№5

ҚАЗАҚСТАН РЕСПУБЛИКАСЫ ПРЕЗИДЕНТІНІҢ ЖАНЫНДАҒЫ ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ

ISSN 2304-3334
№05(113)2026

ІЗДЕНІСТЕР, НӘТИЖЕЛЕР
ҒЫЛЫМИ ЖУРНАЛ

ИССЛЕДОВАНИЯ, РЕЗУЛЬТАТЫ
НАУЧНЫЙ ЖУРНАЛ

RESEARCH, RESULTS
SCIENTIFIC JOURNAL

АЛМАТЫ

KAZAKH NATIONAL AGRARIAN RESEARCH UNIVERSITY
NATIONAL ACADEMY OF SCIENCES OF KAZAKHSTAN UNDER THE PRESIDENT OF THE REPUBLIC OF KAZAKHSTAN

ҚАЗАҚ ҰЛТТЫҚ АГРАРЛЫҚ ЗЕРТТЕУ УНИВЕРСИТЕТІ
ҚАЗАҚСТАН РЕСПУБЛИКАСЫ ПРЕЗИДЕНТІНІҢ ЖАНЫНДАҒЫ
ҚАЗАҚСТАН РЕСПУБЛИКАСЫ ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ

КАЗАХСКИЙ НАЦИОНАЛЬНЫЙ АГРАРНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ УНИВЕРСИТЕТ
НАЦИОНАЛЬНАЯ АКАДЕМИЯ НАУК РЕСПУБЛИКИ КАЗАХСТАН
ПРИ ПРЕЗИДЕНТЕ РЕСПУБЛИКИ КАЗАХСТАН

Research, results	**Ізденістер, нәтижелер**	**Исследования, результаты**
Published since 1999.	Издается с 1999 г. Том	Издается с 1999 г.
Volume 28. No.113. 2026	28. No.113. 2026	Том 28. No.113. 2026

Зарегистрировано в Министерстве информации и общественного согласия РК. Свидетельство об учетной регистрации №482-Ж от 25 ноября 1998 года.
Зарегистрировано в Международном центре регистрации серийных изданий ISSN (ЮНЕСКО, Париж, Франция). ISSN 2304–3334.

Приказом №148 от 27.12.2022 г. Комитета по обеспечению качества в сфере науки и высшего образования МНВО РК научный журнал «Research, results – Ізденістер, нәтижелер – Исследования, результаты» КазНАИУ включен в Перечень изданий, рекомендуемых для публикации основных результатов научной деятельности (сельскохозяйственные науки).

С целью объединения усилий, продвижения и популяризации результатов научных изысканий казахстанских ученых в мировом сообществе, согласно Соглашения №27 от 15 августа 2023 года НАО «Казахский национальный аграрный исследовательский университет» совместно с НАО «Национальная академия наук Республики Казахстан при Президенте Республики Казахстан» издает научный журнал «Research, results – Ізденістер, нәтижелер – Исследования, результаты».

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Scientific Journal "Research, Results"
Publication frequency: 6 issues per year
Languages: Kazakh, Russian, English
DOI prefix: 10.37884
ISSN: 2304-3334.
Scope: "Stock-Raising and Veterinary"; "Agriculture, Agrochemical, Feed Production, Agroecology"; "Water, Land, and Forest Resources"; "Agriculture Mechanization and Electrification".
Distribution: Materials are distributed under the Creative Commons Attribution 4.0
Website: https://journal.kaznaru.edu.kz
Founder/Publisher: Kazakh National Agrarian Research University; National Academy of Sciences of Kazakhstan under the President of the Republic of Kazakhstan
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Тимурбекова Айгуль Кулахметовна — техника ғылымдарының кандидаты. Қазақ ұлттық аграрлық зерттеу университеті, «Тамақ өнімдерінің технологиясы және қауіпсіздігі» кафедрасының профессоры; (Scopus h-9)
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Кененбай Гүлмира Серікбайқызы — техника ғылымдарының кандидаты, қауымдастырылған профессор (доцент). «Қазақ қайта өңдеу және тамақ өнеркәсібі ғылыми-зерттеу институты» ЖШС; (Scopus h-5)

«Зерттеулер, нәтижелер» ғылыми журналы
Жиілігі: жылына 6 шығарылым.
Басылым тілі: қазақ, орыс, ағылшын.
Префикс DOI: 10.37884
ISSN: 2304-3334.
Тақырыптық бағыты: «мал шаруашылығы және ветеринария»; «егіншілік, агрохимия, жемшөп өндірісі, агроэкология»; «су, жер және орман ресурстары»; «ауыл шаруашылығын механикаландыру және электрлендіру».
Тарату: материалдар Creative Commons Attribution 4.0 лицензиясы бойынша таратылады
Веб-сайт: https://journal.kaznaru.edu.kz
Құрылтайшысы / баспагері: Қазақ ұлттық аграрлық зерттеу университеті; Қазақстан Республикасы Президентінің жанындағы Қазақстан Республикасының Ұлттық Ғылым академиясы
Авторлық құқық: © Зерттеулер, нәтижелер, 2026

РЕДАКЦИЯ

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Iancu Ionica Mihaela — доцент, PhD. Факультет ветеринарной медицины Университета сельскохозяйственных наук и ветеринарной медицины Баната имени короля Михая I (г. Тимишоара, Румыния). Области специализации: ветеринарные науки, микробиология, инфекционные заболевания, антимикробная резистентность; (Web of Science – 8).

Jan MICIŃSKI — PhD, Варминско-Мазурский университет, Польша; (Scopus h-8)

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Жаппарова Айгул Абсултановна — кандидат сельскохозяйственных наук, профессор. Казахский национальный аграрный исследовательский университет. Профессор кафедры почвоведения, агрохимии и экологии; (Scopus h-6)

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Wenfeng Liu — PhD, профессор. Китайский сельскохозяйственный университет (China Agricultural University); (Scopus h-39)

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Daskalov Plamen — PhD, профессор, Университет Русе имени Ангела Кънчева, проректор по вопросам развития, координации и повышения квалификации, Болгария; (Scopus h-10)
Бердышев Абдурахим Сулейманович — доктор технических наук, Казахский национальный аграрный исследовательский университет, профессор кафедры «Энергетика и электротехника»; (Scopus h-8)
Остриков Анатолий Николаевич — доктор технических наук, профессор. Воронежский государственный университет инженерных технологий (РФ), заведующий кафедрой «Процессы и аппараты химических и пищевых производств»; (Scopus h-7)
Ливию Гачео — профессор Трансильванского университета (г. Брашов, Румыния); (Scopus h-9)
Тимурбекова Айгуль Кулахметовна — кандидат технических наук. Казахский национальный аграрный исследовательский университет, профессор кафедры «Технология и безопасность пищевых продуктов»; (Scopus h-9)
Тойшиманов Максат Рисбекович — PhD, Казахский национальный аграрный исследовательский университет, старший преподаватель кафедры «Технология и безопасность пищевых продуктов»; (Scopus h-8)
Кененбай Гүлмира Серікбайқызы — кандидат технических наук, ассоциированный профессор (доцент). ТОО «Казахский научноисследовательский институт перерабатывающей и пищевой промышленности»; (Scopus h-5)

Научный журнал «Исследования, результаты»
Периодичность: 6 выпусков в год.
Язык издания: казахский, русский, английский.
Префикс DOI: 10.37884
ISSN: 2304-3334.
Тематическая направленность: «животноводство и ветеринария»; «земледелие, агрохимия, кормопроизводство, агроэкология»; «водные, земельные и лесные ресурсы»; «механизация и электрификация сельского хозяйства».
Распространение: материалы распространяются по лицензии Creative Commons Attribution 4.0
Веб-сайт: https://journal.kaznaru.edu.kz
Учредитель/издатель: Казахский национальный аграрный исследовательский университет; Национальная академия наук Республики Казахстан при Президенте Республики Казахстан
Авторские права: © Исследования, результаты, 2026

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RESEARCH, RESULTS – ІЗДЕНІСТЕР, НӘТИЖЕЛЕР – ИССЛЕДОВАНИЯ, РЕЗУЛЬТАТЫ
ISSN 2304-3334 (print)
Vol. 28. Is. 5. Number 113 (2026). Pp. 150–166
Journal homepage: https://journal.kaznaru.edu.kz
https://doi.org/10.37884/5-2026/13
IRSTI / ҒТАХР / МРНТИ / 70.27.19

N. Ilyassova[1]*, A. Meshyk[2], L. Ryskulbekova[1], A. Tangirbergenova[1], Zh. Zhakupova[1]
[1]Kazakh National Agrarian Research University, Almaty, Kazakhstan;
[2]Brest State Technical University, Brest, Belarus.
E-mail: Ilyasova.Narkyz@kaznaru.edu.kz

INVESTIGATION OF HYDRAULIC PARAMETERS OF TUBELESS GROUNDWATER LIFTING TECHNOLOGY

Narkyz Ilyassova, Doctoral student of the Department «Water Resources and Melioration», Republic of Kazakhstan, 050026, Almaty
E-mail: Ilyasova.Narkyz@kaznaru.edu.kz, https://orcid.org/0009-0008-5053-0516;
Meshyk Aleh, Candidate of Technical Sciences, Associate Professor, Dean of the Faculty of Engineering Systems and Ecology Brest State Technical University, Brest, Belarus
E-mail: omeshik@mail.ru, https://orcid.org/0000-0002-7037-7669;
Laura Ryskulbekova, PhD, Acting Associate Professor of the Department of Water Resources and Melioration, Kazakh National Agrarian Research University, Republic of Kazakhstan, 050026, Almaty
E-mail: ryskulbekova.laura@kaznaru.edu.kz, https://orcid.org/0000-0003-4782-2047;
Tangirbergenova Altynay, Doctoral student of the Department «Water Resources and Melioration», Republic of Kazakhstan, 050026, Almaty
E-mail: 521308@kaznaru.edu.kz, https://orcid.org/0009-0006-7275-2895;
Zhakupova Zhanar, PhD, Senior lecturer of the Department «Water Resources and Melioration», Republic of Kazakhstan, 050026, Almaty, microdistrict 9, 39
E-mail: zhakupova.zhanar@kaznaru.edu.kz, https://orcid.org/0000-0002-4933-762X.

Abstract. This study investigates the hydraulic parameters of tubeless groundwater lifting technology. Currently, ensuring a stable water supply for agricultural production, promoting the rational use of water resources, and reducing energy consumption are among the key challenges in regions experiencing water scarcity in Kazakhstan. In this regard, the development of energy-efficient groundwater lifting technologies represents an important scientific and engineering task. Compared with conventional groundwater lifting systems, tubeless groundwater lifting technology features a simpler design, reduced material consumption, and lower operating costs. The research was conducted using analytical, theoretical, and experimental approaches. The operating characteristics of a groundwater lifting system consisting of a submersible electric pump and a hydraulic packer were evaluated and the main hydraulic parameters were determined. Particular attention was given to the factors influencing discharge rate, pumping head, hydraulic resistance, pressure losses, flow conditions and overall system efficiency. Hydraulic equations were applied to evaluate the system performance and determine its optimal operating conditions. The theoretical results were validated against the experimental data to assess the reliability of the proposed approach. The results showed that the application of tubeless groundwater lifting technology reduces hydraulic losses, decreases energy consumption, improves the energy efficiency of pumping equipment and increases well productivity. The proposed technology contributes to the rational use of groundwater resources, enhances the reliability of water supply for irrigated agriculture and improves the operational efficiency of reclamation systems. The obtained results provide a scientific and practical basis for the design, optimization and implementation of tubeless groundwater lifting systems under field operating conditions.

Keywords: groundwater extraction, tubeless groundwater lifting technology, hydraulic parameters, hydraulic packer, submersible electric pump, energy efficiency, wells

For citation: Ilyassova N., Meshyk A., Ryskulbekova L., Tangirbergenova A., Zhakupova Zh. (2026). Investigation of Hydraulic Parameters of Tubeless Water Lifting Technology from Wells // Research, results – Ізденістер, нәтижелер – Исследования, результаты. Vol. 28. Is. 5. Number 113. Pp. 150–166. https://doi.org/10.37884/5-2026/13 [In Eng.].

Conflict of interest: The authors declare that there is no conflict of interest.

Acknowledgements. *The authors express their gratitude to the Department of Water Resources and Melioration of the Kazakh National Agrarian Research University for supporting this research. This study was conducted without specific grant funding.*

Н.Х. Ильясова[1]*, О.П. Мешик[2], Л.М. Рыскулбекова[1], А.С. Тангирбергенова[1], Ж.З. Жакупова[1]

[1]Қазақ ұлттық аграрлық зерттеу университеті, Алматы, Қазақстан;

[2]Брест мемлекеттік техникалық университеті, Брест, Беларусь.

E-mail: Ilyasova.Narkyz@kaznaru.edu.kz

ҰҢҒЫМАЛАРДАН ҚҰБЫРСЫЗ СУ КӨТЕРУ ТЕХНОЛОГИЯСЫНЫҢ ГИДРАВЛИКАЛЫҚ ПАРАМЕТРЛЕРІН ЗЕРТТЕУ

Ильясова Нарқыз Хайруллақызы, «Су ресурстары және мелиорация» кафедрасының докторанты, Қазақстан, 050026, Алматы
E-mail: Ilyasova.Narkyz@kaznaru.edu.kz, https://orcid.org/0009-0008-5053-0516;
Мешик Олег Павлович, т.ғ.к., доцент, Инженерлік жүйелер және экология факультетінің деканы, Брест мемлекеттік техникалық университеті, Брест, Беларусь
E-mail: omeshik@mail.ru, https://orcid.org/0000-0002-7037-7669;
Рыскулбекова Лаура Молдахановна, PhD, «Су ресурстары және мелиорация» кафедрасының қауымдастырылған проф.м.а., Қазақстан, 050026, Алматы
E-mail: ryskulbekova.laura@kaznaru.edu.kz, https://orcid.org/0000-0003-4782-2047;
Тангирбергенова Алтынай Сабиткызы, «Су ресурстары және мелиорация» кафедрасының докторанты, Қазақстан, 050026, Алматы
E-mail: 521308@kaznaru.edu.kz, https://orcid.org/0009-0006-7275-2895;
Жакупова Жанар Зиядовна, PhD, «Су ресурстары және мелиорация» кафедрасының аға оқытушысы, Қазақстан , 050026, Алматы, микроаудан 9/39
E-mail: zhakupova.zhanar@kaznaru.edu.kz, https://orcid.org/0000-0002-4933-762X.

Аннотация. Мақалада ұңғымалардан жерасты суларын құбырсыз көтеру технологиясының гидравликалық параметрлері зерттелген. Қазіргі уақытта Қазақстанның су ресурстары шектеулі өңірлерінде ауыл шаруашылығы өндірісін тұрақты сумен қамтамасыз ету, су ресурстарын тиімді пайдалану және энергия шығындарын азайту мәселелері ерекше маңызға ие. Осыған байланысты жерасты суларын көтерудің энергия үнемдейтін және пайдалану тиімділігі жоғары технологияларын әзірлеу мен жетілдіру өзекті ғылыми-техникалық міндеттердің бірі болып табылады. Құбырсыз су көтеру технологиясы дәстүрлі су көтеру жүйелерімен салыстырғанда құрылымдық қарапайымдылығымен, металл сыйымдылығының төмендігімен және пайдалану шығындарының аздығымен ерекшеленеді. Зерттеу барысында аналитикалық, теориялық және эксперименттік әдістер қолданылды. Суасты электрсорғысы мен пакерлік гидравликалық құрылғыдан тұратын жүйенің жұмыс ерекшеліктері қарастырылып, оның негізгі гидравликалық көрсеткіштері анықталды. Атап айтқанда, су шығынына, су көтеру биіктігіне, гидравликалық кедергілерге, қысым шығынына, ағын қозғалысының режиміне және жүйенің пайдалы әсер коэффициентіне әсер ететін факторлар зерттелді. Технологиялық жүйенің гидравликалық сипаттамаларын анықтауға арналған есептеу тәуелділіктері пайдаланылып, құрылғының тиімді жұмыс режимдері негізделді. Теориялық есептеулер нәтижелері эксперименттік зерттеулер барысында алынған деректермен салыстырылып, олардың өзара сәйкестігі бағаланды. Зерттеу нәтижелері құбырсыз су көтеру технологиясын қолдану гидравликалық шығындарды төмендетуге, энергияны тұтыну деңгейін азайтуға, сорғы қондырғысының энергетикалық тиімділігін арттыруға және ұңғымалардың өнімділігін арттыруға мүмкіндік беретінін көрсетті. Ұсынылған технология жерасты сулары ресурстарын ұтымды пайдалануға, суармалы егіншілік нысандарын сумен қамтамасыз ету сенімділігін арттыруға және мелиорациялық жүйелердің пайдалану тиімділігін жақсартуға ықпал етеді. Алынған нәти-

желер құбырсыз су көтеру жүйелерін жобалау, жетілдіру және өндірістік жағдайда қолдану кезінде ғылыми-практикалық негіз ретінде пайдаланылуы мүмкін.

Түйін сөздер: жерасты сулары, құбырсыз су көтеру технологиясы, гидравликалық параметрлер, пакерлік гидравликалық құрылғы, суасты электрсорғысы, энергия тиімділігі, ұңғыма

Дәйексөз үшін: Ильясова Н.Х., Мешик О.П., Рыскулбекова Л.М., Тангирбергенова А.С., Жакупова Ж.З. (2026). Ұңғымалардан құбырсыз су көтеру технологиясының гидравликалық параметрлерін зерттеу // Research, results – Ізденістер, нәтижелер – Исследования, результаты. Т. 28. Is. 5. Number 113. Pp. 150–166. https://doi.org/10.37884/5-2026/13 [In Eng.].

Мүдделер қақтығысы: Авторлар осы мақалада мүдделер қақтығысы жоқ деп мәлімдейді.

Қаржыландыру: *зерттеу жұмысы авторлардың жеке қаражаты есебінен орындалды.*

Алғыс. *Авторлар зерттеу жұмысының орындалуына жағдай жасаған Қазақ ұлттық аграрлық зерттеу университетінің «Су ресурстары және мелиорация» кафедрасына алғыс білдіреді. Зерттеу арнайы гранттық қаржыландырусыз орындалды.*

Н.Х. Ильясова[1]*, О.П. Мешик[2], Л.М. Рыскулбекова[1], А.С. Тангирбергенова[1], Ж.З. Жакупова[1]

[1]Казахский национальный аграрный исследовательский университет, Алматы, Казахстан;

[2]Брестский государственный технический университет, Брест, Беларусь.

E-mail: Ilyasova.Narkyz@kaznaru.edu.kz

ИССЛЕДОВАНИЕ ГИДРАВЛИЧЕСКИХ ПАРАМЕТРОВ ТЕХНОЛОГИИ БЕСТРУБНОГО ВОДОПОДЪЕМА ИЗ СКВАЖИН

Ильясова Наркыз Хайруллакызы, докторант кафедры «Водные ресурсы и мелиорация», Казахский национальный аграрный исследовательский университет, 050026, Алматы, Казахстан
E-mail: Ilyasova.Narkyz@kaznaru.edu.kz, https://orcid.org/0009-0008-5053-0516;
Мешик Олег Павлович, к.т.н., доцент, декан факультета инженерных систем и экологии, Брестский государственный технический университет, Брест, Беларусь
E-mail: omeshik@mail.ru, https://orcid.org/0000-0002-7037-7669;
Рыскулбекова Лаура Молдахановна, PhD, и.о. ассоциированного профессора кафедры «Водные ресурсы и мелиорация», Казахский национальный аграрный исследовательский университет, 050026, Алматы, Казахстан
E-mail: ryskulbekova.laura@kaznaru.edu.kz, https://orcid.org/0000-0003-4782-2047;
Тангирбергенова Алтынай Сабиткызы, докторант кафедры «Водные ресурсы и мелиорация», 050026, Алматы, Казахстан
E-mail: 521308@kaznaru.edu.kz, https://orcid.org/0009-0006-7275-2895;
Жакупова Жанар Зиядовна, PhD, старший преподаватель кафедры «Водные ресурсы и мелиорация», 050026, микрорайон 9/39, Алматы, Казахстан
E-mail: zhakupova.zhanar@kaznaru.edu.kz, https://orcid.org/0000-0002-4933-762X.

Аннотация. В статье исследованы гидравлические параметры технологии беструбного водоподъема подземных вод из скважин. В настоящее время обеспечение стабильного водоснабжения сельскохозяйственного производства, рациональное использование водных ресурсов и снижение энергозатрат являются одними из наиболее актуальных задач в регионах Казахстана, испытывающих дефицит водных ресурсов. В связи с этим разработка и совершенствование энергоэффективных технологий подъема подземных вод с высокими эксплуатационными показателями представляет собой важную научно-техническую задачу. По сравнению с традиционными системами водоподъема технология беструбного водоподъема отличается более простой конструкцией, сниженной металлоемкостью и меньшими эксплуатационными затратами. В ходе исследования использованы аналитические, теоретические и экспериментальные методы. Рассмотрены особенности функционирования системы, включающей погружной электронасос и пакерное гидравлическое устройство, а также определены ее основные гидравлические показатели. Особое внимание уделено факторам, влияющим на подачу воды, высоту водоподъема, гидравлические сопротивления, потери давления, режим движения потока и коэффициент полезного действия системы. Для оценки характеристик технологической системы использованы расчетные гидравлические зависимости, на основе которых обоснованы рациональные

режимы ее работы. Результаты теоретических расчетов сопоставлены с данными экспериментальных исследований, что позволило оценить степень их соответствия. Установлено, что применение технологии беструбного водоподъема способствует снижению гидравлических потерь, уменьшению потребления энергии, повышению энергетической эффективности насосной установки и увеличению производительности скважины. Предлагаемая технология обеспечивает более рациональное использование ресурсов подземных вод, повышает надежность водоснабжения орошаемых земель и улучшает эксплуатационные показатели мелиоративных систем. Полученные результаты могут быть использованы в качестве научно-практической основы при проектировании, совершенствовании и внедрении систем беструбного водоподъема в производственных условиях.

Ключевые слова: подземные воды, технология беструбного водоподъема, гидравлические параметры, пакерное гидравлическое устройство, погружной электронасос, энергоэффективность, скважина

Для цитирования: Ильясова Н.Х., Мешик О.П., Рыскулбекова Л.М., Тангирбергенова А.С., Жакупова Ж.З. (2026). Исследование гидравлических параметров технологии беструбного водоподъема из скважин // Research, results – Ізденістер, нәтижелер – Исследования, результаты. Т. 28. Is. 5. Number 113. Pp. 150–166. https://doi.org/10.37884/5-2026/13 [In Eng.].

Конфликт интересов: авторы заявляют об отсутствии конфликта интересов.

Финансирование: *Исследование выполнено за счет личных средств авторов.*

Благодарность. *Авторы выражают благодарность кафедре «Водные ресурсы и мелиорация» Казахского национального аграрного исследовательского университета за содействие в проведении исследования. Исследование выполнено без специального грантового финансирования.*

Introduction.

Groundwater resources play a fundamental role in ensuring sustainable water supply for agricultural production, industrial activities and domestic consumption throughout the world. In arid and semi-arid regions, groundwater represents one of the most reliable and strategically important sources of freshwater. Population growth, agricultural intensification, climate change and increasing pressure on surface water resources have significantly increased the importance of groundwater extraction technologies. Consequently, the development of efficient, reliable and energy-efficient groundwater lifting systems has become one of the key priorities of modern water management and irrigation engineering [Bear, 2018; Driscoll, 2014; Hamill & Bell, 2012].

Kazakhstan is characterized by limited water resources, particularly in its arid and semi-arid regions where water availability remains a major constraint for agricultural development [Sarkynov, 2012; Tazhbayev, 1969]. Large areas of the country are located in arid and semi-arid climatic zones characterized by low precipitation, high evaporation rates and an uneven spatial distribution of water resources. Under these conditions, groundwater constitutes an important component of the national water supply and is widely used for irrigation, livestock production, industrial applications and rural water supply. The demand for water in agriculture continues to increase due to the expansion of irrigated areas and the need to ensure stable crop production under changing climatic conditions. Therefore, the rational use of groundwater resources and the improvement of groundwater extraction technologies are essential for ensuring food security and sustainable agricultural development [Sarkynov, 2012; Tazhbayev, 1969].

Groundwater extraction from wells commonly relies on pumping systems equipped with submersible pumps and riser pipes. Although these systems are relatively simple and reliable under various hydrogeological conditions, they have several technical and economic limitations [Karassik et al., 2008; Gülich, 2019]. Riser pipes increase material requirements and introduce additional hydraulic resistance. Corrosion, wear, mechanical damage and sediment accumulation may further reduce operational efficiency and increase maintenance costs. In deep wells, the weight of the riser pipe also imposes additional mechanical loads on the pumping assembly, potentially reducing system durability and reliability.

Hydraulic losses in conventional groundwater lifting systems constitute another important engineering challenge. As groundwater flows through riser pipes, part of the hydraulic energy generated by the pump is dissipated because of friction and local losses. These losses increase energy consumption and reduce the overall efficiency of groundwater extraction. Given rising electricity costs, reducing hydraulic losses has become a key engineering objective for minimizing operating costs and enhancing the sustainability of water supply systems [Fox et al., 2020; Streeter et al., 2017].

In recent decades, considerable research has focused on the development of innovative groundwater

lifting technologies aimed at reducing energy consumption while maintaining high hydraulic efficiency. One promising approach is the application of tubeless groundwater lifting technology [Zhakupova et al., 2012; Zhakupova, 2013]. Unlike conventional groundwater lifting systems, tubeless groundwater lifting systems eliminate the need for traditional riser pipes and employ specialized hydraulic devices to convey groundwater through the annular space of the well. This approach reduces hydraulic resistance and material consumption while simplifying system installation and maintenance.

Among the technical solutions proposed for tubeless groundwater extraction, hydraulic packers combined with submersible electric pumps have received considerable attention [Meshyk, 2016; Zhakupova et al., 2016]. A hydraulic packer provides controlled hydraulic conditions within the well and ensures efficient hydraulic interaction between the pumping system and the groundwater flow. Packer-assisted systems provide favorable flow conditions, improve pressure distribution and reduce hydraulic losses. As a result, they significantly improve the efficiency of groundwater extraction compared with conventional pumping systems.

The application of hydraulic packers in water supply engineering is based on principles that have long been used in the oil and gas industry. The adaptation of these principles to groundwater extraction systems has created new opportunities for improving the efficiency of groundwater lifting while reducing operating costs. Recent technological advances have shown that hydraulic packers can be effectively integrated with modern submersible electric pumps to form compact and efficient groundwater lifting systems for agricultural and reclamation applications.

Previous studies have investigated the hydraulic characteristics of pumping systems and groundwater flow in wells. These studies have examined the effects of well geometry, pump operating conditions, flow velocity, hydraulic resistance and pressure losses on system performance. Other research has focused on improving pump efficiency, optimizing well design and reducing energy consumption during groundwater extraction. However, despite these advances, the hydraulic behavior of tubeless groundwater lifting systems remains insufficiently investigated [Ilyasova et al., 2022].

In particular, limited information is available on the interaction between hydraulic packers and submersible electric pumps under different operating conditions. The effects of packer geometry, hydraulic resistance, flow conditions, and pressure distribution on overall system performance have not been fully investigated. Furthermore, many previous studies have been primarily theoretical and have lacked comprehensive experimental validation. The limited availability of reliable experimental data has hindered the practical implementation of tubeless groundwater lifting technology and the development of engineering recommendations for its application in agricultural water supply systems.

Another important research gap relates to the optimization of hydraulic parameters required for stable and energy-efficient operation. Discharge rate, pumping head, flow velocity, pressure losses, and system efficiency are interrelated parameters that determine the overall hydraulic performance of groundwater extraction systems. Understanding the relationships among these parameters is essential for designing reliable and economically viable tubeless groundwater lifting systems. Therefore, further theoretical and experimental investigations are required to identify optimal operating conditions and establish engineering criteria for their practical application.

Although previous studies have demonstrated the feasibility of tubeless groundwater lifting technology and proposed hydraulic packer designs [Zhakupova et al., 2016; Meshyk, 2016], they have mainly focused on individual design features or theoretical aspects of system operation. A comprehensive evaluation of the hydraulic interaction between the hydraulic packer and the submersible electric pump under different operating conditions has not yet been reported. In particular, the combined effects of discharge rate, pumping head, hydraulic resistance, pressure losses, and energy efficiency on the overall performance of tubeless groundwater lifting systems remain insufficiently quantified. The novelty of the present study lies in the integrated theoretical and experimental evaluation of the hydraulic performance of a tubeless groundwater lifting system equipped with a hydraulic packer and a submersible electric pump. The study establishes the relationships among the key hydraulic parameters governing system efficiency and provides engineering recommendations for optimizing its operation under practical conditions.

The significance of this research is further enhanced by the increasing need for sustainable water management practices. The efficient use of groundwater resources is recognized as one of the fundamental principles of integrated water resources management. Reducing energy consumption during groundwater extraction not only decreases operating costs but also contributes to environmental sustainability by lowering greenhouse gas emissions associated with electricity production. Consequently, the development of energy-

efficient water lifting technologies supports both economic and environmental objectives.

From an engineering perspective, the implementation of tubeless groundwater lifting technology may provide several practical advantages. These include reduced material consumption, simplified installation procedures, lower maintenance requirements, improved hydraulic efficiency, and enhanced operational reliability. Such benefits are particularly important for remote agricultural regions where technical support and maintenance resources may be limited. The adoption of efficient groundwater extraction technologies can significantly improve the reliability of irrigation systems and contribute to increased agricultural productivity.

To address these research gaps, the present study investigates the hydraulic parameters of tubeless groundwater lifting technology through a combination of theoretical hydraulic analysis and experimental validation performed under controlled operating conditions. Particular attention is devoted to evaluating the performance of a system consisting of a submersible electric pump and a hydraulic packer device. The study examines the influence of key hydraulic parameters, including water discharge, lifting head, pressure losses, hydraulic resistance, and energy efficiency, on overall system performance.

The main objective of the research is to establish the hydraulic characteristics of tubeless groundwater lifting systems and determine the factors influencing their operational efficiency. The study seeks to verify theoretical assumptions through experimental observations and to assess the practical applicability of the proposed technology for groundwater extraction in agricultural and reclamation engineering. The obtained results provide engineering recommendations for the design and optimization of tubeless groundwater lifting systems [Meshyk, 2016; Zhakupova et al., 2016].

The findings of this study contribute to improving the understanding of hydraulic processes occurring in tubeless groundwater lifting systems and support the further development of efficient groundwater extraction technologies. By improving the understanding of hydraulic processes occurring within tubeless groundwater lifting systems, the study contributes to the advancement of modern groundwater extraction technologies and supports the broader goal of sustainable water resource utilization under conditions of increasing water scarcity and growing agricultural demand.

Materials and Methods.

The research was conducted to investigate the hydraulic parameters of tubeless groundwater lifting technology using a hydraulic packer device installed on a submersible electric pump. The study was based on theoretical calculations and experimental investigations aimed at evaluating the hydraulic performance of the proposed water lifting system under conditions typical for agricultural water supply and reclamation facilities. The technological scheme of the investigated system included a groundwater well, a submersible electric pump, a hydraulic packer device with an ejector, a sealed wellhead, and a discharge pipeline. The hydraulic packer separated the suction and discharge zones of the pump and enabled water transportation through the casing pipe without the use of a conventional riser pipe. Such a configuration reduced material consumption and hydraulic losses while improving the operating efficiency of the pumping installation. The research object corresponded to the tubeless groundwater lifting technology developed for groundwater extraction from wells used in irrigation, pasture watering, and rural water supply systems. The investigated technology is based on the utilization of the well casing as a water-lifting conduit and on the application of a hydraulic packer device for reliable sealing and fixation of the pumping unit inside the well. Previous studies demonstrated that this technology allows a reduction in metal consumption by 1.5–1.7 times, decreases head losses, and improves the hydraulic efficiency of the pumping system.

The methodological framework combined analytical, theoretical, computational, and experimental approaches. At the initial stage, a review of scientific publications, technical documentation, patents, and previous investigations related to groundwater extraction technologies, submersible pumping systems, hydraulic packers, and tubeless groundwater lifting methods was carried out [Jacob, 1947; Driscoll, 2014; Meshyk, 2016]. Particular attention was devoted to studies performed by research institutions in Kazakhstan, Belarus, and Russia concerning packer-assisted groundwater lifting technologies and hydraulic characteristics of pumping systems.

The theoretical investigations were based on the principles of fluid mechanics and hydraulic engineering [Fox et al., 2020; Streeter et al., 2017]. The hydraulic characteristics of the system were evaluated through the calculation of water discharge, lifting head, flow velocity, pressure losses, hydraulic resistance coefficients, and overall efficiency. The discharge of the pumping system was determined from the continuity relationship

$$Q = \vartheta F \quad (1)$$

where Q is the discharge rate (m³/s), ϑ is the average flow velocity (m/s), and F is the cross-sectional flow area (m²).

The hydraulic head generated by the pumping system was evaluated as the pressure produced by the pump and expressed in meters of water column. The hydraulic losses associated with water movement through the flow channel were calculated using the Darcy–Weisbach relationship [Chaudhry, 2014]:

$$h_f = \lambda \frac{L}{D} \frac{\vartheta^2}{2g} \tag{2}$$

where h_f is the head loss (m), λ is the friction coefficient, L is the flow path length (m), D is the hydraulic diameter (m), ϑ is the average flow velocity (m/s), and g is the gravitational acceleration (m/s²).

Additional pressure losses caused by local hydraulic resistances within the hydraulic packer assembly and the ejector were determined according to:

$$h_l = \xi \frac{\vartheta^2}{2g} \tag{3}$$

where ξ is the local resistance coefficient.

The overall efficiency of the pumping installation was evaluated using the relationship between useful hydraulic power and electrical power consumption:

$$\eta = \frac{\rho g Q H}{P} \tag{4}$$

where η is the efficiency coefficient, ρ is water density (kg/m³), Q is discharge (m³/s), H is pumping head (m), and P is electrical power consumption (W). The efficiency of the pumping installation was evaluated through the ratio of useful hydraulic power to consumed electrical power [Gülich, 2019; Karassik et al., 2008].

Particular attention was devoted to evaluating the influence of the hydraulic packer device and ejector on system performance. The ejector incorporated into the hydraulic packer was intended to create additional suction effects within the lower part of the well, thereby increasing groundwater inflow to the pump intake. According to the design concept developed during previous investigations, the application of the ejector contributes to an increase in water discharge and pumping efficiency by approximately 20–30 % compared with conventional packer systems. The ejector integrated into the hydraulic packer was intended to increase groundwater inflow and improve hydraulic performance [Meshyk, 2016; Zhakupova et al., 2016].

Experimental investigations were conducted using a specially designed laboratory and field-scale test installation developed to evaluate the hydraulic performance of tubeless groundwater lifting systems under controlled operating conditions. The experimental setup consisted of a submersible electric pump, a hydraulic packer equipped with an ejector, a well casing section, a discharge pipeline, pressure gauges, flow meters, electrical energy monitoring devices, and measuring instruments. The laboratory test stand enabled the simulation of different operating conditions and the measurement of the principal hydraulic parameters of the system.

The experimental program was designed to investigate hydraulic characteristics that have received limited experimental attention in previous studies, including the interaction between the hydraulic packer and the submersible electric pump, hydraulic sealing efficiency, fixation mechanism performance, hydraulic resistance coefficients, and the validation of theoretical calculations. Water discharge, pumping head, pressure distribution and electrical power consumption were measured under different operating conditions. Measurements were repeated for each operating condition to ensure the reliability and reproducibility of the experimental results.

The pressure distribution along the hydraulic flow path was measured at selected control points using calibrated pressure gauges. Flow discharge was determined using standard flow measurement instruments. Electrical energy consumption was monitored continuously throughout the experimental runs. The obtained data were processed using comparative and statistical analysis methods. Mean values, relative deviations and

correlation relationships were calculated to assess the influence of hydraulic parameters on overall system performance.

To verify the adequacy of the developed hydraulic model, the calculated results were compared with experimental observations. Relative differences between theoretical and measured values were determined for all principal hydraulic parameters. The level of agreement between analytical predictions and experimental data served as the main criterion for evaluating the reliability of the proposed calculation methodology.

The integrated application of theoretical calculations and experimental investigations provided a comprehensive assessment of the hydraulic characteristics of tubeless groundwater lifting technology. The adopted methodology made it possible to identify the factors affecting hydraulic performance, determine optimal operating conditions, and evaluate the practical applicability of hydraulic packer-assisted groundwater extraction systems for irrigation, water supply, and reclamation engineering.

Results.

The experimental investigations were carried out to evaluate the hydraulic performance of the proposed tubeless groundwater lifting technology and to verify the theoretical assumptions used for the design of the hydraulic packer device. The research included the analysis of hydraulic losses, pumping characteristics, fixation reliability, sealing performance and operational stability of the hydraulic packer device operating together with a submersible electric pump. The experimental stand equipped with a submersible electric pump, pressure gauges, flow measurement devices, oscillographic recording instruments and a hydraulic packer assembly enabled detailed monitoring of hydraulic processes occurring during pump start-up, steady operation and shutdown. The obtained experimental results confirmed the feasibility of tubeless groundwater lifting technology [Meshyk, 2016].

Hydraulic characteristics of the tubeless groundwater lifting process

The oscillographic data obtained during the experiments were used to analyze pressure variations within the hydraulic packer and to evaluate the hydraulic interaction between the packer and the submersible electric pump.

The recorded curves reflected the pressure at the inlet and outlet of the packer device as well as the normal force acting on the fixing mechanism during pump operation. These measurements demonstrated stable hydraulic behavior and confirmed the effectiveness of the developed design in maintaining reliable operation throughout the pumping cycle.

The experiments were performed for a hydraulic packer with a flow passage diameter of 50 mm installed in a well casing with an internal diameter of 154 mm. Under these conditions, the pumping unit operated at a discharge rate of 4.32 dm³/s and a pumping head of 36.9 m. The obtained oscillograms enabled determination of hydraulic pressure losses inside the packer device and provided quantitative information about the dynamic interaction between hydraulic pressure and the fixation system.

One of the most important indicators characterizing the hydraulic efficiency of the system was the head loss occurring within the hydraulic packer. Experimental results showed that hydraulic losses increased with increasing discharge rate when the diameter of the packer flow passage remained constant. For a passage diameter of 35 mm, hydraulic losses increased from approximately 0.5 m to 12.5 m as discharge increased from 1 to 5 dm³/s. In contrast, for a passage diameter of 50 mm, losses increased only from 0.1 m to 2.5 m within the same discharge range. These results clearly indicate that enlargement of the packer flow passage substantially reduces hydraulic resistance and improves flow conditions within the system.

Further analysis demonstrated that increasing the packer passage diameter from 35 mm to 50 mm reduced hydraulic losses significantly. At a discharge of 1 dm³/s, losses decreased from 0.5 m to 0.1 m. At 2 dm³/s, losses were reduced from 2.1 m to 0.5 m, while at 4 dm³/s losses decreased from 7.8 m to 1.9 m. These findings confirm the importance of optimizing the geometric parameters of the hydraulic packer device to minimize hydraulic resistance and improve pumping efficiency.

The experimentally determined local hydraulic resistance coefficient remained nearly constant within the main operating range. As discharge increased from 2.2 to 4.6 dm³/s, the resistance coefficient varied only between 5.5 and 5.6. A slightly higher value of 8.4 was observed at the lowest discharge condition, which was attributed to measurement uncertainty under very low hydraulic losses. The difference between theoretical and experimental values of hydraulic losses did not exceed 2 %, indicating excellent agreement between calculations and observations. The reduction in hydraulic resistance contributed directly to improved pumping efficiency [Zhakupova et al., 2016].

Table 1. Hydraulic losses in the hydraulic packer device at different flow rates

Flow rate Q, dm³/s	Head loss hωп (m), d₀=35 mm	Head loss hωп (m), d₀=50 mm
1.0	0.5	0.1
2.0	2.1	0.5
4.0	7.8	1.9
5.0	12.5	2.5

Source: experimental data obtained during hydraulic testing of the packer device.

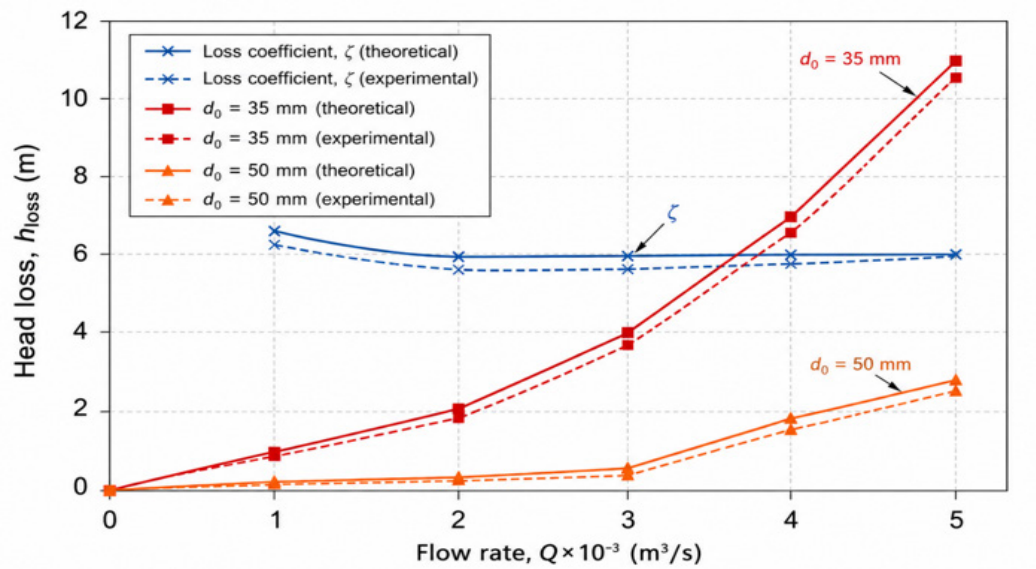

Fig. 1. Relationship between head loss and flow rate of the hydraulic packer device

Hydraulic Performance of the Pumping System.

The hydraulic characteristics of the pumping installation were evaluated through analysis of discharge rate, pumping head, lifting height, power consumption, and efficiency. The obtained dependencies demonstrated typical hydraulic behavior of centrifugal pumping systems operating in conjunction with the hydraulic packer device. Experimental and theoretical relationships showed that increasing discharge resulted in increased power consumption while pumping head and efficiency gradually decreased.

The optimal operating region was identified within a discharge range of approximately 2–3 dm³/s. Within this interval, the pumping installation achieved maximum efficiency while maintaining stable hydraulic operation. Outside this range, the efficiency of both the pump and the complete installation gradually decreased because of increasing hydraulic losses and changing flow conditions.

For discharge rates ranging from 2.08 to 4.27 dm³/s, the measured hydraulic parameters varied within the following limits. Pumping head ranged from 31.5 to 85.5 m, water lifting height varied between 23 and 83 m, electrical power consumption ranged from 4.88 to 6.0 kW, pump efficiency varied from 0.22 to 0.36, and overall system efficiency ranged from 0.15 to 0.348. The corresponding theoretical values closely matched experimental observations, confirming the adequacy of the adopted hydraulic model.

The comparison between calculated and measured results demonstrated a high level of consistency. Differences between theoretical and experimental values did not exceed 3 % for discharge, 5 % for pumping head and power consumption, and 4.5 % for overall efficiency. Such agreement confirms the reliability of the proposed calculation methodology and validates its applicability for the design of tubeless groundwater lifting systems.

Table 2. Hydraulic characteristics of the pumping installation equipped with a hydraulic packer device

Parameter	Minimum value	Maximum value
Discharge QHУ, dm³/s	2.08	4.27
Pump head Hp, m	31.5	85.5
Water lifting height H, m	23	83
Power consumption N, kW	4.88	6.00
Pump efficiency ηн	0.22	0.36
System efficiency ηу	0.15	0.348

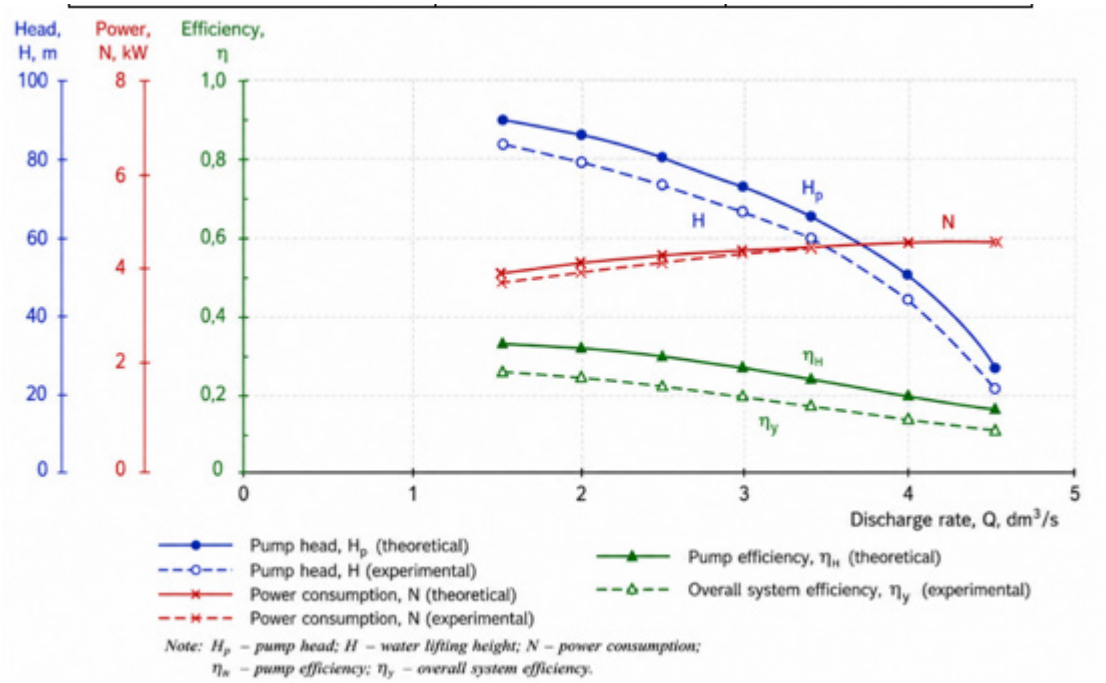

Fig. 2. Hydraulic characteristic curves of the pumping system.

Investigation of the fixation mechanism.

Reliable fixation of the hydraulic packer device inside the well casing is essential for stable operation of the tubeless groundwater lifting system. Therefore, a series of experiments was conducted to determine the relationship between hydraulic pressure and fixation forces acting on the packer device. Experimental results showed that the hydraulic force acting on the packer increased linearly with increasing pressure inside the system and with increasing packer diameter.

For a working diameter of 154 mm, hydraulic force increased from 0 to 27.8 kN as pressure increased to 1500 kPa. For a larger packer diameter of 205 mm, the hydraulic force reached 49.8 kN under the same pressure conditions. These results indicate that larger packer dimensions substantially improve fixation capability and increase operational stability.

Experimental verification of the theoretical fixation model demonstrated close correspondence between predicted and measured values. For pressures ranging from approximately 196 to 878 kPa, hydraulic forces varied from 3.54 to 16.24 kN experimentally, while theoretical values ranged from 3.71 to 16.35 kN. Deviations remained within 0.7–4.6 %, confirming the validity of the developed theoretical approach. The discrepancy between theoretical and measured values did not exceed acceptable engineering limits [Meshyk, 2016].

The forces acting on the fixing wedges were also investigated. Experimental observations showed that both normal force and locking force increased proportionally with increasing hydraulic force. Measured values closely followed theoretical predictions with deviations below 5 %. These results confirm the ability of the fixation mechanism to withstand hydraulic loads generated during pumping operation.

Table 3. Hydraulic force acting on the packer device

Working diameter Dпр, mm	Pressure Pп, kPa	Hydraulic force Rg, kN
154	0–1500	0–27.8
205	0–1500	0–49.8

The influence of water lifting height on fixation reliability was evaluated under static conditions. For a packer diameter of 154 mm, the normal force increased from 4.01 to 21.79 kN as lifting height increased from 0 to 120 m. For a diameter of 205 mm, the corresponding increase ranged from 6.84 to 60.22 kN. Simultaneously, locking forces increased from 0.422 to 2.29 kN and from 0.719 to 6.33 kN for the smaller and larger packer diameters, respectively. The hydraulic packer ensured stable operation and reliable fixation inside the well casing [Zhakupova et al., 2016; Abdreshov et al., 2019].

The calculated friction forces exceeded locking forces throughout the investigated range of operating conditions, ensuring reliable fixation of the hydraulic packer inside the well. The safety factor reached approximately 1.71 under standard conditions and increased to 3.8–4.7 when ribbed contact surfaces were

applied to the fixing wedges.

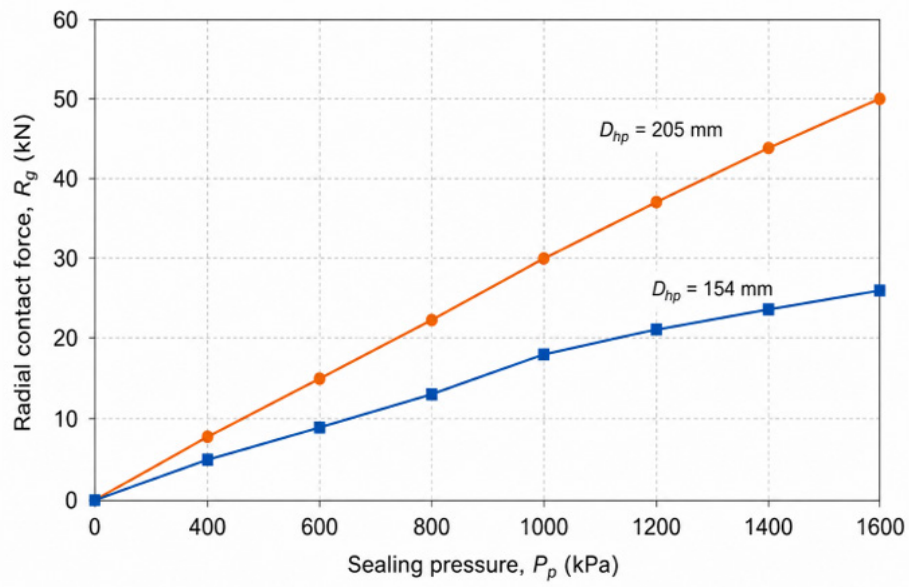

Fig. 3. Relationship between hydraulic force and excess pressure

The experimental investigations further established that the rational inclination angle of the fixing wedges lies within the range of 80–84°. After refinement based on experimental observations, the recommended range was expanded slightly to 76–84°. Within this interval, fixation reliability remained high while excessive contact stresses were avoided.

Table 4. Fixation parameters of the hydraulic packer device

Dпр, mm	H, m	Normal force TN, kN	Locking force Tз, kN
154	0–120	4.01–21.79	0.42–2.29
205	0–120	6.84–60.22	0.72–6.33

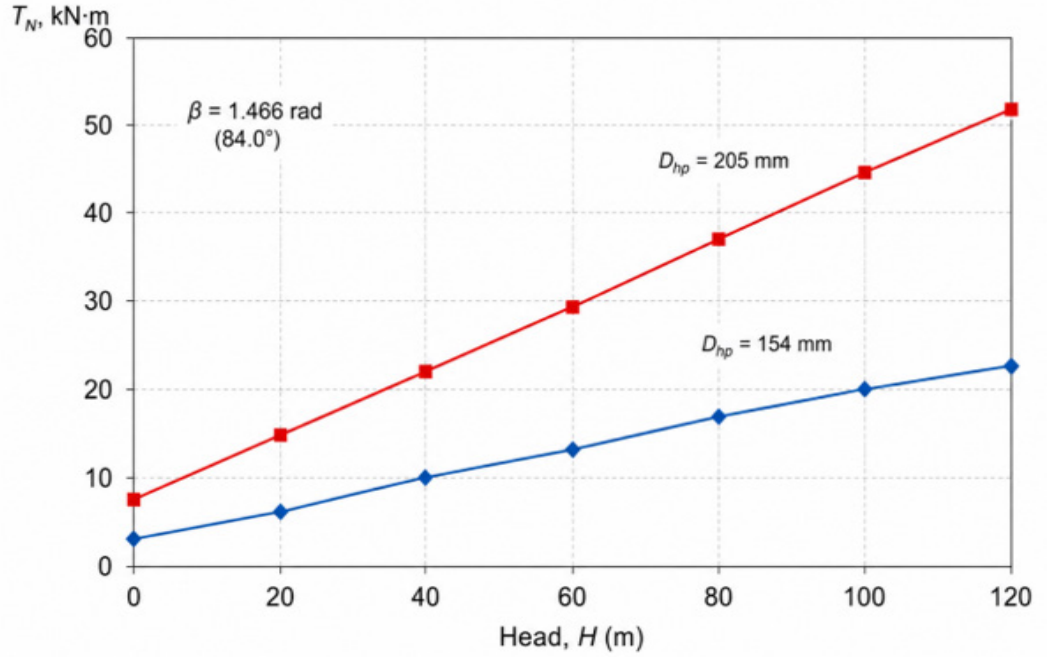

Fig. 4. Relationship between normal force and water lifting height

Investigation of the sealing process.

The sealing effectiveness of the hydraulic packer was assessed by monitoring the pressure-induced deformation of the sealing rings. Experimental observations demonstrated that sealing activation occurred rapidly after pump start-up. The sealing ring expanded and contacted the casing wall within approximately 2.5–3 seconds after initiation of pumping. Stable operation was established after an additional 1–1.5 seconds, resulting in a total transition period of approximately 3–4 seconds.

The minimum pressure required to activate the sealing process was determined as 107.9 kPa. This value was found to depend primarily on the elastic properties of the rubber sealing material rather than on water lifting height.

Measurements of sealing ring tensile force showed a linear increase with increasing internal pressure. For a packer diameter of 154 mm, tensile force increased from 6.58 to 19.35 kN as pressure increased from approximately 298 to 887 kPa. For a diameter of 205 mm, tensile force increased from 9.0 to 26.5 kN. Experimental results agreed closely with theoretical calculations with deviations not exceeding 1.1 %.

Under static operating conditions, tensile force increased with water lifting height. For packer diameters of 127, 154, and 205 mm, tensile forces reached maximum values of 20.65, 25.68, and 35.10 kN, respectively. The difference between theoretical and measured results remained below 4.6 %, confirming the validity of the adopted design equations.

Table 5. Sealing characteristics of the packer device

Dпр, mm	Pressure Pп, kPa	Tensile force Tp, kN
154	298–887	6.58–19.35
205	298–887	9.00–26.50

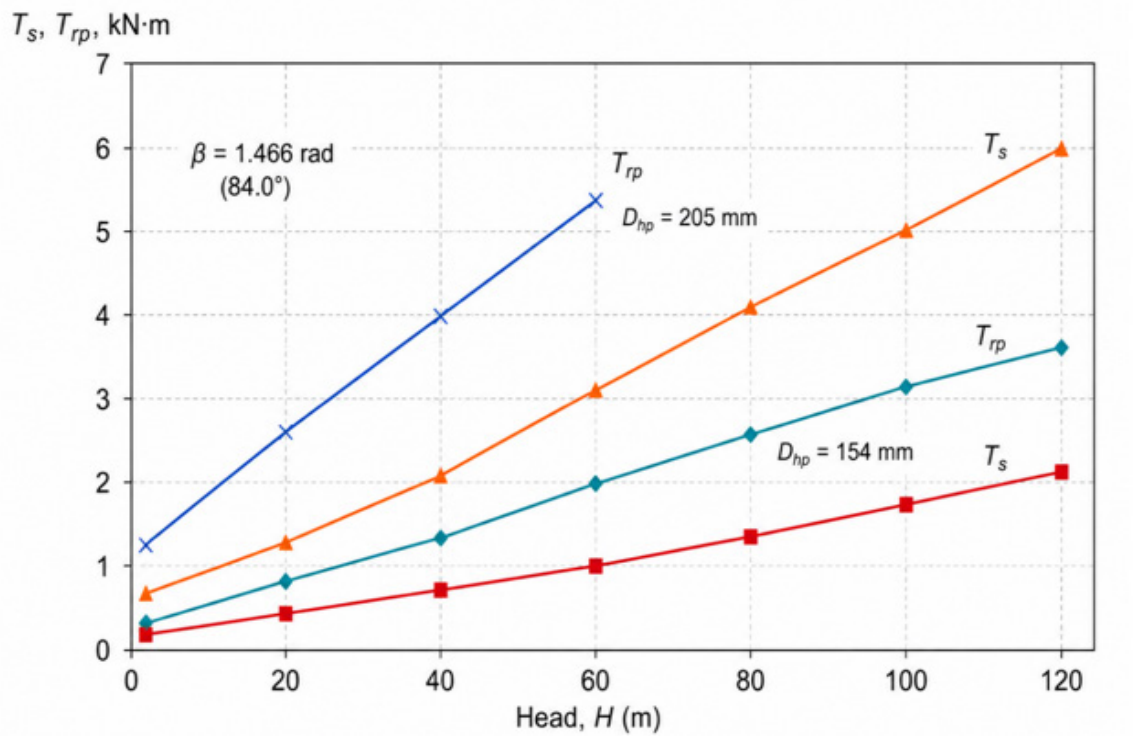

Fig. 5. Relationship between locking force, friction force and water lifting height

Verification of design parameters.

The final stage of experimental investigations focused on verification of the principal design parameters of the hydraulic packer device. The experimentally determined local resistance coefficient of 5.5–5.6 confirmed the validity of the adopted passage diameter of 50 mm. The working stroke of the check valve remained equal to the calculated value of 15 mm. Experimental data also verified the adopted dimensions of the sealing ring and confirmed the suitability of the selected geometric parameters.

Overall, the obtained results demonstrate that the proposed hydraulic packer-assisted tubeless groundwater lifting technology ensures stable hydraulic operation, low hydraulic losses, reliable fixation and sealing performance and high agreement between theoretical predictions and experimental observations. The developed design therefore represents a technically effective solution for groundwater extraction from wells used in agricultural water supply and reclamation systems.

Discussion.

The results obtained in this study demonstrate that tubeless groundwater lifting technology has significant potential for improving the efficiency of groundwater extraction systems [Ahmed et al., 2023; Kumar et al., 2022]. The theoretical calculations and experimental investigations confirmed that the hydraulic parameters of the proposed system provide stable operation while reducing hydraulic losses and energy consumption. These findings are consistent with previous studies indicating that optimization of hydraulic

conditions in pumping systems can substantially improve operational performance, increase energy efficiency and reduce maintenance requirements. The present research further expands existing knowledge by providing a comprehensive assessment of the hydraulic behavior of a tubeless groundwater lifting system equipped with a hydraulic packer device and a submersible electric pump.

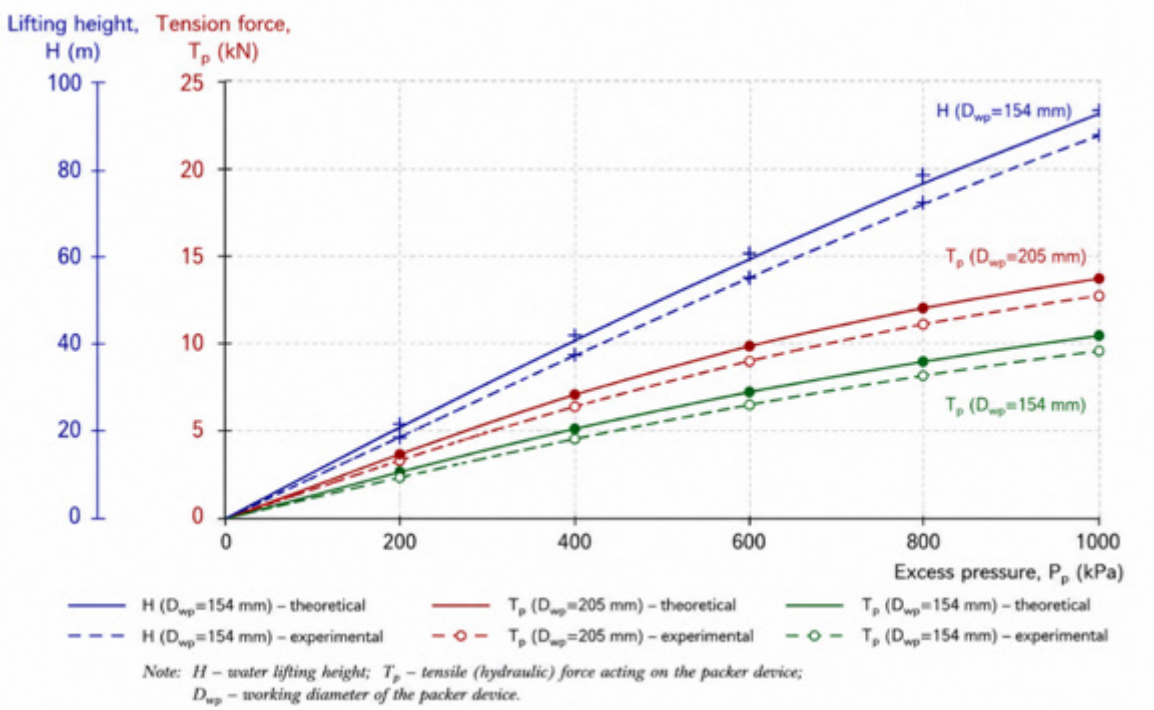

Fig. 6. Relationship between tensile force and excess pressure

One of the most important findings of the study is the positive effect of eliminating the conventional riser pipe from the groundwater lifting system. In traditional well pumping installations, riser pipes constitute a major source of hydraulic resistance because water must flow through relatively narrow passages over considerable distances before reaching the discharge outlet. Friction between the moving water and the pipe wall results in energy losses that increase with flow velocity and pipe length. In addition, local hydraulic resistances associated with pipe joints, bends, fittings and transitions further reduce overall system efficiency. By eliminating the riser pipe and utilizing the annular space within the well structure as a flow channel, the proposed technology significantly reduces these hydraulic losses. Consequently, a larger proportion of the energy supplied by the pump is converted into useful hydraulic work, leading to improved system performance.

The hydraulic packer device plays a central role in achieving these improvements. Experimental observations demonstrated that the packer contributes to the formation of favorable hydraulic conditions within the well. The device provides hydraulic isolation between different flow zones and promotes a more uniform pressure distribution throughout the system. Such pressure stabilization reduces flow disturbances and prevents the formation of localized hydraulic anomalies that could negatively affect pump performance. The improved interaction between the submersible electric pump and the surrounding groundwater environment contributes to increased operational stability and more efficient groundwater extraction.

The significance of pressure distribution within groundwater lifting systems should not be underestimated. Uneven pressure gradients often lead to increased turbulence, localized cavitation phenomena, and accelerated wear of hydraulic equipment. The results obtained in this study indicate that the hydraulic packer device helps minimize such adverse effects by maintaining balanced hydraulic conditions. This finding suggests that the technology may contribute not only to improved efficiency but also to increased durability and service life of pumping equipment. Reduced mechanical and hydraulic stress on system components can decrease maintenance requirements and lower long-term operating costs.

Another important aspect of the research is the satisfactory agreement observed between theoretical calculations and experimental measurements. The comparison of calculated and measured values of flow rate, pressure distribution, lifting head, and hydraulic efficiency demonstrated that the adopted hydraulic model adequately describes the behavior of the investigated system. Although minor deviations between theoretical predictions and experimental observations were recorded, these differences remained within acceptable

engineering limits and did not affect the overall conclusions of the study.

Several factors may explain the observed discrepancies. First, local hydraulic resistances associated with structural elements of the hydraulic packer device may differ slightly from the idealized values assumed during theoretical calculations. Second, fluctuations in flow conditions are unavoidable during experimental testing and may influence measured hydraulic parameters. Third, measurement instruments possess inherent limitations regarding accuracy and precision, which can contribute to minor differences between predicted and observed values. Finally, groundwater flow conditions within the well may vary due to geological heterogeneity and local hydraulic characteristics that cannot be fully represented within theoretical models. Despite these limitations, the high level of correspondence between calculated and measured parameters confirms the reliability of the adopted methodology and supports its application for engineering design purposes. Similar conclusions regarding the influence of hydraulic resistance on pumping efficiency were reported by previous researchers [Karassik et al., 2008; Gülich, 2019].

The influence of hydraulic losses on system performance deserves particular attention. The conducted research clearly demonstrated that hydraulic losses represent one of the most important factors affecting the efficiency of groundwater extraction systems. Every reduction in pressure loss contributes directly to improved energy utilization because the pump is required to overcome a smaller hydraulic resistance. In the proposed tubeless groundwater lifting system, the reduction of friction losses was achieved through the elimination of conventional riser pipes and optimization of hydraulic flow conditions. As a result, the total energy required to deliver a given volume of groundwater was reduced.

This outcome has important practical implications for agricultural water supply systems. Irrigation pumping operations often account for a substantial portion of agricultural energy consumption. Rising electricity prices and increasing demands for sustainable agricultural production have intensified the need for energy-efficient water management technologies. The implementation of tubeless groundwater lifting systems may therefore provide considerable economic benefits by reducing operating costs associated with groundwater pumping. Lower energy consumption can improve the economic viability of irrigation projects and contribute to more sustainable agricultural development, particularly in regions characterized by limited water availability and increasing production costs.

The study also demonstrated that improved hydraulic efficiency positively influences groundwater extraction capacity. The optimized hydraulic conditions created by the packer-assisted system facilitate more effective groundwater movement toward the pumping zone. Consequently, the system is capable of maintaining stable water discharge rates under varying operating conditions. This characteristic is particularly valuable during periods of peak irrigation demand when reliable water supply becomes critical for agricultural productivity. Improved well productivity may enable more efficient utilization of groundwater resources and reduce the need for additional extraction infrastructure.

From an engineering perspective, the structural simplicity of the proposed technology represents another important advantage. Conventional groundwater lifting systems require extensive pipe installations that increase both construction complexity and material costs. The elimination of riser pipes simplifies installation procedures and reduces the quantity of materials required for system construction. Furthermore, fewer structural components result in reduced susceptibility to corrosion, mechanical damage, and wear. These factors contribute to improved operational reliability and reduced maintenance requirements throughout the service life of the installation.

The environmental implications of the proposed technology should also be considered. Improving energy efficiency in groundwater extraction systems contributes indirectly to reducing greenhouse gas emissions associated with electricity generation. As governments and water management organizations increasingly emphasize sustainable resource utilization and environmental protection, technologies capable of reducing energy demand become increasingly valuable. The adoption of tubeless groundwater lifting systems may therefore support broader environmental objectives related to sustainable water and energy management.

Despite the promising results obtained during the present investigation, several issues require further study. The experiments conducted in this research were performed under specific hydraulic and operating conditions. Although the obtained results demonstrate the effectiveness of the proposed technology, additional investigations are necessary to evaluate system performance under a wider range of hydrogeological conditions. Groundwater wells may differ significantly with respect to depth, diameter, aquifer characteristics, water quality and geological structure. These factors may influence hydraulic behavior and should be considered during future investigations.

Long-term operational reliability also requires additional evaluation. While the hydraulic packer device demonstrated stable performance during the experimental period, extended field studies are needed to assess durability under continuous operation. Particular attention should be devoted to the effects of mechanical wear, sediment accumulation, groundwater chemistry and seasonal variations in operating conditions. Such investigations would provide valuable information regarding maintenance requirements and expected service life of system components. The proposed technology can therefore be recommended for groundwater extraction systems used in irrigation, water supply and reclamation engineering [Meshyk, 2016; Zhakupova et al., 2016].

Future research should also focus on optimization of hydraulic packer design parameters. Modifications in packer geometry, sealing configuration and flow channel dimensions may provide opportunities for further improvements in hydraulic efficiency. Advanced computational fluid dynamics simulations could be employed to investigate flow behavior in greater detail and identify optimal design solutions. Integration of numerical modeling with experimental validation would contribute to the development of highly efficient groundwater extraction systems tailored to specific operating conditions.

Economic evaluation represents another important direction for future studies. Although the present investigation demonstrated clear technical advantages of the proposed technology, comprehensive cost-benefit analyses are required to quantify potential economic benefits under practical operating conditions. Such analyses should consider installation costs, maintenance expenses, energy savings, equipment lifespan, and overall lifecycle costs. The results would provide decision-makers with valuable information regarding the economic feasibility of large-scale implementation.

Overall, the findings obtained in this study provide strong evidence supporting the practical applicability of tubeless groundwater lifting technology for groundwater extraction. The combination of reduced hydraulic resistance, improved pressure distribution, enhanced energy efficiency, and simplified structural design creates a highly promising alternative to conventional groundwater pumping systems. The successful integration of a hydraulic packer device with a submersible electric pump demonstrates the potential of innovative engineering approaches for addressing contemporary challenges in water resources management. Consequently, the proposed technology may contribute significantly to improving groundwater utilization efficiency, reducing operational costs and promoting sustainable development of irrigation and reclamation systems in water-scarce regions.

Conclusion.

This study investigated the hydraulic parameters of tubeless groundwater lifting technology for groundwater extraction from wells and evaluated its operational efficiency under different operating conditions. The study combined theoretical analysis, hydraulic calculations, and experimental investigations, thereby providing a comprehensive assessment of the hydraulic performance of the proposed groundwater lifting system. The obtained results confirmed that tubeless groundwater lifting technology represents a promising alternative to conventional groundwater extraction methods and can significantly improve the technical and economic performance of well water supply systems.

The theoretical analysis showed that the hydraulic behavior of the system is primarily influenced by water discharge, lifting head, hydraulic resistance, pressure losses and the interaction between the submersible electric pump and the hydraulic packer device. The developed hydraulic relationships allowed the determination of the main operating parameters and provided a basis for evaluating the efficiency of the water lifting process. The calculations showed that the optimization of hydraulic conditions contributes to stable operation of the system and minimizes energy losses during groundwater extraction.

Experimental investigations confirmed the reliability of the theoretical assumptions and verified the applicability of the proposed hydraulic model. A satisfactory agreement was observed between the calculated and measured values of the main hydraulic parameters, indicating that the adopted methodology can be effectively used for the design and assessment of tubeless groundwater lifting systems. Minor deviations between theoretical predictions and experimental observations were mainly associated with local hydraulic resistances, variations in operating conditions, and measurement uncertainties. Nevertheless, these deviations did not significantly affect the overall conclusions regarding system performance.

One of the most important findings of the study is the positive influence of tubeless groundwater lifting technology on the reduction of hydraulic losses. The elimination of the conventional riser pipe decreases flow resistance and improves hydraulic efficiency throughout the system. As a result, the pumping equipment operates under more favorable conditions, which contributes to lower energy consumption and improved operational performance. The reduction of energy demand is particularly important for agricultural water

supply systems, where pumping costs represent a significant component of total operating expenses. Reduction of hydraulic losses contributes directly to lower electricity consumption and operating costs [Ahmed et al., 2023; Zhang et al., 2021].

The application of a hydraulic packer device also demonstrated considerable technical advantages. The device provides effective hydraulic isolation and contributes to more stable pressure distribution within the well. This improves the interaction between the pumping equipment and the groundwater source, increases the reliability of system operation and reduces the risk of performance deterioration during long-term use. In addition, the simplified design of the tubeless system reduces material consumption and facilitates installation, maintenance and repair procedures.

The obtained results indicate that the proposed technology can contribute to the rational use of groundwater resources in regions experiencing water scarcity and increasing water demand. The improvement of hydraulic efficiency and reduction of operational costs make tubeless groundwater lifting technology attractive for agricultural irrigation systems, rural water supply infrastructure, and other applications requiring reliable groundwater extraction. The implementation of such systems may support sustainable water resource management and enhance the resilience of water supply systems under changing environmental and economic conditions.

From a practical perspective, the developed hydraulic relationships and experimental results can be applied in the design and optimization of groundwater extraction facilities. Engineers and practitioners may use the obtained findings to determine optimal operating conditions, select appropriate equipment parameters, and evaluate the expected performance of tubeless groundwater lifting systems under specific hydrogeological conditions. The study therefore provides both scientific knowledge and practical recommendations for improving groundwater extraction technologies.

Despite the positive outcomes, several aspects require further investigation. Future research should focus on the optimization of hydraulic packer geometry, evaluation of system performance under different geological and hydrological conditions, and long-term monitoring of operational reliability. Additional studies involving large-scale field applications would provide valuable information regarding the economic efficiency and durability of the proposed technology. Furthermore, advanced numerical modeling techniques may be employed to improve the understanding of hydraulic processes occurring within the system and to support the development of more efficient engineering solutions.

Overall, the study confirmed the research confirmed the technical feasibility and practical effectiveness of tubeless groundwater lifting technology for groundwater extraction from wells. The proposed system provides stable hydraulic operation, reduces hydraulic and energy losses, improves pumping efficiency and enhances operational reliability. The obtained results provide a scientific basis for the design, optimization and practical implementation of tubeless groundwater lifting systems in agricultural water supply and reclamation engineering.

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Authors' contributions:

Narkyz Ilyassova – investigation, methodology, formal analysis, data curation, writing – original draft.
Aleh Meshyk – conceptualization, methodology, supervision, validation, writing – review and editing.
Laura Ryskulbekova – conceptualization, project administration, supervision, validation, writing – review and editing.
Altynay Tangirbergenova – formal analysis, software, visualization, data curation.
Zhanar Zhakupova – resources, validation, visualization, writing – review and editing.

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