

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

**ACADEMIC JOURNAL  
OF PHYSICAL AND CHEMICAL SCIENCES**

**№1  
2026**

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

2026 • 1



**ACADEMIC JOURNAL  
OF PHYSICAL AND  
CHEMICAL SCIENCES**

PUBLISHED SINCE JANUARY 1944

ALMATY, NAS RK

## EDITOR-IN-CHIEF

**ZHURINOV Murat Zhurinovich**, Doctor of Chemical Sciences, Professor, Academician of IAAS and NAS RK, General Director Oil refining and Petrochemistry Research Institute (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=6602177960>, <https://www.webofscience.com/wos/author/record/2017489>

## DEPUTY EDITOR-IN-CHIEF:

**KALIMOLDAYEV Maksat Nuradilovich**, Doctor of Physical and Mathematical Sciences, Professor, Academician of NAS RK (Almaty, Kazakhstan), <https://www.scopus.com/authid/detailuri?authorId=56153126500>, <https://www.webofscience.com/wos/author/record/2428551>

**ABILMAGZHANOV Arlan Zainutallaevich**, PhD in Chemistry, General Director of JSC "Institute of Fuel, Catalysis and Electrochemistry named after D.V. Sokolsky", (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=57197468109>, <https://www.webofscience.com/wos/author/record/2024265>

## EDITORIAL BOARD:

**ADEKENOV Sergazy Mynzhasarovich**, Doctor of Chemical Sciences, Professor, Academician of NAS RK, Director of the JSC "Phytochemistry Research and Production Center", (Karaganda, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=7006153118>, <https://www.webofscience.com/wos/author/record/48648658>

**RAMAZANOV Tlekkabul Sabitovich**, Doctor of Physical and Mathematical Sciences, Professor, Academician of NAS RK (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=6701328029>, <https://www.webofscience.com/wos/author/record/13503476>

**ABIEV Rufat**, Doctor of Technical Sciences (Biochemistry), Professor, Head of the Department of Optimization of Chemical and Biotechnological Equipment, St. Petersburg State Technological Institute (St. Petersburg, Russia), <https://www.scopus.com/authid/detail.uri?authorId=6602431781>, <https://www.webofscience.com/wos/author/record/1405661>

**OLIVIERO Rossi Cesare**, PhD (Chemistry), Professor at the University of Calabria (Calabria, Italy), <https://www.scopus.com/authid/detail.uri?authorId=57221375979>, <https://www.webofscience.com/wos/author/record/399768>

**TIGINYANU Ion Mihailovich**, Doctor of Physical and Mathematical Sciences, Academician, President of the Academy of Sciences of Moldova, Technical University of Moldova (Chisinau, Moldova), <https://www.scopus.com/authid/detail.uri?authorId=7006315935>, <https://www.webofscience.com/wos/author/record/524462>

**SANG SU Kwak**, PhD (Biochemistry, Agricultural Chemistry), Professor, Chief Scientist, Research Center for Plant Systems Engineering, Korea Research Institute of Bioscience and Biotechnology (KRIBB), (Daecheon, Korea), <https://www.scopus.com/authid/detail.uri?authorId=59286321700>, <https://www.webofscience.com/wos/author/record/30028581>

**BERSIMBAYEV Rakhmetkazhi Iskenderovich**, Doctor of Biological Sciences, Professor, Academician of NAS RK, L.N. Gumilyov Eurasian National University (Astana, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=7004012398>, <https://www.webofscience.com/wos/author/record/19854255>

**CALANDRA Pietro**, PhD (Physics), Professor, Institute for the Study of Nanostructured Materials (Rome, Italy), <https://www.scopus.com/authid/detail.uri?authorId=7004303066>, <https://www.webofscience.com/wos/author/record/616360>

**BOSHKAEV Kuantai Avgazyevich**, PhD, Associate Professor, Department of Theoretical and Nuclear Physics, Al-Farabi Kazakh National University (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=54883880400>, <https://www.webofscience.com/wos/author/record/2080231>

**BURKITBAEV Mukhambetkali**, Doctor of Chemical Sciences, Professor, Academician of NAS RK, (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=8513885600>, <https://www.webofscience.com/wos/author/record/29017135>

**QUEVEDO Hernando**, Professor, National Autonomous University of Mexico (UNAM), Institute of Nuclear Sciences (Mexico City, Mexico), <https://www.scopus.com/authid/detail.uri?authorId=55989741100>, <https://www.webofscience.com/wos/author/record/30353742>

**ZHUSUPOV Marat Abzhanovich**, Doctor of Physical and Mathematical Sciences, Professor of the Department of Theoretical and Nuclear Physics, Al-Farabi Kazakh National University (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=6602166928>, <https://www.webofscience.com/wos/author/record/566>

**KOVALEV Alexander Mikhailovich**, Doctor of Physical and Mathematical Sciences, Academician of NAS of Ukraine, Institute of Applied Mathematics and Mechanics (Donetsk, Ukraine), <https://www.scopus.com/authid/detail.uri?authorId=7202799321>, <https://www.webofscience.com/wos/author/record/65533963>

**TAKIBAEV Nurgali Zhabagaevich**, Doctor of Physical and Mathematical Sciences, Professor, Academician of NAS RK, Al-Farabi Kazakh National University (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=24077239000>, <https://www.webofscience.com/wos/author/record/1671760>

**KHARIN Stanislav Nikolaevich**, Doctor of Physical and Mathematical Sciences, Professor, Academician of NAS RK, Kazakh-British Technical University (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=6701353063>, <https://www.webofscience.com/wos/author/record/2023295>

**ABISHEV Medeu Erzhanovich**, Doctor of Physical and Mathematical Sciences, Professor, Corresponding Member of NAS RK, (Almaty, Kazakhstan), <https://www.scopus.com/authid/detail.uri?authorId=26530759900>, <https://www.webofscience.com/wos/author/record/1556025>

## ACADEMIC JOURNAL OF PHYSICAL AND CHEMICAL SCIENCES.

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

Owner: «Central Asian Academic Research Center» LLP (Almaty).

The certificate of registration of a periodical printed publication in the Committee of Information of the Ministry of Information and Social Development of the Republic of Kazakhstan № KZ93VPY00121157 issued 05.06.2025

Thematic scope: *physics and chemistry*.

Periodicity: 4 times a year.

<http://reports-science.kz/index.php/en/archive>

## БАС РЕДАКТОР

**ЖҰРЫНОВ Мұрат Жұрынулы**, химия ғылымдарының докторы, профессор, ХҒАҚ және ҚР ҰҒА академигі, Мұнай өңдеу және мұнай-химиясы ғылыми-зерттеу институтының бас директоры (Алматы, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=6602177960>, <https://www.webofscience.com/wos/author/record/2017489>

## БАС РЕДАКТОРДЫҢ ОРЫНБАСАРЛАРЫ:

**КАЛИМОЛДАЕВ Мақсат Нұрәділұлы**, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі (Алматы, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=56153126500>, <https://www.webofscience.com/wos/author/rec-ord/2428551>

**ӘБИЛМАҒЖАНОВ Арлан Зайнуталлайұлы**, химия ғылымдарының кандидаты, Д.В. Сокольский атындағы «Жанармай, катализ және электрохимия институты» АҚ Бас директоры (Алматы, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=57197468109>, <https://www.webofscience.com/wos/author/record/2024265>

## РЕДАКЦИЯ АЛҚАСЫ:

**ӘДЕКЕНОВ Серғазы Мынжасарұлы**, химия ғылымдарының докторы, профессор, ҚР ҰҒА академигі, «Фитохимия» ғылыми-өндірістік орталығы» АҚ директоры (Қарағанды, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=7006153118>, <https://www.webofscience.com/wos/author/record/48648658>

**РАМАЗАНОВ Тілеккабыл Сәбитұлы**, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі (Алматы, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=6701328029>, <https://www.webofscience.com/wos/author/record/13503476>

**ӘБИЕВ Руфат**, техника ғылымдарының докторы (биохимия), профессор, Санкт-Петербург мемлекеттік технологиялық институты «Химиялық және биотехнологиялық аппаратураны оңтайландыру» кафедрасының меңгерушісі (Санкт-Петербург, Ресей), <https://www.scopus.com/author/detail.uri?authorId=6602431781>, <https://www.webofscience.com/wos/author/record/1405661>

**ОЛИВЬЕРО Росси Сезаре**, PhD (химия), Калабрия университетінің профессоры (Калабрия, Италия), <https://www.scopus.com/author/detail.uri?authorId=57221375979>, <https://www.webofscience.com/wos/author/record/399768>

**ТИГИНЯНУ Ион Михайлович**, физика-математика ғылымдарының докторы, академик, Молдова Ғылым академиясының президенті, Молдова техникалық университеті (Кишинев, Молдова), <https://www.scopus.com/author/detail.uri?authorId=7006315935>, <https://www.webofscience.com/wos/author/record/524462>

**САНГ-СУ Квак**, PhD (биохимия, агрохимия), профессор, Корей Биоғылым және биотехнология ғылыми-зерттеу институты (KRIBB), өсімдіктердің инженерлік жүйелері ғылыми-зерттеу орталығының бас ғылыми қызметкері (Дэчон, Корея), <https://www.scopus.com/author/detail.uri?authorId=59286321700>, <https://www.webofscience.com/wos/author/record/30028581>

**БЕРСІМБАЕВ Рахметқажы Есендірұлы**, биология ғылымдарының докторы, профессор, ҚР ҰҒА академигі, Л.Н. Гумилев атындағы Еуразия ұлттық университеті (Астана, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=7004012398>, <https://www.webofscience.com/wos/author/record/19854255>

**КАЛАНДРА Пьетро**, PhD (физика), нанокүрылымды материалдарды зерттеу институтының профессоры (Рим, Италия), <https://www.scopus.com/author/detail.uri?authorId=7004303066>, <https://www.webofscience.com/wos/author/record/616360>

**БОШКАЕВ Қуантай Авғазыұлы**, PhD теориялық және ядролық физика кафедрасының доценті, әл-Фараби атындағы Қазақ ұлттық университеті (Алматы, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=54883880400>, <https://www.webofscience.com/wos/author/record/2080231>

**БҮРКІТБАЕВ Мұхамбетқали**, химия ғылымдарының докторы, профессор, ҚР ҰҒА академигі (Алматы, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=8513885600>, <https://www.webofscience.com/wos/author/record/29017135>

**QUEVEDO Hernando**, профессор, Мексика ұлттық автономиялық университеті (UNAM), Ядролық ғылымдар институты (Мехико, Мексика), <https://www.scopus.com/author/detail.uri?authorId=55989741100>, <https://www.webofscience.com/wos/author/record/30353742>

**ЖҮСІПОВ Марат Абжанұлы**, физика-математика ғылымдарының докторы, теориялық және ядролық физика кафедрасының профессоры, әл-Фараби атындағы Қазақ ұлттық университеті (Алматы, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=6602166928>, <https://www.webofscience.com/wos/author/record/566>

**КОВАЛЕВ Александр Михайлович**, физика-математика ғылымдарының докторы, Украина ҰҒА академигі, Қолданбалы математика және механика институты (Донецк, Украина), <https://www.scopus.com/author/detail.uri?authorId=7202799321>, <https://www.webofscience.com/wos/author/record/65533963>

**ТАКИБАЕВ Нұрғали Жабағаұлы**, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі, әл-Фараби атындағы Қазақ ұлттық университеті (Алматы, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=24077239000>, <https://www.webofscience.com/wos/author/record/1671760>

**ХАРИН Станислав Николаевич**, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі (Алматы, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=6701353063>, <https://www.webofscience.com/wos/author/record/2023295>

**ӘБИШЕВ Медеу Ержанұлы**, физика-математика ғылымдарының докторы, профессор, ҚР ҰҒА академигі (Алматы, Қазақстан), <https://www.scopus.com/author/detail.uri?authorId=26530759900>, <https://www.webofscience.com/wos/author/record/1556025>

## ACADEMIC JOURNAL OF PHYSICAL AND CHEMICAL SCIENCES

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

Меншіктеуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).

Ақпарат агенттігінің мерзімді баспасөз басылымын, ақпарат агенттігін және желілік басылымды қайта есепке қою туралы ҚР Мәдениет және Ақпарат министрлігі «Ақпарат комитеті» Республикалық мемлекеттік мекемесі 05.06.2025 ж. берген № KZ93VPY00121157 Куәлік.

Тақырыптық бағыты: *физика, химия.*

Мерзімділігі: жылына 4 рет.

<http://reports-science.kz/index.php/en/archive>

## ГЛАВНЫЙ РЕДАКТОР

**ЖУРИНОВ Мурат Журинович**, доктор химических наук, профессор, академик МАН и НАН РК, Генеральный директор Научно-исследовательского института нефтепереработки и нефтехимии (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=6602177960>, <https://www.webofscience.com/wos/author/record/2017489>

## ЗАМЕСТИТЕЛИ ГЛАВНОГО РЕДАКТОРА:

**КАЛИМОЛДАЕВ Максат Нурадилович**, доктор физико-математических наук, профессор, академик НАН РК (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=56153126500>, <https://www.webofscience.com/wos/author/record/2428551>

**АБИЛЬМАГЖАНОВ Арлан Зайнуталлаевич**, кандидат химических наук, Генеральный директор АО «Институт топлива, катализа и электрохимии им. Д.В. Сокольского», (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=57197468109>, <https://www.webofscience.com/wos/author/record/2024265>

## РЕДАКЦИОННАЯ КОЛЛЕГИЯ:

**АДЕКЕНОВ Сергазы Мынжасарович**, доктор химических наук, профессор, академик НАН РК, директор АО «Научно-производственного центра «Фитохимия» (Караганда, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=7006153118>, <https://www.webofscience.com/wos/author/record/48648658>

**РАМАЗАНОВ Тлеккабул Сабитович**, (заместитель главного редактора), доктор физико-математических наук, профессор, академик НАН РК (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=6701328029>, <https://www.webofscience.com/wos/author/record/13503476>

**АБИЕВ Руфат**, доктор технических наук (биохимия), профессор, заведующий кафедрой «Оптимизация химической и биотехнологической аппаратуры», Санкт-Петербургский государственный технологический институт (Санкт-Петербург, Россия), <https://www.scopus.com/authid/detail.uri?authorId=6602431781>, <https://www.webofscience.com/wos/author/record/1405661>

**ОЛИБЬЕРО Россин Чезаре**, доктор философии (PhD, химия), профессор Университета Калабрии (Калабрия, Италия), <https://www.scopus.com/authid/detail.uri?authorId=57221375979>, <https://www.webofscience.com/wos/author/record/399768>

**ТИГИНЯНУ Ион Михайлович**, доктор физико-математических наук, академик, президент Академии наук Молдовы, Технический университет Молдовы (Кишинев, Молдова), <https://www.scopus.com/authid/detail.uri?authorId=7006315935>, <https://www.webofscience.com/wos/author/record/524462>

**САНГ-СУ Квак**, доктор философии (PhD, биохимия, агрохимия), профессор, главный научный сотрудник, Научно-исследовательский центр инженерных систем растений, Корейский научно-исследовательский институт бионауки и биотехнологии (KRIBB) (Дэчон, Корея), <https://www.scopus.com/authid/detail.uri?authorId=59286321700>, <https://www.webofscience.com/wos/author/record/30028581>

**БЕРСИМБАЕВ Рахметкажи Искендиринович**, доктор биологических наук, профессор, академик НАН РК, Евразийский национальный университет им. Л.Н. Гумилева (Астана, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=7004012398>, <https://www.webofscience.com/wos/author/record/19854255>

**КАЛАНДРА Пьетро**, доктор философии (PhD, физика), профессор Института по изучению наноструктурированных материалов (Рим, Италия), <https://www.scopus.com/authid/detail.uri?authorId=7004303066>, <https://www.webofscience.com/wos/author/record/616360>

**БОШКАЕВ Куантай Агазыевич**, PhD, преподаватель, доцент кафедры теоретической и ядерной физики, Казахский национальный университет им. Аль-Фараби (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=54883880400>, <https://www.webofscience.com/wos/author/record/2080231>

**БУРКИТБАЕВ Мухамбетали**, доктор химических наук, профессор, академик НАН РК, (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=8513885600>, <https://www.webofscience.com/wos/author/record/29017135>

**QUEVEDO Hernando**, профессор, Национальный автономный университет Мексики (UNAM), Институт ядерных наук (Мехико, Мексика), <https://www.scopus.com/authid/detail.uri?authorId=55989741100>, <https://www.webofscience.com/wos/author/record/30353742>

**ЖУСУПОВ Марат Абжанович**, доктор физико-математических наук, профессор кафедры теоретической и ядерной физики, Казахский национальный университет имени аль-Фараби (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=6602166928>, <https://www.webofscience.com/wos/author/record/566>

**КОВАЛЕВ Александр Михайлович**, доктор физико-математических наук, академик НАН Украины, Институт прикладной математики и механики (Донецк, Украина), <https://www.scopus.com/authid/detail.uri?authorId=7202799321>, <https://www.webofscience.com/wos/author/record/65533963>

**ТАКИБАЕВ Нурғали Жабағаевич**, доктор физико-математических наук, профессор, академик НАН РК, Казахский национальный университет им. Аль-Фараби (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=24077239000>, <https://www.webofscience.com/wos/author/record/1671760>

**ХАРИН Станислав Николаевич**, доктор физико-математических наук, профессор, академик НАН РК (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=6701353063>, <https://www.webofscience.com/wos/author/record/2023295>

**АБИШЕВ Медеу Ержанович**, доктор физико-математических наук, профессор, академик НАН РК, (Алматы, Казахстан), <https://www.scopus.com/authid/detail.uri?authorId=26530759900>, <https://www.webofscience.com/wos/author/record/1556025>

## ACADEMIC JOURNAL OF PHYSICAL AND CHEMICAL SCIENCES

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

Собственник: ТОО «Центрально-азиатский академический научный центр» (г. Алматы).

Свидетельство № KZ93VPY00121157 о повторной регистрации периодического печатного издания информационного агентства, информационного агентства и сетевого издания, выданное Республиканским государственным учреждением «Комитет информации» Министерства культуры и информации Республики Казахстан **05.06.2025**Тематическая направленность: *физика, химия*.

Периодичность: 4 раза в год.

<http://reports-science.kz/index.php/en/archive>

CONTENTS

PHYSICS

**Aimaganbetova Z.K., Kulshymbayev Y.A., Zhanturina N.N., Beketova G.K.**  
 First-principles calculation of the electronic properties of the Double Halide  
 Perovskite  $\text{Cs}_2\text{Ag}_{0.2}\text{Na}_{0.4}\text{In}_{0.6}\text{Ti}_{0.4}\text{Cl}_6$  based on the quantum ESPRESSO software.....14

**Amangeldinova S., Zhuniskhan S., Kalzhigitov N., Kurmangaliyeva V.**  
 Study of the cluster structure of  $^5\text{He}$  and  $^5\text{Li}$  mirror nuclei in two-cluster  
 approximation.....35

**Chokin K., Otunchi Ye., Kozhahmetova A., Kasenova A., Shongalova A.**  
 Development and testing of a laboratory pyrometallurgical installation for recycling  
 lithium-ion batteries.....46

**Issayeva A., Beisebayeva A., Madybekova G., Shynazbekova Sh., Issa A.**  
 Comparative analysis of physico-chemical characteristics of drinking, spring  
 and natural water in the South Kazakhstan.....65

**Kim V.Yu., Aimuratov Y.K.**  
 Search for transient cosmic events by scanning the sky with wide-field telescopes.....78

**Koshtybayev T.B., Tatenov A.M., Aliyeva M.E., Tugelbaeva G.T., Zhanaliyeva G.Zh.**  
 Study of the electromagnetic field based on thermodynamics principles.....89

**Mukamedenkyzy V., Akberdiyev B.**  
 Numerical investigation of the effect of inclination angle on the stability  
 of mechanical equilibrium in Ar–N<sub>2</sub> binary gas mixtures.....105

**Myasnikova L.N., Uzakbaeva S.S., Shanina Z.K., Bekeshev A.Z.**  
 Kinetic properties of high-density polyethylene filled with chromium spinel powder.....119

**Nurbayev B.M., Dmitriyeva E.A., Kemelbekova A.E.**  
 The role of low-dimensional layered structures in enhancing the stability of tin-based  
 perovskite materials.....136

**Sattinova Z., Ermakhanova F., Assilbekov B., Taimuratova L.**  
 Influence of various cooling conditions and heat transfer coefficients on solidification  
 during the formation of beryllium ceramic products.....149

**Shestakova L.I., Serebryanskiy A.V., Spassyyuk R.R., Omarov Ch.T.**  
 Search for gas of comet-meteor origin in the inner Solar System: caii ion emission.....165

**Ualikhanova U., Tursynkazy F., Syzdykova A.M., Altayeva G.S., Altaibayeva A.B.**  
 Studying the amplitude of  $f(T)$  gravitational waves using Bessel functions.....179

<b>Zhexenbayeva G.A., Nasirova D.M., Aimanova G.K., Shomshekova S.A.</b> Photometric study of the symbiotic object V725 Tau.....	194
<b>Zhusupova N.K., Zhadyranova A.A.</b> Bounce cosmology in $f(T, \mathcal{T})$ gravity based on energy condition analysis.....	205
<b>Ziyatbekova G., Abdimanapova P., Sagyntay O., Nurym A., Ilinov R.</b> Using artificial intelligence to predict diseases based on medical data.....	225

## CHEMISTRY

<b>Almassov N.Zh., Zhumagaliyeva A.N., Duisenbekov S.E., Zhakiyev N.K.</b> Design and optimization of hybrid renewable energy systems for hydrogen production in Kazakhstan.....	236
<b>Amangeldi B., Zhanikulov N., Taimasov B., Aitureev M.M., Dauletiyarov M.</b> Calculation of the Raw material composition for obtaining white Portland cement clinker.....	251
<b>Baeshov A., Tashenov E.A., Atykhanova S.B., Koshkarbayeva Sh.T.</b> Preparation of cadmium sulfide by electrochemical method using a composite sulfur-graphite electrode.....	267
<b>Baisalova G.Zh., Azhikhanova Zh., Taltenov A.A., Kuzhatova P.</b> Determination of the total phenolic content in perennial herbaceous plants of the flora of Kazakhstan.....	277
<b>Darmenbayeva A.S., Rajasekharan R., Zhussipnazarova G.M., Mukazhanova Zh.B., Begenova B.E.</b> Composites based on chitosan and cellulose: synthesis, properties, and application prospects.....	287
<b>Erkasov R.Sh., Zhamkenova A.S., Sergazina S.M., Nurmukhanbetova N.N., Kassenova N.B.</b> Halide-dependent modulation of hydrogen bonding in Mn(II) complexes with protonated acetamide: a QAIM, NCI, and energy decomposition study.....	304
<b>Kalimoldina L.M., Shaikhova Zh.E., Kaliyeva B.K., Bubish Sh., Askarova Sh.K.</b> The effect of silver nanoparticles on the germination of bean, lemon, tangerine and avocado seeds.....	320
<b>Kurtebayeva A.A., Alvarez-Torrellas S., Gomes H.T., Orynbayev S.A., Kalmakhanova M.S.</b> Activated-carbon-enhanced polymeric membranes for efficient elimination of emerging contaminants.....	334

<b>Massenova A.T., Zhumakanova A.S., Torlopov I.I., Rakhmetova K.S., Abilmagzhanov A.Z.</b> Optimization of the hierarchical zeolite ZSM-5 synthesis process by steam-assisted alkaline modification.....	350
<b>Mutushev A.Zh., Nuraly A.M., Sanat A.S., Shaukharova M.A., Yessimsiitova Z.B.</b> The effect of light-converting films on the accumulation of bioactive compounds and the quality of fruits.....	366
<b>Nefedov A.N., Taikenova A.T.</b> Current state of organic corrosion inhibitor application in oil refining.....	379
<b>Omarov B.T., Altybayev Zh.M., Serikbayeva B.S.</b> Production of biohumus by vermicomposting of organic wastes and study of its agroecological effectiveness.....	399
<b>Rakhman D.M., Kappasuly A., Makhayeva D.N., Kazybayeva D.S., Irmukhametova G.S.</b> Development and investigation of mucoadhesive hydrogels based on gellan–cysteine complexes.....	414
<b>Sabyrzhanova A.E., Bolatkyzy N., Berganaeva G.E., Dyusebaeva M.A.</b> Study of amino acids and fatty acids in the aerial part of <i>Plantago major</i> .....	428
<b>Satayeva S., Akhmetova F., Urazova A., Aituganova S., Yerniyazova K.</b> The influence of PEPA concentration on the physical, mechanical, and operational properties of ED-20 epoxy adhesives.....	439
<b>Zamanbek A.Zh., Koshkarbayeva Sh.T., Satayev M.S.</b> Methods of Obtaining Silver Nanoparticles and Antibacterial Properties.....	450
<b>Zhortarova A.A., Salkeyeva L.K., Minayeva Ye.V., Ibrayev M.K., Fazylov S.D.</b> New possibilities for the synthesis and phosphorylation of phosphonoacetic acid ester.....	462

## МАЗМҰНЫ

### ФИЗИКА

- Аймағанбетова З.К., Құлшымбаев Е.А., Жантурина Н.Н., Бекетова Г.К.**  
Quantum Espresso бағдарламасы негізінде Cs<sub>2</sub>Ag<sub>0.2</sub>Na<sub>0.4</sub>In<sub>0.6</sub>Ti<sub>0.4</sub>Cl<sub>6</sub>  
кос галогенді перовскиттің электрондық қасиеттерін бірінші принциптік есептеу.....14
- Амангелдинова С., Жүнісхан С., Калжигитов Н., Курманғалиева В.**  
Екі кластерлік жуықтауда <sup>5</sup>He және <sup>5</sup>Li айналық ядроларының кластерлік  
құрылымын зерттеу.....35
- Чокин К., Отунчи Е., Кожаметова А., Касенова А., Шонғалова А.**  
Литий-ионды аккумуляторларды қайта өңдеуге арналған зертханалық  
пирометаллургиялық қондырғыны әзірлеу және сынау.....46
- Исаева А.Б., Бейсебаева А.С., Мадыбекова Г.М., Шиназбекова Ш.С., Иса А.Б.**  
Сравнительный анализ физико-химических характеристик питьевой, родниковой  
и природной воды юга Казахстана.....65
- Ким В.Ю., Аймуратов Е.К.**  
Кең бұрышты телескоптармен аспанды сканерлеу арқылы өтпелі ғарыштық  
оқиғаларды іздеу.....78
- Коштыбаев Т.Б., Татенов А.М., Алиева М.Е., Тугелбаева Г.Т., Жаналиева Г.Ж.**  
Электромагниттік өрісті термодинамикалық бастамалар тұрғысында зерттеу.....89
- Мукамеденқызы В., Ақбердиев Б.**  
Ar–N<sub>2</sub> бинарлы газ қоспаларындағы механикалық тепе-теңдік тұрақтылығына  
қиғаш бұрыштың әсерін сандық зерттеу.....105
- Мясникова Л.Н., Узакбаева С.С., Шанина З.К., Бекешев А.З.**  
Хром-шпинельді ұнтақ қосылған жоғары тығыздықты полиэтиленнің кинетикалық  
қасиеттері.....119
- Нұрбаев Б.М., Дмитриева Е.А., Кемелбекова А.Е.**  
Қалайы негізіндегі перовскитті материалдардың тұрақтылығын  
арттырудағы төменөлшемді қабатты құрылымдардың рөлі.....136
- Саттинова З., Ермаханова Ф., Асылбеков Б., Таймуратова Л.**  
Бериллий керамикалық бұйымдарын қалыптастыру кезінде әр түрлі салқындату  
жағдайлары мен жылу беру коэффициенттерінің қатаюға әсері.....149
- Шестакова Л.И., Серебрянский А.В., Спасюк Р.Р., Омаров Ш.Т.**  
Күн жүйесінің ішкі аймағындағы комета-метеорлық тектегі газды іздеу:  
CaII иондарының жарқырауы.....165

**Уалиханова У.А., Тұрсынқазы Ф., Сыздықова А.М., Алтаева Г.С., Алтайбаева А.Б.**  
Бессель функцияларын пайдаланып  $f(T)$  гравитациялық толқындардың  
амплитудасын зерттеу.....179

**Жексенбаева Г.А., Насирова Д.М., Айманова Г.К., Шомшекова С.А**  
V725 Тау симбиотикалық объектiсiн фотометрлiк зерттеу.....194

**Жусупова Н.К., Жадыранова А.А.**  
Энергия шарттарын талдауға негiзделген  $f(T, T)$  серпiлiс космологиясы.....205

**Зиятбекова Г.З., Абдиманапова П.Б., Сағынтай О.А., Нұрым А.А., Ильинов Р.А.**  
Жасанды интеллект көмегiмен медициналық деректер бойынша  
ауруларды болжау.....225

### ХИМИЯ

**Алмасов Н.Ж., Жумагалиева А.Н., Дүйсенбеков С.Е., Жакиев Н.К.**  
Қазақстанда сутегi өндiруге арналған гибрирдiк жаңартылатын энергия жүйелерiн  
жобалау және оңтайландыру.....236

**Амангелдi Б., Жаникулов Н., Таймасов Б., Айтуреев М., Даулетияров М.**  
Ақ портландцемент клинкерiн алу үшiн шикiзат шихта құрамын есептеу.....251

**Баешов А., Ташенов Е.А., Атыханова С.Б., Кошкарбаева Ш.Т.**  
Композициялы күкiрт-графит электродын қолдану арқылы кадмий  
сульфидiн электрохимиялық әдiспен алу.....267

**Байсалова Г.Ж., Ажиханова Ж., Талтенов А.А., Құжатова П.**  
Қазақстан флорасындағы көпжылдық шөптесiн өсiмдiктердiң фенолдық  
қосылыстарының жиынтық мөлшерiн анықтау.....277

**Дарменбаева А.С., Rajasekharan R., Жусипназарова Г.М., Мукажанова Ж.Б.,  
Бегенова Б.Е.**  
Хитозан және целлюлоза негiзiндегi композиттер: синтез, қасиеттерi және қолдану  
перспективалары.....287

**Еркасов Р.Ш., Жамкенова А.С., Сергазина С.М., Нурмуханбетова Н.Н.,  
Касенова Н.Б.**  
Mn (II) кешендерiндегi сутектiк байланыстардың энергиясы мен табиғатына  
галогеннiң әсерi: QТАІМ, NCI және энергия декомпозициясы.....304

**Калимолдина Л.М., Шаихова Ж.Е., Калиева Б.К., Бубиш Ш., Аскарова Ш.К.**  
Күмiс нанобөлшектерiнiң бұршақ, лимон, мандарин, авокадо тұқымдарының  
өнуiне әсерi.....320

<b>Қуртебаева А.А., Álvarez-Torrellas S., Gomes Н.Т., Орынбаев С.Ә., Калмаханова М.С.</b> Алаңдаушылық тудыратын ластаушы заттарды тиімді жою үшін белсендірілген көмір полимерлі мембраналар.....	334
<b>Масенова А.Т., Жұмақанова А.С., Торлопов И.И., Рахметова К.С., Абильмагжанов А.З.</b> ZSM-5 иерархиялық цеолитін бумен сілтілі модификациялау арқылы алу процесін онтайландыру.....	350
<b>Мутушев А.Ж., Нұралы Ә.М., Санат А.С., Шаукарова М.А., Есимситова З.Б.</b> Жарық түрлендіретін пленкалардың биоактивті қосылыстардың жинақталуына және жеміс сапасына әсері.....	366
<b>Нефедов А.Н., Тайекенова А.Т.</b> Мұнай өңдеу өнеркәсібінде органикалық коррозия ингибиторларын қолданудың қазіргі жағдайы.....	379
<b>Омаров Б.Т., Алтыбаев Ж.М., Серикбаева Б.С.</b> Органикалық қалдықтарды вермикомпостинг арқылы биогумус өндіру және оның агроэкологиялық тиімділігін зерттеу.....	399
<b>Рахман Д.М., Қаппасұлы Ә., Махаева Д.Н., Қазыбаева Д.С., Ирмухаметова Ғ.С.</b> Геллан–цистеин кешендері негізінде мукоадгезиялық гидрогельдерді әзірлеу және зерттеу.....	414
<b>Сабыржанова А.Е., Болатқызы Н., Берганаева Г.Е., Дюсебаева М.А.</b> Plantago Major жер үсті бөлігінің құрамындағы амин қышқылдары мен май қышқылдарын зерттеу.....	428
<b>Сатаева С., Ахметова Ф., Уразова А., Айтуганова С., Ерниязова К.</b> ЭД-20 эпоксидті желімдерінің физика-механикалық және эксплуатациялық қасиеттеріне ПЭПА концентрациясының ықпалы.....	439
<b>Заманбек А.Ж., Кошкарбаева Ш.Т., Сатаев М.С.</b> Күміс нанобөлшектерінің алыну әдістері мен антибактериалдық қасиеттері.....	450
<b>Жоргарова А.А., Салькева Л.К., Минаева Е.В., Ибраев М.К., Фазылов С.Д.</b> Фосфоносірке қышқылының эфирін синтездеу мен фосфорландырудың жаңа мүмкіндіктері.....	462

## СОДЕРЖАНИЕ

## ФИЗИКА

<b>Аймаганбетова З.К., Кулшымбаев Е.А., Жантурина Н.Н., Бекетова Г.К.</b> Расчет по первому принципу электронных свойств двойного галогенидного перовскита Cs <sub>2</sub> Ag <sub>0.2</sub> Na <sub>0.4</sub> In <sub>0.6</sub> Ti <sub>0.4</sub> Cl <sub>6</sub> на основе программы Quantum Espresso.....	14
<b>Амангелдинова С., Жүнісхан С., Калжигитов Н., Курмангалиева В.</b> Исследование кластерной структуры зеркальных ядер <sup>5</sup> He и <sup>5</sup> Li в двухкластерном приближении.....	35
<b>Чокин К., Отунчи Е., Кожаметова А., Касенова А., Шонгалова А.</b> Разработка и испытания лабораторной пирометаллургической установки для переработки литий-ионных аккумуляторов.....	46
<b>Исаева А.Б., Бейсебаева А.С., Мадыбекова Г.М., Шиназбекова Ш.С., Иса А.Б.</b> Сравнительный анализ физико-химических характеристик питьевой, родниковой и природной воды юга Казахстана.....	65
<b>Ким В.Ю., Аймуратов Е.К.</b> Поиск транзиентных космических событий методом сканирования неба широкоугольными телескопами.....	78
<b>Коштыбаев Т.Б., Татенов А.М., Алиева М.Е., Тугелбаева Г.Т., Жаналиева Г.Ж.</b> Исследование электромагнитного поля на основе термодинамических принципов.....	89
<b>Мукамеденкызы В., Акбердиев Б.</b> Численное исследование влияния угла наклона на устойчивость механического равновесия в бинарной газовой смеси Ar–N <sub>2</sub> .....	105
<b>Мясникова Л.Н., Узакбаева С.С., Шанина З.К., Бекешев А.З.</b> Кинетические свойства высокоплотного полиэтилена с добавлением хром-шпинельного порошка.....	119
<b>Нурбаев Б.М., Дмитриева Е.А., Кемелбекова А.Е.</b> Роль низкоразмерных слоистых структур в повышении стабильности перовскитных материалов на основе олова.....	136
<b>Саттинова З., Ермаханова Ф., Асылбеков Б., Таймуратова Л.</b> Влияние различных условий охлаждения и коэффициентов теплопередачи на затвердевание при формировании бериллиевых керамических изделий.....	149

<b>Шестакова Л.И., Серебрянский А.В., Спасюк Р.Р., Омаров Ш.Т.</b> Поиск газа кометно-метеорного происхождения во внутренней области Солнечной Системы: Свечение ионов СаII.....	165
<b>Уалиханова У.А., Турсынказы Ф., Сыздыкова А.М., Алтаева Г.С., Алтайбаева А.Б.</b> Изучение амплитуды $f(T)$ гравитационных волн с использованием функций Бесселя.....	179
<b>Жексенбаева Г.А., Насирова Д.М., Айманова Г.К., Шомшекеева С.А.</b> Фотометрическое исследование симбиотического объекта V725 Tau.....	194
<b>Жусупова Н.К., Жадыранова А.А.</b> Космология отскока в $f(T, \mathcal{J})$ гравитации на основе анализа энергетических условий.....	205
<b>Зиятбекова Г.З., Абдимананова П.Б., Сағынтай О.А., Нұрым А.А., Ильинов Р.А.</b> Использование искусственного интеллекта для прогнозирования заболеваний на основе медицинских данных.....	225

## ХИМИЯ

<b>Алмассов Н.Ж., Жумагалиева А.Н., Дуйсенбеков С.Е., Жакиев Н.К.</b> Проектирование и оптимизация гибридных возобновляемых источников энергии для производства водорода в Казахстане.....	236
<b>Амангелді Б., Жаникулов Н., Таймасов Б., Айтуреев М., Даулетияров М.</b> Расчёт состава сырьевой шихты для получения белого порландцементного клинкера.....	251
<b>Башов А., Ташенов Е.А., Атыханова С.Б., Кошкарбаева Ш.Т.</b> Получение сульфида кадмия электрохимическим методом с использованием композитного сера-графитового электрода.....	267
<b>Байсалова Г.Ж., Ажиханова Ж., Талтенов А.А., Кужатова П.</b> Определение суммы фенольных соединений в многолетних травянистых растениях флоры Казахстана.....	277
<b>Дарменбаева А.С., Rajasekharan R., Жусиппазарова Г.М., Мукажанова Ж.Б., Бегенова Б.Е.</b> Композиты на основе хитозана и целлюлозы: синтез, свойства и перспективы применения.....	287
<b>Еркасов Р.Ш., Жамкенова А.С., Сергазина С.М., Нурмуханбетова Н.Н., Касенова Н.Б.</b> Влияние галогена на энергетику и природу водородных связей в Mn(II): QTAIM, NCI и энергодекомпозиция.....	304

- Калимолдина Л.М., Шаихова Ж.Е., Калиева Б.К., Бубиш Ш., Аскарова Ш.К.**  
Влияние наночастиц серебра на прорастание семян фасоли, лимона,  
мандарина, авокадо.....320
- Куртебаева А.А., Álvarez-Torrellas S., Gomes Н.Т., Орынбаев С.А., Калмаханова М.С.**  
Полимерные мембраны с активированным углем для эффективного удаления  
загрязняющих веществ вызывающих обеспокоенность.....334
- Масенова А.Т., Жұмақанова А.С., Торлопов И.И., Рахметова К.С.,  
Абильмагжанов А.З.**  
Оптимизация процесса получения иерархического цеолита ZSM-5 паровой  
щелочной модификацией.....350
- Мутушев А.Ж., Нуралы А.М., Санат А.С., Шаукарова М.А., Есимсиитова З.Б.**  
Влияние светопреобразующих плёнок на накопление биоактивных соединений  
и качество плодов.....366
- Нефедов А.Н., Тайекенова А.Т.**  
Современное состояние применения органических ингибиторов коррозии  
в нефтепереработке.....379
- Омаров Б.Т., Алтыбаев Ж.М., Серикбаева Б.С.**  
Получение биогумуса путем вермикомпостирования органических отходов  
и исследование его агроэкологической эффективности.....399
- Рахман Д.М., Қаппасұлы Ә., Махаева Д.Н., Казыбаева Д.С., Ирмухаметова Г.С.**  
Разработка и исследование мукоадгезивных гидрогелей на основе комплексов  
геллан–цистеин.....414
- Сабыржанова А.Е., Болаткызы Н., Берганаева Г.Е., Дюсебаева М.А.**  
Исследование аминокислот и жирных кислот в составе надземной  
части *Plantago Major*.....428
- Сатаева С., Ахметова Ф., Уразова А., Айтуганова С., Ерниязова К.**  
Влияние концентрации ПЭПА на физические, механические и эксплуатационные  
свойства эпоксидных клеев ЭД-20.....439
- Заманбек А.Ж., Кошкарбаева Ш.Т., Сатаев М.С.**  
Методы получения наночастиц серебра и антибактериальные свойства.....450
- Жоргарова А.А., Салькева Л.К., Минаева Е.В., Ибраев М.К., Фазылов С.Д.**  
Новые возможности синтеза и фосфорилирования фосфонуксусного эфира.....462

ACADEMIC JOURNAL  
OF PHYSICAL AND CHEMICAL SCIENCES  
ISSN 2224-5227  
Volume 1.  
Number 357 (2026), 105–118

<https://doi.org/10.32014/2026.2518-1483.408>

UDC: 533.1  
IRSTI: 29.17.15

©Mukamedenkyzy V.<sup>1</sup>, Akberdiyev B.<sup>2</sup>, 2026.

<sup>1</sup>Al-Farabi Kazakh National University, Almaty, Kazakhstan;

<sup>2</sup>Abay Kazakh National Pedagogical University, Almaty, Kazakhstan.

E-mail: [bekzhan\\_akberdiyev@mail.ru](mailto:bekzhan_akberdiyev@mail.ru)

## NUMERICAL INVESTIGATION OF THE EFFECT OF INCLINATION ANGLE ON THE STABILITY OF MECHANICAL EQUILIBRIUM IN Ar–N<sub>2</sub> BINARY GAS MIXTURES

**Mukamedenkyzy Venera** — Candidate of Physical and Mathematical Sciences, Associated Professor, Al-Farabi Kazakh National University, Almaty, Kazakhstan,

E-mail: [mukameden@inbox.ru](mailto:mukameden@inbox.ru), <https://orcid.org/0000-0003-3921-2812>;

**Akberdiyev Bekzhan** — PhD student, Abay Kazakh National Pedagogical University, Almaty, Kazakhstan, E-mail: [bekzhan\\_akberdiyev@mail.ru](mailto:bekzhan_akberdiyev@mail.ru), <https://orcid.org/0009-0001-2108-9556>.

**Abstract.** This work presents a numerical study of the influence of the diffusion channel inclination angle on the stability of mechanical equilibrium and mass transfer in a binary Ar–N<sub>2</sub> gas mixture under gravity. Isothermal mixing in a two-flask apparatus is considered, where the loss of mechanical equilibrium results from unstable concentration-induced density stratification during mutual diffusion of components with different molecular weights. The resulting concentration-driven gravitational convection strongly affects both the rate and structure of mass transfer.

The aim of the study is to determine how the channel inclination angle influences diffusion–convective regimes under fixed thermobaric conditions. Numerical simulations were performed in ANSYS Fluent using a three-dimensional formulation with species transport equations and the  $k-\omega$  turbulence model. The geometry and boundary conditions correspond to laboratory experimental conditions. Calculations were conducted for inclination angles of 0°, 10°, 20°, and 30°, with analysis of concentration fields, velocity distributions, and integral mixing characteristics.

The results show that increasing the inclination angle leads to a gradual weakening of concentration-driven convection due to the reduction of the gravitational acceleration component along the channel axis. This is reflected in lower convective intensity, reduced argon transfer to the lower flask, and smoother temporal concentration variations. At 30°, the system approaches a diffusion-dominated regime. The findings agree with the theoretical dependence of the critical Rayleigh number on  $\cos\varphi$  and

reproduce experimental trends, confirming the validity of the numerical model and the applicability of the CFD approach for stability analysis in binary gas mixtures.

**Keywords:** binary gas mixtures, mechanical equilibrium, inclination angle, diffusion–convection transport, numerical modeling

*For citations:* Mukamedenkyzy V., Akberdiyev B. Numerical Investigation of the Effect of Inclination Angle on the Stability of Mechanical Equilibrium in Ar–N<sub>2</sub> Binary Gas Mixtures. Academic Journal of Physical and Chemical Sciences. 2026. No.1. Pp. 105–118. DOI: <https://doi.org/10.32014/2026.2518-1483.408>

©Мукамеденқызы В.<sup>1</sup>, Ақбердиев Б.<sup>2</sup>, 2026.

<sup>1</sup>Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан;

<sup>2</sup>Абай атындағы Қазақ ұлттық педагогикалық университеті, Алматы, Қазақстан.

E-mail: [bekzhan\\_akberdiyev@mail.ru](mailto:bekzhan_akberdiyev@mail.ru)

## Ar–N<sub>2</sub> БИНАРЛЫ ГАЗ ҚОСПАЛАРЫНДАҒЫ МЕХАНИКАЛЫҚ ТЕПЕ-ТЕҢДІК ТҰРАҚТЫЛЫҒЫНА ҚИҒАШ БҰРЫШТЫҢ ӘСЕРІН САНДЫҚ ЗЕРТТЕУ

**Мукамеденқызы Венера** — физика-математика ғылымдарының кандидаты, қауымдастырылған профессор, әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан, E-mail: [mukameden@inbox.ru](mailto:mukameden@inbox.ru), <https://orcid.org/0000-0003-3921-2812>;

**Ақбердиев Бекжан** — PhD докторант, Абай атындағы Қазақ ұлттық педагогикалық университеті, Алматы, Қазақстан,

E-mail: [bekzhan\\_akberdiyev@mail.ru](mailto:bekzhan_akberdiyev@mail.ru), <https://orcid.org/0009-0001-2108-9556>.

**Аннотация.** Бұл жұмыс гравитациялық өрістегі екікомпонентті Ar–N<sub>2</sub> газ қоспасында диффузиялық арнаның қисаю бұрышының механикалық тепе-теңдік тұрақтылығы мен масса алмасу сипатына әсерін сандық зерттеуге арналған. Бұл жұмыс екі колбалы аппараттағы газдардың изотермиялық араласуын қарастырады, онда молекулалық массалары әртүрлі компоненттердің өзара диффузиясы кезінде тығыздықтың тұрақсыз концентрациялық стратификациясының пайда болуы механикалық тепе-теңдіктің бұзылуына әкеледі. Нәтижесінде пайда болатын концентрацияға негізделген гравитациялық конвекция масса алмасу жылдамдығы мен құрылымына елеулі әсер етеді, сондықтан оның қарқынын анықтайтын факторларды талдау маңызды.

Зерттеудің негізгі мақсаты – берілген термобариялық жағдайларда диффузия-конвективті масса алмасу режимдерінің қалыптасуы мен дамуында каналдың қисаю бұрышының рөлін анықтау. Сандық модельдеу ANSYS Fluent бағдарламалық пакетінде үшөлшемді кеңістікте компонент тасымалдау теңдеулері мен k– $\omega$  турбуленттік моделі қолданылып жүргізілді. Құрылымының геометриялық конфигурациясы мен шекаралық шарттары зертханалық тәжірибе жағдайларына сәйкес келеді. Есептеулер 0°, 10°, 20° және 30° еңкіш бұрыштары үшін жүргізіліп, концентрация өрістерінің уақыттық динамикасы, ағын жылдамдықтары және интегралды араласу сипаттамалары талданды.

Еңіс бұрышының ұлғаюы еркін түсу үдеуінің арнаның осіне проекциясының азаюына байланысты концентрациялық гравитациялық конвекцияның біртіндеп әлсіреуіне әкеп соғатыны анықталды. Бұл конвекциялық ағындардың қарқындылығының төмендеуімен, төменгі колбаға өткен аргонның молярлық үлесінің азаюымен және концентрация өзгерістерінің уақыттық динамикасының тегістелуімен көрініс табады.  $30^\circ$  бұрышта жүйе диффузия басым режимге өтуге бейімділікті көрсетеді. Алынған нәтижелер критикалық Рейлей санының  $\phi$  косинусына тәуелділігінің теориялық заңдылығына сәйкес келеді және белгілі эксперименттік үлгілерді қайталай отырып, сандық модельдің дұрыстығын және екікомпонентті газ қоспаларындағы механикалық тепе-теңдіктің тұрақтылығын талдауда CFD тәсілінің қолданылу мүмкіндігін растайды.

**Түйін сөздер:** бинарлы газ қоспалары, механикалық тепе-теңдік, көлбеу бұрыш, диффузия-конвективті тасымалдау, сандық модельдеу

©Мукамеденкызы В.<sup>1</sup>, Акбердиев Б.<sup>2</sup>, 2026.

<sup>1</sup>Казахский Национальный университет имени аль-Фараби, Алматы, Казахстан;

<sup>2</sup>Казахский Национальный педагогический университет имени Абая,  
Алматы, Казахстан.

e-mail: bekzhan\_akberdiev@mail.ru

## ЧИСЛЕННОЕ ИССЛЕДОВАНИЕ ВЛИЯНИЯ УГЛА НАКЛОНА НА УСТОЙЧИВОСТЬ МЕХАНИЧЕСКОГО РАВНОВЕСИЯ В БИНАРНОЙ ГАЗОВОЙ СМЕСИ Ar–N<sub>2</sub>

**Мукамеденкызы Венера** — кандидат физико-математических наук, ассоциированный профессор, Казахский национальный университет имени аль-Фараби, Алматы, Казахстан,

E-mail: mukameden@inbox.ru, <https://orcid.org/0000-0003-3921-2812>;

**Акбердиев Бекжан** — PhD докторант, Казахский национальный педагогический университет имени Абая, Алматы, Казахстан,

E-mail: bekzhan\_akberdiev@mail.ru, <https://orcid.org/0009-0001-2108-9556>.

**Аннотация.** Работа посвящена численному исследованию влияния угла наклона диффузионного канала на устойчивость механического равновесия и характер массопереноса в бинарной газовой смеси Ar–N<sub>2</sub> в гравитационном поле. Рассматривается изотермическое смешение газов в двухколбовом аппарате, при котором потеря механического равновесия обусловлена формированием неустойчивой концентрационной стратификации плотности в процессе взаимной диффузии компонентов с различными молекулярными массами. Возникающая при этом концентрационная гравитационная конвекция существенно влияет на скорость и структуру массопереноса, что обуславливает актуальность анализа факторов, определяющих ее интенсивность. Основной целью исследования является установление роли угла наклона канала в формировании и эволюции диффузионно-конвективных режимов массопереноса при фиксированных термобарических условиях. Численное моделирование выполнено в программном

комплексе ANSYS Fluent в трехмерной постановке с использованием уравнений переноса компонентов модели турбулентности  $k-\omega$ . Геометрическая конфигурация аппарата и граничные условия соответствуют условиям лабораторного эксперимента. Расчеты проведены для углов наклона  $0^\circ$ ,  $10^\circ$ ,  $20^\circ$  и  $30^\circ$  с анализом временной динамики концентрационных полей, скоростей течения и интегральных характеристик смешения. Установлено, что увеличение угла наклона приводит к последовательному ослаблению концентрационной гравитационной конвекции вследствие уменьшения проекции ускорения свободного падения на ось канала. Это проявляется в снижении интенсивности конвективных течений, уменьшении мольной доли аргона, перешедшего в нижнюю колбу, и сглаживании временной динамики концентрационных изменений. При угле  $30^\circ$  система демонстрирует тенденцию к переходу в диффузионно-доминируемый режим. Полученные результаты согласуются с теоретической зависимостью критического числа Рэлея от  $\cos \varphi$  и воспроизводят известные экспериментальные закономерности, подтверждая корректность численной модели и применимость CFD-подхода для анализа устойчивости механического равновесия в бинарных газовых смесях.

**Ключевые слова:** бинарные газовые смеси, механическое равновесие, угол наклона, диффузионно-конвективный перенос, численное моделирование

**Introduction.** Due to that mass transfer mechanisms in these systems control the dynamic properties of stratified media, studying binary gas mixtures is vital in both theoretical and applied hydrodynamics. These mixtures play a key role in many technological and physical processes. For areas like astrophysics, climatology, aerodynamics, and chemical and energy technologies, understanding mass transfer in binary gas mixtures is essential (Kossov and Altenbach, 2023; Mialdun et al., 2019; Fedorenko et al., 2024; Kossov et al., 2022).

Under gravitational field conditions, even in the absence of a temperature gradient, isothermal mutual diffusion of gases with different molecular weights can lead to the formation of concentration stratification of density (Valiati et al., 2021; Ankusheva et al., 2010). Such stratification can cause the loss of mechanical equilibrium stability of the system and initiate a transition from the diffusion mode of mass transfer to the mode of concentration gravitational convection. The development of instability is greatly affected by the orientation of the diffusion channel relative to gravity. Changing the inclination angle impacts the effective convection driving force because it alters how free-fall acceleration projects along the channel (Liyanage et al., 2024; Banerjee et al., 2020; Kossov et al., 2023).

The formation of complex convective regimes in binary gas systems is associated with the heterogeneity of concentration fields and changes in gravitational conditions when the channel inclination angle varies. In an inclined configuration, the critical stability conditions are modified, which is reflected in changes in the effective Rayleigh number and the transition boundary between diffusion and convective regimes. Thus, the angle of inclination acts as an external control parameter that can both enhance and

suppress the development of concentration-driven gravitational convection (Kosov et al., 2020; Qiu et al., 2025; Dilman et al., 2015).

Despite the existence of experimental studies devoted to the influence of channel orientation on the stability of mechanical equilibrium, the quantitative description of this effect using modern numerical methods remains limited (Kossov et al., 2025; Qui et al., 2025). Modern computational approaches allow for detailed analysis of the structure of flows and concentration fields, but require comparison with reliable experimental data (Kossov et al., 2023).

The aim of this work is to analyze the structure of concentration fields in a binary argon-nitrogen gas mixture at different angles of inclination of the diffusion channel, as well as to develop and verify a numerical model of mass transfer that takes into account the parametric dependence of the mechanical equilibrium boundary on the angle of inclination. Particular attention is paid to determining the critical values of dimensionless parameters characterizing the transition from the diffusion mode of mass transfer to the mode of concentration gravitational convection. The study is conducted within the framework of hydrodynamic stability theory using numerical simulation methods in the ANSYS Fluent software package (Kosov et al., 2025; Qui et al., 2025; Mukamedenkyzy 2025; Zhakebayev et al., 2022). The obtained calculation results are compared with known experimental data and demonstrate satisfactory agreement.

**Materials and methods.** The experimental results obtained in (Kulzhanov 2002) for a binary Ar–N<sub>2</sub> gas mixture at a pressure of 0.584 MPa and a temperature of 298 K using a two-flask method, the diagram of which is shown in Fig. 1, were used as initial data. The diffusion apparatus consisted of two flasks of equal volume  $V_u = V_l = 69.5 \text{ cm}^3$ , connected by a cylindrical diffusion channel with a diameter of  $d = 4 \text{ mm}$  and a length of  $L = 70 \text{ mm}$ . The duration of one experiment was 17 min.

Unlike previous studies, this work focuses on analyzing the effect of the angle of inclination of the diffusion channel relative to the vertical on the nature of mass transfer and the stability of the mechanical equilibrium of the system. In numerical calculations, the geometry of the installation remained unchanged, while the orientation of the channel in the gravitational field was varied, which made it possible to vary the projection of the acceleration of free fall along its axis.

The ANSYS Fluent software package provides the ability to perform three-dimensional modeling of diffusion channels of arbitrary geometry (Kulzhanov 2002), including taking into account the spatial orientation of the system relative to the gravity vector, as well as visualization of the evolution of concentration and velocity fields over time. This allows for a detailed analysis of the effect of the angle of inclination on the development of concentration gravitational convection and the transition between diffusion and convective mass transfer modes.

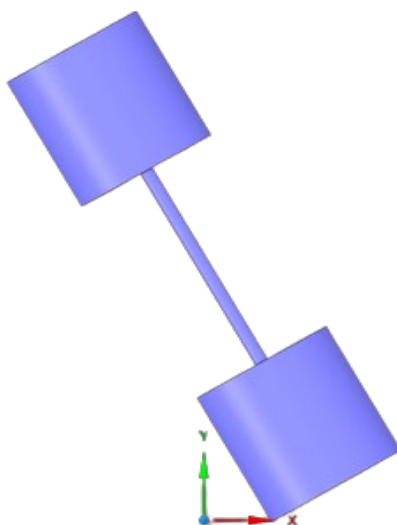


Figure 1 – Three-dimensional model of the diffusion cell and the calculated simulation area inclined at 30°

To model a binary gas mixture, a mixed-method approach was used to create a mesh for discretizing the computational domain. The unstructured triangular mesh represented the cylindrical parts of the installation, and the structured square mesh represented the diffusion channel. This type of mesh adequately represents the geometric features of each area of the installation. Since the characteristic cell size was 1 mm, it creates a correctly represented model geometry and allows for stable convergence of the numerical solution (Ansys, 2025). The total number of elements in the calculation domain is about 425,000. This amount of resolution should provide a reliable representation of mass transfer and mixing phenomena in a binary gas system. The use of triangular and square meshes offers an optimal balance between accuracy and efficiency. The triangular cells in the cylindrical section accurately represent curved surfaces, while the structured mesh in the diffusion channel significantly reduces computation costs. Both of these aspects follow current guidelines for creating computational meshes to simulate processes in binary gas mixtures, where the choice of element type and size balances the complexity of the geometry with the needed accuracy (Kutkan et al. 2021).

Mass transfer modeling in the Ar-N<sub>2</sub> system was done under initial conditions. In this setup, argon sits in the upper flask and nitrogen in the lower one (Kulzhanov, 2002). This arrangement, caused by the difference in molecular weights of the gases, creates a clear gravitational separation of the mixture's density. This allows for the study of how mechanical equilibrium can be disrupted. Within the framework of mathematical modeling, the assumption was made that the physicochemical characteristics of the gas environment are constant. The numerical values of the corresponding parameters were obtained from the built-in database of substances in the ANSYS Fluent software package.

Since the apparatus is modeled as a closed system, impermeability conditions are set at all its boundaries. This type of boundary conditions mathematically excludes

the possibility of any mass transfer through the control surface, thereby ensuring the isolation of the system from the external environment in terms of material components. To maintain a constant temperature during the mixing process, suitable thermal boundary conditions were applied. The apparatus was designed with a solid wall made of structural stainless steel. Its thermal and strength properties were sourced from the ANSYS Fluent materials library (Ansys, 2025; Kutkan et al., 2021; Slavinskaya et al., 2023).

Convective flows driven by mechanical equilibrium instability show complex changes during the initial stage. The evolution of convective flows includes a sequence of stages: linear growth of small convective perturbations, nonlinear interaction of instability modes, transition to a turbulent regime with the formation of multiscale vortex structures, and other specific features determined by the parameters of the system (Kulzhanov, 2002). To analyze partial flows in media with convective flows of variable intensity, it is advisable to use the  $k-\omega$  turbulence model (Kutkan et al., 2021; Slavinskaya et al., 2023; Nouhaila et al., 2024) which allows adequate description of mass transfer processes in a wide range. The initial and boundary conditions were set as follows: at the initial moment of time, the upper and lower chambers of the diffusion apparatus contained different binary gas mixtures. The molar fractions of the components were determined using the patch method for the corresponding grid zones.

In ANSYS Fluent, binary gas mixtures are simulated using component transport equations (mass fractions  $Y_1$  and  $Y_2$ ) and equations of motion. Mass transfer is described by convective-diffusion equations taking into account molecular and turbulent diffusion, and the density of the mixture is calculated according to the selected state model. The formulas include the transport equation for mass fraction (Ansys, 2025):

$$\begin{aligned} \frac{\partial(\rho Y_1)}{\partial t} + \nabla(\rho \vec{u} Y_1) &= \nabla(\rho D_{eff} \nabla Y_1) + S_1 \\ \frac{\partial(\rho Y_2)}{\partial t} + \nabla(\rho \vec{u} Y_2) &= \nabla(\rho D_{eff} \nabla Y_2) + S_2 \end{aligned} \quad (1)$$

where  $D_{eff}$  is effective diffusion,  $S_1$  and  $S_2$  are generalized source terms that account for possible mass sources or sinks of components. In the context of the problem under consideration, there are no additional mass sources.

The standard  $k-\omega$  model is based on a system of semi-empirical transport equations, including equations for turbulent kinetic energy  $k$  and its specific dissipation rate  $\omega$ , where  $\omega$  is interpreted as the ratio of the turbulent energy dissipation rate  $\varepsilon$  to  $k$  (Ansys, 2025).

$$\begin{aligned} \frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho \vec{u}_i k) &= \frac{\partial}{\partial x_j} \left( \Gamma_k \frac{\partial k}{\partial x_j} \right) + G_k - Y_k + S_k + G_k \\ \frac{\partial}{\partial t}(\rho \omega) + \frac{\partial}{\partial x_i}(\rho \vec{u}_i \omega) &= \frac{\partial}{\partial x_j} \left( \Gamma_\omega \frac{\partial \omega}{\partial x_j} \right) + G_\omega - Y_\omega + S_\omega + G_\omega \end{aligned} \quad (2)$$

$G_k$  – describes the generation of kinetic energy of turbulence caused by mean velocity gradients;  $\rho$  – density of the medium;  $\vec{u} = (u_x, u_y, u_z)$  – velocity vector;  $G_\omega$  – characterizes the generation of specific dissipation rate  $\omega$ . In the presented system of equations,  $\Gamma_k$  and  $\Gamma_\omega$  characterize the effective turbulent diffusion for  $k$  and  $\omega$ , respectively;  $Y_k$  and  $Y_\omega$  are dissipation terms;  $S_k$  and  $S_\omega$  are user source terms, which are assumed to be zero in this work (Qui, et al., 2025). The indices  $i, j$  imply summation over the coordinates ( $i, j=1,2,3$ ).

The effective diffusion coefficients for the  $k$ - $\omega$  model are given by the formulas

$$\begin{aligned}\Gamma_k &= \mu + \frac{\mu_t}{\sigma_k} \\ \Gamma_\omega &= \mu + \frac{\mu_t}{\sigma_\omega}\end{aligned}\quad (3)$$

Prandtl turbulence numbers  $\sigma_k$  and  $\sigma_\omega$  determine the efficiency of diffusion transfer of turbulent kinetic energy and the rate of its dissipation. Within the framework of the model used, constant values  $\sigma_k = \sigma_\omega = 2$  are assumed. Molecular viscosity  $\mu$  is supplemented by turbulent viscosity  $\mu_t$ , which is a function of  $k$  and  $\omega$ :

$$\mu_t = \alpha^* \frac{\rho k}{\omega} \quad (4)$$

where  $\alpha^*$  is a coefficient that dampens turbulent viscosity and has a constant value of  $\alpha^*=1$  (Ansys, 2025).

Diffusion fluxes  $J_1$  and  $J_2$  for substances 1 and 2, respectively, are calculated using the following formulas:

$$\begin{aligned}\vec{J}_1 &= -\left(\rho D_{12} + \frac{\mu_t}{Sc_t}\right) \nabla Y_1 \\ \vec{J}_2 &= -\left(\rho D_{12} + \frac{\mu_t}{Sc_t}\right) \nabla Y_2\end{aligned}\quad (5)$$

In the presented model:  $\mu_t$  is the turbulent viscosity;  $Sc_t$  is the turbulent Schmidt number, defined as  $Sc_t = \mu_t/(\rho D_t)$ ; the standard value of  $Sc_t$  is taken to be 0.7.  $D_{12}$  is the binary diffusion coefficient;  $T$  is the temperature.

The binary diffusion coefficient  $D_{12}$  is determined within the framework of the Chapman-Enskog kinetic theory (Ansys, 2025) by the formula:

$$D_{12} = 0.00186 \frac{\left[T^{\frac{1}{2}} \left(\frac{1}{M_{w,1}} + \frac{1}{M_{w,2}}\right)\right]^{\frac{1}{2}}}{p_{abs} \sigma_{12}^2 \Omega_D} \quad (6)$$

where  $M_w$  is the molar mass (g/mol),  $T$  is the temperature (K),  $p_{abs}$  is the absolute pressure (atm),  $\Omega_D$  is the dimensionless diffusion collision integral, which quantitatively characterizes the intensity of molecular interactions in the system.

An approach based on the pressure method was used for all calculation models. For spatial discretization of computational fluid dynamics equations, the schemes listed in Table 1 were used, which were tested and validated in (Kossov et al., 2025; Mukamedenkyzy, 2025).

Table 1. Solution methods

Quantity	Discretization
Gradient	Least Square Cell Based
Pressure	PRESTO!
Momentum	Second Order Upwind
Turbulent Kinetic Energy	Second Order Upwind
Specific Dissipation Rate	Second Order Upwind
Pseudo Time Method	Off
Transient Formulation	Second Order Implicit

The parameters listed characterize the configuration of the numerical solution in the ANSYS Fluent environment, detailing the methods used to discretize the basic equations, approximation schemes, and computational algorithms involved in the modeling process. The selected and tested combination of discretization schemes guarantees an optimal balance between the accuracy of the numerical solution and computational efficiency, which is particularly critical for problems with the combined influence of convective and diffusion processes, and makes it the preferred choice for this class of problems (Ansys, 2025; Abd Halim et al., 2018).

**Results and discussions.** Results and discussions. Numerical simulations of the dynamics of a binary gas mixture were performed using Ansys Fluent 2025 R2. The numerical experiments were conducted on a Lenovo LOQ 15IAX9 platform equipped with an Intel Core I5-12450HX processor, 16 GB of RAM, and an NVIDIA GeForce RTX 3050 GPU. Each simulation required between 120 and 180 minutes, depending on the complexity of the scenario and the convergence rate.

Figure 2 shows the dependence of the  $\alpha$  parameter on temperature for the Ar–N<sub>2</sub> binary gas system at a fixed pressure of  $P=0.584$  MPa and a mixing time of  $\tau=17$  min. The parameter  $\alpha$  is introduced as the ratio of the molar fraction of the component obtained in the experiment to the corresponding value calculated under the assumption of pure diffusion mass transfer based on the Stefan–Maxwell equations. Thus,  $\alpha$  is an integral characteristic that allows quantitative assessment of the deviation of the actual mass transfer process from the diffusion regime.

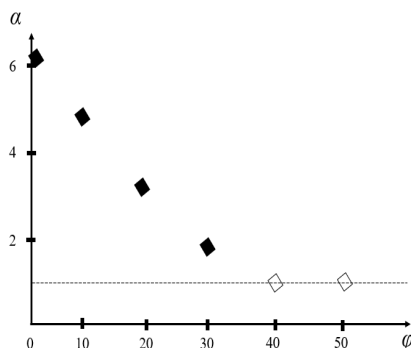


Figure 2 - Dependence of parameter  $\alpha$  on temperature for the Ar – N<sub>2</sub> system at P = 0.584 MPa,  $\tau = 17$  min: ■, □ - experimental data (Kulzhanov, 2002); dotted line - calculation assuming diffusion

Figure 2 shows the experimental dependence of the parameter  $\alpha$  on the angle of inclination of the diffusion channel for the Ar–N<sub>2</sub> system at a pressure of P=0.584 MPa and a temperature of T=298 K. The parameter  $\alpha$  characterizes the deviation of actual mass transfer from the diffusion regime and allows quantitative estimation of the contribution of concentration-driven gravitational convection. When the channel is in a vertical position ( $\varphi=0^\circ$ ), the maximum value of  $\alpha$  is observed, which corresponds to the intensive development of mechanical equilibrium instability and the formation of convective currents.

With an increase in the angle of inclination, the experimental values of  $\alpha$  decrease monotonically, which indicates a consistent suppression of the convective transport mechanism. At  $\varphi \approx 30^\circ$ , the system approaches the transition boundary to the diffusion regime, and a further increase in the angle leads to an almost complete coincidence of the experimental data with the calculation assuming pure diffusion.

Table 2. Dependence of the diffusion of gas from one flask to another on the angle of inclination of the diffusion cell

Angle of inclination	Ar	N <sub>2</sub>
0	0.1367	0.1354
10	0.1055	0.0965
20	0.0738	0.0698
30	0.0401	0.0477

The table shows the results of numerical modeling of the molar fraction of argon that has passed into the opposite flask at angles of inclination of 0°, 10°, 20°, and 30°. The calculated values demonstrate a steady tendency toward a decrease in substance transfer with an increase in  $\varphi$ . Thus, when moving from a vertical position to an angle of 30°, the molar fraction decreases more than threefold. This quantitatively confirms the decrease in the intensity of concentration gravitational convection with a decrease in the effective projection of free-fall acceleration along the channel axis.

The physical mechanism of the observed phenomenon is associated with a change in the component of gravity responsible for the development of density instability. Changing

the angle of inclination of the channel affects  $g_{\text{eff}} = g\cos(\varphi)$ , where  $g_{\text{eff}}$  represents the effective free fall (gravity) of the fluid inside the channel. As the angle of inclination,  $\varphi$ , increases the effective Rayleigh number decreases proportionately to the value of  $\cos(\varphi)$ , which means the system is moved away from the critical stability state. The effective Rayleigh number decreases through the angle range tested, moving from a convective to molecular regime as the system is diminished in Rayleigh number. The numerical results demonstrate good qualitative agreement with the experimental dependence  $\alpha(\varphi)$ . Although the experimental graph is presented without exact numerical values, the nature of the decrease and the position of the critical region are reproduced correctly. This confirms the adequacy of the chosen mathematical model and the correctness of the gravitational vector assignment when modeling an inclined configuration.

Additional analysis of the temporal dynamics of concentrations in the upper and lower flasks shows that as the angle of inclination increases, the amplitude of the initial non-stationary oscillation's characteristic of the stage of convective structure formation decreases. At small angles, a pronounced nonlinear growth of concentration perturbations is observed, while at  $\varphi=30^\circ$ , the temporal dependencies become smoothed and close to diffusion evolution. This indicates the suppression of vortex structures and a decrease in the intensity of exchange between the flasks. Thus, the angle of inclination of the diffusion channel acts as an effective control parameter for the stability of the mechanical equilibrium of a binary gas mixture. The results obtained confirm the theoretical dependence of the critical Rayleigh number on  $\cos\varphi$  and demonstrate that even relatively small deviations from the vertical significantly affect the nature of mass transfer.

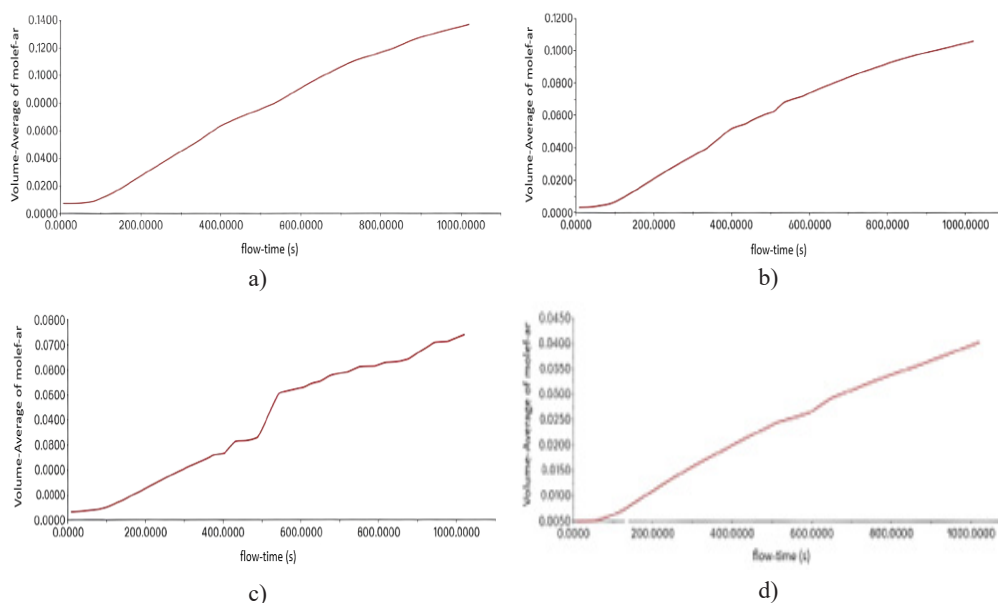


Figure 3 – Dependence of the change in argon concentration in the lower flask on time at different angles of inclination for the system Ar-N<sub>2</sub> at p=0.584 MPa and T=298 K: a)  $\varphi=0^\circ$ ; b)  $\varphi=10^\circ$ ; c)  $\varphi=20^\circ$ ; d)  $\varphi=30^\circ$

Figure 3 demonstrates that the temporal evolution of argon concentration in the lower flask depends systematically and monotonically on the inclination angle of the diffusion channel. As the inclination increases, the concentration-time curves indicate a progressive reduction in both the rate and total amount of mass transfer from the lower to the upper flask. Configurations closer to the vertical orientation display more pronounced initial concentration increases with evident nonlinear acceleration, attributable to buoyant convective movements combined with molecular diffusion. With increasing inclination angle, the concentration profiles become smoother, indicating a transition from convection-driven to diffusion-dominated mass transfer, as reflected by the increasingly flat slopes of the curves. The decreasing slope signifies a reduction in the effective gravitational force component along the channel axis, thereby diminishing the mechanism responsible for concentrated convection. Additionally, the cumulative concentration change over a given period decreases with increasing angle, confirming that mixing efficiency declines as the inclination increases. The absence of distinct accelerative mixing stages at larger angles suggests that vortex structures are significantly attenuated or insufficiently developed. These results confirm that even moderate deviations from vertical orientation substantially affect mixing kinetics and stabilize the mechanical equilibrium of the binary gas system, consistent with the theoretical  $\cos\varphi$  dependence of the effective Rayleigh parameter.

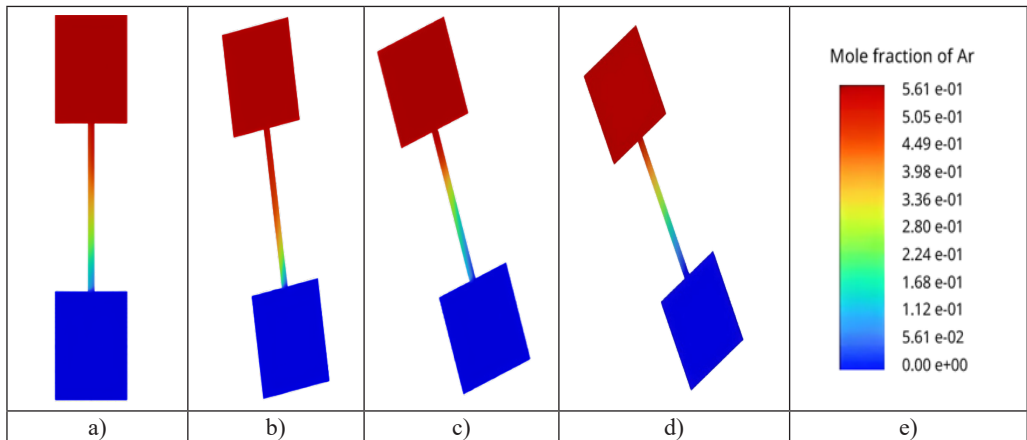


Figure 4 – Convective structures formed in the diffusion channel for the system Ar-N<sub>2</sub> at  $p=0.584$  MPa,  $T=298$  K at the moment  $t=120$  s depending on the channel inclination: a)  $\varphi=0^\circ$ ; b)  $\varphi=10^\circ$ ; c)  $\varphi=20^\circ$ ; d)  $\varphi=30^\circ$ ; e) concentration scale for cases (a), (b), (c) and (d) describing numerical values of colors

Figure 4(a–d) illustrates that the inclination angle of the diffusion channel significantly influences the spatial structure of the concentration field. In the vertical position ( $\varphi = 0^\circ$ ), gravity aligns with the channel axis, promoting the formation of convective patterns within the diffusion zone. As the inclination increases to  $\varphi = 10\text{--}20^\circ$ , the symmetry of the concentration field is gradually restored and convective disturbances weaken. At  $\varphi = 30^\circ$ , the concentration profile becomes notably more uniform along the channel, indicating suppression of large-scale convection. This stabilizing effect results from a

reduction in the effective gravitational component along the density gradient, which diminishes buoyancy-driven flow. The numerical results confirm that increasing channel inclination enhances the stability of mechanical equilibrium in the Ar-N<sub>2</sub> system under the examined thermobaric conditions.

**Conclusion.** Conclusion. This study investigates the influence of diffusion channel inclination on the stability of mechanical equilibrium and mass transfer in an isothermal Ar-N<sub>2</sub> gas mixture under gravity. Transient three-dimensional simulations in ANSYS Fluent were conducted for inclination angles of 0°, 10°, 20°, and 30°. The findings demonstrate that inclination angle is a key parameter governing the interplay between diffusion and convection, with gravitational convection driven by concentration gradients diminishing as the effective vertical gravity component decreases. Quantitatively, the molar fraction of argon transferred decreases by more than threefold as the channel is tilted from vertical to 30°, indicating a substantial reduction in convective mass transfer. This observation aligns with the theoretical criterion that the effective Rayleigh number is proportional to the cosine of the inclination angle. As inclination increases, the system transitions toward a diffusion-dominated regime, and concentration fields become progressively smoother, reflecting reduced convection. Comparison with experimental data shows that the instability parameter decreases monotonically with increasing inclination. The numerical model accurately represents the system's physical processes and may assist in defining stability limits for inclined diffusion channels. Overall, the results confirm that channel orientation significantly affects mass transfer in binary gases and may serve as a passive means to control concentration-driven convection in practical applications.

### References

- Abd Halim M.A., Nik Mohd N.A.R., Mohd Nasir M.N., & Dahalan M.N. (2018). The evaluation of k- $\epsilon$  and k- $\omega$  turbulence models in modelling flows and performance of S-shaped diffuser. *International Journal of Automotive and Mechanical Engineering*, 15. – P. 5171-5177. <https://doi.org/10.15282/ijame.15.2.2018.2.0399> (in Eng.).
- Ankusheva N.V., Kossov V.N., & Seleznev V.D. (2010). Effect of diffusion channel inclination on stability of mechanical equilibrium in isothermal binary gas mixtures. *Journal of Applied Mechanics and Technical Physics*, 51. – P. 62-64. <https://doi.org/10.1007/s10808-010-0009-y> (in Eng.).
- Banerjee A. (2020). Rayleigh–Taylor instability: A status review of experimental designs and measurement diagnostics. *Journal of Fluids Engineering*, 142(12). – P. 1–18. <https://doi.org/10.1115/1.4048349> (in Eng.).
- Dil'man V.V., & Lotkhov V.A. (2015). Molecular turbulent evaporation in a gravitational field. *Theoretical Foundations of Chemical Engineering*, 49(1). – P. 102–106. <https://doi.org/10.1134/S0040579515010017> (in Eng.).
- Fedorenko O., & Poyarkov I. (2024). Instability of mechanical equilibrium in non-ideal gas mixtures. *Recent Contributions to Physics*, 90(3). – P. 116-124. <https://doi.org/10.26577/RCPH.2024v90i3-014> (in Eng.).
- Kosov V., Fedorenko O.V., Asembaeva M.K., & Mukamedenkyzy V. (2020). Changing diffusion–convection modes in ternary mixtures with a diluent gas. *Theoretical Foundations of Chemical Engineering*, 54(2). – P. 289-296. <https://doi.org/10.1134/S0040579520020086> (in Eng.).
- Kossov V., Altenbach H. (2023). Diffusion mechanisms of convective instability in liquid and gas mixtures. *ZAMM – Journal of Applied Mathematics and Mechanics*, 103, e202300801. <https://doi.org/10.1002/zamm.202300801> (in Eng.).
- Kossov V., Fedorenko O., Zhakebayev D., Mukamedenkyzy V., & Kulzhanov D. (2022). Convective

mass transfer of a binary gas mixture in an inclined channel. *ZAMM – Journal of Applied Mathematics and Mechanics*, 102, e201900197. <https://doi.org/10.1002/zamm.201900197> (in Eng.).

Kossov V.N., Krasikov S.A., Belov S.M., Fedorenko O.V., & Zhaneli M. (2023). Comparative study of evolution of structured flows at boundary of the regime change “diffusion — concentration convection” in isothermal multicomponent mixing in gases by techniques of visual and numerical analysis. *Bulletin of the Karaganda University. Physics Series*, 109(1). – P. 49-58. <https://doi.org/10.31489/2023ph1/49-58> (in Eng.).

Kossov V.N., Mukamedenkyzy V., Tolepbergen A., & Altenbach H. (2025). Peculiarities of combined mixing caused by instability of mechanical equilibrium of isothermal ternary gas mixture at diffusion. *International Journal of Chemical Engineering*, 1, 9643371. <https://doi.org/10.1155/ijce/9643371> (in Eng.).

Kulzhanov D.U. (2002). Stability of mechanical equilibrium in binary gas mixtures at different temperatures. *Recent Contributions to Physics*, 2. – P. 115-118. (in Eng.).

Kutkan H., & Guerrero J. (2021). Turbulent premixed flame modeling using the algebraic flame surface wrinkling model: A comparative study between OpenFOAM and ANSYS Fluent. *Fluids*, 6. – P. 462. <https://doi.org/10.3390/fluids6120462> (in Eng.).

Liyanage R. (2024). Direct comparison of density-driven convective mixing in a three-dimensional porous medium. *Physical Review Fluids*, 9, 043802. <https://doi.org/10.1103/PhysRevFluids.9.043802> (in Eng.).

Mialdun A., Bataller H., Bou-Ali M.M., Braibanti M., Crococolo F., Errarte A., Ezquerro J.M., Fernández J.J., Gaponenko Y., García-Fernández L., Rodríguez J., & Shevtsova V. (2019). Preliminary analysis of diffusion coefficient measurements in ternary mixtures (DCMIX4) experiment on board the International Space Station. *The European Physical Journal E*, 42. – P. 87. <https://doi.org/10.1140/epje/i2019-11851-6> (in Eng.).

Mukamedenkyzy V., & Tolepbergen A.G. (2025). Some features of Rayleigh–Taylor convection in the mixing of ideal gas mixtures. *Recent Contributions to Physics*, 92(1). – P. 110-119. <https://doi.org/10.26577/RCPH202592112> (in Eng.).

Nouhaila O., Hassane M., Scutaru M.L., & Jelenschi L. (2024). On the accuracy of turbulence model simulations of the exhaust manifold. *Applied Sciences*, 14. – P. 5262. <https://doi.org/10.3390/app14125262> (in Eng.).

Qiu T., Li C., Zhang Y., & Ge W. (2025). HS-PPM simulation for diffusion coefficients of binary and multicomponent gas mixtures. *AIChE Journal*, 71(9), e18891. <https://doi.org/10.1002/aic.18891> (in Eng.).

Slavinskaya N., & Haidn O. (2023). Direct numerical simulation of spray and dispersion of liquid fuel droplets. *Recent Contributions to Physics*, 84(1). – P. 72-80. <https://doi.org/10.26577/RCPH.2023.v84.i1.09> (in Eng.).

User’s ANSYS Fluent Guide. (2025). Release 2025. ANSYS Inc. <https://www.ansys.com/> (in Eng.).

Zhakebayev D.B., Fedorenko O.V., Kossov V.N., Mukamedenkyzy V., & Karuna O.L. (2022). Simulation of concentration convection in an inclined channel. *Heat Transfer Research*, 53(15). – P. 39-52. <https://doi.org/10.1615/HeatTransRes.2022043133> (in Eng.).

## **Publication Ethics and Publication Malpractice in the journals of the Central Asian Academic Research Center LLP**

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

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

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The Central Asian Academic Research Center LLP follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct ([http://publicationethics.org/files/u2/New\\_Code.pdf](http://publicationethics.org/files/u2/New_Code.pdf)). To verify originality, your article may be checked by the Cross Check originality detection service <http://www.elsevier.com/editors/plagdetect>.

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

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

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the Central Asian Academic Research Center LLP.

The Editorial Board of the Central Asian Academic Research Center LLP will monitor and safeguard publishing ethics.

Правила оформления статьи для публикации в журнале смотреть на сайте:

**[www:nauka-nanrk.kz](http://www.nauka-nanrk.kz)  
ISSN 2518-1483 (Online), ISSN 2224-5227 (Print)  
<http://reports-science.kz/index.php/en/archive>**

Ответственный редактор *А. Ботанқызы*  
Редакторы: *Д.С. Аленов, Т. Апендиев*  
Верстка на компьютере *Г.Д. Жадырановой*

Подписано в печать 16.03.2026.

Формат 60x88<sup>1</sup>/<sub>8</sub>.  
18,0 п.л. Заказ 1.