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Review article

Oil and Algorithms: How Artificial Intelligence Turns Data into Energy

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ABSTRACT
The article explores howartificial intelligence is applied in the oil industry, with a focus on transforming data into new energy sources. AI is used to optimize oil extraction and refining processes, leading to higher productivity, lower costs, and improved safety. The use of advanced algorithms – such as machine learning and the Internet of Things - significantly enhances forecasting accuracy, reveals hidden patterns, and enables automation. These technologies support effective risk management, cost reduction, and faster operations, while also improving environmental sustainability. AI encourages the efficient use of natural resources and helps reduce environmental impact, improving both the economic and environmental performance of oil companies. Overall, the use of AI in the oil industry creates new opportunities for cleaner, more efficient production, making operations more sustainable over the long term.

Keywords: *artificial intelligence; oil industry; forecasting; automation.*

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Научный обзор

Нефть и алгоритмы: как искусственный интеллект превращает данные в энергию

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АННОТАЦИЯ
В статье рассматривается применение искусственного интеллекта в нефтяной промышленности, особое внимание уделяется трансформации данных в новые источники энергии. Искусственный интеллект используется для оптимизации процессов добычи и переработки нефти, что способствует повышению производительности, снижению затрат и увеличению безопасности. Внедрение инновационных алгоритмов, таких как машинное обучение и интернет вещей, позволяет значительно улучшать точность прогнозирования, выявлять скрытые закономерности и автоматизировать процессы. Эти технологии помогают эффективно управлять рисками, минимизировать затраты и ускорять операции, а также повышают экологическую устойчивость. Искусственный интеллект способствует рациональному использованию природных ресурсов и снижению воздействия на окружающую среду, улучшая как экономические, так и экологические показатели нефтяных компаний. В целом использование искусственного интеллекта в нефтяной отрасли открывает новые возможности для более эффективного и экологически безопасного производства, делая процессы более устойчивыми в долгосрочной перспективе.

Ключевые слова: *искусственный интеллект, нефтяная промышленность, прогнозирование, автоматизация.*

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Ғылыми шолу

Мұнай және алгоритмдер: жасанды интеллект деректерді энергияға қалай айналдырады

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АННОТАЦИЯ
Мақалада деректерді жаңа энергия көздеріне айналдыруға баса назар аудара отырып, мұнай өнеркәсібінде жасанды интеллекттің қолданылуы қарастырылады. Жасанды интеллект өнімділікті арттыруға, шығындарды азайтуға және қауіпсіздікті арттыруға ықпал ететін мұнай өндіру және өңдеу процестерін оңтайландыру үшін қолданылады. Машиналық оқыту және Заттар Интернеті сияқты инновациялық алгоритмдерді енгізу болжау дәлдігін, жасырын үлгілерді анықтауды және процестерді автоматтандыруды айтарлықтай жақсартады. Бұл технологиялар тәуекелдерді тиімді басқаруға, шығындарды азайтуға және операцияларды жеделдетуге, сондай-ақ экологиялық тұрақтылықты арттыруға көмектеседі. Жасанды интеллект табиғи ресурстарды ұтымды пайдалануға ықпал етеді және қоршаған ортаға әсерді азайтады, мұнай компанияларының экономикалық және экологиялық көрсеткіштерін жақсартады. Тұтастай алғанда, мұнай өнеркәсібінде жасанды интеллектті пайдалану тиімдірек және экологиялық таза өндіріс үшін жаңа мүмкіндіктер ашады.
Негізгі сөздер: *жасанды интеллект, мұнай өнеркәсібі, болжау, автоматтандыру.*

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Introduction

Today's oil and gas industry faces numerous challenges, including the need to improve production efficiency, reduce environmental risks, and lower costs across all stages of the production cycle. Amid global climate change, rising energy demand, and growing operational costs, finding innovative solutions to improve efficiency has become a top priority for the industry. One of the most promising tools for addressing these challenges is artificial intelligence (AI), which can convert large volumes of data into valuable insights and practical solutions [1].

In recent years, AI has been actively introduced into various aspects of the oil and gas industry, from equipment monitoring and fault prediction to drilling optimization and logistics management. Machine learning algorithms and big data analysis can significantly enhance forecasting accuracy, accelerate decision-making, and strengthen process control – ultimately reducing costs and improving operational safety.

This article aims to explore how AI, through data integration, serves as new "energy driver" for the oil and gas industry, supporting both economic growth and environmental sustainability. The paper examines key areas of AI application in this oil and gas sector, outlines its advantages and challenges, and discusses potential directions for future technological development and optimization.

Literature review

In the oil and gas industry, AI not only boosts efficiency, but also helps reduce costs, enhance safety, and support environmental sustainability. Modern data processing technologies and AI algorithms enable the industry to address a wide range of challenges – from improving production efficiency to predicting equipment failures [2].

Practical Applications of AI in Kazakhstan. In recent years, a number of AI-driven projects have been launched in Kazakhstan's oil and gas sector. A study by E.S. Kolbikova demonstrates the use of machine learning algorithms (including clustering and the nearest neighbor method) for lithofacies classification and forecasting reservoir properties using geophysical data [3]. Zhetruov Zh.T., et al. demonstrated improved transparency and explainability of predictive models of neural network-based predictive models for managing oil field development [4].

Big Data Analysis in The Oil and Gas. Today, oil companies generate massive volumes of data – from seismic surveys to equipment performance. AI enables efficient processing of this data, accelerating decision-making and enhancing forecasting accuracy. For example, machine learning algorithms are applied to sensor data to accurately identify hydrocarbon reservoirs and optimize drilling strategies.

Failure Prediction and Operational Safety Enhancement. AI is increasingly being used to monitor equipment conditions and predict potential failures. Neural networks and other algorithms analyze sensor data and help prevent costly failures, reduce downtime, and enhance operational safety. AI systems provide timely warnings of possible failures, helping to ensure more stable operations.

Automation and Enhanced Oil Recovery (EOR) Methods. AI supports the implementation of advanced oil production techniques, including EOR. Algorithms analyze geophysical data to identify the most effective strategies for injecting water or carbon dioxide into reservoirs. This approach increases oil recovery rates while reducing the chemical costs.

Environmental Monitoring and Emission Control. The oil and gas sector increasingly relies on AI to monitor emissions and mitigate environmental risks. Algorithms can detect gas or oil leaks in real time, enabling rapid emergency response and minimizing environmental damage.

Optimization of Logistics and Inventory Management. AI is also used to streamline logistics, enhance inventory management, and forecast resource needs. Data-driven algorithms enable accurate route planning and reduce logistics costs.

Materials and methods

The oil and gas sector has long been one of the most dynamic and capital-intensive industries. In recent years, AI and data processing algorithms have become key drivers of process optimization across all stages, from production and transportation to hydrocarbon processing. However, several important aspects remain underexplored in the literature, despite their potential significance for the industry's future.

Integrating Diverse Data Sources in Geologically Complex Reservoirs. One of the key challenges in the oil and gas sector is managing the wide range of data types originating from different sources – such as drilling rigs, pressure and temperature sensors, equipment monitoring systems, geological reservoir data, satellite images, and aerial photographs. This data is often non-standardized, and highly variable in format. AI can play a crucial role in harmonizing this heterogeneous data into unified systems, enabling more accurate modeling of well dynamics and equipment performance. A major limitation is that current algorithms often struggle to efficiently process such heterogeneous data. This highlights the need for new machine learning techniques capable of handling multimodal data (text, numeric, images, etc.), which would enable real-time forecasting and data-driven decision-making [5].

AI-Driven Development of Advanced Oil Recovery Methods. Enhanced Oil Recovery (EOR) techniques include injecting carbon dioxide, water-based fluids, or chemicals to increase reservoir output. Despite advances in these technologies, many reservoirs around the world remain underutilized, and conventional extraction methods fail to recover a significant portion of the oil. In this context, AI can support the development of more effective tools for predicting the fluid behavior in reservoirs

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and optimizing EOR strategies tailored to specific geological conditions.

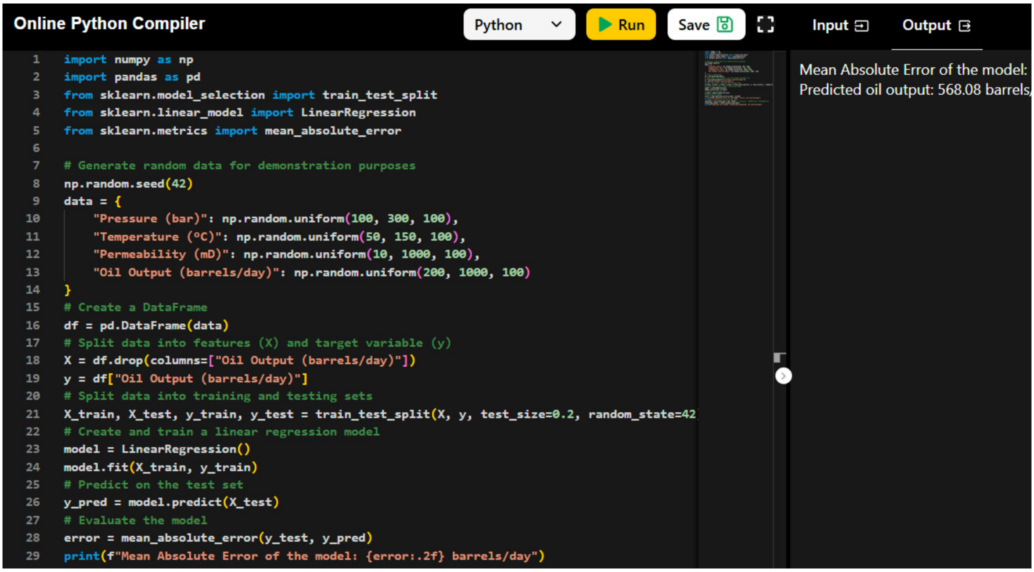
By analyzing historical data and seismic data, AI can identify the most effective injection method for each stage of field development, helping to avoid the cost of deploying inefficient technologies.

AI-Based Approaches to Forecasting Equipment Failures and Industrial Accident. In the oil and gas industry, equipment-related accidents often occur during periods of peak production, when operational systems are under maximum stress. However, beyond traditional forecasting methods based on statistical data, AI can analyze the equipment behavior in real time, detect subtle patterns, and anticipate breakdowns by identifying early-stage anomalies in system performance [6].

Modern machine learning algorithms, such as neural networks, can not only assess the current condition of equipment, but also detect subtle data anomalies that often go unnoticed by human operators. Such early-stage anomalies may appear weeks or even months before a failure and allow for proactive maintenance planning, helping to prevent critical incidents [7].

Autonomous Oil Production Systems Powered by AI. A particularly promising direction is the development of autonomous oil rigs capable of operating in remote and inaccessible environments. By integrating AI with robotics and Internet of Things technologies, it becomes possibile to develop rigs that not only perform routine operations autonomously, but also adapt to changing external conditions, predict maintenance needs, and determine optimal operating modes without human intervention [8].

For example, drilling rigs can be designed to automatically adjust their operational parameters in real time based on sensor data received at specific depths. Additionally, these rigs may be equipped with self-diagnostics and self-healing systems to minimize human error and lower maintenance costs [9].




```python
import numpy as np
import pandas as pd
from sklearn.model_selection import train_test_split
from sklearn.linear_model import LinearRegression
from sklearn.metrics import mean_absolute_error

# Generate random data for demonstration purposes
np.random.seed(42)
data = {
    "Pressure (bar)": np.random.uniform(100, 300, 100),
    "Temperature (ºC)": np.random.uniform(50, 150, 100),
    "Permeability (mD)": np.random.uniform(10, 1000, 100),
    "Oil Output (barrels/day)": np.random.uniform(200, 1000, 100)
}
# Create a DataFrame
df = pd.DataFrame(data)
# Split data into features (X) and target variable (y)
X = df.drop(columns=["Oil Output (barrels/day)"])
y = df["Oil Output (barrels/day)"]
# Split data into training and testing sets
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2, random_state=42
# Create and train a linear regression model
model = LinearRegression()
model.fit(X_train, y_train)
# Predict on the test set
y_pred = model.predict(X_test)
# Evaluate the model
error = mean_absolute_error(y_test, y_pred)
print(f"Mean Absolute Error of the model: {error:.2f} barrels/day")
```

Figure 1. Program

Digital Transformation in the Oil and Gas Industry. Despite rapid progress, most oil companies still rely on conventional methods of production management and oil extraction. Shifting to digital and more sustainable technologies requires not only the adoption of advanced digital solutions, but also a cultural transformation within the organizations. AI plays a critical role in accelerating this transition by enabling companies to leverage new data sources, generate more accurate forecasts and streamline operations. An often-overlooked factor is the role of digital infrastructure in shaping the broader oil and gas ecosystem. Effective AI integration demands high-speed, secure communication channels, and new models of collaboration with data and equipment providers. Seamless AI-enabled collaboration across the supply chains lays the foundation for developing digital twins of fields and production systems [10].

AI and Environmental Sustainability in Oil and Gas. AI enhances not only operational efficiency but also environmental sustainability. This is achieved through accurate carbon emission forecasting, more efficient resource utilization, and reduced atmospheric pollution. For instance, AI can minimize methane emissions by predicting leak locations and associated risks in real time during oil production and refining [11].

Fig 1 illustrates a Python-based simulation that generates synthetic data on pressure, temperature, permeability, and oil output, and trains a linear regression model. This program uses historical data to train the model, evaluate its accuracy, and forecast oil output on new input parameters [12].

This program performs the following tasks:

– Generates synthetic datasets for pressure, temperature, permeability, and oil output.

– Builds a linear regression model to estimate oil output from input features.
– Trains and validates the model on historical data.
– Generates oil output predictions for new input values.

Fig. 2 presents a scatter plot comparing actual and predicted oil output values. The red dashed line indicates perfect prediction alignment. Fig. 3 shows a 3D scatter plot of pressure, temperature, and oil output, visualizing the relationships among these key parameters [13].

The figures illustrate the effectiveness of machine learning models in predicting oil output using key parameters such as pressure, temperature, and permeability. The linear regression model presented in Fig. 1 offers a basic framework for analyzing historical data and generating accurate predictions [14]. The scatter plot in Fig. 2 highlights the correlation between actual and predicted values, offering insights into the model's accuracy. Additionally, the 3D visualization in Fig. 3 helps reveal the complex interdependencies among variables, demonstrating how AI can enhance decision-making in oil production.

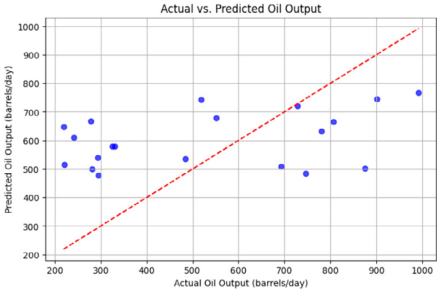


Figure 2. Actual vs. Predicted Oil Output

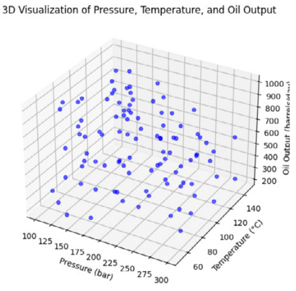


Figure 3. Visualization of Pressure, Temperature and Oil Output

These visualizations highlight the value of AI-driven data analysis in optimizing oil production, reducing operational risks, and enhancing efficiency. Future developments may include more sophisticated machine learning models, deeper feature analysis, and real-time predictive analytics to further refine accuracy and adaptability in oil and gas systems [15].

Results and Further Research Prospects

AI integration in the oil and gas industry already demonstrates strong potential to enhance operational efficiency and safety across all stages – from exploration and production to hydrocarbon processing and transportation. AI supports process optimization, cost reduction, enhanced operational monitoring, and improved safety at production facilities. However, unlocking the full potential of AI in this domain requires addressing several key challenges. First, new methods are needed to effectively process heterogeneous, unstructured data from diverse sources. Second, more advanced algorithms are required to handle large-scale data processing in real time, enhancing both predictive accuracy and decision-making speed.

Future research should focus on developing next-generation enhanced oil recovery systems, advancing failure prediction techniques, and further automating production and refining processes. A key driver of future progress will be the integration of AI with other advanced technologies, including the Internet of Things and robotics – enabling the development of autonomous and highly efficient oil production systems.

Another critical aspect is environmental sustainability, achievable through precise emission forecasting and optimized resource utilization. Through the adoption of AI, the oil and gas industry can significantly improve environmental performance, operational safety, and cost efficiency. The continued evolution of this field relies on advancing technologies that integrate AI, robotics and data analysis – paving the way for more intelligent and adaptive systems capable of addressing the challenges of the future [16].

Conclusion

In recent years, AI has become an integral component of the oil and gas industry, offering new solutions to both long-standing and emerging challenges – including improving production efficiency, optimizing equipment management, reducing costs, and mitigating environmental risks. AI applications in this field significantly enhance data processing and analysis, enabling more accurate prediction of reservoir behavior and early detection of equipment anomalies.

Applying machine learning to data from sensors, geophysical logs, and seismic surveys enhances decision-making accuracy in drilling and exploration. This not only accelerates operations but also reduces the risks associated with inaccurate forecasts. At the same time, AI algorithms also enable early prediction of equipment failures, minimizing unplanned downtime and repair costs. The integration of AI with real-time monitoring and process automation systems helps oil and gas companies enhance safety and mitigate negative environmental impact.

AI-powered enhanced oil recovery enables more efficient resource utilization in mature and depleted fields. This approach helps reduce costs and increase production, and minimize environmental risks [17]. In the context of environmental sustainability, AI is actively used to monitor emissions of carbon dioxide, methane, and other pollutants. This helps prevent environmental incidents, and ensures compliance with increasingly stringent regulations.

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AI also plays an important role in optimizing logistics and inventory management, helping to reduce hydrocarbon transportation costs and improve supply chain efficiency. Through AI-based demand forecasting and route optimization, companies can streamline logistics operations and further lower distribution costs. However, fully realizing AI's potential in the oil and gas sector requires addressing several key challenges. These include integrating heterogeneous data, improving data processing algorithms, and developing flexible systems capable of adapting to dynamic market and environmental conditions. Given these factors, AI will continue to evolve and play a critical role in ensuring the sustainability and competitiveness of the oil and gas industry.

ADDITIONAL INFORMATION

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Authors' contribution. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work. The greatest contribution is distributed as follows: Aigerim B. Seitimbetova – performed a deep analysis of scientific literature on the use of AI algorithms in the oil and gas industry, and also developed the structure of the article taking into account the logic of scientific presentation and industry specifics; Alevtina S. Shulgina-Tarashchuk reviewed and systematized current international and Kazakhstani practices in AI implementing for oil production and refining, also developed the section on practical applications, including English-language sources; Aizhan S. Smailova was responsible for the applied component of the article: prepared a Python program to demonstrate a machine learning algorithm using oil and gas data, adapted it for result visualization, and authored the section with technical explanations.

ДОПОЛНИТЕЛЬНО

Источник финансирования. Авторы заявляют об отсутствии внешнего финансирования при проведении исследования.

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

Вклад авторов. Все авторы подтверждают соответствие своего авторства международным критериям ICMJE (все авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией). Наибольший вклад распределён следующим образом: Сейтимбетова А.Б. – анализ научной литературы по использованию алгоритмов искусственного интеллекта в нефтегазовой отрасли, структурирование статьи с учетом логики научного изложения и отраслевой специфики; Шульгина-Таращук А.С. – анализ и систематизация современных международных и казахстанских практик внедрения искусственного интеллекта для добычи и переработки нефти, разработка раздела о практическом применении, работа с англоязычными источниками; Смаилова А.С. – подготовка Python-программы, её адаптация для визуализации результатов, технические пояснения.

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