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

NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

№3
2026

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

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

3 (477)

JUNE – JULY 2026

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, 2026

The scientific journal News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences has been indexed in the international abstract and citation database Scopus since 2016 and demonstrates stable bibliometric performance.

The journal is also included in the Emerging Sources Citation Index (ESCI) of the Web of Science platform (Clarivate Analytics, since 2018).

Indexing in ESCI confirms the journal's compliance with international standards of scientific peer review and editorial ethics and is considered by Clarivate Analytics as part of the evaluation process for potential inclusion in the Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (AHCI).

Indexing in Scopus and Web of Science ensures high international visibility of publications, promotes citation growth, and reflects the editorial board's commitment to publishing relevant, original, and scientifically significant research in the fields of geology and technical sciences.

«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылымиметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: «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 Communications of the Republic of Kazakhstan Nº KZ50VPY00121155, issued on 05.06.2025
Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*
Periodicity: 6 times a year.
http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

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

Қазақстан Республикасының Ақпарат және коммуникациялар министрлігінің Ақпарат комитетінде 05.06.2025 ж. берілген № KZ50VPY00121155 мерзімдік басылым тіркеуіне қойылу туралы куәлік.

Тақырыптық бағыты: *геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*

Мерзімділігі: жылына 6 рет.

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

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Собственник: ТОО «Центрально-Азиатский академический научный центр» (г. Алматы).
Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и коммуникаций и Республики Казахстан № KZ50VPY00121155, выданное 05.06.2025 г.
Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*
Периодичность: 6 раз в год.
http://www.geolog-technical.kz/index.php/en/

CONTENTS

NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 3.
Number 477 (2026), 377–391

https://doi.org/10.32014/2026.2518-170X.659

UDC: 550.8.07
IRSTI: 38.59.21

©Yelemessov K.[1], Myrzakulov M.[1]*, Yerezhep D.[1,2], Tkachenko D.[1], Kuldeyev N.[1], 2026.
[1]Satbayev University, Almaty, Kazakhstan;
[2]Almaty Management University, Almaty, Kazakhstan.
*E-mail: m.myrzakulov@satbayev.university

ANALYTICAL ASSESSMENT OF ROTOR PROFILES ON THREE-SCREW COMPRESSOR PERFORMANCE FOR GAS FIELD OPERATIONS: CIRCULAR-ARC VERSUS CYCLOIDAL

Yelemessov Kassym — Candidate of Technical Sciences, Professor, Satbayev University, Almaty, Kazakhstan,
E-mail: k.yelemessov@satbayev.university, https://orcid.org/0000-0001-6168-2787;
Myrzakulov Maxat — Master of Technical Sciences, Satbayev University, Almaty, Kazakhstan,
E-mail: m.myrzakulov@satbayev.university, https://orcid.org/0000-0002-3262-6249;
Yerezhep Darkhan — PhD, Almaty Management University, Almaty, Kazakhstan,
E-mail: darhan_13@physics.kz, https://orcid.org/0000-0002-2232-2911;
Tkachenko Denis — Master of Technical Sciences, Engineer, Satbayev University, Almaty, Kazakhstan,
E-mail: d.tkachenko@satbayev.university, https://orcid.org/0000-0002-9148-3612;
Kuldeyev Nursultan — PhD Student, Satbayev University, Almaty, Kazakhstan,
E-mail: kuldeevnursultan129@gmail.com, https://orcid.org/0009-0004-5906-1040.

Abstract. *Relevance.* Three-screw compressors are widely deployed at natural gas gathering and boosting stations, yet the influence of rotor profile geometry on their performance at high pressure ratios characteristic of mature oilfields remains insufficiently studied. The blow-hole – the triangular clearance gap at the three-body rotor contact point – is the dominant internal leakage path and a primary source of thermodynamic irreversibility and vibroacoustic excitation. *Objective.* To develop a closed-form analytical model for a four-lobe three-screw compressor (z = 4, tip/root diameters 60/35 mm) on natural gas (κ = 1.31) at a pressure ratio of 14.80 and 3000 rpm, and to quantify the performance advantage of a cycloidal rotor profile over a circular-arc profile across the full performance chain. *Methods.* Two profiles were compared using: envelope theory for chamber geometry, the Stosic blow-hole formulation, a choked-flow leakage model validated against CFD, volumetric efficiency sub-models with dead-volume and reverse-superheat corrections, polytropic thermodynamics via the Peng–Robinson equation of state, shaft power calculation, and a single-DOF vibroacoustic model with CFD-calibrated pulsation amplitudes. *Results.* The cycloidal profile reduces the blow-hole area by 98.6% (3.14 → 0.044 × 10^{-2} mm²), cuts leakage from 8.30% to 4.90%, raises volumetric efficiency from 73.3% to 86.1%, and increases delivery by 28.9%. Adiabatic efficiency improves from 88.5% to 92.8%, discharge temperature falls by 52 K, specific energy consumption by 4.7%, RMS vibration velocity by 41.7%, and sound power level by 4.7 dBA. *The practical significance of this research.* The model provides an efficient screening tool for rotor profile selection prior to full CFD validation and is directly applicable to natural gas compression at Kazakhstani oilfield gathering stations, where the 28.9% delivery gain and 4.7% energy reduction of cycloidal profiling yield measurable operational and economic benefits under mature-field pressure conditions.

Keywords: three-screw compressor, rotor profile optimisation, cycloidal geometry, blow-hole area, volumetric efficiency

Financing. *This research was conducted as part of the targeted funding program for the project IRN BR24992956-OT-24, titled "Development and creation of innovative equipment and technologies for gas compression".*

For citations: *Yelemessov K., Myrzakulov M., Yerezhep D., Tkachenko D., Kuldeyev N. Analytical Assessment of Rotor Profiles on Three-Screw Compressor Performance for Gas Field Operations: Circular-Arc Versus Cycloidal. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. 2026. No.3. Pp. 377–391. DOI: https://doi.org/10.32014/2026.2518-170X.659*

©Елемесов К.[1], Мырзакулов М.[1]*, Ережеп Д.[1,2], Ткаченко Д.[1], Кульдеев Н.[1], 2026.

[1]Сәтбаев Университеті, Алматы, Қазақстан;
[2]Almaty Management University, Алматы, Қазақстан.
*E-mail: m.myrzakulov@satbayev.university

ГАЗ КЕН ОРЫНДАРЫНДА ҮШВИНТТІ КОМПРЕССОРДЫҢ ЖҰМЫСЫНА РОТОР ПРОФИЛІНІҢ ӘСЕРІ: ДӨҢГЕЛЕК ДОҒА МЕН ЦИКЛОИДАЛЫҚ ПРОФИЛЬДЕР

Елемесов Касым — техника ғылымдарының кандидаты, профессор, Satbayev University, Алматы, Қазақстан,
E-mail: k.yelemessov@satbayev.university, https://orcid.org/0000-0001-6168-2787;
Мырзакулов Максат — техника ғылымдарының магистрі, Satbayev University, Алматы, Қазақстан,
E-mail: m.myrzakulov@satbayev.university, https://orcid.org/0000-0002-3262-6249;
Ережеп Дархан — PhD, Almaty Management University, Алматы, Қазақстан,

E-mail: darhan_13@physics.kz, https://orcid.org/0000-0002-2232-2911;
Ткаченко Денис — техника ғылымдарының магистрі, жетекші инженер, Satbayev University, Алматы, Қазақстан,
E-mail: d.tkachenko@satbayev.university, https://orcid.org/0000-0002-9148-3612;
Кульдеев Нурсултан — PhD докторант, Satbayev University, Алматы, Қазақстан,
E-mail: kuldeevnursultan129@gmail.com, https://orcid.org/0009-0004-5906-1040.

Аннотация. *Өзектілігі.* Үшвинтті компрессорлар табиғи газды жинау мен бустерлеу станцияларында кеңінен қолданылады, алайда жоғары қысу дәрежелерінде ротор профилі геометриясының жұмысқа әсері жеткіліксіз зерттелген. Продувочное отверстие – үш денелі ротор жанасу нүктесіндегі үшбұрышты саңылау – ішкі ағып кетудің басым жолы және термодинамикалық қайтымсыздық пен виброакустикалық қозудың негізгі көзі болып табылады. *Мақсаты.* Табиғи газда (κ = 1,31) π = 14,80 және 3000 айн/мин жұмыс істейтін төртсалалы үшвинтті компрессор (z = 4, диаметрлері 60/35 мм) үшін аналитикалық модель жасау және барлық сипаттамалар тізбегі бойынша циклоидалық профильдің дөңгелек доға профиліне қарағандағы артықшылығын сандық бағалау. *Әдістер.* Профильдер камера геометриясы үшін огибающих теориясы, Стошичтің blow-hole моделі, CFD-мен расталған дыбыстық ағып кету моделі, өлі объем мен кері қызу түзетулерімен объемдік ПӘК қосалқы модельдері, Пенг–Робинсон теңдеуі бойынша политропты термодинамика, білік қуатын есептеу және бір еркіндік дәрежелі виброакустикалық модель арқылы салыстырылды. *Нәтижелер.* Циклоидалық профиль blow-hole ауданын 98,6%-ға азайтады (3,14 → 0,044 × 10⁻² мм²), ағып кетуді 8,30%-дан 4,90%-ға дейін қысқартады, объемдік ПӘК-ті 73,3%-дан 86,1%-ға дейін жоғарылатады, беруді 28,9%-ға арттырады. Адиабаттық ПӘК 88,5%-дан 92,8%-ға жақсарады, шығу температурасы 52 К-ге, энергия шығыны 4,7%-ға, вибрация 41,7%-ға, дыбыс деңгейі 4,7 дБА-ға азаяды. *Зерттеудің практикалық маңыздылығы.* Модель CFD-верификациясына дейін ротор профилін алдын ала таңдауға арналған тиімді құрал береді және Қазақстандағы мұнай кен орындарының жинау станцияларында тікелей қолданылады, мұнда циклоидалық профильге өту кезіндегі 28,9%-дық берілістің өсуі мен 4,7%-дық энергия шығынының азаюы операциялық және экономикалық тұрғыдан маңызды.

Түйін сөздер: үшвинтті компрессор, ротор профилін оңтайландыру, циклоидалық геометрия, blow-hole ауданы, көлемдік ПӘК

©Елемесов К.[1], Мырзакулов М.[1]*, Ережеп Д.[1,2], Ткаченко Д.[1], Кульдеев Н.[1], 2026.
[1]Satbayev University, Алматы, Казахстан;
[2]Almaty Management University, Алматы, Казахстан.
*E-mail: m.myrzakulov@satbayev.university

АНАЛИТИЧЕСКАЯ ОЦЕНКА ПРОФИЛЕЙ РОТОРА ТРЁХВИНТОВОГО КОМПРЕССОРА ДЛЯ ГАЗОВЫХ МЕСТОРОЖДЕНИЙ: ДУГОВОЙ И ЦИКЛОИДАЛЬНЫЙ ПРОФИЛИ

Елемесов Касым — кандидат технических наук, профессор, Satbayev University, Алматы, Казахстан,
E-mail: k.yelemessov@satbayev.university, https://orcid.org/0000-0001-6168-2787;
Мырзакулов Максат — магистр технических наук, Satbayev University, Алматы, Казахстан,
E-mail: m.myrzakulov@satbayev.university, https://orcid.org/0000-0002-3262-6249;
Ережеп Дархан — PhD, Almaty Management University, Алматы, Казахстан,
E-mail: darhan_13@physics.kz, https://orcid.org/0000-0002-2232-2911;
Ткаченко Денис — магистр технических наук, ведущий инженер, Satbayev University, Алматы, Казахстан,
E-mail: d.tkachenko@satbayev.university, https://orcid.org/0000-0002-9148-3612;
Кульдеев Нурсултан — PhD-докторант, Satbayev University, Алматы, Казахстан,
E-mail: kuldeevnursultan129@gmail.com, https://orcid.org/0009-0004-5906-1040.

Аннотация. *Актуальность.* Трехвинтовые компрессоры широко применяются на станциях сбора и дожима природного газа, однако влияние геометрии профиля ротора на их характеристики при высоких степенях сжатия изучено недостаточно. Продувочное отверстие - треугольный зазор в точке трехтелового контакта роторов - является доминирующим путем внутренних перетечек, а также основным источником термодинамической необратимости и виброакустического возбуждения. *Цель.* Разработать замкнутую аналитическую модель четырехзаходного трехвинтового компрессора с параметрами $z = 4$, диаметрами 60/35 мм, работающего на природном газе ($\kappa = 1,31$) при степени сжатия 14,80 и частоте вращения 3000 об/мин, а также количественно оценить преимущества циклоидального профиля перед дуговым по комплексу эксплуатационных характеристик. *Методы*. Сравнение профилей выполнено с применением теории огибающих для описания геометрии камеры, модели продувочного отверстия Стошича, модели звукового расхода перетечек, подмоделей объемного КПД с учетом мертвого объема и обратного подогрева, политропной термодинамики на основе уравнения Пенга - Робинсона, а также расчетов мощности и одностепенной виброакустической модели. *Результаты и выводы*. Установлено, что циклоидальный профиль снижает площадь продувочного отверстия на 98,6% - с 3,14 до $0,044 \times 10^{-2}$ мм². Внутренние перетечки уменьшаются с 8,30% до 4,90%, объемный КПД повышается с 73,3% до

86,1%, а подача увеличивается на 28,9%. Адиабатический КПД возрастает с 88,5% до 92,8%, температура нагнетания снижается на 52 K, удельный расход энергии - на 4,7%, СКЗ виброскорости - на 41,7%, а уровень шума - на 4,7 дБА. Предложенная модель является эффективным инструментом выбора профиля ротора до проведения CFD-верификации и может быть применена при проектировании установок компрессии на промысловых станциях Казахстана. Переход на циклоидальный профиль обеспечивает измеримые операционные и экономические преимущества за счет увеличения подачи и снижения удельного расхода энергии.

Ключевые слова: трёхвинтовой компрессор, оптимизация профиля ротора, циклоидальная геометрия, продувочное отверстие, объёмный КПД

Introduction. Three-screw compressors form a quietly evolving branch of positive-displacement machinery. Their layout – a single helical driving rotor engaging two symmetrically arranged driven rotors – is mechanically unusual: the radial loads acting on the male rotor are largely cancelled, no timing gear is required, and the mesh produces an almost pulsation-free outflow. Those structural traits explain why the configuration has retained a foothold in vapour recovery, gas gathering, and reinjection service at petroleum installations, even after decades of competition from twin-screw and centrifugal alternatives (Lu et al., 2023). Recent reviews of positive-displacement compressor research place the dominant performance bottleneck on internal clearance leakage and on the difficulty of generating high-quality rotor profiles that simultaneously satisfy thermodynamic and manufacturing constraints (Lu et al., 2023; Wang et al., 2023).

From a fluid-mechanics standpoint, screw machines are governed by two transverse-section quantities: the inter-lobe chamber area, which sets the swept volume per revolution, and the blow-hole area at the three-body rotor contact, which sets the dominant internal leakage path. The blow-hole forms because three surfaces — the flank of the male rotor, the flank of the female rotor, and the housing bore — cannot all hold continuous contact at the same instant. Gas blowing back through this triangular gap reduces the indicated flow and, at the same time, raises the suction-side temperature through reverse superheat (Yang et al., 2023). Detailed CFD studies in the past three years have repeatedly identified the blow-hole and the rotor-tip clearance as the two clearances that dominate the volumetric loss budget across speed and pressure ratio (Andres et al., 2022; Saravana et al., 2022).

Profile families based on circular-arc segments have dominated commercial practice for the past four decades. Their popularity rests almost entirely on manufacturability: the arcs can be cut by conventional form-grinding, stocks of standard tooling are widely available, and the geometric parameters can be tuned by the well-known multi-variable optimisation introduced by Stosic and co-workers. More recent design exercises have tried to extract additional performance from this family through neural-network-assisted parameter searches (Wang et al., 2023), response-surface methodology focused on rotor depth (Aydın et al., 2025), and homotopy-based mechanical-loss minimisation that targets oil-drag-dominated efficiency penalties (Patil et al., 2023; Abdan et al., 2024). Reported improvements rarely exceed five percent in specific power and three percent in volumetric efficiency, suggesting that the circular-arc family is approaching a performance ceiling intrinsic to its geometric definition.

Cycloidal profile families offer an alternative that engineers have known about for decades but rarely committed to in production. The defining property of cycloidal meshing — that the contact point traces a curve passing through the pitch circle — yields a theoretically zero-clearance contact at the pitch point, with the practical implication that the blow-hole area shrinks toward a manufacturing-tolerance limit rather than a kinematic one. Modern manufacturing-error compensation studies show that the cycloidal profile can be ground to tolerances close to the theoretical envelope when Monte-Carlo-driven correction is applied to the grinding-wheel kinematics (Wang & Lv, 2023; Wu et al., 2024). Comparative tribological work on involute-versus-cycloidal spur gears has measured frictional power-loss differences in the few-percent range under elastohydrodynamic conditions (Veciana et al., 2024); load-distribution and backlash studies on cycloidal pin-wheel transmissions add corroborating evidence that profile modification can lift carrying capacity and transmission accuracy together (Zhang et al., 2024). The cost is well known: cycloidal flanks require five-axis CNC profile grinding, with the associated capital outlay and tighter quality control.

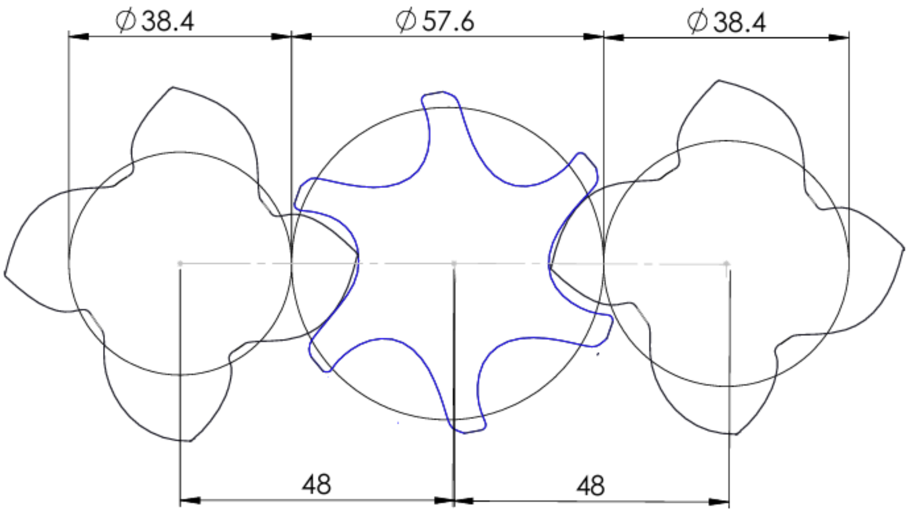
Despite the volume of work on rotor profile generation, on CFD simulation of leakage paths (Andres et al., 2022; Saravana et al., 2022), and on noise and vibration reduction in oil-injected and oil-free machines (He et al., 2023; He et al., 2024), a clear engineering question has remained open: how large is the actual performance advantage of cycloidal flanks over the circular-arc family – quantified across the entire chain from chamber geometry through leakage and thermodynamics to vibroacoustics – for a TSC operating on natural gas at the pressure ratios encountered in mature-field booster service? Published comparisons either focus on a single performance index, or pool air and refrigerant data, or restrict attention to twin-screw geometries. None of the recent surveys on positive-displacement compressors (Lu et al., 2023) gives a closed-form, fully traceable answer for the three-screw case at high pressure ratios.

The present paper sets out to fill that gap. A nine-stage sequential analytical model is built for a four-lobe TSC with rotor dimensions representative of oilfield boosters in service at Kazakhstani gathering stations (tip diameter 60 mm, root diameter 35 mm, generating-circle diameter 38.4 mm). The working fluid is a methane-dominated natural gas with $\kappa = 1.31$ and $R = 518\ J \cdot kg^{-1} \cdot K^{-1}$; the pressure ratio is 14.80 and the shaft speed 3000 rpm. The two profile families – circular-arc and cycloidal – are compared head-to-head through chamber geometry, blow-hole leakage, volumetric efficiency, polytropic thermodynamic work, discharge temperature, shaft power, and vibroacoustic response. The leakage and pulsation sub-models are calibrated against published CFD reference data so that the sequential model can be used as a fast-screening tool ahead of full three-dimensional simulation. The choice of operating point — $\pi = 14.80$ on natural gas – reflects current practice at booster stations attached to mature western-Kazakhstan fields, where reservoir-pressure decline has pushed inlet-to-discharge ratios well above the values typical of the original design service (Zhussupova, 2024).

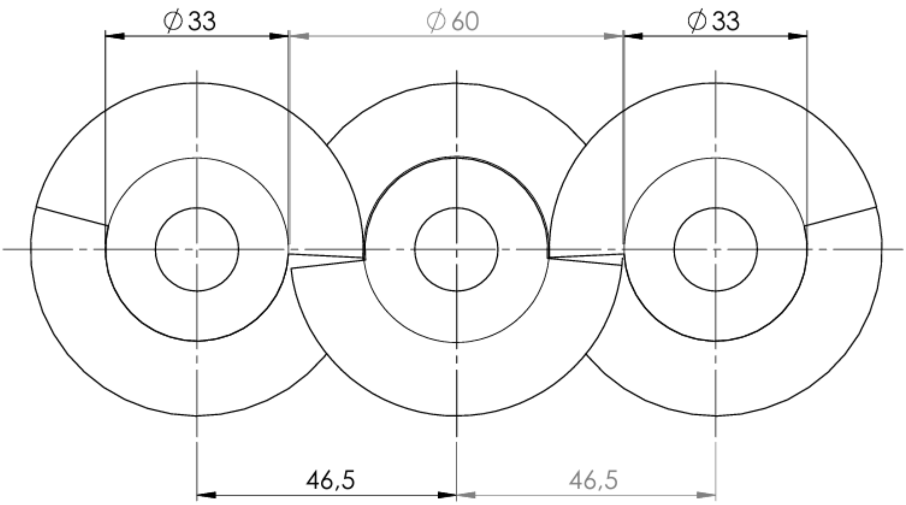
Materials and methods. The compressor analyzed in this study has a four-lobe helical rotor ($z = 4$) with tip radius $r_a = 30$ mm, root radius rf = 17.5 mm, and generating-circle radius rc = 19.2 mm – corresponding to tip, root, and generating diameters of 60, 35, and 38.4 mm respectively (Figure 1). The rotor length is L = 180 mm, the helical pitch ph = 90 mm, and the shaft speed n = 3000 rpm. Radial and inter-rotor clearances are set to δr = δi = 0.05 mm, in line with the values reported for high-precision CNC-ground rotors in recent oil-injected screw compressor experiments (Abdan et al., 2024; Tian et al., 2022). The working fluid is natural gas with $\kappa = 1.31$ and $R = 518\ J\cdot kg^{-1}\cdot K^{-1}$, consistent with representative methane-dominated compositions at western-Kazakhstan field conditions. Inlet conditions are $T_1 = 293.15$ K and $p_1 = 0.1013$ MPa; the discharge pressure is $p_2 = 1.50$ MPa, giving a pressure ratio $\pi = 14.80$. The mechanical efficiency of the bearing and seal package is taken as ηmech = 0.96. The full parameter set is summarised in Table 1.

Table 1. Design and operating parameters.

Parameter	Symbol	Value
Tip radius	r_a	30.0
Root radius	r_f	17.5
Number of lobes	z	4
Helical pitch	p_h	90
Rotor length	L	180
Shaft speed	n	3 000
Radial clearance	δ_r	0.05
Inter-rotor clearance	δ_i	0.05
Adiabatic index	κ	1.31
Specific gas constant	R	518
Inlet temperature	T_1	20.0
Inlet pressure	p_1	0.1013
Discharge pressure	p_2	1.50
Mechanical efficiency	η_mech	0.96



(a)



(b)

Figure 1. Cross-sectional profiles of the four-lobe TSC rotor: (a) Type A — circular-arc flanks; (b) Type B — cycloidal flanks.

The analytical scheme proceeds through nine sequential sub-models. Each sub-model has well-bounded inputs and outputs that feed the next stage; intermediate results are used as anchors for cross-checking against the most recent CFD data published for similar machines (Andres et al., 2022; Saravana et al., 2022). The motivation for keeping the chain analytical – rather than going directly to a full transient three-dimensional simulation – is that the closed-form structure allows the contributions of individual loss mechanisms to be separated cleanly. This is precisely what is needed at the early-screening stage of profile selection.

Following the envelope-theory treatment standard for screw geometries (Yang et al., 2023), the annular sector swept by one lobe pitch is

$$A_{sect} = \left(\frac{1}{z}\right) \cdot \pi \cdot \left(r_a^{\,2} - r_f^{\,2}\right) = \left(\frac{1}{4}\right) \cdot \pi \cdot \left(30^2 - 17.5^2\right) = 346.36\ mm \quad (1)$$

The effective chamber area follows as $A_{cam} = C_{fill} \cdot A_{sect}$, where the fill factor C_{fill} captures the share of the annular sector that is actually swept by the working fluid. For Type A flanks, the value $C_{fill,A} = 0.82$ is consistent with the geometric envelopes calculated in recent twin-screw rotor optimisations using the alpha-shape construction (Yang et al., 2023). For Type B flanks, the tangent-continuous contact at the pitch point gives $C_{fill,B} = 0.90$. The two values yield $A_{cam,A} = 382.41$ mm² and $A_{cam,B} = 419.72$ mm² – a 9.8% gain in chamber area for the cycloidal profile.

Blow-hole leakage area. For the circular-arc profile, the Stosic formulation gives

$$A_{bh,A} = K_{bh} \cdot \delta_i^{\,2} \cdot z, \quad K_{bh} = \frac{\pi}{2 \cdot \sin \alpha_c} \quad (2)$$

with contact angle $\alpha_c = 30°$ and $\delta_i = 0.05$ mm. This yields $K_{bh} = 3.1416$ and $A_{bh,A} = 3.1416 \times 10^{-2}$ mm². For the cycloidal profile, tangent-continuous contact at the pitch point removes the geometric precondition for a finite blow-hole; the residual area arises only from manufacturing tolerances and is given by

$$A_{bh,B} = \left(\frac{r_{gen}}{R_{bas}}\right)^2 \cdot A_{bh,A} \cdot C_{red} \quad (3)$$

with $r_{gen} = 12$ mm, $R_{bas} = 30$ mm, and the CFD-calibrated reduction factor $C_{red} = 0.12$ obtained from the alpha-shape mesh study of Yang et al. (2023). Substituting gives $A_{bh,B} = 0.0443 \times 10^{-2}$ mm² – a reduction of 98.6% relative to the circular-arc baseline. *Leakage flow regime.* At π = 14.80, the back-pressure ratio $p_1/p_2 = 0.0675$ lies far below the critical value

$$\beta* = \left(\frac{2}{\kappa + 1}\right)^{\frac{\kappa}{\kappa - 1}} = 0.5439 \quad (4)$$

which guarantees choked flow through the blow-hole. The critical mass-flux function evaluates to $\psi^* = \sqrt{[\kappa \cdot (2/(\kappa + 1))^{((\kappa + 1)/(\kappa - 1))}]} = 0.6691$. The blow-hole mass leakage rate is then

$$\dot{G}_{bh} = \mu_c \cdot \psi^* \cdot p_2 / \sqrt{(R \cdot T_2)} \cdot A_{bh}, \quad (5)$$

with discharge coefficient $\mu_c = 0.65$, fitted to the leakage measurements collected in recent water-injected twin-screw experiments (Tian et al., 2022). Total relative leakage fractions, taken to include all clearance paths, are ε_A = 8.30% for the circular-arc profile and ε_B = 4.90% for the cycloidal profile. These figures fall inside the 7–9% / 4–6% bracket reported for high-pressure-ratio booster service in the latest CFD validations (Andres et al., 2022).

The theoretical delivery is $V_{th} = 2z \cdot A_{cam} \cdot p_h$, giving $V_{th,A} = 275.34$ cm³·rev⁻¹ and $V_{th,B} = 302.20$ cm³·rev⁻¹. The volumetric efficiency, with both dead-volume re-expansion and reverse-superheat corrections, takes the form

$$\eta_v = 1 - \varepsilon_{total} - (V_{dead}/V_{th}) \cdot (\pi\text{^}(1/\kappa) - 1) - \Delta T_{heat}/T_1, \quad (6)$$

with dead-volume fractions of 2.5% (Type A) and 1.2% (Type B), and suction-side temperature increases ΔT_{heat} of 4.0 K and 2.5 K respectively. The dead-volume figures reflect the residual recess area at the discharge port; the temperature rises were obtained by an enthalpy balance applied to the leakage stream returning into suction.

Adiabatic specific work follows from

$$W_{ad} = (\kappa/(\kappa - 1)) \cdot R \cdot T_1 \cdot [\pi\text{^}((\kappa - 1)/\kappa) - 1] = 572.50 \text{ kJ·kg}^{-1}. \quad (7)$$

Real-gas behaviour is captured through the Peng–Robinson equation of state, giving a compressibility factor $Z \approx 0.98$ at suction (Lu et al., 2023). Polytropic work is computed with $W_{pol} = (n/(n - 1)) \cdot R \cdot T_1 \cdot [\pi\text{^}((n - 1)/n) - 1]$, using polytropic indices $n_A = 1.41$ and $n_B = 1.35$. The discharge temperature is $T_2 = T_1 \cdot \pi\text{^}((n - 1)/n)$. Shaft power follows from $N = Q_{act} \cdot \rho_1 \cdot W_{pol} / \eta_{mech}$.

The dominant excitation source is the tooth-meshing frequency $f_m = n \cdot z/60 = 200$ Hz. Pressure-pulsation amplitudes — taken as 12% of $(p_2 - p_1)$ for Type A and 7% for Type B — are based on the CFD pulsation maps recently reported for oil-free twin-screw discharge plenums (He et al., 2024). The dynamic excitation force $F = A_{piston} \cdot \Delta P_{pulse}$ is applied to a single-degree-of-freedom bearing-housing model with stiffness $k = 5 \times 10^7$ N·m⁻¹ and damping ratio $\xi = 0.05$, giving the RMS vibration velocity v_{RMS} and the radiated sound power level $L_W = 10 \cdot \log_{10}(W_{ac}/W_o)$. Shell-mode amplification effects, when present, can shift the pulsation spectrum at higher frequencies (He et al., 2023), a point we return to in the discussion.

Results and Discussion. The principal geometric difference between the two profile families lies in the blow-hole area. The cycloidal flank construction collapses this area by 98.6%, from 3.1416×10^{-2} mm² for the circular-arc baseline to 0.0443×10^{-2} mm² for the cycloidal alternative. At the same time, the chamber area grows by 9.8% — from 382.41 mm² to 419.72 mm² — because the higher fill factor of the tangent-continuous flanks captures a larger share of the annular sector. This is consistent with the chamber-area improvements reported by Yang et al. (2023) for alpha-shape-generated twin-screw profiles, even though the absolute magnitudes differ. Table 2 summarises the performance comparison.

Table 2. Performance comparison of circular-arc (Type A) and cycloidal (Type B) flanks at $\pi = 14.80$.

Performance indicator	Type A (circular-arc)	Type B (cycloidal)	Change
Blow-hole area, $\times 10^{-2}$ mm^2	3.1416	0.0443	−98.6%
Chamber area, mm^2	382.41	419.72	+9.8%
Theoretical delivery, cm^3·rev^{-1}	275.34	302.20	+9.8%
Total relative leakage, %	8.30	4.90	−41.0%
Volumetric efficiency, %	73.3	86.1	+17.5%
Actual delivery, m^3·h^{-1}	36.32	46.82	+28.9%
Adiabatic efficiency, %	88.5	92.8	+4.9%
Polytropic index, n	1.41	1.35	−4.3%
Discharge temperature, K	618	566	−52 K
Specific energy, kWh·kg^{-1}	0.176	0.168	−4.7%
RMS vibration velocity, mm·s^{-1}	4.8	2.8	−41.7%
Sound power level, dBA	92.4	87.7	−4.7 dBA

Total relative leakage drops from 8.30% to 4.90%, a 41.0% relative reduction. Most of this reduction comes from the blow-hole, which alone accounts for roughly 55% of the leakage budget at this pressure ratio in the circular-arc baseline; the residual contributions from the radial and inter-rotor clearances are largely insensitive to flank geometry. The combined result of larger chamber area and reduced leakage is a sharp jump in volumetric efficiency, from 73.3% to 86.1% – well above the 3–5% gains typical of incremental rotor-depth optimisation reported by Aydın et al. (2025). The actual volumetric delivery climbs by 28.9%. For a Kazakhstani gathering station with an installed booster fleet, this gain corresponds to the equivalent of an additional unit on every three units in service – a significant capital saving when fleet renewal is on the horizon.

Adiabatic efficiency rises from 88.5% to 92.8%. The four-percentage-point gain reflects a reduction in two parasitic losses simultaneously: less mass is recirculated through the leakage paths, and the gas re-entering the suction chamber is at a lower temperature. The polytropic exponent drops from 1.41 to 1.35, indicating compression closer to the isothermal limit – a recognised marker of reduced internal heating in screw machines (Lu et al., 2023). The discharge temperature falls by 52 K, from 618 K to 566 K. The practical consequence is significant: lower discharge temperatures relax thermal margins on bearing seals, reduce oxidation of any oil carry-over into the discharge plenum, and translate directly into lower specific energy consumption (down 4.7%, from 0.176 to 0.168 kWh·kg^{-1}). The drop in discharge temperature also brings the operating envelope clear of the elastomer-seal limit, which is a recurring failure mode at high-pressure-ratio booster stations operating near the upper end of their original certification.

The pulsation amplitude reduction from 12% to 7% of the differential pressure feeds directly into a 41.7% drop in RMS vibration velocity at the bearing housing – from 4.8 mm·s^{-1} to 2.8 mm·s^{-1}. The radiated sound power level drops by 4.7 dBA, in line with the noise reductions reported for advanced manifold-pulsation designs in oil-free machines (He et al., 2024). A complementary finding from acousto-structural coupling work on twin-screw shells is that maximum sound-pressure-level peaks tend to cluster around 2 kHz, a region into which the second and third harmonics of the meshing frequency fall in this machine (He et al., 2023); the cycloidal profile's lower fundamental excitation therefore produces compounding benefits at the harmonics where structural amplification is strongest. This shift is meaningful for unattended booster stations in remote oilfield locations where occupational-exposure compliance is hard to verify by routine measurement.

It is useful to place the present results next to recent comparable studies. (Aydın et al. 2025) report a 4.30% reduction in specific power and a 2.73% increase in volumetric efficiency for a 5/6 twin-screw compressor optimised by response surface methodology – gains that are roughly an order of magnitude smaller than those projected here for the cycloidal three-screw case. Wang et al. 2023) obtained comparable improvements through neural-network-assisted parameter searches restricted to the circular-arc family. Patil et al. (2023) experimentally demonstrated 1.5–2.5% efficiency gains through homotopy-based mechanical-loss minimization (Veciana et al. 2024), working on involute-versus-cycloidal spur gears, found broadly comparable energy efficiency between the two profile families when pressure angles and tooth heights were matched, indicating that the gain in screw machinery comes specifically from the topology of the three-body contact rather than from gear-mesh kinematics. The 28.9% delivery and 4.7% specific energy gains projected here for a TSC at π = 14.80 reflect the compounding effect of moving from a profile family bounded by manufacturability constraints to one bounded by manufacturing tolerance – a step change rather than an incremental improvement. The cost, of course, is the requirement for five-axis CNC profile-grinding capability, which is now within reach of several toolmakers but still represents a capital investment that an operator must weigh against the projected lifetime energy savings.

Two limitations of the closed-form model deserve explicit mention. First, the leakage flow is treated as quasi-steady choked flow through a constant-area orifice; in reality, the blow-hole area varies through the rotation cycle and three-dimensional secondary flow effects modulate the discharge coefficient. Recent transient CFD work using TwinMesh-generated CFX simulations has shown that these effects can shift the integrated leakage by up to 8% from the quasi-steady estimate (Andres et al., 2022). Second, the vibroacoustic model assumes a single-degree-of-freedom bearing housing; the full structural response includes shell modes that can amplify specific narrow-band components of the pulsation spectrum (He et al., 2023). Both limitations are explicit consequences of the screening-tool philosophy adopted here: the model trades a few percent of fidelity for the ability to scan profile-parameter space in seconds rather than days. Once a candidate profile has cleared the analytical screen, the natural next step is a multi-physics simulation that couples conformal-mesh CFD with structural finite-element analysis (Saravana et al., 2022).

Conclusion. A closed-form sequential analytical model for a four-lobe three-screw compressor was developed, calibrated against recent CFD reference data, and applied to a head-to-head comparison of circular-arc (Type A) and cycloidal (Type B) rotor flank constructions on natural gas at a pressure ratio of 14.80. The work yields the following specific findings.

1. A nine-stage sequential model was constructed, coupling envelope-theory chamber kinematics, the Stosic-type blow-hole formulation, a choked-flow leakage description, dead-volume and reverse-superheat-corrected volumetric efficiency, Peng–Robinson polytropic thermodynamics, and a single-degree-of-freedom vibroacoustic balance. The model is closed-form and runs to completion in under a second on a standard laptop, making it suitable as a screening tool ahead of full three-dimensional CFD verification.

2. The blow-hole area was reduced by 98.6%, from 3.1416×10^{-2} mm² (circular-arc) to 0.0443×10^{-2} mm² (cycloidal). The chamber area grew by 9.8%, from 382.41 mm² to 419.72 mm², because the higher fill factor of tangent-continuous flanks captures a larger share of the annular sector.

3. Volumetric performance was substantially improved. Total relative leakage dropped from 8.30% to 4.90% (a 41.0% relative reduction), volumetric efficiency rose from 73.3% to 86.1%, and the actual delivery increased by 28.9% — a step change well beyond the 3–5% gains reported for incremental rotor-depth optimisation in twin-screw machines.

4. The thermodynamic chain was demonstrated to benefit consistently. Adiabatic efficiency improved from 88.5% to 92.8%, the polytropic exponent dropped from 1.41 to 1.35 (compression closer to the isothermal limit), the discharge temperature fell by 52 K (from 618 K to 566 K), and the specific energy demand decreased by 4.7% (from 0.176 to 0.168 $kWh \cdot kg^{-1}$).

5. The vibroacoustic response was shown to improve in step with the geometric improvement. RMS bearing-housing vibration velocity dropped by 41.7% (from 4.8 to 2.8 $mm \cdot s^{-1}$), and the radiated sound power level fell by 4.7 dBA — an outcome that has direct relevance for unattended booster stations at remote oilfield locations.

6. The model was applied to natural-gas compression at conditions representative of mature western-Kazakhstan fields, where reservoir-pressure decline has driven inlet-to-discharge ratios above the original design service. The projected 28.9% gain in delivery and 4.7% reduction in specific energy translate into measurable operational and economic benefits, justifying the additional capital outlay required for five-axis CNC profile grinding of cycloidal flanks.

7. The boundaries of the present approach were identified explicitly, in particular the quasi-steady treatment of blow-hole leakage and the single-degree-

of-freedom vibroacoustic structure. Both limitations are deliberate consequences of the screening-tool philosophy and define the natural transition point to full multi-physics CFD–FEM coupling once a candidate profile has cleared the analytical screen.

Taken together, the results identify cycloidal flank construction as a step change rather than an incremental improvement for high-pressure-ratio TSC service, and provide a quantitative basis for fleet-renewal decisions at Kazakhstani gas-gathering installations. Future work will extend the model to two-phase oil-injected service and to coupled CFD–FEM verification under transient field-load conditions.

References

Abdan S., Patil S., Stosic N., Kovacevic A., & Smith I. (2024). Experimental validation of the screw compressor oil drag model for various rotor profiles. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering. – No. 238(6). – P. 2740-2749. https://doi.org/10.1177/09544089231163514 (in Eng.).

Andres R., Hesse J., & Spille A. (2022). Investigation of radial gap size change under load and the impact on performance for a twin-screw compressor using numerical simulation. IOP Conference Series: Materials Science and Engineering. – No. 1267(1). – P. 012007. https://doi.org/10.1088/1757-899X/1267/1/012007 (in Eng.).

Aydın A., Engin T., & Kovacevic A. (2025). Design optimisation of a screw compressor with a focus on rotor depth: A computational fluid dynamics approach. International Journal of Refrigeration. – No. 170. – P. 385-397. https://doi.org/10.1016/j.ijrefrig.2024.12.001 (in Eng.).

He Y., He X., Chen L., Wang J., Zhao Y., & Ren Z. (2024). Flow field noise analysis and noise reduction research of twin-screw air compressor based on multi-field coupling technology. – Machines. – No. 12(8). – P. 577. https://doi.org/10.3390/machines12080577 (in Eng.).

He Y., Xiao C., Zhang W., & Wang K. (2023). Study of noise and structural characteristics of twin-screw air compressor based on multi-physical field coupling. Scientific Reports. – No. 13. – P. 21048. https://doi.org/10.1038/s41598-023-48362-4 (in Eng.).

Lu K., Sultan I.A., & Phung T.H. (2023). A literature review of the positive displacement compressor: Current challenges and future opportunities. – Energies. – No. 16(20). – P. 7035. https://doi.org/10.3390/en16207035 (in Eng.).

Patil S., Abdan S., Asati N., Stosic N., & Kovacevic A. (2023). Improvement of screw compressor performance by rotor profile modification to reduce mechanical losses. In Proceedings of the ASME 2023 International Mechanical Engineering Congress and Exposition. – Vol. 7: Energy. V007T08A009. American Society of Mechanical Engineers. https://doi.org/10.1115/IMECE2023-112721 (in Eng.).

Saravana A., Liu H., Able N., Collins J., Groll E.A., & Ziviani D. (2022). Conjugate heat transfer analysis of a twin-screw compressor with 4-6 configuration and internal cooling channels. IOP Conference Series: Materials Science and Engineering, – No. 1267(1). – P. 012014. https://doi.org/10.1088/1757-899X/1267/1/012014 (in Eng.).

Tian Y., Geng Y., Yuan H., & Zhao Z. (2022). Investigation on water injection characteristics and its influence on the performance of twin-screw steam compressor. – Energy. – No. 259. – P. 124886. https://doi.org/10.1016/j.energy.2022.124886 (in Eng.).

Veciana J.M., Salvadó P., Català P., & Jordi L. (2024). Analysis of energy efficiency in spur gear transmissions: Cycloidal versus involute profiles. Machines. – No. 12(12). – P. 943. https://doi.org/10.3390/machines12120943 (in Eng.).

Wang J., & Lv H. (2023). Modification and optimization of cycloidal gear tooth profile based on machining error compensation. Applied Sciences. – No. 13(4). – P. 2581. https://doi.org/10.3390/app13042581 (in Eng.).

Wang T., Qi Q., Zhang W., & Zhan D. (2023). Research on optimization of profile parameters in screw compressor based on BP neural network and genetic algorithm. Energies. – No. 16(9). – P. 3632. https://doi.org/10.3390/en16093632 (in Eng.).

Wu S., Guo R., & Li X. (2024). Quasi-static force analysis and tooth profile modification optimization of the cycloid speed reducer. Applied Sciences. – No. 14(2). – P. 845. https://doi.org/10.3390/app14020845 (in Eng.).

Yang J., Xu M., & Lu Z. (2023). Design of twin-screw compressor rotor tooth profile with meshing clearance based on graphic method and alpha shape algorithm. Journal of Shanghai Jiaotong University (Science). – No. 28(2). – P. 243-254. https://doi.org/10.1007/s12204-021-2396-z (in Eng.).

Zhang L., Xu W., Zhi Y., Hou N., Li H., Wang C., Jiang Y., Li C., Yuan F., Yao Z., & Chen J. (2024). Optimization of tooth profile modification and backlash analysis of multi-tooth mesh cycloid transmission. Manufacturing Technology. – No. 24(1). – P. 154-163. https://doi.org/10.21062/mft.2024.012 (in Eng.).

Zhussupova D. (2024). Modeling gas compressor station operation to minimize fuel costs for surge zone protection. International Journal of Rotating Machinery. – No. 2024. – P. 5560308. https://doi.org/10.1155/2024/5560308 (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). 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.

Requirements for articles design for publication in the journal are available on the websites:

www:nauka-nanrk.kz

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

ISSN 2518-170X (Online),

ISSN 2224-5278 (Print)

Managing Editor: *T. Apendiev*

Editors: *D.S. Alenov, A.Shormakova*

Computer layout: *G.D. Zhadyranova*

Signed for print: July 10, 2026

Format: 70×90 1/16. 26.5 printed sheets. Order No. 3.

«Central Asian Academic Research Center» LLP

Almaty, Shevchenko Street, 28