates how the sample's current-voltage characteristics have a rectifier character under both ambient circumstances and gas impact. Additionally, when exposed to all of the gas utilised for the test, the current of the Ni/PS sample increases.

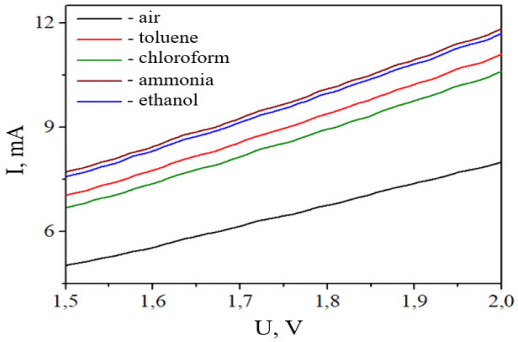

Figure 4 – Current-voltage characteristics of the Ni/PS-based gas sensor under different gas exposures

Figure 5 depicts diagrams of the Ni/PS sensitive element's sensitivity to vapours of ammonia, ethanol, toluene, and chloroform. The sensitivity is greater than 30% for all gas types.

Table 1 provides a summary of the examined properties of the materials employed as gas sensors. The table makes it evident that adding a metal layer to the PS surface can enhance the features of gas sensors.

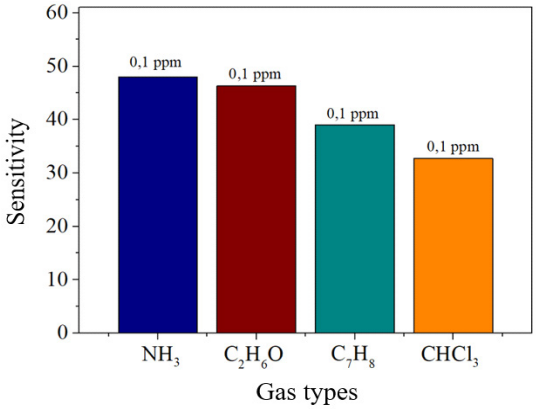

Figure 5 – Diagrams illustrating the gas sensors' sensitivity to various gas molecules based on PS modified with a Ni layer

Table 1 – Comparison of PS and Ni/PS-based gas sensors

No.	Sensitive material	Sensitivity				Response time / recovery rime, sec			
		NH_3	C_2H_6O	C_7H_8	$CHCl_3$	NH_3	C_2H_6O	C_7H_8	$CHCl_3$
1	PS	33.25	5.75	-	-	3 / 270	-	-	-
2	Ni/PS	47.97	46.3	39	32.68	3 / 360	15 / 15	20 / 10	50 / 60

As a result, as compared to the original PS, the Ni/PS gas sensor's sensitivity to non-polar toluene and chloroform vapour concentrations at 0.1 ppm ranges from 1% to 39% and 32.6%, respectively.

Conclusion

In this work, the non-polar gas sensor was constructed from a surface-modified porous silicon sample and given a chemical treatment to improve its performance. SEM analysis and PL spectra were used to examine the structure and morphology of the etched and sputtered nanomaterials, and they supported the deposition of Ni on the PS surface. According to the results of the gas sensing, Ni/PS outperformed PS in terms of toluene and chloroform sensitivity at ambient temperature. As a result, the Ni layer's alteration of the PS surface increased their sensitivity to vapours. This study demonstrates that a highly sensitive, low-cost gas sensor device based on a Ni/PS structure is feasible for detecting toluene and chloroform vapours at room temperature in concentrations up to 0.1 ppm.

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Information about authors

Khaniyev Bakyt Abaiuly

Department of Physics and Technology, Al-Farabi Kazakh National University, 050040, Almaty, Kazakhstan

ORCID ID 0000-0002-0103-9201

E-mail: khaniyev.bakyt@gmail.com

Meirambekuly Nursultan (corresponding author)

Department of Physics and Technology, Al-Farabi Kazakh National University, 050040, Almaty, Kazakhstan

ORCID ID 0000-0003-2250-4763
E-mail: nurs.kaznu@gmail.com

Khaniyeva Ainur Kabylzhankyzy
Department of Physics and Technology, Al-Farabi Kazakh National University, 050040, Almaty, Kazakhstan
ORCID ID 0000-0002-0167-3093
E-mail: mukhanova.kaznu@gmail.com

Ashirkulov Kanat
Graduate school of social sciences, Mugla Sitki Kocman University, Kötekli, Kötekli Mevkii, 48000, Muğla, Türkiye
ORCID ID 0009-0004-3439-5941
E-mail: kanatashirkulov@posta.mu.edu.tr

Beisen Asset Nurboluly
International Taraz Innovative Institute named after Sherkhan Murtaza, Taraz 080000, Kazakhstan
ORCID ID 0009-0000-5144-2616
E-mail: beisen.aset2020@gmail.com

Авторлар туралы мәліметтер

Ханиев Бакыт Абайулы
Физика-техникалық факультет, әл-Фараби атындағы ҚазҰУ, 050040, Алматы қ., Қазақстан
ORCID ID 0000-0002-0103-9201
E-mail: khaniyev.bakyt@gmail.com

Мейрамбекулы Нурсултан (корреспонденция авторы)
Физика-техникалық факультет, әл-Фараби атындағы ҚазҰУ, 050040, Алматы қ., Қазақстан
ORCID ID 0000-0003-2250-4763
E-mail: nurs.kaznu@gmail.com

Ханиева Айнур Кабылжанкызы
Физика-техникалық факультет, әл-Фараби атындағы ҚазҰУ, 050040, Алматы қ., Қазақстан
ORCID ID 0000-0002-0167-3093
E-mail: mukhanova.kaznu@gmail.com

Аширкулов Канат
Әлеуметтік ғылымдар мектебі, Мұғла Сыткы Кочман университеті, Кётекли, Кётекли Мевки, 48000, Мұғла, Түркия
ORCID ID 0009-0004-3439-5941
E-mail: kanataşirkulov@posta.mu.edu.tr

Бейсен Әсет Нұрболұлы
Шерхан Мұртаза атындағы Халықаралық Тараз инновациялық институты, 080000, Тараз қ., Қазақстан
ORCID ID 0009-0000-5144-2616
E-mail: beisen.aset2020@gmail.com

Информация об авторах

Ханиев Бакыт Абайулы
Физико-технический факультет, КазНУ им. аль-Фараби, 050040, г. Алматы, Казахстан
ORCID ID 0000-0002-0103-9201
E-mail: khaniev.bakyt@gmail.com

Мейрамбекулы Нурсултан (автор для корреспонденции)
Физико-технический факультет, КазНУ им. аль-Фараби, 050040, г. Алматы, Казахстан
ORCID ID 0000-0003-2250-4763
E-mail: nurs.kaznu@gmail.com

Ханиева Айнур Кабылжанкызы
Физико-технический факультет, КазНУ им. аль-Фараби, 050040, г. Алматы, Казахстан
ORCID ID 0000-0002-0167-3093
E-mail: mukhanova.kaznu@gmail.com

Аширкулов Канат
Высшая школа социальных наук, Университет Мугла Ситки Кочман, Кётекли, Кётекли Мевки, 48000, Мугла, Турция
ORCID ID 0009-0004-3439-5941
E-mail: kanatashirkulov@posta.mu.edu.tr

Бейсен Асет Нурболулы
Международный Таразский инновационный институт имени Шерхана Муртазы, Тараз 080000, Казахстан
ORCID ID 0009-0000-5144-2616
E-mail: beisen.aset2020@gmail.com

Ханиев Б.А.[1], Мейрамбекұлы Н.[*1], Ханиева А.Қ.[1], Аширкулов К.[2], Бейсен Ә.Н.[3]

[1]Әл-Фараби атындағы ҚазҰУ физика-техникалық факультеті, 050040, Алматы, Қазақстан
[2]Әлеуметтік ғылымдар жоғары мектебі, Мұғла Сыткы Кочман университеті, Кётекли, Кётекли Мевки, 48000, Мұғла, Түркия.
[3]Шерхан Мұртаза атындағы халықаралық Тараз инновациялық институты, 080000, Тараз қ., Қазақстан
*E-mail: nurs.kaznu@gmail.com

БЕЙПОЛЯРЛЫ ГАЗДЫ АНЫҚТАУҒА АРНАЛҒАН БЕТІ ӨЗГЕРТІЛГЕН КЕУЕКТІ КРЕМНИЙЛІ ГАЗ СЕНСОРЛАРЫНЫҢ СЕЗУ ӨНІМДІЛІГІ

Аңдатпа. Газ датчиктері – өнеркәсіптік және экологиялық бақылаудың әртүрлі қосымшаларындағы маңызды құрылғылар. Толуол мен хлороформ – әртүрлі жану процестерінде пайда болатын және ауаның ластануымен, тыныс алу органдарының ауруларымен байланысты зиянды бейполярлы газдар. Кеуекті кремний (КК) аммиак пен этанол газын анықтауға арналған материал ретінде перспективалы нәтижелерді көрсетті. Дегенмен, бейполярлық газды сезіну қолданбалары үшін олардың беттік қасиеттерін оңтайландыру арқылы оны одан әрі жақсарту мүмкіндігі бар. Химиялық өңдеу материалдардың, соның ішінде жартылай өткізгіштердің беткі сипаттамаларын әртүрлі қолданбалар үшін өзгертуде кеңінен қолданылды. Біз химиялық өңдеу арқылы КК бетіне никель (Ni) қабатын қойдық. Ni-тұндырылған КК үлгісінің бейполярлы толуол мен хлороформ буларының 0,1 ppm концентрациясына сезімталдығы КК-мен салыстырғанда тиісінше <1%-дан 39%-ға және 32,6%-ға дейін жоғарылағаны анықталды. Бұл зерттеу қоршаған орта мен өнеркәсіптік қолданбалар үшін алдыңғы қатарлы зондтау технологияларын дамытуға айтарлықтай әсер етуі мүмкін газ датчиктерінің өнімділігін арттыру үшін бетті модификациялау әдістері туралы құнды түсініктерді береді.

Тірек сөздер: газ сенсоры, кеуекті кремний, никель, химиялық өңдеу, сезімталдық.

Ханиев Б.А.[1], Мейрамбекулы Н.[*1], Ханиева А.К.[1], Аширкулов К.[2], Бейсен А.Н.[3]

[1]Физико-технический факультет КазНУ им. Аль-Фараби, 050040, г. Алматы, Казахстан
[2]Высшая школа социальных наук, Университет Мугла Ситки Кочман, Кётекли, Кётекли Мевки, 48000, Мугла, Турция
[3]Международный Таразский инновационный институт имени Шерхана Муртазы, Тараз, 080000, Казахстан
*E-mail: nurs.kaznu@gmail.com

ИЗМЕРИТЕЛЬНЫЕ ХАРАКТЕРИСТИКИ МОДИФИЦИРОВАННЫХ ПОВЕРХНОСТЕЙ ГАЗОВЫХ СЕНСОРОВ НА ПОРИСТОМ КРЕМНИИ ДЛЯ ОБНАРУЖЕНИЯ НЕПОЛЯРНОГО ГАЗА

Аннотация. Датчики газа являются важными устройствами в различных приложениях промышленного и экологического мониторинга. Толуол и хлороформ – вредные неполярные газы, образующиеся в различных процессах горения и связанные с загрязнением воздуха и респираторными заболеваниями. Пористый кремний (ПС) показал многообещающие результаты в качестве материала для измерения газов аммиака и этанола. Однако существует потенциал для дальнейшего улучшения за счет оптимизации свойств их поверхности для приложений, связанных с измерением неполярного газа. Химическая обработка широко используется для модификации характеристик поверхности материалов, в том числе полупроводников, для различных применений. Мы нанесли слой никеля (Ni) на поверхность ПК с помощью химической обработки. Установлено, что чувствительность образца ПС, осажденного Ni, к концентрации 0,1 ppm паров неполярного толуола и хлороформа увеличилась с <1 % до 39 % и 32,6 % соответственно по сравнению с ПС. Это исследование дает ценную информацию о методах модификации поверхности для повышения производительности газовых датчиков, что может оказать существенное влияние на разработку передовых сенсорных технологий для экологических и промышленных применений.

Ключевые слова: газовый сенсор, пористый кремний, никель, химическая обработка, чувствительность.

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Joldassov S.K., Abildaev S.T.*, Tattibaev S.J., Sarbassova G.A.

M.Kh.DulatyTaraz Regional university, 080012, Taraz, Kazakhstan
*E-mail:sultan_feb@mail.ru

ON METHODS FOR DETERMINING THE ROUGHNESS COEFFICIENT OF CHANNELS ALONG THE PERIMETER

Abstract. The scientific article deals with the issues of uniform movement of the riverbed and the determination of the roughness coefficient of the riverbed (roughness coefficient). The analysis of existing methods for calculating the difference in the roughness coefficients of channels along the perimeter, methods for determining the roughness coefficient of the slopes of channels consisting of two or three parts along the perimeter, well–known scientists - P.N.Belokon, G.K.Lotter, N.N.Pavlovsky are given.There are a some varieties of calculation methods assigned for hydraulic calculations of water flow along the perimeter of a soil channel in the field of hydraulic engineering. A number of researchers states that the roughness of the channel bed imitates the motion of the flow in diverse channels with the movement of the flow under the ice layer. Nevertheless, it should be taken into account that the roughness of the channel bed has its own characteristic (specific) features of the movement of water in different open channels and below the ice cover. The common formulas proposed by number of authors for channels with different roughness along the perimeter cannot be used directly in hydraulic calculations of the flow under the ice cover, and vice versa, the equations of motion of water flow beneath the ice cover are not applied even for channels with various roughness along the perimeter. Therefore, the corresponding choice of methods for determining the roughness coefficients of the canal flow along the perimeter will be the key point to its long-term functioning.

Keywords: canal, uniform motion, roughness coefficient, steady motion, average speed, channel perimeter, channel cross-section, hydraulic radius.

Introduction

Majority of canals used in hydraulic engineering have same roughness coefficient on bothonslopes and on bottom.Due to the long term exploitation there is a possibility of change in roughness coefficient of canal along the perimeter caused by effluent change during the vegetation period.

Changes in roughness coefficient of slopes and bottom in canal also depends on water permeability and filtration features on the basic layer. Purpose of our primary research was the common defining of roughness coefficient by perimeter of canal [1].

Small part of efflunt's cross-section is key term for the appearance of canal's considered roughness coefficientfrom resistance along the canal's length and formation of bottom while planning flows passing through confirmed canal. Currently there are few proposed ways of calculated ratios for dealing with hydraulic accounts for water flows along the perimeter of our canal.Many researchers found similarity between flows in canals with various roughness level and flows beneath icy layer.Still, we have to emphasize the fact that they both have some unique features by themselves. Regular calculation formulas proposed by many authors for the canals with various roughness level never can be used in hydraulic accounts for flows under icy layer, as well as equations for flow beneath ice can not possibly be used for canals with different roughness indexes. Modifications made while generating this formulas can not be allowed.

Methods and materials

Method of the research is theoretical, materials in usage was accurately processed. According to the information we have, hydraulic circumstances of flow get more complicated in cases where canal cross-

sectionhave different roughness because of formation of new zones, and so it leads to the fact that planar and vertical distribution of velocities along the cross-section are experiencing sharp changes. To generalize main calculating ratios we make this note - despite of the different states of canal roughness the smoothness of flow remains steadily, that is roughness of canal sides keeps constant along the all considered areas.Moreover, we accept measurements allowed by general hydraulics: magnitude of the slope which could somehow impact to the movement on different partsof flow is same, velocities on separate surfaces of any rectilinear regions of cross-section are same for the first and second parts of the flow and this equals to the maximum velocity. In general, area of canal's cross-sectionapproximately divides to evaluate average index of canal roughness coefficient on bottom and on sides, we assume moisture perimeters χ_1, χ_2, χ_3 and roughness coefficient $n_1, n_2 ... n_N$ ofcanal like that.During calculations of this well-known scientists as Horton and Einstein made this proposal [2] – velocities on considered areas are same and equal to the average speed on any point, about roughness coefficient we are defining it can be determined in this way:

$$n = \left[\frac{\sum_1^N (\chi_N n_N^{1,5})}{\chi} \right]^{2/3} = \frac{(\chi_1 n_1^{1,5} + \chi_2 n_2^{1,5} + ... + \chi_N n_N^{1,5})^{2/3}}{\chi^{2/3}} \quad (1)$$

Pavlovsky, Mulkhofer, Einstein and Bank [2] are recommending this equation for defining canal's roughness coefficient:

$$n = \left[\frac{\sum_1^N (\chi_N n_N^{2})}{\chi^{1/2}} \right]^{1/2} = \frac{(\chi_1 n_1^{2} + \chi_2 n_2^{2} + ... + \chi_N n_N^{2})^{1/2}}{\chi^{1/2}} \quad (2)$$

Another scientist Lotter proposed this way of solution [1],

$$n = \frac{\chi R^{5-3}}{\sum_1^N \left(\frac{\chi_N R_N^{5/3}}{n_N} \right)} = \frac{\chi R^{5/3}}{\frac{\chi_1 R_1^{5/3}}{n_1} + \frac{\chi_2 R_2^{5/3}}{n_2} + ... + \frac{\chi_N R_N^{5/3}}{n_N}} \quad (3)$$

There are $R_1, R_2, ... R_N$-hydraulic radiuses of considered sectors. In the any section $R_1 = R_2 = ... = R_N = R$ will remain.

Canals roughness can be changed due to the ice formation on the surface of our canal. To explain this phenomenon Lotter[2] came to the conclusion that definitions of roughness for deep canals with icy surface can be determined in the following way.

Chart 1 – approximately taken measures for roughness coefficient for deep canals with icy surface

Formation of icy layer	Velocity in the canal, cm/s	Roughness coefficient
With smooth surface:		
Without ice floes	0,39 – 0,6	0,01-0,012
	0,6-high	0,014-0,017
With ice floes	0,39-0,6	0,016-0,018
	0,6-higher than	0,017-0,02
With ice floesandwithroughsurface	-	0,023-0,025

For instance, n1andn2are roughness coefficients for the canals with and without icy layer. Using first and second equations above we can find roughness coefficient for icy layer. Although coefficient defined in that way sometimes can be negative but is has no importance [1].

According to the Pavlovsky [2] to approach to the genuine solution of the equationwe should accept that

the full resistance for liquid motion equals to the sum of resistances formed by canal's bottom and icy layer, so we will have

$$k\upsilon^2 \ell\chi = k_1\upsilon^2 l\chi_1 + k_2\upsilon^2 l\chi_2 \quad (4)$$

There 1 and 2 indexes arerespectively related to the canal bottom and icy layer.

If current and roughness of canal are known, then according to Menning's formula[3] we can find the slope of flow in prizmatic canal in steady motion by using given averagevalue.Slope defined in that way is known as regular slope. Steady surface flow with regular slope could be turbulent or laminar depending on factors like flow, slope, viscosity and roughness of surface. If velocity and depth of flow are relatively low, then viscosity will be dominant factor and flow moves in laminar regime. We certainly can notice thatit is not simple processfrom one glance to the details of flow movement with roughness coefficient.

Results and discussions

In general finding the main calculating ratios lays down on defining moisture perimeters and areas entering to individual sections with roughness.Defining moisture perimeters of individual section is not hard at all, moreover they are determined as relevant edge of geometric figure. It should be noted that edge of rib has to lay on the considered bottom space of canal.

However, finding areas of figures adjoining to sides with individual roughness is really complicated. Methods of P.N.Belokon, G.K.Lotter, N.N.Pavlovsky, E.E.Shiperko which are known in scientific literature are directed to the significant allowances in flow's phenomenon and equality of radiuses of separated parts and of the whole riverbed, and in equality of average velocities on different parts and in the whole flow, but they never have been approved in practical way.Current laborotoric measuresmade by us and other authors shows that they are significantly distinguished in max values and they have considerable mistakes in accounts. So, we came to solution that attempt of evaluating the problem of roughness coefficient by using standard methods not allowed to obtain results necessary for us: using only equation of steady motion is not enough, so according to that we have to consider another ways of dealing with this problem.We believe that dealing with equations for canals with different roughness is the most typical way which is used by all authors.

There can be negative effects caused by roughness. In practices this interaction creates following kinematics of flow's motion which can afford minimum walkthrough of considered cross-section amongst all possible conditions. In canals and open riverbeds with steady motion we can define water's velocity in this way [1, 2]:

$$\upsilon = CR^x i^y \quad (5)$$

there$v$ – average speed, m/s; C – coefficient of Shezi; R – hydraulic radius, м; i –г hydraulic slope; x *and* y – degree's index.

According to the famous scientist Shnekenberg[4]– main formula whencanal has spiral flow has to contain following options: area of canal's cross-section, average velocity of water flow, max speed of water, moisture perimeter of canal, hydraulic radius of canal, depth, slope of flow's free surface, roughness coefficient on cross-section, effluent of major and minor loads in water, dynamic viscosity and temperature of water.

Defining roughness coefficient[2] while solving coefficient of Shezi by formulas of scientists Kutter and Menning in equation of steady motion is really hard.

Main provisions

There was the research of rise of roughness coefficient in field conditions during 1 year in the process of determining the canal's roughness coefficient in natural conditions at university of Illinois and it's measure grew from 0.33 to 0.55 in one season. There shown the methods for defining roughness coefficient in below.

Method for roughness taken by all along the average canal perimeter

Meaning of this method is - measures of private parts along the canal's perimeter we write (n1 and n2) then appropriate to that moisture perimeters written like this χ_1, χ_2, knowing that we can define roughness coefficient of that type of canal by following way:

$$n_{pr} = \frac{(n_1\chi_1 + n_2\chi_2)}{(\chi_1 + \chi_2)} \quad (6)$$

This method is too rough. Considered roughness coefficient of canal is more dependend on hydraulic radius rather than canal's moisture perimeter.

Method of G.K. Lotter. G.K.Lotter [1–5] uses method of account of composite canal while calculating canals with different roughness along the canal's perimeter.

Effluent of composite canal will be:

$$Q = Q_1 + Q_2 \tag{7}$$

there: Q_1 and Q_2 – effluents of first and second parts of the flow.

We resolve effluent of water by formula of Shezi:

$$\omega \cdot C_{pr} \cdot \sqrt{R \cdot J} = \omega_1 \cdot C_1 \cdot \sqrt{R_1 \cdot J_1} + \omega_2 \cdot C_2 \cdot \sqrt{R_2 \cdot J}_2$$

there:–areaofcross-section; –hydraulicradiusofwholecross-sectionarea;–appropriatecoefficientofSheziforwholecross-section; and–cross-sectionareasofflowpartsinfluencedbyzoneswithsteadyroughness; and–hydraulic radiuses of first and second parts of cross-section;and–Shezi coefficient of first and second parts of cross-section; J - piezometricslope.

$\omega = R \cdot \chi$ in first and second parts of canal's cross-section and because of motion affected by slope are equal, we can write previous equation in this way:

$$C_{pr} \chi R^{3/2} = C_1 \chi_1 R_1^{3/2} + C_2 \chi_2 R_2^{3/2} \tag{8}$$

there: χ -moistureperimeterofwholecross-section; χ_1 and χ_2 -moisture perimeter of first and second parts of cross-section.

We divide both part of given equation by χ_1 then we write χ_2 / χ_1 proportion like (a):

$$C_{pr} = \frac{C_1 R^{3/2} + a C_2 R_2^{3/2}}{R^{3/2}(1+a)} \tag{9}$$

From equation(9) we can see that to solve we need both - moisture perimeters of parts with different roughness and hydraulic radiuses of cross-section'spersonal parts. In this situation hydraulic radiuses of cross-section's personal parts are defined exactly like for composite canal. For very wide canals moisture perimeter can be equal to width of canal, about hydraulic radius - it equals to depth of considered place. In this case equation (8) will be written in the following way:

$$Q = \left(C_1 b_1 h_1^{3/2} + C_2 b_2 h_2^{3/2}\right)\sqrt{J} \tag{10}$$

There b_1 and b_2 - relatively width of 1 and 2 parts, h_1 and h_2 - depth on first and second parts.

G.K.Lotter believes that hydraulic radiuses of flow's private parts are equal to the hydraulic radius of whole flow for canals with ice formation:

$$R_1 = R_2 = R \tag{11}$$

Because of moisture perimeter of canal - χ_1 and of ice- χ_2 are equal, then hydraulic radius of whole section is equal:

$$R = \frac{\omega}{\chi_1 + \chi_2} \tag{12}$$

In this case equation(9) will be written in the following way:

$$C_{pr} = \frac{C_1 + a C_2}{(1+a)} \tag{13}$$

Then independent on eachother methods of P.N.Belokon and N.N.Pavlovsky are published[1,6].

Method of P.N. Belokon

We consider canal's cross-section with any shape, then roughness of moisture perimeter on first part will be $n_1$and in the second is n_2.

We define fall along the length of canal by next formula

$$J = \frac{F}{\gamma\omega} \tag{14}$$

There: F - sum of fictitious friction forces on canal sides(walls. We mark average friction force falling on 1m^{2}of canal's side in first part like and in second one

$$F = \tau_1\chi_1 + \tau_2\chi_2 \tag{15}$$

Then we can write equation(14) in following way:

$$\frac{\tau_1\chi_1}{\gamma} + \frac{\tau_2\chi_2}{\gamma} = \omega J$$

If take them as $\chi_1 = a\chi$ and $\chi_2 = a\chi$, then we get this:

$$a_1\frac{\tau_1}{\gamma} + a_2\frac{\tau_2}{\gamma} = \frac{\omega}{\chi}J = RJ\cdot$$

In turbulent steady motion it will look like this:

$$\frac{\tau_1}{\gamma} = \frac{\upsilon_1^2}{C_1^2} \text{ and } \frac{\tau_2}{\gamma} = \frac{\upsilon_2^2}{C_2^2}$$

there: υ_1 and υ_2 - average velocity in first and second parts of flow. Then previous equations will look like that:

$$a_1\frac{\upsilon_1^2}{C_1^2} + a_2\frac{\upsilon_2^2}{C_2^2} = RJ \tag{16}$$

If and solved in Menning's way, then equation(16) will be like this:

$$a_1\frac{n_1^2\upsilon_1^2}{R_1^{1/3}} + a_2\frac{n_2^2\upsilon_2^2}{R_2^{1/3}} = RJ \tag{17}$$

If take this ratio like that $\frac{n_2}{n_1} = \psi$ we will see this:

$$n_1^2\left(a_1\frac{\upsilon_1^2}{R_1^{1/3}} + \psi^2 a_2\frac{\upsilon_2^2}{R_2^{1/3}}\right) = RJ \tag{18}$$

Moreover P.N.Belokon says that: if ratios for areas of cross-section relatively to zones with different roughness equals to θ, then we get this $\frac{\omega_1}{\omega_2} = \theta$

Then $\omega_1 + \omega_2 = \omega$ will be when $\omega_1 = \frac{\theta}{1+\theta}$ and $\omega_2 = \frac{\theta}{1+\theta}\omega\cdot$

P.N.Belokon finds answers of $R_1$and$R_2$from next equations:

$$R_1 = \frac{\omega_1}{\chi_1} = \frac{\theta}{a_1(1+\theta)}R \text{ and } R_2 = \frac{\omega_2}{\chi_2} = \frac{\theta}{a_2(1+\theta)}R \tag{19}$$

Full effluent will be: $Q_1 + Q_2 = Q$.

We resolve effluent by Shezi-Menning formula:

$$Q_1 = \frac{1}{n_1}\omega_1 R_1^{2/3} J^{1/2} \text{ and } Q_2 = \frac{1}{n_2}\omega_2 R_2^{2/3} J^{1/2} \quad (20)$$

We divide first part of equation(20) by second part because the slopes of them are equal: or we put answers of ω_1, ω_2 and R_1, R_2 into this $\frac{Q_1}{Q_2} = \frac{n_1}{n_2} \cdot \frac{R_1^{2/3}\omega_1}{R_2^{2/3}\omega_2}$ equation:

$$\frac{Q_1}{Q_2} = \psi\left(\frac{a_2}{a_1}\right)^{2/3} \theta^{2/3}$$

If we convert that equations, roughness coefficient will be:

$$n = n_1\left(a_1 + a_2\psi^{3/2}\right)^{3/2} \quad (21)$$

Method of N.N. Pavlovsky

According to N.N.Pavlovsky [1,7–20] definition of considered roughness coefficient is taken from equation of steady motion for open canals written below:

$$RJ = \frac{\tau}{\gamma} \quad (22)$$

If sides of canal are distinguished from eachother then we have to exchange this equation with another one, for that we need todivide liquid between cross-sections, direct impacting forces to direction of flow, then construct new motion equation for released part.

Then we get this equation(22):

$$RJ = \frac{\tau_1 + a\tau_2}{\gamma(1+a)} \quad (23)$$

there:and–respectively average special friction in sides ofcanal, – ratio of moisture perimeters on two sides - $a = \frac{\chi_2}{\chi_1}$.

When sides are same average special friction in sides of canal is equal to the average depth in this subsequence $\frac{\tau}{\gamma} = \frac{\upsilon^2}{C^2}$.

According to that we can write and like this:

$$\frac{\tau_1}{\gamma} = \frac{\upsilon^2}{C^2}, \frac{\tau_2}{\gamma} = \frac{\upsilon^2}{C^2} \quad (24)$$

Before getting binders N.N.Pavlovsky takes that the average velocity of each part is equal - $\upsilon = \upsilon_1 = \upsilon_2$.

We put this equation(24) to another one(23):

$RJ = \frac{\upsilon^2}{1+a}\left(\frac{1}{C_1^2} + \frac{a}{C_2^2}\right)$, follows to $\upsilon = C_1 C_2 \sqrt{\frac{1+a}{aC_1^2 + C_2^2}} \cdot \sqrt{RJ}$ (25)

N.N.Pavlovsky counts measure before $\sqrt{RJ}$ as “coefficient of Shezi”, then marks it like Cpr, because of that we can write equation(25) in next way:

$$\upsilon = C_{pr} \cdot \sqrt{RJ} \quad (26)$$

Here $C_{pr} = C_1 C_2 \sqrt{\frac{1+a}{aC_1^2 + C_2^2}}$.

To find C_1 andC_2we have to know measures of and . To determine them Pavlovsky proposed to count areas of private cross-section parts of canal and moisture perimeters as proportional, then

$$\frac{\omega_1}{\omega_2} = \frac{\chi_1}{\chi_2}, \text{ after that } \frac{\omega_1}{\omega} = \frac{\chi_1}{\chi}, \frac{\omega_2}{\omega} = \frac{\chi_2}{\chi} \quad (27)$$

Then we get:

$$R_1 = \frac{\omega_1}{\chi_1} = \frac{\omega}{\chi} = R, \; R_2 = \frac{\omega_2}{\chi_2} = \frac{\omega}{\chi} = R \quad (28)$$

Then, $R_1 = R_2 = R$ (29)

We can get next equation while solving coefficient of Shezi, of course by knowing measure of hydraulic radius, using this formula and define necessary equation for considered roughness coefficient:

$$C_{pr} = R^y \sqrt{\frac{1+a}{n_1^2 + an_2^2}} \quad (30)$$

Applying information about considered roughness coefficient,Pavlovsky reforms equation(30) into this sight:

there: $n = \sqrt{\frac{n_1^2 + a \cdot n_2^2}{1+a}}$ (31)

If sides of canal are from three different parts and relatively moisture perimeters of three parts are not same, then equation for considered roughness coefficient will be like this:

$$n_{pr} = \sqrt{\frac{n_1^2 + a \cdot n_2^2 + a \cdot n_3^2}{1+a}}, \quad (32)$$

there: $a^1 = \frac{\chi_3}{\chi_1}$.

By concluding, N.N.Pavlovsky writes this - method for defining roughness coefficient might be changed from anticipated extra researches in future [1,2,15-23].

Conclusion

Many factors influent to roughness coefficient of canal's bottom in field conditions, by considering them, famous scientist Covan proposed this way to deal with considered roughness coefficient [2]:

$$n = (n_0 + n_1 + n_2 + n_3 + n_4)m_5 \quad (33)$$

there, n_0 – measure of roughness coefficient for canal's bottom with natural, smooth soil; n_1 – coefficient for bottoms with different soil; n_2 – coefficient for measuring and finding canal's cross-section; n_3 – coefficient for measuring possibility of barriers in the canal; n_4 – coefficient for describing regime of flow in the canal and for impact of resistance caused by plants outgrowth; m_5 – coefficient for measuring aftereffectof winding for considered water canal.

According to results of calculations,we get formulated measure of$n$:

$$n = \frac{(x-1)h^{1/6}}{6{,}78(x+0{,}95)} \quad (34)$$

By concluding equation directed on determining of roughness coefficient we get this (34)equation. To approve reality of this equation were taken experimental results of works onconnectionsbetween canal roughness and average depth. Analyze of data taken from results of research shows that there is a some connection between coefficient of Menning and distribution of velocities along the canal's cross-section. To find out how much taken equation can be applied on manufacture, there would be needed data taken from researches occurred in laboratory and natural conditions[1–8,23–30].

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Information about authors

Joldassov Saparbek Kurakbayebich
Candidate of technical sciences, associate professor, M.Kh. DulatyTarazregional university, 40
Tole bi st.,080012, Taraz, Kazakhstan
ORCID ID: 0000-0002-3947-1411
E-mail:arnur_68@mail.ru

Abildaev Sultan Talasbaevish (corresponding author)
Acting Associate Professor, PhD, M.Kh. Dulaty Tarazregional university, 40
Tole bi st., 080012, Taraz, Kazakhstan
ORCID ID: 0000-0002-7525-5097
E-mail:sultan_feb@mail.ru

Tattibaev Sagintay Jakupaliulu
Doctoral student of the 3rd year of the educational program 8D07411 "Hydraulic engineering and structures", M.Kh.DulatyTarazregional university, 40
Tole bi st., 080012, Taraz, Kazakhstan
ORCID ID: 0000-0003-2687-0189
E-mail:tsagin75@mail.ru

Sarbassova Gulmira Azimbaevna
Candidate of technical sciences, associate professor, M.Kh. DulatyTarazregional university, 40
Tole bi st., 080012, Taraz, Kazakhstan
ORCID ID: 0000-0001-7517-234X
E-mail: gulimjan@mail.ru

Авторлар туралы мәліметтер

Джолдасов Сапарбек Куракбаевич
Техника ғылымдарының кандидаты, доцент, М.Х. Дулати атындағы Тараз өңірлік университеті, Төле би көш., 40, 080012, Тараз қ., Қазақстан
ORCID ID: 0000-0002-3947-1411
E-mail:arnur_68@mail.ru

Абилдаев Султан Таласбаевич (корреспонденция авторы)
Доцент м.а., PhD докторы, М.Х.Дулати атындағы Тараз өңірлік университеті, Төле би көш., 40, 080012, Тараз қ., Қазақстан
ORCID ID: 0000-0002-7525-5097
E-mail:sultan_feb@mail.ru

Таттибаев Сагынтай Жакыпалиевич
8D07411 «Гидротехникалық құрылыс және құрылымдар» білім беру бағдарламасының 3-курс докторанты, М.Х.Дулати атындағы Тараз өңірлік университеті, Төле би көш., 40, 080012, Тараз қ., Қазақстан
ORCID ID: 0000-0003-2687-0189
E-mail:tsagin75@mail.ru

Сарбасова Гульмира Азимбаевна
Техника ғылымдарының кандидаты, доцент, М.Х. Дулати атындағы Тараз өңірлік университеті, Төле би көш., 40, 080012, Тараз қ., Қазақстан
ORCID ID: 0000-0001-7517-234X
E-mail: gulimjan@mail.ru

Информация об авторах

Джолдасов Сапарбек Куракбаевич
Кандидат технических наук, доцент, Таразский региональный университет имени М.Х. Дулати, ул. Толе би, 40, 080012, г. Тараз, Казахстан
ORCID ID: 0000-0002-3947-1411
E-mail:arnur_68@mail.ru

Абилдаев Султан Таласбаевич (автор для корреспонденции)
И.о. доцента, доктор PhD, Таразский региональный университет имени М.Х. Дулати, ул. Толе би, 40, 080012, г.Тараз, Казахстан
ORCID ID: 0000-0002-7525-5097
E-mail:sultan_feb@mail.ru

Таттибаев Сагынтай Жакыпалиевич
Докторант 3-го курса образовательной программы 8D07411 «Гидротехническое строительство и сооружения», Таразский региональный университет имени М.Х. Дулати, ул. Толе би, 40, 080012, г. Тараз, Казахстан

ORCID ID: 0000-0003-2687-0189
E-mail:tsagin75@mail.ru

Сарбасова Гульмира Азимбаевна
Кандидат технических наук, доцент, Таразский региональный университет имени М.Х. Дулати, ул. Толе би, 40, 080012, г. Тараз, Казахстан
ORCID ID: 0000-0001-7517-234X
E-mail: gulimjan@mail.ru

Джолдасов С.Қ., Абилдаев С.Т.*, Таттибаев С.Ж., Сарбасова Г.А.

М.Х. Дулати атындағы Тараз өңірлік университеті, 080012, Тараз қ., Қазақстан
*E-mail:sultan_feb@mail.ru

ПЕРИМЕТРІ БОЙЫНША КАНАЛДАРДЫҢ КЕДІР-БҰДЫРЛЫҚ КОЭФФИЦИЕНТІН АНЫҚТАУ ӘДІСТЕРІ ТУРАЛЫ

Аңдатпа. Ғылыми мақалада арнаның бірқалыпты қозғалысын және арнаның кедір-бұдырлық коэффициентін (кедір-бұдырлық коэффициенті) анықтау мәселелері қарастырылады. П.Н. Белоконь, Г.К. Лотер, Н.Н. Павловский сияқты атақты ғалымдардың периметрі бойынша каналдардың екі-үш бөлігінен тұратын кедір-бұдырлық коэффициентін анықтау әдістеріне, периметрі бойынша арналардың кедір-бұдырлық коэффициенттерінің айырмашылығын есептеудің қолданыстағы әдістеріне талдау жасалды. Гидротехника саласында жер асты каналының периметрі бойынша су ағынының гидравликалық есептеулері үшін ұсынылатын бірқатар есептеу әдістері бар. Бірқатар зерттеушілер арнаның кедір-бұдырлығы мұз қабатының астындағы ағынның қозғалысымен әртүрлі арналардағы ағынның қозғалысына ұқсайды деп мәлімдейді. Бірақ канал арнасының кедір-бұдырлығы әртүрлі ашық арналарда және мұз қабаты астындағы су қозғалысының өзіне тән (спецификалық) ерекшеліктеріне ие екенін ескеру қажет. Көптеген авторлардың ұсынған периметрі бойынша әр түрлі кедір-бұдырлы арналарды есептеу формулаларын мұз қабатының астындағы гидравликалық ағынды есептеулерде тікелей қолдану мүмкін емес, тіпті керісінше мұз қабатының астындағы су ағынының қозғалыс теңдеулерінің периметрі әр түрлі кедір-бұдырлы арналарды есептеуде де қолданылмайды. Сол себепті табан периметрі бойынша су арналарының кедір-бұдырлық коэффициенттерін анықтау әдістерін дұрыс таңдау, оның ұзақ мерзімді жұмыс істеуінің кепілі болады.

Тірек сөздер: арна, бірқалыпты қозғалыс, кедір-бұдырлық коэффициенті, тұрақты қозғалыс, орташа жылдамдық, арна периметрі, арнаның өтім (көлденең) қимасы (поперечное сечение), гидравликалық радиус.

Джолдасов С.К., Абилдаев С.Т.*, Тәттібаев С.Ж., Сарбасова Г.А.

Таразский региональный университет имени М.Х. Дулати, г. Тараз, Казахстан
*E-mail:sultan_feb@mail.ru

О МЕТОДАХ ОПРЕДЕЛЕНИЯ КОЭФФИЦИЕНТА ШЕРОХОВАТОСТИ КАНАЛОВ ПО ПЕРИМЕТРУ

Аннотация. В научной статье рассматриваются вопросы равномерного движения русла и определения коэффициента шероховатости русла (коэффициента шероховатости). Приводится анализ существующих методов расчета разности коэффициентов шероховатости каналов по периметру, методы определения коэффициента шероховатости, состоящих из двух-трех частей откосов каналов по периметру, таких известных ученых, как П.Н. Белоконь, Г.К. Лоттер, Н.Н. Павловских. В области гидротехники существует ряд расчетных методов, предлагаемых для гидравлических расчетов расхода воды по периметру грунтового канала. Ряд исследователей утверждают, что шероховатость русла канала имитирует движение потока в разных каналах с движением потока под слоем льда. Но следует учитывать, что шероховатость русла канала имеет свои характерные (специфические) особенности движения воды в различных открытых каналах и под ледяным покровом. Расчетные формулы,

предложенные многими авторами для каналов с разной шероховатостью по периметру, не могут быть использованы непосредственно при гидравлических расчетах потока под ледяным покровом, и, наоборот, уравнения движения потока воды под ледяным покровом не применяются даже для каналов с разной шероховатостью по периметру. Поэтому правильный выбор методов определения коэффициентов шероховатости русла каналов по периметру будет залогом его длительного функционирования.

Ключевые слова: канал, равномерное движение, коэффициент шероховатости, установившееся движение, средняя скорость, периметр канала, поперечное сечение канала, гидравлический радиус.

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Джайлганов С.Н.*[1], Тулемисова Ж.С.[2]

[1]АО «Озенмунайгаз», 130200, г. Жанаозен, Казахстан
[2]Казахстанско-Британский технический университет, 050000, г. Алматы, Казахстан
*E-mail: jailganovs@gmail.com

ПРЯМОЕ СОПОСТАВЛЕНИЕ ИЗМЕРЕНИЙ ГЕОФИЗИЧЕСКИХ ПОЛЕЙ С ЛИТОЛОГИЧЕСКОЙ НЕОДНОРОДНОСТЬЮ ЮРСКОГО ИНТЕРВАЛА НА МЕСТОРОЖДЕНИИ БУЗАЧИНСКОГО СВОДА

Аннотация. Зачастую промысловая геофизика является основным и широко распространенным методом в нефтегазовой отрасли. Наиболее полную характеристику кривые ГИС имеют, когда они основаны на изучении прямого материала, каковым является керн. Данный научный проект в основном направлен на изучение взаимоотношений коллекторов разных генераций и их фациальной принадлежности, которые способствуют более правильному пониманию строения объектов эксплуатации с учетом литологической неоднородности и расчлененности продуктивных горизонтов. Применение практического значения знания особенностей и закономерностей образования песчаных тел при дальнейшей разработке месторождения с целью повышения коэффициентов извлечения нефти. В данной статье сопоставим коллекторские интервалы, сложенные как средне-, так и крупнозернистыми песчаниками, с данными геофизических исследований скважин, а также рассмотрим их пространственное распространение по данным сейсмо-атрибутного анализа, основанного на 3Д-сейсморазведочных данных. Далее по результатам проведенного спектрометрического гамма-каротажа на керне была выполнена увязка керна и ГИС с целью более точного определения петрофизических свойств по литофациям. В заключение подводятся краткие выводы практических и лабораторных работ и делаются окончательные выводы.

Ключевые слова: геология, керн, сейсморазведка, атрибутный анализ, частота, палеорусла, песчаник, глинистость.

Введение

Атрибутный анализ – это результат некоторых математических преобразований сейсмических данных, нацеленных на извлечение дополнительной информации о латеральной неоднородности в пределах исследуемой площади. Однако тут стоит оговориться, что сейсмическая трасса в пространственном эквиваленте является одномерной (1Д) и представляет собой набор следующей информации: частота, амплитуда, изменение частотного диапазона, форма кривой. В свою очередь, объемный массив сейсмических данных, который состоит из суммы большого количества сейсмических трасс, представляет собой пространственное распределение вышеупомянутых параметров (3Д) и характеризуется погружением, азимутальным изменением, прерывистостью, схожестью и криволинейностью [1].

Перечень сейсмических атрибутов очень велик, поскольку каждый из них используется для решения геологических задач. Ниже приведено описание лишь некоторых из них, которые непосредственно применялись в рамках данной работы, а также доказали свою информативность в процессе тестирования [2].

Sweetness

Данный сейсмический атрибут является смесью Envelope и Instantaneous Frequency, формула которого выражается в следующем виде:

$$Sweetnecc = envelope/SQRT(Instantanious\ Filter)$$

RelAcImp

Физический атрибут, который отражает контраст физических свойств и обеспечивает лучшую

привязку со скважинными данными для геологического анализа. Генерируется путем интеграции сейсмической трассы и последующего фильтра низких частот для удаления произвольных длинноволновых трендов [3].

Основные положения

При рассмотрении коллекторских интервалов по данным сейсмо-атрибутного анализа выполнена процедура спектрального преобразования сейсмических кубов с целью подготовки входных данных для выполнения сейсмо-атрибутивного анализа. Преобразование производилось на основе технологии eXchroma^{SG}, основанной на спектральном разложении сейсмических амплитуд на разные частотные составляющие [4].

В начале процесса преобразования задается на вход сейсмический массив данных. Методика преобразования Gapped и расчетные параметры присвоены по умолчанию в соответствии с входными сейсмическими данными. В результате получены три сейсмических массива, названия которых соответствуют буквам аббревиатуры RGB:

- R – низкочастотный сейсмический куб;
- G – среднечастотный сейсмический куб;
- B – высокочастотный сейсмический куб.

Результаты спектральной декомпозиции eXchromaSG возможно визуализировать при помощи стандартного RGB-иллюстратора.

В последующем результирующие сейсмо-спектральные кубы RGB соединены в единый сейсмический куб при помощи опции BOX PROBE программного обеспечения Pertel. В результате объединенный сейсмический куб подвергся спрямлению на поверхность, в пределах которой планировалось локализовать объекты с отличительными плотностными характеристиками или же стратиграфические неоднородности, выделяющиеся в поле упругих колебаний [5].

Материалы и методы

На атрибутных срезах по продуктивному горизонту наблюдается множество стратиграфических тел, которые напрямую коррелируются с русловыми каналами погребенных рек (рисунки 1 и 2). Большинство русел направлены на запад, лишь некоторые из них направлены на юго-запад. Визуально палеорусла можно поделить на 2 категории: крупные и мелкие [6].

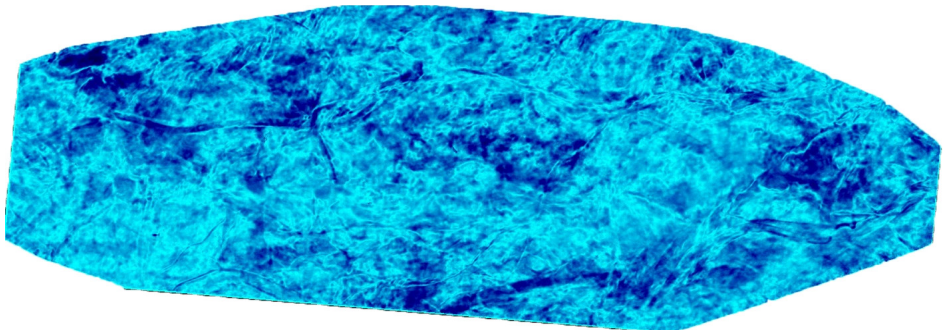

Рисунок 1 – Срез в пределах продуктивного горизонта атрибутного куба Sweetness

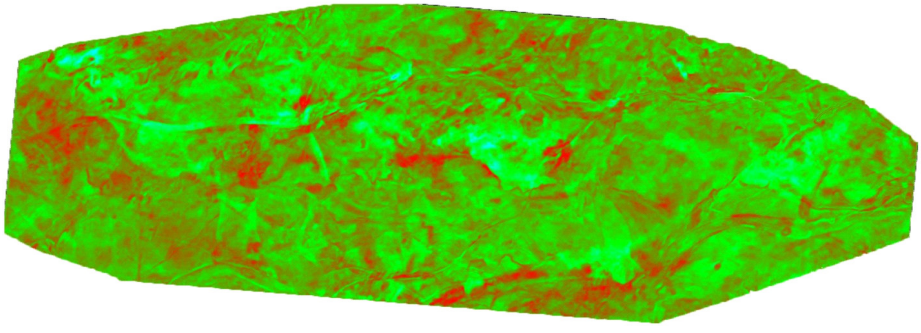

Рисунок 2 – Срез в пределах продуктивного горизонта атрибутного куба Relative Acoustic Impedance

В результирующей карте спектральной декомпозиции выделили русловый канал (рисунок 3). Данный объект был вскрыт несколькими скважинами, но выбрали 8 скважин в пределах выделенного полигона и одну скважину за пределами (скважина №2) (рисунок 4). Основным критерием при выборе скважин были качественные каротажные кривые. На рисунках 5 и 6 приведены каротажные кривые гамма-каротажа и коэффициента глинистости в пределах продуктивного горизонта.

Как показано в корреляционной схеме, русловые каналы подтверждаются скважинными данными. Мощность палеорусла в скважинах изменяется от 12 м до 19 м [7].

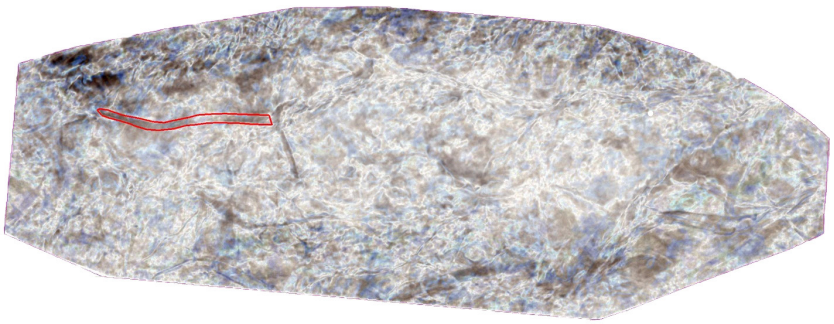

Рисунок 3 – Срез куба спектральной декомпозиции по технологии eXchroma^{SG} в пределах продуктивного горизонта

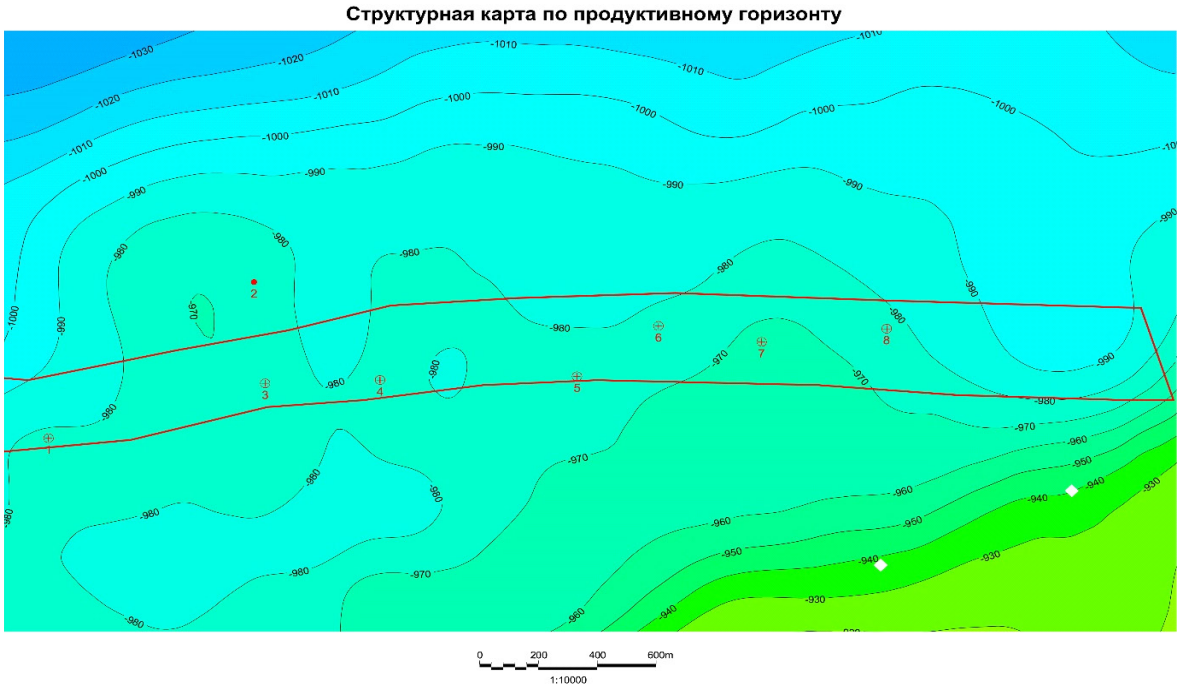

Рисунок 4 – Структурная карта по продуктивному горизонту

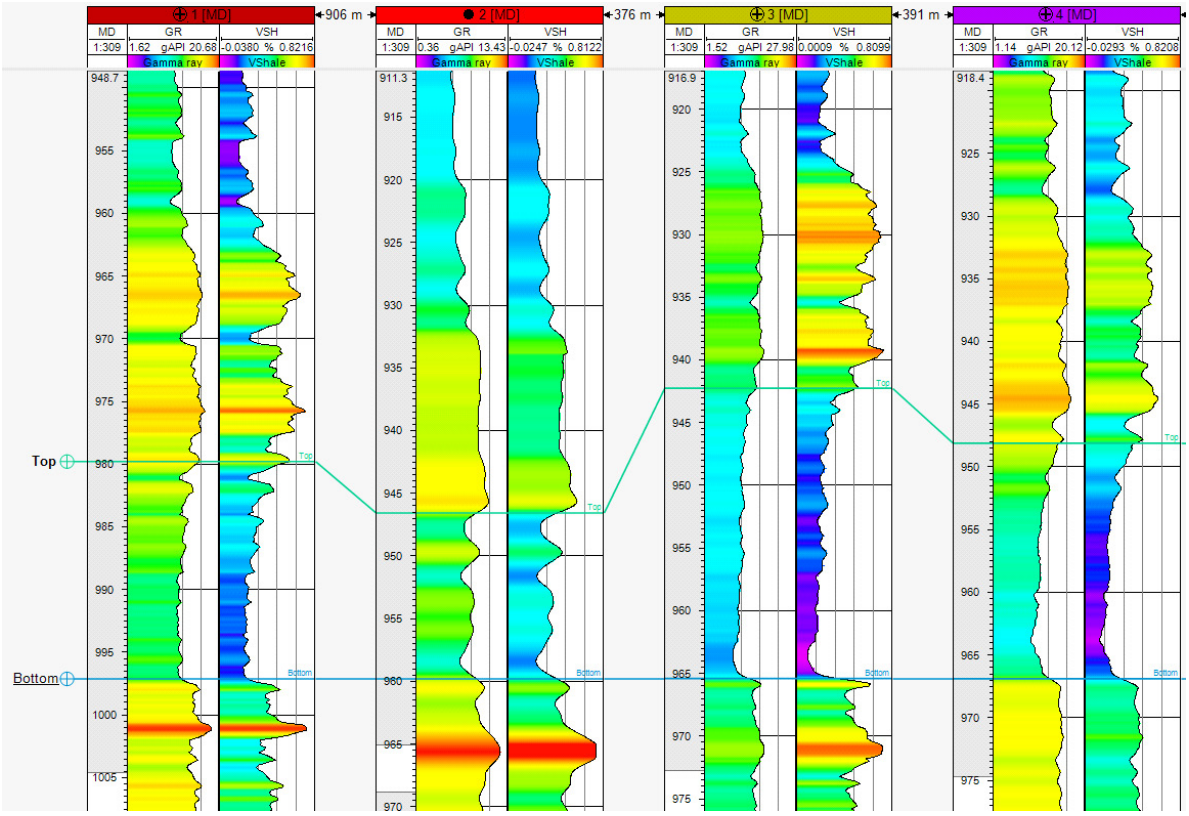

Рисунок 5 – Корреляционная схема

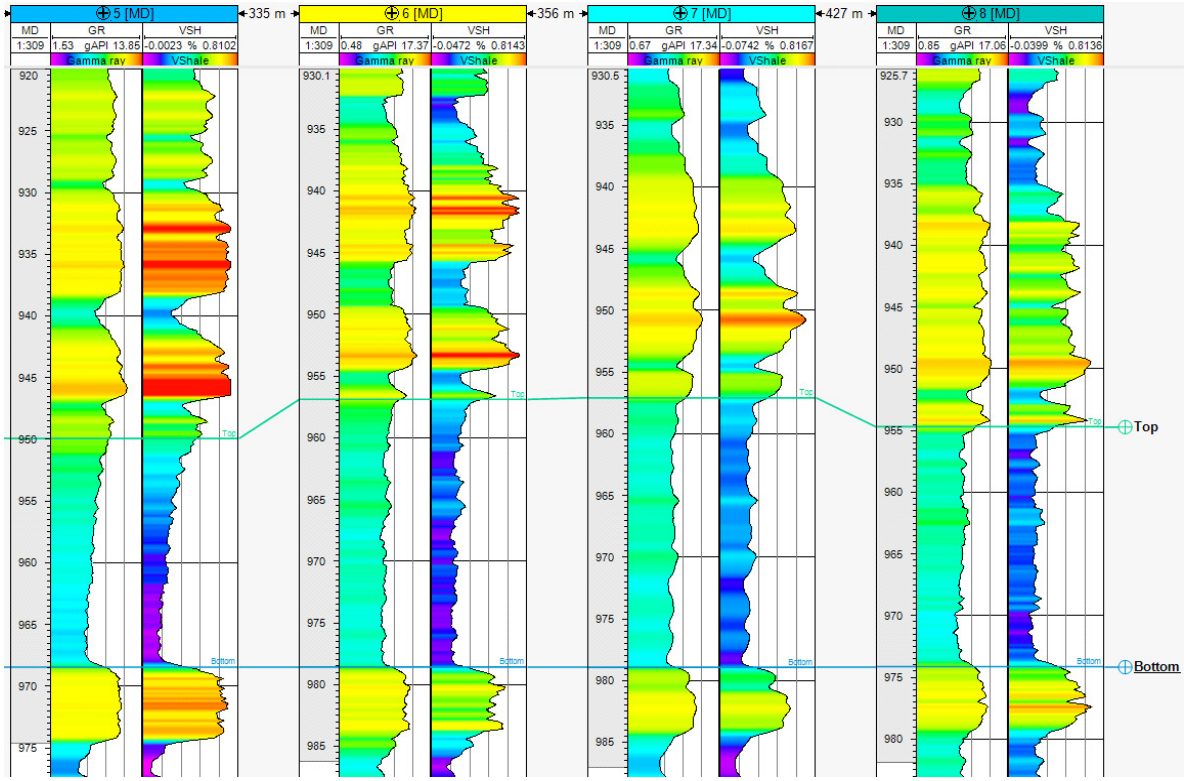

Рисунок 6 – Корреляционная схема

Результаты и обсуждение

Литологические породы в пределах изучаемой залежи представлены песчаниками средне-, крупнозернистыми с различным содержанием алевритистой и глинистой составляющей. Также в изучаемом разрезе имеются уплотненные породы. На рисунке 7 представлено фото песчаника изучаемой залежи.

На рисунке 8 представлена зависимость проницаемости от пористости по изучаемой залежи. Зависимость характеризуется высоким показателем аппроксимации порядка 90%, что указывает на хорошую корреляцию петрофизических свойств в зависимости от литологии [8].

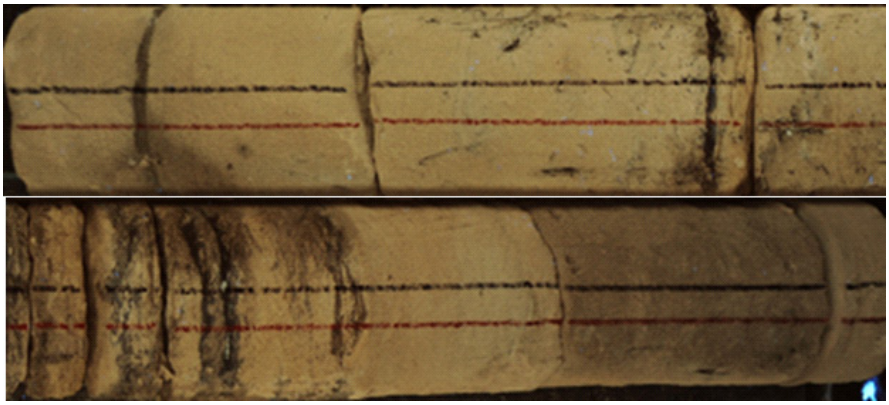

Рисунок 7 – Фото песчаника по скважине 2

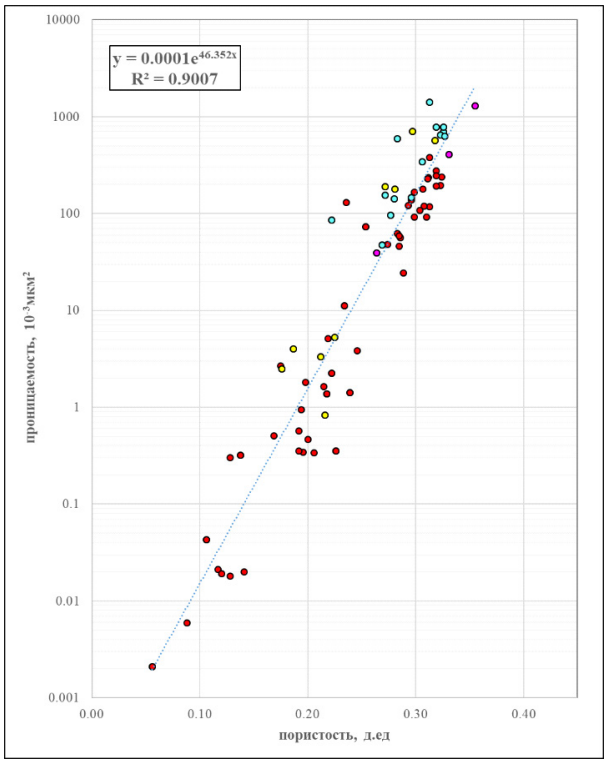

Рисунок 8 – Соотношение «проницемость – пористость» по изучаемой залежи

На рисунке 9 представлена скважина №2, находящаяся вблизи полигона палерусла и которая подтверждает наличие песчаного тела, однако отличается по своей толщине в сторону уменьшения эффективной толщины, поэтому не может быть оконтурена по данным сейсмики [9]. Краткая геофизическая характеристика представлена в таблице 1. Глинистость изучаемой залежи варьируется от 0,17 д.ед до 0,23 д.ед и в среднем составляет 0,20 д.ед. Пористость изменяется от 0,25 д.ед до 0,31 д.ед и в среднем составляет 0,28 д.ед., проницаемость в среднем составляет 220 мД [10].

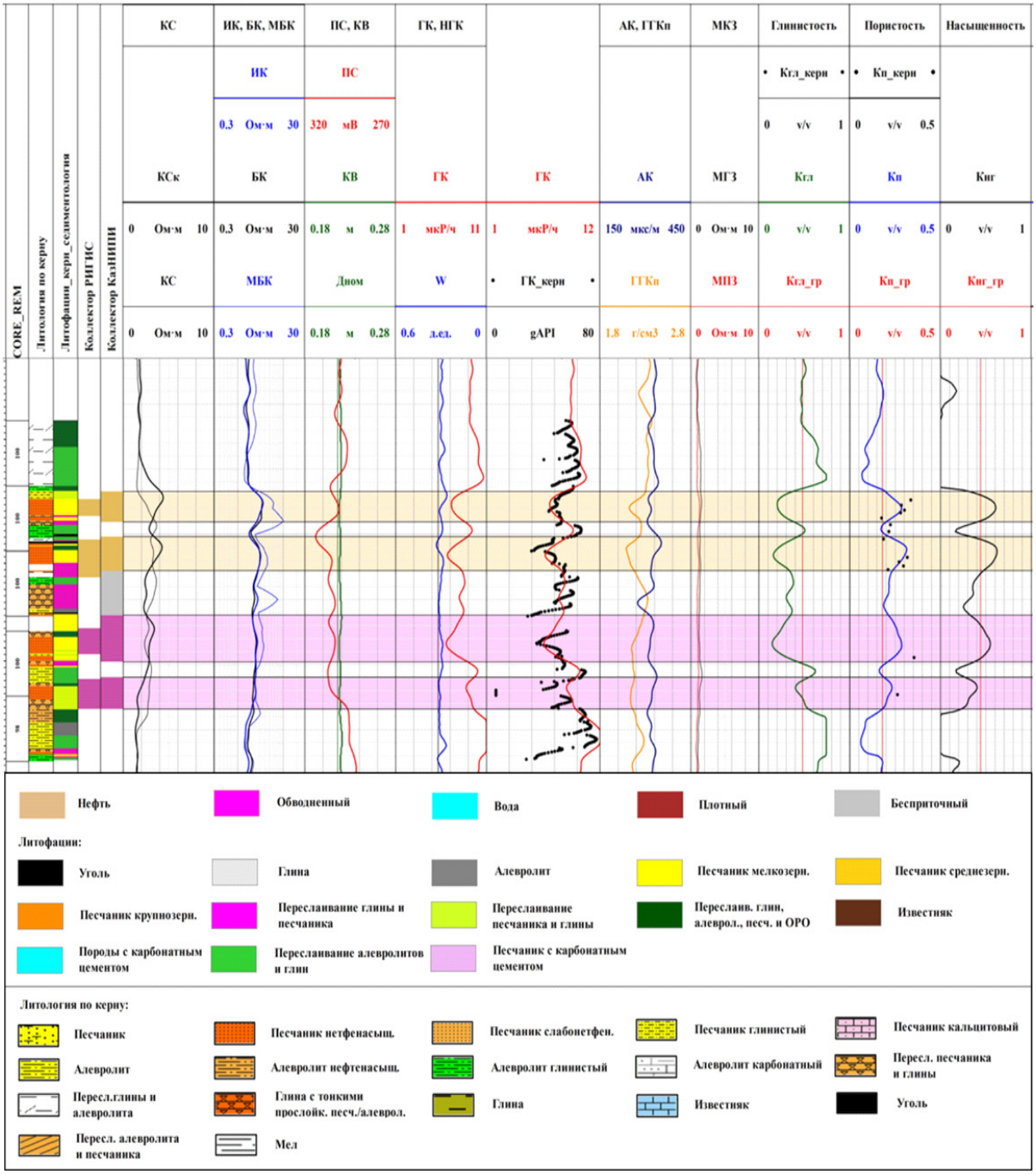

Рисунок 9 – Фрагмент скважины №2 с отбором керна

Таблица 1 – Геофизическая характеристика изучаемой залежи

Скв.	Толщина, м	БК, Ом*м	ГК, мкР/ч	ГГКп, г/см^3	АК, мкс/м	Кгл, д.ед	Кп, д.ед	Кпр, мД
1	8,6	5,52	12.6			0,23	0,29	273
2	9,6	2,61	7,2	2,19	324	0,22	0,29	315
3	18,6	9,02	12.3			0,22	0,28	243
4	14,4	6,02	10.8			0,18	0,31	372
5	14,5	6,55	7.2	2,21	316	0,22	0,25	128
6	11,6	10	7,4	2,25	327	0,17	0,25	128
7	19,3	10	6,3	2,25	329	0,19	0,26	134
8	15,8	2	7,6	2,22	356	0,19	0,26	169

Заключение

По результатам проведенных седиментологических работ получено понимание вертикального и площадного распределения фаций и условий осадконакопления в изучаемых скважинах. Интерпретированы фациальные типы пород, обстановки осадконакопления как в интервалах керна, так и в местах его отсутствия. Составлены детальные седиментологические планшеты и приведены фотографии, которые детально иллюстрируют разнообразие и характеристики выделяемых фациальных типов пород. По совокупности выявленных характеристик сделаны выводы о модели осадконакопления. По каротажным данным проведена нормировка кривой ГК и интерпретация кривой глинистости в едином ключе для целей фациального анализа в интервалах отсутствия керна.

Также были выполнены работы привязки керна по данным СГК, проведен детальный сейсмоатрибутный анализ по продуктивным горизонтам с выполнением структурной интерпретации. Выделено большое количество палеорусел в целевом интервале и сопоставлены с данными сейсмофациальной модели, а также атрибутного анализа.

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Информация об авторах

Джайлганов Саламат Нурнубаевич (автор для корреспонденции)
Бакалавр, техник-геолог цеха по добыче нефти и газа АО «Озенмунайгаз», г. Жанаозен
ORCID ID: 0009-0004-0067-2920
E-mail: jailganovs@gmail.com

Тулемисова Жамал Сериковна
PhD, ассистент-профессор Школы геологии и геологоразведки, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, г. Алматы, Казахстан
ORCID ID: 0000-0003-1803-4535
E-mail: z.tulemissova@kbtu.kz

Авторлар туралы мәліметтер

Джайлганов Саламат Нурнубаевич (корреспонденция авторы)
Бакалавр, «Өзенмұнайгаз» АҚ мұнай және газ өндіру цехының техник-геологы, Жаңаөзен қ.
ORCID ID: 0009-0004-0067-2920
E-mail: jailganovs@gmail.com

Тулемисова Жамал Сериковна
PhD, Геология және геологиялық барлау мектебінің ассистент-профессоры, Қазақстан-Британ техникалық университеті, Төле би көш., 59, 050000, Алматы қ., Қазақстан
ORCID ID: 0000-0003-1803-4535
E-mail: z.tulemissova@kbtu.kz

Information on the authors

Jailganov Salamat Nurnubaevich (corresponding author)
Bachelor, technician-geologist of oil and gas production shop of «Ozenmunaigas» JSC, Zhanaozen.
ORCID ID: 0009-0004-0067-2920
E-mail: jailganovs@gmail.com

Tulemissova Zamal Serikovna
PhD, Assistant professor, School of Geology and Geological Exploration, Kazakh-British Technical University, 59, Tole bi str., 050000, Almaty, Kazakhstan
ORCID ID: 0000-0003-1803-4535
E-mail: z.tulemissova@kbtu.kz

Джайлганов С.Н.*[1], Тулемисова Ж.С.[2]

[1]«Өзенмұнайгаз» АҚ, 130200, Жаңаөзен қ., Казақстан
[2]Қазақстан-Британ техникалық университеті, 050000, Алматы қ., Казахстан
*E -mail: jailganovs@gmail.com

БОЗАЩЫ КҮМБЕЗІНІҢ КЕН ОРНЫНДА ЮРА АРАЛЫҒЫНЫҢ ГЕОФИЗИКАЛЫҚ ӨРІСТЕРІНІҢ ӨЛШЕМДЕРІН ЛИТОЛОГИЯЛЫҚ БІРТЕКТІЛІГІМЕН ТІКЕЛЕЙ САЛЫСТЫРУ

Аңдатпа. Қазіргі таңда өндірістік геофизика мұнай-газ өнеркәсібінде негізгі және кең тараған әдіс болып табылып отыр. Егер ұңғыны геофизикалық зерттеу кернды зерттеумен тікелей негізделгенсе, ол толық сипатқа ие болады.

Бұл ғылыми жоба негізінен литологиялық гетерогенділік пен өнімді горизонттардың бөлінуін ескере отырып, пайдалану объектілерінің құрылымын неғұрлым дұрыс түсінуге ықпал ететін әртүрлі генерациялармен олардың фацияларының байланысын зерттеуге бағытталған. Сонымен қатар, мұнайға қаныққан денелердің қалыптасу ерекшеліктері мен заңдылықтары туралы білімнің практикалық мәнін, және де кен орнын одан әрі игеруге, мұнай беру коэффициенттерін арттыру мақсатында орындалып отыр. Бұл мақалада біз орташа және ірі түйіршікті құмтастардан тұратын қабат интервалдарын, ұңғыны геофизикалық зерттеу деректерімен салыстырамыз және 3D сейсмикалық деректерге негізделген сейсмикалық атрибуттық талдауға сәйкес олардың кеңістікте таралуын бөлшектік түрде қарастыратын боламыз. Әрі қарай, литофациялардың петрофизикалық қасиеттерін дәлірек анықтау үшін ядродағы спектрометриялық гамма-каротаждың нәтижелері бойынша керн мен ұңғыма каротажы жоспар бойынша байланыстырылды. Соңғы қорытынды бөлімде практикалық және зертханалық жұмыстардың қысқаша әрі нақты сынақ нәтижелері жинақталып, соңғы талдау жұмыстары жүргізілді.

Тірек сөздер: геология, керн, сейсмикалық барлау, атрибуттық талдау, жиілік, палеорусла, құмтас, саздылық.

Jailganov S.N.*[1], Tulemissova Z.S.[2]

[1]«Ozenmunaigas» JSC, 130200, Zhanaozen, Kazakhstan
[2]Kazakh-British Technical University, 050000, Almaty, Kazakhstan
*E -mail: jailganovs@gmail.com

DIRECT COMPARISON OF MEASUREMENTS OF GEOPHYSICAL FIELDS WITH LITHOLOGICAL HETEROGENEITY OF THE JURASSIC PERIOD AT THE FIELD OF BUZASHY VAULT

Abstract. Often, production geophysics is the main and widespread method in the oil and gas industry. Well logging curves have the most complete characteristics when they are based on the study of direct material, which is the core. This scientific project is mainly aimed at studying the relationship of reservoirs of different generations and their facies belonging, which contribute to a more correct understanding of the structure of exploitation objects, taking into account lithological heterogeneity and dissection of productive horizons. Application of the practical value of knowledge of the features and patterns of formation of sand bodies in the further development of the field, in order to increase oil recovery factors. In this article, we compare reservoir intervals composed of both medium and coarse-grained sandstones with well logging data, and consider their spatial distribution according to seismic-attribute analysis based on 3D seismic data. Further, based on the results of the spectrometric gamma logging on the core, the core and well logging were linked in order to more accurately determine the petrophysical properties of lithofacies. In conclusion, brief conclusions of practical and laboratory work are summarized and final conclusions are drawn.

Key words: geology, core, seismic, attribute analysis, frequency, paleochannel, sandstone, shale.

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Sultan S.

Kazakh-British Technical University, 050000, Almaty, Kazakhstan
E-mail: s_samat@kbtu.kz

ANALYSIS OF THE INTERNATIONAL PRACTICE OF CO^2 INJECTION AS ONE OF THE EOR METHODS

Abstract. CO^2 flooding is currently a popular method employed for enhanced oil recovery (EOR). The initial mention of utilizing CO^2 as an injection gas to enhance oil production dates back to 1916, although its economic feasibility was not established until the 1950s. Initially, alternative gases such as propane, liquefied petroleum gas, and natural gas were utilized, but CO^2 emerged as a more cost-effective and efficient option. The first CO^2 flooding project commenced in 1964, followed by a larger-scale project in 1972. Subsequently, successful CO^2 flood implementations have been witnessed in diverse regions including the United States, Canada, Hungary, Turkey, Trinidad, and Brazil. Among these, the United States stands out with 67 operational CO^2 flood projects, while other countries face challenges such as limited infrastructure and sources. To date, over 100 EOR projects involving CO^2 flooding have been recorded. This publication presents a comprehensive overview of international experiences and methodologies pertaining to the application of CO^2 flooding for enhancing oil production efficiency. Furthermore, it emphasizes the potential projects and applications of this technology within the context of Kazakhstan.

Key words: EOR, CO^2 injection, oil recovery, miscible mode, immiscible mode, Kazakhstan.

Introduction

In the 21st century, the volume of hard-to-recover reserves is increasing. With the development and discovery of new fields, the percentage of hard-to-recover reserves has increased markedly, and a significant number of large deposits have approached the withdrawal threshold from the initial recoverable reserves of 70%, which is the boundary after which the residual reserves become hard-to-recover. In this regard, one has to deal with an increasing number of problems in oil production, the solution of which by applying classical methods of enhanced oil recovery becomes impossible.

A possible extended-term solution to alleviate the adverse impacts of global warming is a technique of infusing CO^2 into geological structures in oil fields, which serves the dual objective of capturing CO^2 and concurrently improving oil retrieval (EOR). This article presents a summary of worldwide investigations and field initiatives concerning EOR-CO^2 procedures.

Oil extraction operations are conventionally divided into primary, secondary, and tertiary phases, as depicted in Figure 1. The primary stage entails initial oil production facilitated by the inherent displacement energy within a reservoir. When primary recovery diminishes, secondary recovery techniques come into play, including gas injection, water flooding, or water-alternating-gas injection. Tertiary recovery, also known as enhanced oil recovery (EOR), is employed to augment oil production beyond what conventional methods can achieve. Traditional oil production typically recovers approximately 35-45% of the original oil reserves, while EOR methods are typically implemented towards the later stages of an oil field's lifespan. These methods involve the utilization of miscible gases (e.g., CH^4, CO^2), chemicals, and/or thermal energy to displace additional oil, typically ranging from 5-15% of the original reserves [1].

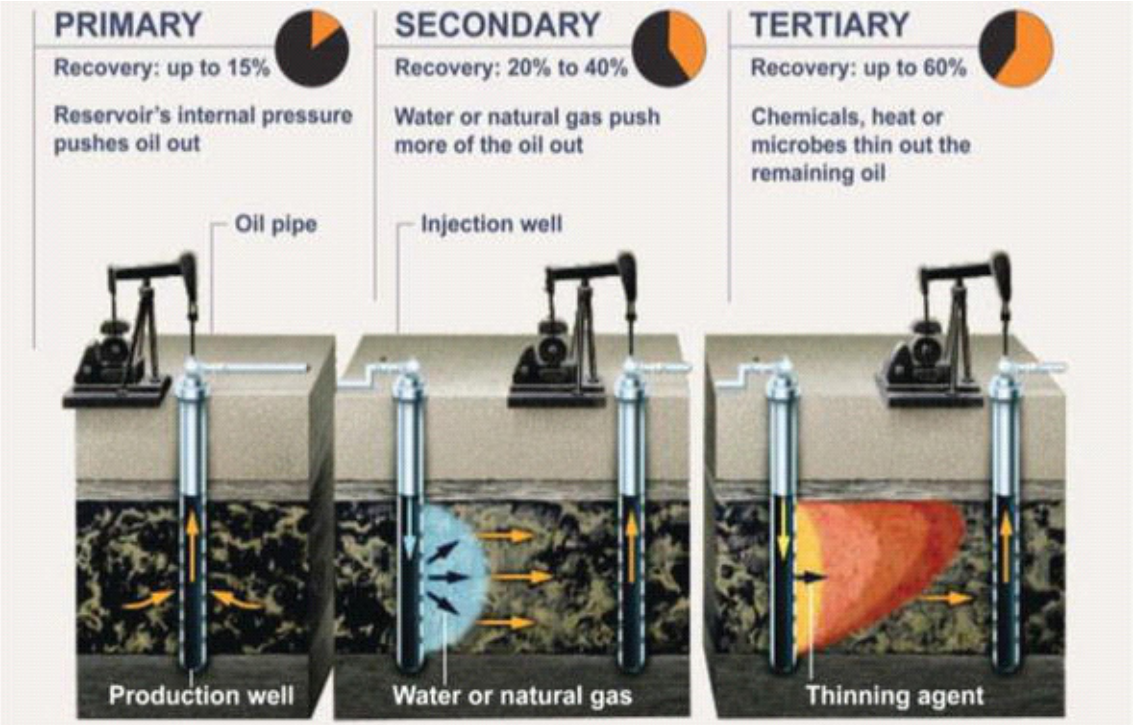

Figure 1 – Oil recovery stages

The injection of CO^2 into oil fields is one of the methods for improving oil recovery, which uses mixing and immiscible displacement. In mixing displacement, CO^2 is introduced into the field, mixes with the oil and increases its mobility, which makes it easier to drive it to the well. In immiscible displacement, CO^2 is introduced into the field without mixing with the oil and pushes it to the well with the help of pressure. In both cases, the injection of CO^2 helps to increase oil production, because. it provides additional pressure, which helps drive the oil to the well. In addition, CO^2 injection can also increase the volume of recoverable oil due to the additional solubility of oil in CO^2, which is the basis of the CO^2 injection method for recovering additional oil. (Figure 2. Scheme of EOR-CO^2 operation) [2].

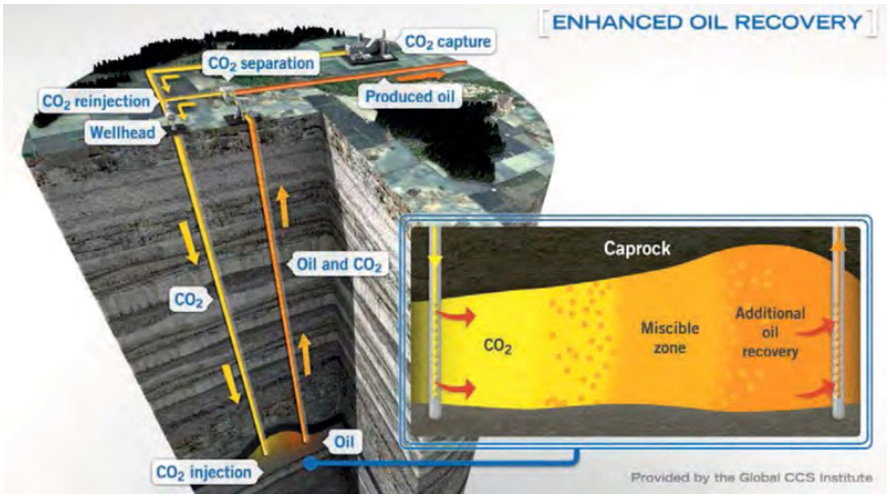

Figure 2 – Scheme of EOR-CO2 operation

The scholarly publication examines the technique of carbon dioxide injection (both miscible and immiscible modes) and evaluates global initiatives associated with this methodology. The potential application of this approach in the oil and gas sector of Kazakhstan will be explored, considering its current relevance and extensive discourse.

Main provisions

The injection of carbon dioxide into oil reservoirs is one of the strategies for increasing oil recovery, using both mixed and immiscible modes. The CO^2-EOR process allows the recovery of residual oil from the reservoir after primary and secondary production by stimulating volume sweep (Ev) and displacement efficiency (Ed). Depending on the pressure, temperature and characteristics of the oil in the reservoir, the injected CO^2 can either mix with the oil or remain immiscible. The miscible CO^2-EOR mode is the preferred choice as it often provides higher recovery rates than the immiscible method [3].

Miscible Mode.

The minimal miscibility pressure (MMP) represents the threshold pressure for achieving miscibility. The MMP corresponds to the pressure level at which over 80% of the original oil-in-place (OIP) is recovered during the breakthrough of CO^2, as stated by Holm and Josendal (1974). Despite being more recent, a general guideline for assessing the MMP is an oil recovery rate of at least 90% when injecting 1.2 HCPV (hydrocarbon pore volume) of CO^2, according to Yellig and Metcalfe (1980). Figure 3 demonstrates the rapid increase in oil recovery with increasing pressure, followed by a plateau once the MMP is reached.

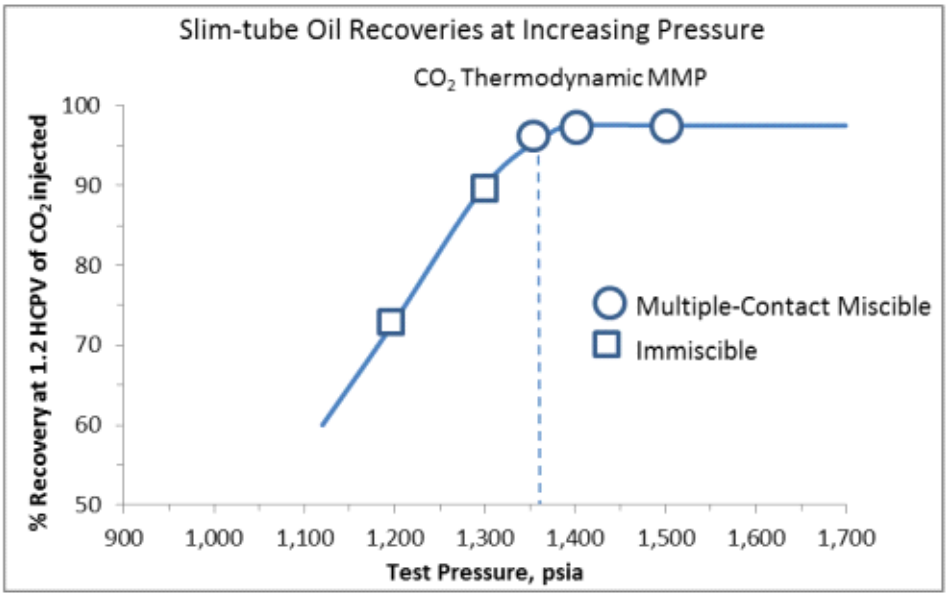

Figure 3 – Oil recovery rates in slim-tube experiments were measured at various pressures, with a constant oil composition and temperature (adapted from Yellig and Metcalfe, 1980). CO^2, referred to as carbon dioxide; psia, representing pounds per square inch absolute; % indicating percent

Three mechanisms of hydrocarbon miscibility are identified, as outlined by Stalkup (1983). The initial mechanism is referred to as first-contact miscibility, where solvents can mix with oil in any proportion and remain as a single phase. However, certain solvents, including CO^2, may not exhibit miscibility upon initial contact but can develop dynamic miscibility with repeated interactions, resulting in a significant enhancement in oil recovery. The second mechanism is the vaporizing gas-drive process, also known as high-pressure gas drive, which achieves dynamic miscibility by vaporizing intermediate-molecular-weight hydrocarbons from the reservoir oil into the injected CO^2 or gas. Lastly, the condensing gas-drive process, or enriched gas drive, achieves dynamic miscibility by transferring intermediate-molecular-weight hydrocarbons or CO^2 (in the case of CO^2-EOR) into the reservoir oil.

In CO^2-EOR, dynamic miscibility occurs when the reservoir pressure exceeds the minimum miscibility pressure (MMP) and displacement takes place. During this process, the intermediate and higher molecular weight hydrocarbons present in the reservoir oil vaporize into the CO^2, a phenomenon known as the vaporization gas-drive process. Additionally, a portion of the injected CO^2 dissolves into the oil, referred to as the condensation gas-drive process. This exchange of mass between the oil and CO^2 leads to complete miscibility without any discernible interface, resulting in the formation of a transition zone that exhibits miscibility with the oil in the front and the CO^2 in the rear, as depicted in Figure 4 (Jarrell et al., 2002; Merchant, 2010).

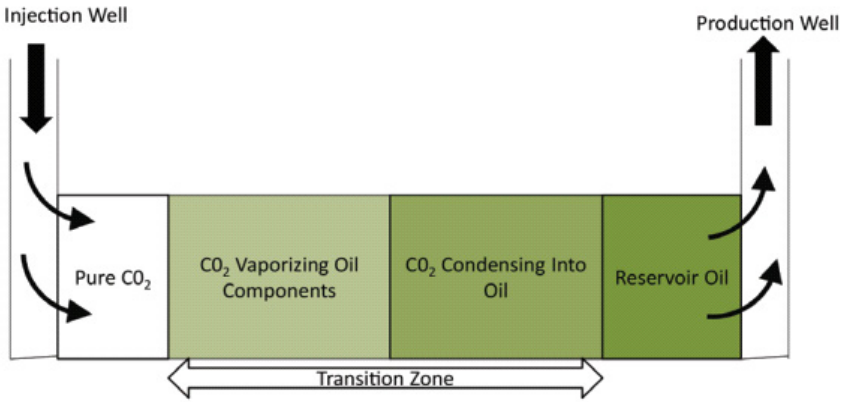

Figure 4 – The transition zone between the injection and production wells is depicted in the schematic of the CO^2 (carbon dioxide) miscible process. (Modified from Jarrell et al., 2002.)

The MMP is measured using slim-tube tests, which are seen to be more trustworthy than mathematical models or correlations. Since slim-tube tests are pricey, there are still two more ways to evaluate MMP: mathematical models and correlations.

Mathematical models, unlike correlations, offer superior findings by utilizing equilibrium data and equation-of-state (EOS), providing a more precise approach to calculating the minimal miscibility pressure (MMP). While correlations are easier to implement, they come with certain limitations and should be relied upon only in the absence of mathematical models or slim-tube tests.

Immiscible Mode.

If the reservoir pressure falls below the minimal miscibility pressure (MMP) or if the composition of the reservoir oil is not conducive to miscibility, the CO^2-oil miscibility will not be attained. However, the presence of CO^2 can still yield positive effects on oil recovery through its dissolution in the oil, resulting in viscosity reduction and oil swelling. These factors contribute to improved sweep efficiency and additional oil recovery. Similar to hydrocarbon gases, the solubility of CO^2 in oil increases with increasing pressure and decreases with decreasing temperature, as depicted in Figure 5, based on research conducted by Simon and Graue (1965) and Welker and Dunlop (1963) [3].

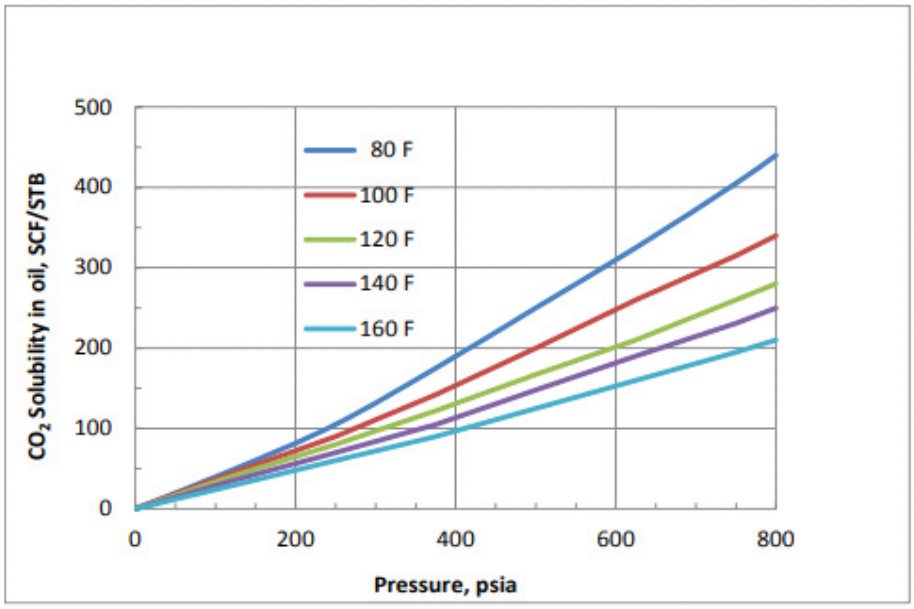

Figure 5 – Solubility of carbon dioxide (CO^2) in crude oil from the Moran field in Kansas is dependent on pressure and temperature, as observed in studies conducted by Welker and Dunlop (1963). The solubility is measured in units of pounds per square inch absolute (psia) and standard cubic feet per stock tank barrel (SCF/STB), while the temperature is indicated in degrees Fahrenheit (F).

Through the process of mixing and non-mixing regimes when CO^2 is injected into the fields, oil production can be improved. the non-mixing method gives fewer production figures because a CO^2-EOR mixing method which, by achieving a minimum mixing pressure (MMP) and obtaining dynamic miscibility, gives higher recovery. Thin tube tests, mathematical models or correlations are used to determine the MWD. Dissolving in oil, reducing viscosity and swelling oil, CO^2 will still have a positive effect on oil recovery, even if the reservoir pressure is below the MMP or the composition of the reservoir oil is not suitable. The amount of oil that can be recovered from reservoirs can increase dramatically as a result of CO^2-EOR [3].

Materials and methods

To analyze the international practice of CO^2 injection, data from scientific articles, oil company reports and other open sources such as the official website were used. Analyzed the experience of injection of CO^2 into oil reservoirs in several fields in different countries, including the United States, Norway and Canada.

Results and discussion

In the 21st century, the surge in carbon dioxide (CO^2) emissions poses a significant challenge to humanity. In this context, globally, initiatives are underway to explore deep reservoir CO^2 infusion as a method to combat climate change and enhance oil recovery. This section examines various CO^2 injection projects and technologies employed to augment oil recovery, including prospects in Kazakhstan.

The Northern Lights venture in Norway commenced in 2020 with the objective of establishing infrastructure for the capture, conveyance, and deep reservoir CO^2 infusion at a depth of 2.5 kilometers. The project leverages refrigeration techniques to attain a stable liquid state of CO^2, subsequently transporting it to deeper strata. Furthermore, a monitoring system has been developed to oversee the process of CO^2 infusion into profound formations. Northern Lights has secured funding from the Norwegian government and anticipates commencing CO^2 injection by 2024 [4].

In Canada, the Quest project, initiated by Shell in 2015, stands as one of the world's largest CO^2 infusion endeavors. Situated in the province of Alberta, the project encompasses CO^2 collection from an oil platform, its transportation, and injection into deep layers at a depth of 2 kilometers. Employing refrigeration technology, CO^2 is liquefied and transported 80 km to the injection site. A monitoring system is also employed to ensure the safety and control of the injection process. The deep reservoir injection of CO^2 has led to a significant decrease of 35% in carbon dioxide emissions [5].

The Petra Nova project in the United States was launched in 2017 as the world's first commercial carbon dioxide separation and storage facility. It is a joint project between NRG Energy and JX Nippon Oil & Gas Exploration, to be installed at the W.A. Parish in Texas.

The project involved the implementation of equipment that effectively separates carbon dioxide from the emissions of a coal-fired power plant. The captured CO^2 is then transported through a pipeline to a designated disposal site located deep underground. As a result, the project has the capacity to annually separate and securely store up to 1.6 million tons of carbon dioxide.

The project implementation involved the utilization of technologies for carbon dioxide liquefaction, compression, well drilling, and gas injection into deep layers. The outcomes of the project indicate its successful operation and its capability to effectively reduce carbon dioxide emissions into the atmosphere. It is important to highlight that the Petra Nova project stands out as one of the world's largest and most triumphant initiatives focused on carbon dioxide separation and storage. Furthermore, it serves as a compelling demonstration of the potential application of similar technologies in various power plants and industries [6,7].

In Kazakhstan, work has also been carried out to inject carbon dioxide into oil and gas deposits to increase their production. The Tengiz Sour Gas Injection project by Chevron was launched in 2008 and was the first large-scale CO^2 injection project in Kazakhstan. It was based on Enhanced Oil Recovery (EOR) technology, which allows for enhanced oil recovery through the introduction of various substances, including CO^2.

The project included the construction of a compressor station for gas compression, as well as a pipeline system for transporting CO^2 from the source to the injection site. According to data obtained from Chevron, CO^2 injection resulted in a 3-5% increase in production and a reduction in greenhouse gas emissions by 3-4 million tons per year [8].

In addition to the Tengiz Sour Gas Injection project, research and development activities in the field of CCS and EOR are being carried out in Kazakhstan. For example, the Kazakhstanmunaigas company is planning to

launch a project to inject CO^2 into a field in the Kulsary region, which could potentially result in an increase of 8-10% in production. It is also worth noting that in 2020, the Kazakhstan CCS Association was established, which is responsible for coordinating research and development in the field of CCS in Kazakhstan.[9]

Thus, the analysis of international practice shows that the injection of carbon dioxide into oil and gas deposits is an effective way to increase oil recovery and reduce greenhouse gas emissions. Various projects in Norway, Canada, USA and Kazakhstan show that CCS and EOR technologies can be successfully applied in different conditions and fields. However, it is important to carry out more research and development to improve the efficiency and economic feasibility of these technologies.

Conclusion

In conclusion, the analysis of international practice has shown that CO^2 injection is an effective method of increasing oil recovery. This technology will also help increase production rates at the fields of Kazakhstan. However, the successful implementation of CO^2 injection projects requires taking into account many factors and additional research. Despite this, the prospects for using CO^2 as an injection fluid to increase oil recovery remain high and require further research and development. With the economic benefits of CO^2-EOR proven by many active CO^2-EOR projects, further expansion of its application in oil fields around the world is expected. This indicates the significance and prospects for its use in the future.

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Information about author

Sultan Samat
Master student, Kazakh-British Technical University, 59 Tole bi st., 050000, Almaty, Kazakhstan
ORCID ID 0008-0001-4643-4212
E-mail: s_samat@kbtu.kz

Автор туралы мәлімет

Сұлтан Самат
Магистрант, Қазақстан-Британ техникалық университеті, Төле би көш., 59, 050000, Алматы қ., Қазақстан
ORCID ID 0008-0001-4643-4212
E-mail: s_samat@kbtu.kz

Информация об авторе

Султан Самат
Магистрант, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, г. Алматы, Казахстан
ORCID ID 0008-0001-4643-4212
E-mail: s_samat@kbtu.kz

Султан С.

Қазақстан-Британ техникалық университеті, 050000, Алматы қ., Қазақстан
E-mail: s_samat@kbtu.kz

Мұнай бергіштікті арттыру әдістерінің бірі ретінде CO^2 кері айдау халықаралық тәжірибесін талдау

Аңдатпа. Қазіргі уақытта CO^2 кері айдау мұнай бергіштікті жоғарылату (EOR) үшін қолданылатын танымал әдіс болып табылады. Мұнай бергіштікті арттыру үшін кері айдау газы ретінде CO^2-ні пайдалану туралы алғашқы тұжырымдар 1916 ж. басталады, бірақ 1950 жылға дейін оның экономикалық тұрақтылығы анықталған жоқ. Бастапқыда пропан, сұйытылған мұнай газы және табиғи газ сияқты балама газдар пайдаланылды, бірақ CO^2 үнемді және тиімді нұсқа ретінде пайда болды. Бірінші CO^2 кері айдау жобасы 1964 ж. басталып, 1972 ж. ауқымды жобаға айналды. Нәтижесінде АҚШ, Канада, Венгрия, Түркия, Тринидад және Бразилия сияқты әртүрлі аймақтарда CO^2 кері айдау сәтті жүзеге асырылды. Басқа елдер шектеулі инфрақұрылым мен көздер сияқты қиындықтармен кездессе, Америка Құрама Штаттары 67 белсенді CO^2 кері айдау жобасымен ерекшеленді. Бүгінгі күні CO^2 кері айдаумен байланысты 100-ден астам мұнай бергіштікті арттыру жобалары тіркелді. Бұл мақалада мұнай бергіштіктің тиімділігін арттыру үшін CO^2 кері айдауды қолданудың халықаралық тәжірибелері мен әдістемелеріне толық шолу жасалады. Сонымен қатар, осы әлеуетті жобаларды және технологияны Қазақстан контекстінде қолдануға ерекше назар аударылады.

Тірек сөздер: МБАӘ, CO^2 кері айдау, мұнай өндіру, араластыру режимі, араласпау режимі, Қазақстан

Султан С.

Казахстанско-Британский технический университет, 050000, г. Алматы, Казахстан
E-mail: s_samat@kbtu.kz

Анализ международной практики закачки CO^2 как один из методов увеличения нефтеотдачи

Аннотация. Закачка CO^2 в настоящее время является популярным методом, используемым для повышения нефтеотдачи (EOR). Первое упоминание об использовании CO^2 в качестве закачиваемого газа для увеличения добычи нефти относится к 1916 г., хотя его экономическая целесообразность не была установлена до 1950-х гг. Первоначально использовались альтернативные газы, такие как пропан, сжиженный нефтяной газ и природный газ, но CO^2 стал более экономичным и эффективным вариантом. Первый проект заводнения CO^2 начался в 1964 г., за ним последовал более масштабный проект в 1972 г. Впоследствии успешные реализации заводнения CO^2 были засвидетельствованы в различных регионах, включая США, Канаду, Венгрию, Турцию, Тринидад и Бразилию. Среди них выделяются Соединенные Штаты с 67 действующими проектами по наводнению CO^2, в то время как другие страны сталкиваются с такими проблемами, как ограниченная инфраструктура и источники. На сегодняшний день зарегистрировано более 100 проектов повышения нефтеотдачи, связанных с заводнением CO^2. В данной публикации представлен всесторонний обзор международного опыта и методологий, касающихся применения заводнения CO^2 для повышения эффективности добычи нефти. Кроме того, в нем подчеркиваются потенциальные проекты и применение этой технологии в контексте Казахстана.

Ключевые слова: МӨАӘ, закачка CO^2, добыча нефти, смешиваемый режим, несмешиваемый режим, Казахстан

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Amangeldiyev A.[1], Yesmurzayeva A.[2*], Bibassarova R.[3]

[1]Al-Farabi Kazakh National University, Almaty, 050040, Kazakhstan
[2]Institute for Advanced Study and sustainable development Almaty, 050040, Kazakhstan
[3] Kaskelen Vocational and Technical College named after S. Zhandosov Kaskelen, 040901, Kazakhstan
*E-mail: aknur.yesmurzayeva@gmail.com

ASSESSING THE PROJECT MANAGEMENT MATURITY LEVEL IN THE PRODUCTION LOGISTICS FIELD

Abstract. This study examines the practice of implementing project management standards in production logistics. The goal of the study is to evaluate the maturity level of PM at the company engaged in the field of production logistics. The research was conducted on the materials of the company "Mehelektromontazh" LLP for the period of 2020-2022 through the analysis of key performance indicators and data from interviews. The study employed comparative and statistical analysis to assess the company's position. Standards in the field of project management, such as PMBOK, ISO, P2M, SSPM, etc. were compared. Research methodology is based on using the OPM3 model which helped to evaluate the PM maturity in logistics company. According to the evaluation results, the most developed areas in LLP "Mehelektromontazh" are procurement and scheduling management (100%), cost management (90%), and human resources management (75%). The least utilized project practices in this company are content management (25%), stakeholders management (50%), senior management (60%), and integration management (55%). The analysis conducted allowed for the formulation of recommendations for the implementation of project management standards to optimize logistics in the company's production process.

Key words: project management, production logistics, project maturity level, PM standard, OPM3 standard.

Introduction

In conditions of high competitive struggle, companies strive to optimize the work of all components of the production process. The logistics approach allows for the development of an open system for the formation and management of material, informational, and financial flows during order fulfillment, as well as ensuring coordination of work among all departments and units involved in the movement of materials from source to consumer.

The effective application of the logistics approach can be enhanced through the implementation of project management. By developing project management within a company, it is possible to reduce costs, increase efficiency, improve interaction with customers and company management, and gain more competitive advantages. According to research by Economist Intelligence, 80% of company executives worldwide consider project management a key competency that helps them remain competitive during economic recessions. Some authors found that on average, higher levels of project management maturity are associated with better cost and schedule results [1, 2]. However, in most organizations, expenditures on project management do not have direct impacts on revenue or profits [3]. Even when an economic downturn is followed by an upturn, there is no doubt that mature project management applied to all company activities contributes to achieving better results and obtaining long-term business advantages. However, managers of domestic companies are not rushing to implement project management standards in their company management, one of the reasons being a lack of sufficient knowledge in this area, indicating the need for this research.

The goal of the study is to evaluate the level of implementing project management standards at the company engaged in production logistics.

To achieve this goal the following research questions have been defined:

What standards are applicable to measure the PM maturity at the logistics companies?

What is the level of PM maturity at the chosen logistics company?

What the company should do to increase its PM maturity level?

Main provisions

The implementation of TSR PT across the entire production program ensures the optimal utilization of resources, enabling the organization to establish a smooth, unidirectional flow of materials.

LLP "Mehelektromontazh" excels in procurement management and time management (both at 100%), cost management (90%), and human resource management (75%). In contrast, scope management (25%), stakeholder management (50%), high-level management (60%), and integration management (55%) are areas where project practices are less utilized.

Scope management's lower percentage is attributed to the infrequent changes in initial customer requirements, even though unique requirements emerge during the initial order formation, necessitating a more comprehensive approach.

The quantitative utilization and qualitative implementation of project practices are assessed, revealing that while quality management has a 70% utilization rate, its qualitative implementation is at 45%.

Streamlining material flows through project management practices offers several benefits, including a tenfold reduction in interdepartmental routes, fewer internal links between production areas, and simplified production planning and management.

Literature Review

PM evolution

The historical origins of project management can be traced back to the development of human civilization, as evidenced by the great projects of the past such as the Egyptian pyramids, the Great Wall of China, the Taj Mahal, and many others.

Project management is associated with the works of classics such as Gantt, Fayol, and Taylor. For example, the American engineer H. Gantt developed the technique of calendar planning, which later became a project planning tool. Henri Fayol is the creator of classical management theory, which established the functions of management and became the foundation of project management.

The project management was established as a knowledge field in 1950s. In 1959, NASA proposed a systemic approach to project management based on the project life cycle stages.

In 1966, the GERT system was introduced, which represents a probabilistic method of network planning. This method is used to assess the probability of event occurrence based on statistical data obtained through modeling. It is applied when it is not possible to determine the exact sequence of work to achieve the project's goal.

In the 1970s, a systemic approach to project management was actively developed, taking into account external project factors. Conflict management methods were developed and implemented, and project organizational structures were formed with the definition of each participant's role.

Project management as a professional field was formed in the 1980s. Concepts such as resource management, risk management, and quality management emerged within project management. Significant attention was given to team formation.

The widespread adoption of project management methods in various industries began in the 1990s. During this period, the process of unification and standardization of project management methods began, leading to the introduction of international and national project management standards.

Production Logistics evolution

In foreign literature, "logistics" is considered a management function associated with planning. American scholars view logistics as a planning structure, a mechanism for cost savings.

English scholars perceive logistics as "the study and prediction of the market, production planning, procurement of raw materials, materials, and equipment, including inventory control and a series of operations related to the movement of goods."

Therefore, logistics allows for the optimization of production and information flows both within and outside the company. In the subsequent years, logistics began to be based on the integration of all spheres of economic activity into a system.

Using PM standards for the assessment of PM maturity in the Production Logistics field

There are many international standards of PM that can be applicable in different fields of economy. They specifically differ from each other depending on particular criteria. Table 1 presents a comparative analysis of international project management standards.

Table 1– Comparative Analysis of International Project Management Standards

Criteria / standards	PMBOK	P2M	PRINCE2
Approach Used	process	systemic	process
Project review	in isolation	Organization context	Organization context
Composition of project management subject areas	Management of integration, content, timelines, cost, personnel, risks, communications, quality, contracts, and deliveries	Management of strategy, finances, systems, project organization, tasks, resources, risks, project IT, relationships, project value and communication	project start, initiation, planning, project management project stage control, product delivery management, completion
Availability of management document templates	No	No	Yes
Availability of an individual certification system	Yes	Yes	Yes

In addition to that, the simplified PMBoK model, known as SSPM (Small and Simple Project Management), is actively used. This model consists of four stages that a project must go through: initiation, planning, control, and closure. The difference from the full model lies in the consolidation of two process groups, namely the "executing" group and the "monitoring and controlling" group, into a single group.

The discussed standards are integrated into a unified system of standards that allows for diagnosing and improving the maturity of an organization in the field of production logistics.

Different models are used to determine the level at which project management is implemented in a particular company. The organizational Project Management Maturity Model (OPM3) is a model that guides organizations to find solutions that bridge the gap between strategy and the realization of their projects [4]. This model includes tools and methods that allow continuous evaluation, through diagnostic techniques that identify potential problems and deficiencies with projects. At the same time, it identifies improvements to be implemented [5]. These standard benefits different organizations in terms of dimension, complexity, and geography. Silva et al stated that this model is one of the suitable tools for measuring PM maturity in the field of logistics. That's why the study uses the mentioned model in the analytical part of the research.

Materials and methods

The study uses statistical data from official internet resources, constituent and financial documents of "Mehelektromontazh," as well as publications from open sources.

The research methods used include logical-structural analysis, comparative and statistical analysis, and graphical analysis method. Data was collected by using the interview method for building an OMP3 model to assess the PM maturity at the chosen company. Respondents were 26 PM managers and project team members at "Mehelektromontazh" experienced in managing projects in the field of production logistics.

Before using the project management evaluation procedure, it is necessary to specify the constraints used. The assessment of project maturity was conducted by compiling a list of project-level questions. The weights of the questions were considered equal, and the process groups and knowledge areas were defined based on theoretical knowledge.

The main method used was in-depth interviews with the director of LLP "Mehelektromontazh" to assess the implementation of project management in the enterprise. The interview questions were derived from the OPM3 model, and the interpretation of the results was carried out by quantitatively calculating the number of project management processes used in the enterprise out of the total number of processes in the considered category. The questions are presented in Appendix A. When using a process in the enterprise, its implementation level was determined on a 4-point scale, where each subsequent category included the previous one:

Standardized process: observed in the company, possibly formally regulated.

Measurable process: quantitative or qualitative analysis is conducted on this process.

Controlled process: controlled to achieve planned results, deviations are promptly identified.

Improved process: negative practices identified in this process are analyzed, and a continuous procedure for their elimination is carried out.

At the end of this interview, a report was generated with a percentage determination of the quantity and

quality of the project management processes used. This percentage represents the level of utilization of only those project practices listed in the questions and may not take into account certain processes.

The interpretation of the results was performed using MS Excel software, whose capabilities allowed achieving the set goal.

Results and discussion

In LLP "Mehelektromontazh" the orderliness of material movement in production is achieved through the design of a typical scheme for the movement of work items in production (TSR PT). Designing TSR PT for the entire production program ensures the utilization of all potential capabilities of organizing unidirectional material flows.

The logistics department, while ensuring the flow of materials, must participate in decisions regarding the launch of production.

Below is a graphical representation of the results of the conducted in-depth interview.

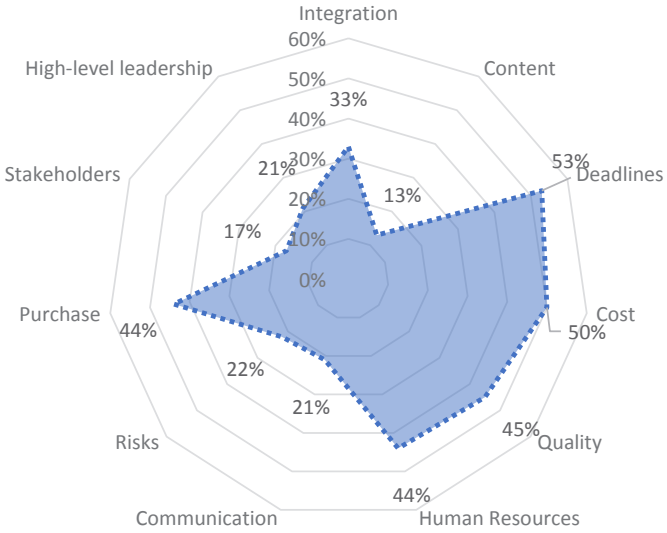

Figure 1 – Diagram of the implementation of PM processes by knowledge areas

As shown in the presented radar chart, the percentage of overall implementation of project management processes is displayed by knowledge areas. The most developed areas in LLP "Mehelektromontazh" are procurement management and time management (100%), cost management (90%), and human resource management (75%). The least utilized project practices in this company are scope management (25%), stakeholder management (50%), high-level management (60%), and integration management (55%).

The low percentage of scope management is due to the formation of initial customer requirements, where the order structure rarely undergoes significant changes. However, during the initial order formation, unique requirements are established, and a more comprehensive project approach for managing the scope is clearly necessary.

Time management and procurement management have demonstrated the highest level of implementation of project practices. This is due to the specific nature of production activities, which operate on a "just-in-time" principle, as well as the serious penalties in case of order delays. Similarly, there is a well-planned distribution of human resources for the same reason.

An important point for the analysis was the visual determination of the percentage of project practice utilization, as well as the cumulative percentage of project management implementation, which was calculated as the ratio of the current indicator of used project practices in production to the total number of project practices from the questions. The percentage of project management implementation in LLP "Mehelektromontazh" is 74%.

As mentioned above, questions were asked about the quality of the utilization of these practices in the enterprise during the interview. In comparison to the level of practice utilization, the percentage of qualitative implementation showed lower results, as presented in the figure.

The most developed areas in the enterprise, after determining the qualitative level, are time management (53%), cost management (50%), quality management (45%), procurement management, and human resource management (44%). The least utilized project practices in this company are scope management (13%), stakeholder management (17%), high-level management and communication (21%), and risk management (22%).

Although the percentage of project management utilization in quality showed an average indicator of 70%, the level of qualitative implementation of project management demonstrates high performance at 45%. The quality management is also crucial to detect and eliminate defects; otherwise, the produced goods may become unsuitable for use.

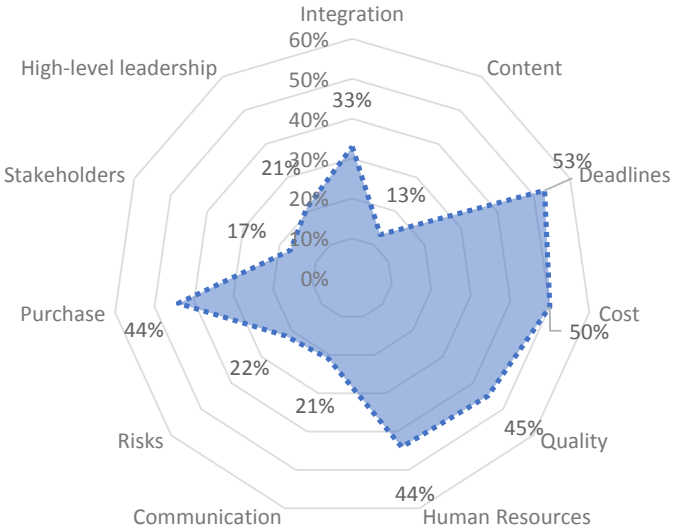

Figure 2 – Diagram of the qualitative implementation of PM processes by knowledge areas

Among the low indicators, new weaknesses have emerged in LLP "Mehelektromontazh", specifically in stakeholder management, communication, and risk management. Project communication management among employees is carried out in an informal manner, and there are only rare procedures for clarification calls with stakeholders. Thus, the administrative staff does not see the need for thorough communication planning, which was confirmed during the analysis of the company's project activities and the identification of only clarification call procedures with major clients. Risk management processes are considered without due attention, as the management perceives the occurrence of risks as completely unpredictable.

The OPM3 model itself serves as an excellent tool for a comprehensive understanding of the extent and quality of project management practices in all knowledge areas of project management. The developed questionnaire, consolidated table, and graphs will be provided to the management of LLP "Mehelektromontazh", allowing them to conduct a re-evaluation of their activities when necessary. However, this model has significant limitations, including unintentional overestimation of results since managers of their own enterprises potentially believe that the practices mentioned in the questions are used in their enterprises, although significant work is still required for their full implementation. Another drawback of this model is the lack of specific recommendations for improving project activities due to the nature of continuous and petal maturity models.

The weaknesses of LLP "Mehelektromontazh" lie in stakeholder management, communication, and risk management. Project communication management among employees is carried out in an informal style, and communication with stakeholders is limited to rare clarifying phone calls. This indicates that the administrative staff does not see the need for thorough communication planning, which was confirmed during the analysis of the company's project activities, where only clarifying phone call procedures were identified for major clients. Risk management processes are considered with insufficient attention, as the management perceives the occurrence of risks as unpredictable.

To increase the sales of services (products) at LLP "Mehelektromontazh" and expand the geographical scope of deliveries, it is necessary to implement new technologies used by foreign companies, both in terms of manufacturing techniques and materials management, i.e., the implementation of logistics management

systems. In a more advanced form of the "Kanban" system, it is possible to reduce material costs related to maintaining the staff and reduce the non-rational use of materials. Additionally, it can shorten the turnover time of materials into products, products into monetary funds, monetary funds into materials, and so on.

The logistical approach to managing material flows in the enterprise allows for the maximum optimization of a complex set of logistical operations, which can be achieved through the implementation of project management. Therefore, the use of design in LLP "Mehelektromontazh" provides the following advantages:

More than a tenfold reduction in the number of different interdepartmental technological routes.

Reduction in the number of internal links between production areas.

Reduced complexity and labor intensity of production planning and management.

Conclusion

Thus, the study results helped to answer the research questions put forward before. Based on the evaluation results of the project management level in LLP "Mehelektromontazh", it can be noted that the company is at an initial level of project maturity, characterized by the following features: limited support for project management, minor implementation of project management practices, the management's lack of awareness about the benefits of project management due to fear of change, decision-making driven by personal interests, lack of project management knowledge, and absence of investment in staff training. Despite the relatively high percentage of implemented project practices in the company and the management's willingness to learn new knowledge, the absence of confident knowledge of project methodology by the management prevents the transition to a higher level of the project management implementation assessment model. The implementation of project management in production logistics will ensure the timely fulfillment of obligations by LLP "Mehelektromontazh", which means delivering supplies on schedule without delays. The research limitation is the fact that the study covered the activity of only one company engaged in production logistics. Therefore, future research can expand the topic by adding new companies or additional fields as an object of the research.

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Information about authors

Amangeldiyev Azamat

Master of Economic science, Al-Farabi Kazakh National University, 71 al-Farabi Ave., 050040, Almaty, Kazakhstan

ORCI ID: 0000-0002-0489-1627

E-mail: a_amangeldiyev@kbtu.kz

Aknur Yesmurzayeva (corresponding author)

Master of Economic science, PhD student, Institute for Advanced Study and sustainable development, N. Nazarbayev Ave., 113/55, 050000, Almaty, Kazakhstan

ORCID ID: 0000-0001-8164-2539

E-mail: aknur.yesmurzayeva@gmail.com

Roza Bibassarova
Deputy Director for Educational and Industrial Work, Kaskelen Vocational and Technical College named after S. Zhandosov, Nauryzbai batyr str., 040901, Kaskelen, Kazakhstan
ORCID ID:0009-0001-8488-0521
E-mail: roza.bibasarova@mail.ru

Авторлар туралы мәліметтер

Амангелдиев Азамат
Экономика ғылымдарының магистрі, әл-Фараби атындағы Қазақ ұлттық университеті, әл-Фараби даңғылы, 71, Алматы қ., Қазақстан
ORCI ID: 0000-0002-0489-1627
E-mail: a_amangeldiyev@kbtu.kz

Акнур Есмурзаева (корреспонденция авторы)
Экономика ғылымдарының магистрі, Жетілдірілген зерттеулер және тұрақты даму институтының асипиранты, Н. Назарбаев даңғылы, 113/55, 050000, Алматы қ., Казақстан
ORCID ID: 0000-0001-8164-2539
E-mail: aknur.yesmurzayeva@gmail.com

Роза Бибасарова
С. Жандосов атындағы Қаскелең кәсіптік-техникалық колледжі директорының оқу-өндірістік жұмысы жөніндегі орынбасары, Наурызбай батыр көш., 040901, Қаскелең қ., Казақстан
ORCID ID:0009-0001-8488-0521
E-mail: roza.bibasarova@mail.ru

Информация об авторах

Амангельдиев Азамат
Магистр экономических наук, Казахский национальный университет им. аль-Фараби, 050040, пр. Аль-Фараби, 71, г. Алматы, Казахстан.
ORCI ID: 0000-0002-0489-1627
E-mail: a_amangeldiyev@kbtu.kz

Акнур Есмурзаева (автор для корреспонденции)
Магистр экономических наук, аспирант Института перспективных исследований и устойчивого развития, пр. Н.Назарбаева, 113/55, 050000, г. Алматы, Казахстан
ORCID ID: 0000-0001-8164-2539
E-mail: aknur.yesmurzayeva@gmail.com

Роза Бибасарова
Заместитель директора по учебно-производственной работе Каскеленского профессионально-технического колледжа имени С. Жандосова, ул. Наурызбай батыра, 040901, г. Каскелен, Казахстан
ORCID ID:0009-0001-8488-0521
E-mail: roza.bibasarova@mail.ru

Амангельдиев А.[1], Есмурзаева А.*[2], Бибасарова Р.[3]

[1]әл-Фараби атындағы Қазақ ұлттық университеті, Алматы қ., 050040, Қазақстан
[2]Жетілдірілген зерттеулер және тұрақты даму институты, Алматы қ., 050040, Қазақстан
[3]С. Жандосов атындағы Қаскелең кәсіптік-техникалық колледжі, Қаскелең қ., 040901, Қазақстан
*E-mail: aknur.yesmurzayeva@gmail.com

ҚАЗАҚСТАН КӘСІПОРЫНДАРЫНДАҒЫ ТҰРАҚТЫ ИННОВАЦИЯЛЫҚ ДАМУДЫ БАҒАЛАУ

Аңдатпа. Бұл мақалада өндірістік логистикаға жобалық менеджмент стандарттарын енгізу тәжірибесі қарастырылады. Зерттеу 2020–2022 жж. «Мехэлектромонтаж» ЖШС материалдары негізінде қызметтің негізгі көрсеткіштерін талдау және сұхбат деректерін өңдеу арқылы жүргізілді. Әдебиеттерге шолу кезінде ашық ақпараттық ресурстарда орналастырылған отандық және шетелдік ғалымдардың ғылыми еңбектері пайдаланылды. Зерттеу барысында компанияның жағдайын бағалауға мүмкіндік беретін салыстырмалы және статистикалық талдау қолданылды. PMBOK, ISO, P2M, SSPM және т.б. жобалық менеджмент саласындағы стандарттар қарастырылды. Сұхбат әдісі арқылы зерттелетін объектінің жобалық кемелдену деңгейіне баға беріледі. Жүргізілген талдау компанияның өндірістік процесінде логистиканы оңтайландыру мақсатында жобалық менеджмент стандарттарын енгізу бойынша ұсыныстар қалыптастыруға мүмкіндік берді.

Тірек сөздер: жобалық менеджмент, өндіріс, логистика, жобалық жетілу деңгейі, сұхбат, стандарттар.

Амангельдиев А.[1], Есмурзаева А.*[2], Бибасарова Р.[3]

[1] Казахский национальный университет имени аль-Фараби, г. Алматы, 050040, Казахстан
[2]Институт перспективных исследований и устойчивого развития, г. Алматы, 050040, Казахстан
[3] Каскеленский профессионально-технический колледж им. С. Жандосова
Каскелен, 040901, Казахстан
*E-mail: aknur.yesmurzayeva@gmail.com

ОЦЕНКА РАЗВИТИЯ УСТОЙЧИВЫХ ИННОВАЦИЙ В КАЗАХСТАНСКИХ КОМПАНИЯХ

Аннотация. В данной статье рассматривается практика внедрения стандартов проектного менеджмента в производственную логистику. Исследование проведено на материалах ТОО «Мехэлектромонтаж» за период 2020–2022 гг. посредством анализа основных показателей деятельности и обработки данных интервью. При обзоре литературы были использованы научные труды отечественных и зарубежных ученых, размещенные в открытых информационных ресурсах. В ходе исследования были использованы сравнительный и статистический анализ, который позволил оценить положение компании. Рассмотрены стандарты в области проектного менеджмента, такие как PMBOK, ISO, P2M, SSPM и пр. При оценке уровня проектного менеджмента в компании была использована модель зрелости управления проектами Керцнера. Посредством метода интервью дана оценка уровню проектной зрелости исследуемого объекта. Проведенный анализ позволил сформировать рекомендации по внедрению стандартов проектного менеджмента с целью оптимизации логистики в производственном процессе компании.

Ключевые слова: проектный менеджмент, производство, логистика, уровень проектной зрелости, интервью, стандарты.

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Zhambyl A.*[1], Kenzhibayeva Z.[1], Narbaev T.[1], Castelblanco G.[2]

[1]Kazakh-British Technical University 050000, Almaty, Kazakhstan
[2]University of Florida Gainesville, FL, 32611-5703, USA
*E-mail: aibekzhambyl@gmail.com

THE CHALLENGES OF USING THE AGILE APPROACH WHILE DEALING WITH SUPPORTERS OF THE CONSERVATIVE APPROACH IN PROJECT MANAGEMENT

Abstract. Project management (PM) is one of the most important aspects of modern business and society. Successful completion of projects can ensure the growth and development of organizations, as well as the social well-being of society and the country. As businesses continue to operate in a dynamic environment, the need for a flexible and responsive PM approach has become increasingly important. This led to the popularity of Agile methodology, which emphasizes collaboration, continuous improvement, and customer satisfaction. While Agile has proven successful in many projects, it also comes with its challenges and risks. Therefore, understanding the success and risk factors associated with using Agile is crucial for project managers to plan and manage Agile projects effectively. The aim is to understand if the implementation of Agile is vital to revolutionize PM or if Agile has a placebo effect by presenting numerically represented proofs. The aim of the study is also to identify risk and success factors influenced by the Agile methodology. To achieve this goal, theoretical study of other countries and the practical part. The theoretical part considers the project concept, risk factors and project success. In the empirical part, a questionnaire was used among PM experts to collect primary information. To analyze the results of the questionnaire, the following methods were used: Cronbach's Alpha and Manna Whitney. As a result of the study, risk and success factors were identified in projects positively influenced by Agile. Namely, it increases the probability and influence of success factors and reduces the likelihood and influence of risk factors. These recommendations are for future research. The results of the study can be used to decide on the implementation of Agile methodology and further improve the practical experience of implementing Agile methodology.

Key words: Agile, Project Management, Success factor, Risk factor.

1. Introduction

The relevance of research lies in the increasing popularity of Agile in Project Management (PM) and the need for a clear interpretation of the factors that impact its success and risk attributes. This study can be valuable for project managers and organizations to make a more precise approach when adopting Agile and can improve project outcomes. Additionally, it can aid in identifying areas that require improvement and developing strategies to mitigate potential risks. With the growing demand for Agile, this research is crucial in ensuring organizations have the knowledge and skills to successfully implement Agile methodology. PM is an urgent topic in the modern world, as it allows you to manage resources and achieve your goals effectively. No matter what industry an organization works in or what type of project it leads, PM is necessary for completing tasks and achieving results. Now, Kazakhstan is actively developing in this direction. Firstly, Kazakhstan is actively developing in various fields, including economy, industry, transport and communications, and social infrastructure. To ensure the effective execution of these projects, it is essential to oversee them optimally, reducing potential risks and maximizing achievements. Secondly, Kazakhstan is working to improve the investment climate and attract foreign investment. To use these investments effectively, it is necessary to conduct projects that will be successful and profitable. Finally, Kazakhstan is a member of international organizations such as the World Trade Organization and Organization for Economic Co-operation and Development and participates in international projects. This study can help in the areas mentioned above.

This research aims to explore the factors contributing to the achievement and potential risks related to the utilization of Agile methodology in PM, specifically in multinational corporations. The investigation will analyze the crucial elements that facilitate the effective implementation of Agile methodology and the possible

difficulties and hazards that may emerge during the adoption phase. Additionally, the research will assess the influence of Agile on significant factors influencing both success and risk.

To achieve the research objective, we must answer the following questions. Do companies that use Agile in projects have more success rates than companies with traditional project approaches? Are the factors of risk less in companies practicing the Agile approach than in companies with the traditional approach? How the level of resistance against Agile methodologies can be evaluated? To what extent do project managers find it challenging to implement Agile in projects for traditional companies?

In the research, firstly, the literature review will be done to study the use of Agile in PM thoroughly. Then, the proper questionnaire will be done among experienced project managers to identify the level of Agile in PM in Kazakhstan. Later, the data will be analyzed, and the effects will be discussed based on numerical data.

The paper is organized as follows. We provide the main provisions including the literature review, materials and methods, and the discussion of the main results and findings. The last section concludes the study highlighting its limitation and future research directions.

2. Main provisions

2.1. Literature review

One challenge identified in the literature is resistance to change. The supporters of a conservative approach may resist Agile methodology as it requires a significant shift in mindset and work practices. According to Eklund and Wilson (2018), change resistance can manifest in many ways, including lack of engagement, skepticism, and outright opposition to the Agile approach. This resistance can stem from the fear of the unknown or the belief that the traditional approach has worked in the past and, therefore, should continue. [1], [2], [3]

Another challenge highlighted in the literature is a lack of trust. Conservative supporters may not trust the Agile methodology or the team responsible for implementing it. According to Conboy et al. (2016), trust is essential to implement Agile successfully. Without trust, stakeholders may not believe in the project's goals or the team's ability to deliver, leading to project failure. [4], [5], [6], [7], [8],

Different goals and priorities can also present a challenge when implementing Agile with conservative supporters. According to Hazzan and Dubinsky (2013), the goals of Agile, which prioritize customer value and adaptability, may conflict with the conservative approach, which prioritizes adherence to the plan and minimizing risks. The differing goals can lead to a lack of alignment between stakeholders, which can cause significant problems in project implementation. [9], [10], [11],

Communication is another critical factor identified in the literature that can affect the success of Agile implementation with conservative supporters. According to Beigbeder and Picard (2016), communication issues can arise due to language, terminology, and approach differences. Conservative supporters may not be familiar with Agile terminology, leading to misunderstandings, delays, and other communication issues. [12], [13], [14], [15], [16],

Finally, a lack of understanding of the Agile methodology can pose a significant challenge when implementing it with conservative supporters. According to Boehm and Turner (2013), adopting Agile methodology necessitates a notable shift in mindset and work practices, which can pose challenges for individuals accustomed to more traditional approaches. To address this challenge, organizations may need to invest in training and education to help stakeholders understand the Agile approach and its principles. [17], [18], [19],

The reviewed literature suggests that implementing the Agile approach while dealing with supporters of a conservative approach in PM can be challenging. Resistance to change, lack of trust, differing goals, communication issues, and a lack of understanding are some primary challenges that can arise. Organizations that wish to implement Agile successfully with conservative supporters must address these challenges through effective communication, collaboration, and education. [20], [21], [22], [23], [24].

2.2. Materials and methods

This section focuses on the methodology used to obtain the data for the research. The first part of this section focuses on the methodology to gather the data, and the second part focuses on the interpretation of the numerical data. The analysis is conducted using the data analysis methods and tools.

The data is collected by sending a questionnaire to the top managers of companies who practice the Agile approach from the IT, telecom, governmental, and construction companies. The questionnaire has three

sections and twelve questions are asked. Each question has two parameters for probability and impact values, where six out of twelve questions are related to probability factors and six out of twelve are related to risks. The questionnaire questions include the factors indicated in Table 1. The collected data will later be processed with Excel calculations.

There are three methods used for the research. Firstly, for the study of secondary information - literature review and analysis using the program VOSViewer. As well as a summary table by articles. The next method includes a survey, and qualitative interviews were used to prepare the primary information. Finally, analyzing the results were analyzed using different parameters.

Two methods were used for data analysis: Cronbach's alpha and the Mann-Whitney method. The reliability of the questionnaire was assessed using Cronbach's alpha method. To directly analyze the questionnaire data, we used the Mann-Whitney method. Based on a survey conducted among companies using Agile and not using it, data was obtained that allows us to analyze the impact of Agile on risk factors and success in PM. There were twenty respondents in total. The data obtained were divided into two groups: companies using Agile and companies not using Agile. For each risk or success factor, the U value and the p-value were calculated. The Excel tool was used to calculate, and the following steps were performed. Consider the example of a success factor such as an adequate budget for planning and design projects (impact). The first step is the ranking of the data. The results were ordered in ascending order, and each value was assigned ranks. The second step is the calculation of the sum of ranks. We calculate the sum of the ranks for each company. Let us denote the sum of the ranks of a company using Agile as U1 and the sum of a company not using Agile as U2, where U1=172 and U2=38. The third step is the calculation of U statistics. Calculate U statistics using the formula:

$$U = \min(U1, U2), \quad (1)$$

The fourth step is the calculation of the expected value of U. We determine the expected value of U using the following formula, where n1 and n2 are sample sizes for a company using Agile and a company not using Agile, respectively, where E(U)=42:

$$E(U) = (n1 * n2) / 2, \quad (2)$$

The fifth step is the calculation of the standard deviation (SD). We calculate the SD for the U statistic using the following formula, where SD=12.12:

$$SD = \text{sqrt}[(n1 * n2 * (n1 + n2 + 1)) / 12], \quad (3)$$

The sixth step is the calculation of the Z-statistic value. We calculate the value of the Z-statistics using the following formula, where Z=-2.06:

$$Z = (U - E(U)) / SD, \quad (4)$$

The seventh step is determining the p-value. Using the standard normal distribution Excel formula, we determine the p-value associated with the resulting Z-statistic value, p-value=0.019. The eighth step is deciding. We compare the obtained p-value with the selected significance level (0.05). If the p-value is less than the selected significance level, we reject the null hypothesis and assume that there is a statistically significant difference between the companies. Otherwise, the non-null hypothesis is not rejected, and it is accepted that there are no statistically significant differences between the samples. 0.019<0.05 - we reject the null hypothesis and assume that there is a statistically significant difference between the companies.

2.3. Results and discussion

The results obtained for all factors are presented numerically (Table 1) and graphically (Table 2) below. Green indicates alternative hypotheses confirming the differences between companies using and not using Agile. Red marks companies where null hypotheses are accepted, which confirm the absence of differences between companies with and without Agile. According to data analysis (Mann-Whitney U test), companies using Agile have a greater impact and probability of success factors such as Adequate budget for planning and

designing projects, Clear goals and technical requirements of the project, and Support from stakeholders. Also, according to data analysis (Mann-Whitney U test), companies using Agile have less impact and probability of such risk factors as poor time management and financial risks (including inflation and currency exchange rate changes).

Table 1 – Results of the analysis by the Mann-Whitney method. Numerical values:

Success factors	Values	Adequate budget for planning and design projects		Experienced and qualified team		Adequate financing		Clear goals and technical requirements of the project		Support from stakeholders		Strict project planning and control	
		Im-pact	Proba-bility	Im-pact	Proba-bility	Im-pact	Proba-bility	Im-pact	Proba-bility	Impact	Proba-bility	Impact	Proba-bility
Results	a	0.05											
	U-total	17	24.5	34.5	22.5	28	27.5	0	16.5	0	19	22.5	39
	sig	yes	no	no	no	no	no	yes	yes	yes	yes	no	no
	U-crit	21.56											
	p-value	0.02	0.07	0.27	0.05	0.12	0.12	0.00027	0.02	0.00027	0.03	0.05	0.40
	sig	yes	no	no	no	no	no	yes	yes	yes	yes	no	no
Risk factors	Values	Political instability		Financial risks: inflation and currency exchange rate changes		Legal risks		Lack of procurement materials		Poor time management		Reputational risks	
		Im-pact	Proba-bility	Im-pact	Proba-bility	Im-pact	Proba-bility	Im-pact	Proba-bility	Impact	Proba-bility	Impact	Proba-bility
	a	0.05											
	U-total	40.5	35	28	21	39	40	31	39.5	21	23	34	20.5
	sig	no	no	no	yes	no	no	no	no	yes	no	no	no
	U-crit	21.56											
	p-value	0. 4508	0.2819	0. 1241	0.0432	0.4023	0.4345	0.1821	0.4183	0.0416	0.0585	0.2547	0.0580
	sig	no	no	no	yes	no	no	no	no	yes	no	no	no

Table 2 – Results of the analysis by the Mann-Whitney method. Graphically values:

Success factors	Impact	Probability
Adequate budget for planning and design projects	Yes	No
Experienced and qualified team	No	No
Adequate financing	No	No
Clear goals and technical requirements of the project	Yes	Yes
Support from stakeholders	Yes	Yes
Strict project planning and control	No	No
Risk factors	Impact	Probability
Political instability	No	No
Financial risks: inflation and currency exchange rate changes	No	Yes
Legal risks	No	No
Lack of procurement materials	No	No
Poor time management	Yes	No
Reputational risks	No	No

To summarize, the collected data shows that the success factor with the Agile approach application in projects positively affects the success rate, and the risk factors correspondingly decrease. The results' analysis demonstrates that the minimum requirements for the correct level of data are met.

0.7 is commonly regarded as a benchmark value for Cronbach's alpha by analysts. When the coefficient reaches this threshold or higher, it suggests that the items in the measure exhibit sufficient consistency, indicating reliability. Values close to 0.7 are considered minimally acceptable but fall short of ideal. Nevertheless, it is worth noting that different fields and industries may have varying minimum values for Cronbach's alpha based on their specific requirements and standards. The benchmark results show that success rates for factors 4, 5 and 6 are highly affected by implementing the Agile approach in projects, whereas they are decreased significantly for factors 1, 2 and 6.

3. Conclusion

According to the study results, the success and risk factors positively influenced by the Agile methodology are identified, as well as the main obstacles companies face when implementing Agile. Thus, this work will be useful for companies that doubt the need to implement Agile. For future researchers, there is ground for further consideration of the impact of Agile on other risk and success factors that were not reflected in this work.

The analysis of the conducted research and practical examples allows us to draw the following conclusions. Firstly, Agile methodology helps to reduce risks in projects. Thanks to an iterative and incremental approach, Agile allows early identification of problems and change of plans based on feedback. This helps to reduce the likelihood of critical risks and improve project control. The study determined the impact of Agile on reducing risks such as Poor time management and financial risks (including inflation and currency exchange rate changes). Secondly, Agile increases the probability of project success. Agile's flexibility and adaptability allow teams to respond more effectively to changes in requirements, the market, and the competitive environment. Agile contributes to creating more relevant and successful products through regular demonstrations of interim results and interaction with stakeholders. During the study, the influence of Agile on the increase of such success factors as Adequate budget for planning and design projects, Clear goals and technical requirements of the project, and Support from stakeholders. Thirdly, Agile methodology changes the approach to PM. Instead of rigid planning and consistent execution, Agile offers incremental product development and active interaction with the team and stakeholders. This requires a change in the culture and processes in the organization, as well as the active support of management.

However, it should be noted that implementing Agile methodology may also face certain obstacles and difficulties, such as lack of trust, different goals, and priorities, as well as communication problems. However, these problems can be overcome by improving communication processes, training, and creating trusting relationships. As a result, Agile methodology significantly impacts risk factors and success in PM. It helps to reduce risks, increase the likelihood of success, and provide a more flexible and collaborative PM. The introduction of Agile requires changes in processes, working methods, and the organization's culture and management approach. Successful implementation of Agile methodology can bring significant benefits and improve project results. Due to the scale, time duration, expertise and other reasons, several limitations restrict the scale of the research. The first recommendation is that it is required to consider the limits of this current research. A wider sample in terms of quantity of respondents, wider area of professions, and wider geography is recommended. The second recommendation is to consider the questionnaire. It is recommended to increase the sample size and ask people with distinct roles, workplaces, and departments to understand the common trends rather than derive the answer from the limited areas of fields. The third recommendation is to dedicate more time to getting more responses, which solves the problem of busy seasons. The fourth recommendation is that the risks were not fully covered because there was insufficient data for the Mann-Whitney U test analysis. More data is needed, and deeper research on types of risks can be done.

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Information about authors

Aibek Zhambyl (corresponding author)

Master's graduate in Project Management, Kazakh-British Technical University, Tole bi 59, 050000, Almaty, Kazakhstan

ORCID ID 0009-0006-1091-8108

E-mail: aibekzhambylmail@gmail.com

Zhanel Kenzhibayeva
Master's graduate in Project Management, Kazakh-British Technical University, Tole bi 59, 050000, Almaty, Kazakhstan
ORCID ID 0009-0004-8792-590X
E-mail: kenzhibaeva1997@gmail.com

Timur Narbaev
PhD, Senior Lecturer**,** Kazakh-British Technical University, Tole bi 59, 050000, Almaty, Kazakhstan
ORCID ID 0000-0002-6401-2700
E-mail: t.narbaev@kbtu.kz

Gabriel Castelblanco
PhD, Assistant Professor
M.E. Rinker, Sr. School of Construction Management University of Florida, 315 Rinker Hall, Gainesville, FL 32611-5703 USA, Office: 352-273-0563
ORCID ID 0000-0001-6820-6644
E-mail: gabriel.castelbl@ufl.edu

Авторлар туралы мәліметтер

Айбек Жамбыл (корреспонденция авторы)
Жобаларды басқару магистрі, Қазақстан-Британ техникалық университеті, Төле би көш., 59, 050000, Алматы қ., Қазақстан
ORCID ID 0009-0006-1091-8108
E-mail: aibekzhambylmail@gmail.com

Жанель Кенжибаева
Жобаларды басқару магистрі, Қазақстан-Британ техникалық университеті, Төле би көш., 59, 050000, Алматы қ., Қазақстан
ORCID ID 0009-0004-8792-590X
E-mail: kenzhibaeva1997@gmail.com

Тимур Нарбаев
PhD, аға оқытушы, Қазақстан-Британ техникалық университеті, Төле би көш., 59, 050000, Алматы қ., Қазақстан
ORCID ID 0000-0002-6401-2700
E-mail:: t.narbaev@kbtu.kz

Габриэль Кастельбланко
PhD, Assistant Professor, Флорида Университетінің құрылысты басқару мектебі, 315 Rinker Hall, Гейнсвилл қ., Флорида, 32611-5703 АҚШ, офис: 352-273-0563
ORCID ID 0000-0001-6820-6644
E-mail: gabriel.castelbl@ufl.edu

Информация об авторах

Айбек Жамбыл (автор для корреспонденции)
Магистр управления проектами, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, г. Алматы, Казахстан
ORCID ID 0009-0006-1091-8108
E-mail: aibekzhambylmail@gmail.com

Жанель Кенжибаева
Магистр управления проектами, Казахстанско-Британский технический университет, ул. Толе би, 59, 050000, г. Алматы, Казахстан
ORCID ID 0009-0004-8792-590X
E-mail: kenzhibaeva1997@gmail.com

Тимур Нарбаев
PhD, старший преподаватель, Казахстанско-Британский технический университет, Толе би, 59, 050000, г. Алматы, Казахстан
ORCID ID 0000-0002-6401-2700
E-mail: t.narbaev@kbtu.kz

Габриэль Кастельбланко
PhD, Assistant Professor, Школа управления строительством Университета Флориды, 315 Rinker Hall, Гейнсвилл, Флорида, 32611-5703 США, офис: 352-273-0563
ORCID ID 0000-0001-6820-6644
E-mail: gabriel.castelbl@ufl.edu

Жамбыл А.[*1], Кенжибаева Ж.[1], Нарбаев Т.[1], Кастелбланко Г.[2]

[1]Қазақстан-Британ техникалық университеті, Алматы қ., 050000, Қазақстан
[2]University of Florida Gainesville, FL, 32611-5703, АҚШ
*E-mail: a.zhambyl@kbtu.kz

ЖОБАНЫ БАСҚАРУДА КОНСЕРВАТИВТІК ТӘСІЛДЕРДІ ҚОЛДАУШЫЛАРМЕН ЖҰМЫС КЕЗІНДЕГІ AGILE ТӘСІЛДІ ПАЙДАЛАНУДЫҢ ҚИЫНДЫҚТАРЫ

Аңдатпа. Жобаларды басқару қазіргі бизнес пен қоғамның маңызды аспектілерінің бірі болып табылады. Жобаларды сәтті аяқтау ұйымдардың өсуі мен дамуын, сондай-ақ қоғам мен елдің әлеуметтік әл-ауқатын қамтамасыз ете алады. Кәсіпорындар динамикалық ортада жұмыс істеуді жалғастырған сайын, икемді және жауапты жобаларды басқару тәсілінің қажеттілігі барған сайын маңызды бола бастады. Бұл ынтымақтастыққа, үздіксіз жетілдіруге және тұтынушылардың қанағаттанушылығына баса назар аударатын Agile әдістемесінің танымалдығының артуына әкелді. Agile көптеген жобаларда табысты болғанымен, оның өзіндік қиындықтары мен тәуекелдері де бар. Сондықтан, Agile пайдаланумен байланысты табыс пен тәуекел факторларын түсіну жоба менеджерлері үшін Agile жобаларын тиімді жоспарлау және басқару үшін өте маңызды. Мақсат Agile-ні енгізу PM-де төңкеріс жасау үшін маңызды ма, әлде сандық түрде ұсынылған дәлелдерді ұсыну арқылы Agile плацебо әсері бар ма екенін түсіну. Зерттеудің мақсаты сонымен қатар Agile әдістемесі әсер ететін тәуекел мен сәттілік факторларын анықтау болып табылады. Осы мақсатқа жету үшін басқа елдерді теориялық зерттеу мен практикалық бөлімде қарастырылды. Теориялық бөлімде жоба түсінігі, тәуекел факторлары және жобалардағы табыстар қарастырылады. Эмпирикалық бөлімде бастапқы ақпаратты жинау үшін PM сарапшылары арасында сауалнама жүргізілді. Сауалнама нәтижелерін талдау үшін келесі әдістер қолданылды: Кронбах Альфа және Манна Уитни. Зерттеу нәтижесінде Agile оң әсер ететін жобаларда тәуекел және сәттілік факторлары анықталды, атап айтқанда, ол сәттілік факторларының ықтималдығы мен әсерін арттырады және тәуекел факторларының ықтималдығы мен әсерін азайтады. Бұл ұсыныстар болашақ зерттеулерге арналған. Зерттеу нәтижелері Agile әдіснамасын енгізу туралы шешім қабылдау және Agile әдістемесін енгізудің практикалық тәжірибесін одан әрі жетілдіру үшін пайдаланылуы мүмкін.

Тірек сөздер: Agile, жобаны басқару, жетістік факторы, тәуекел факторы, проджект менеджмент.

Жамбыл А.*[1], Кенжибаева Ж.[1], Нарбаев Т.[1], Кастелбланко Г.[2]

[1]Қазахстанско-Британский технический университет г. Алматы, 050000, Казахстан
[2]University of Florida Gainesville, FL, 32611-5703, США
*E-mail: a.zhambyl@kbtu.kz

ПРОБЛЕМЫ ИСПОЛЬЗОВАНИЯ AGILE-ПОДХОДА ПРИ РАБОТЕ СО СТОРОННИКАМИ КОНСЕРВАТИВНОГО ПОДХОДА В УПРАВЛЕНИИ ПРОЕКТАМИ

Абстракт. Управление проектами является одним из важнейших аспектов современного бизнеса и общества. Успешное завершение проектов может обеспечить рост и развитие организаций, а также социальное благополучие общества и страны. Поскольку предприятия продолжают работать в динамичной среде, необходимость гибкого и оперативного подхода к управлению проектами становится все более важной. Это привело к росту популярности методологии Agile, которая делает упор на сотрудничество, постоянное совершенствование и удовлетворенность клиентов. Хотя Agile доказала свою эффективность во многих проектах, она также имеет свои проблемы и риски. Поэтому понимание факторов успеха и риска, связанных с использованием Agile, имеет решающее значение для менеджеров проектов для эффективного планирования и управления Agile-проектами. Цель состоит в том, чтобы понять, важно ли внедрение Agile для революции в управлении проектами или же Agile имеет эффект плацебо, путем представления доказательств в числовом виде. Целью исследования также является выявление факторов риска и успеха, на которые влияет методология Agile. Для достижения этой цели проводится теоретическое изучение других стран и практическая часть. В теоретической части рассматривается концепция проекта, факторы риска и успешность проектов. В эмпирической части для сбора первичной информации использовалось анкетирование среди экспертов Управления проектами. Для анализа результатов анкетирования использовались следующие методы: Альфа Кронбаха и Манна Уитни. В результате исследования были выявлены факторы риска и успеха в проектах, на которые Agile оказывает положительное влияние, а именно увеличивает вероятность и влияние факторов успеха и снижает вероятность и влияние факторов риска. Эти рекомендации предназначены для будущих исследований. Результаты исследования могут быть использованы для принятия решения о внедрении методологии Agile и дальнейшего улучшения практического опыта внедрения методологии Agile.

Ключевые слова: Agile, управление проектами, фактор успеха, фактор риска, проджект менеджмент.

ҚАЗАҚСТАН-БРИТАН ТЕХНИКАЛЫҚ УНИВЕРСИТЕТІНІҢ
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