***Original Research Article***

**Comprehensive Study of Modern Oil Extraction Techniques in the Ak Darya Area**

**Abstract**

The Ak Darya oil field in northern Afghanistan represents a strategically important petroleum resource with an estimated reserve of approximately 22 million tons. This study presents a comprehensive evaluation of the geological framework, reservoir characteristics, oil composition, and extraction potential of the Ak Darya field. Using a multidisciplinary approach, the research integrates data from geological field surveys, laboratory analyses, and structured questionnaires completed by petroleum engineers with academic and field expertise.The objective of the study is to identify the most effective extraction technique tailored to the field’s specific structural and physical-chemical attributes. Quantitative analysis of the survey data reveals a strong preference over 70% of respondents for mechanized pumping methods, citing advantages aligned with the field’s anticline folding, moderate porosity and permeability, and relatively shallow reservoir depth. Qualitative feedback further supports this consensus, highlighting lithological features such as interbedded clays, carbonate layers, and gravelly textures, as well as active neotectonics and groundwater conditions that influence operational efficiency. Alternative methods, including water and gas injection, were also evaluated but generally viewed as less effective due to the reservoir’s permeability and fluid composition. The study concludes that mechanical pumping offers the most technically suitable and economically viable method for hydrocarbon extraction in this field. The findings contribute to strategic planning and decision-making in Afghanistan’s energy sector and provide insights applicable to similar geological environments across the region, where resource optimization is a priority for sustainable development.

Keywords: Ak Darya oil field, Afghanistan petroleum resources, Modern oil extraction, Petroleum geology

1. **Introduction**

Afghanistan’s strategic pursuit of energy independence and economic revitalization increasingly hinges upon the exploration and development of its domestic hydrocarbon resources. In recent years, significant attention has turned to the country's northern oil-bearing regions, which hold untapped potential for national development. Among the most promising of these is the Ak Darya oil field, located approximately 13 kilometers southeast of Sar-e-Pol city and 10 kilometers northeast of the kashqari oil field. This field lies within a prominent anticlinal fold structure that is part of the northern Afghan basement uplift zone, an area that has long been recognized for its petroleum-generating capacity (Mahdi et al., 2023). The geological setting of Ak Darya makes it a high-priority target for both domestic and foreign energy investments, and an ideal case study for assessing modern oil extraction strategies under local conditions.

The development of the Ak Darya oil field holds profound implications not only for Afghanistan’s energy security but also for regional economic growth, job creation, and the establishment of long-term infrastructure. However, tapping into these reserves efficiently and sustainably requires the application of modern extraction technologies tailored to the field’s unique geological characteristics, including its lithology, structural configuration, and hydrogeological dynamics. Unlike older oil fields where traditional methods may still be viable, emerging fields like Ak Darya demand innovative, adaptable, and environmentally responsible approaches.

In this context, the global petroleum industry has made significant advancements in extraction technologies, such as mechanized pumping, enhanced oil recovery (EOR) techniques, and intelligent well systems. These methods are designed not only to maximize recovery rates but also to reduce operational costs and environmental impact (Ackah, 2025). For Afghanistan where infrastructure, security, and environmental constraints are persistent challenges the selection of an appropriate extraction method becomes even more critical. Therefore, understanding which technologies align best with the geological and physical-chemical properties of the Ak Darya field is essential to inform future development strategies.

The aim of this study is to conduct a comprehensive evaluation of modern oil extraction techniques suitable for the Ak Darya area by analyzing geological data, reservoir characteristics, fluid properties, and expert insights. Through a combination of field surveys, laboratory analyses, and professional questionnaires, the study identifies which techniques are most feasible and effective for this field. Particular attention is given to mechanical pumping methods, which are widely used in regions with similar geological features, as well as the potential applicability of water flooding, gas injection, and other secondary recovery techniques.

By aligning extraction technologies with local geological realities, this research contributes to more informed and sustainable decision-making in Afghanistan’s oil sector. The findings can guide policymakers, energy investors, and technical professionals in optimizing production while preserving environmental and economic sustainability. Ultimately, this study seeks not only to enhance oil recovery in Ak Darya but also to provide a model for the responsible development of Afghanistan’s broader hydrocarbon resources in pursuit of long-term energy independence.

**Geological and Geographical Overview of the Ak Darya Area**

This section provides foundational insights into the Ak Darya oil field by examining the region's geological background, reservoir characteristics, and environmental considerations. Understanding these components is essential for selecting and implementing the most appropriate and effective oil extraction methods (Ulmishek, n.d.). The structure was identified during geological aerial photography surveys conducted in 1958–1959 at a scale of 1:200,000 and was later studied in more detail through structural-geological photography at a scale of 1: 50,000 (Frotan et al., 2019). According to Soviet Geologist Gory (Sovit Ghori), the Ak darya structure exhibits a broad anticlinal folding pattern with a transverse development. It measures approximately 3.5 × 1.5 kilometers with an amplitude of 150 meters (Presentation, 2012).

 Table 1: Productive Horizons of the Ak darya Oil Field (Chai et al., 2024).



**Physical and Chemical Properties of Fluids**

In the Ak Darya oil field, a total of 8 exploratory and reconnaissance wells have been drilled, of which 6 wells are productive. The total reserves of this field are estimated at approximately 22 million tons. Since its exploration and discovery, the Ak Darya structure has attracted the attention of various researchers due to its promising potential for oil and gas development and industrialization (Overview, 2015).

This area contains two oil-bearing formations, each of which is described separately below:

1. Productive Hetref Formation: In the Ak Darya area, it is primarily composed of limestone and marlstone, and is stabilized by wells numbered (1), (2), and (3). The thickness of Hetref sediments in the Ak Darya area varies between 135 and 145 meters. Its open porosity is 17%, the effective oil-saturated thickness is 5.6 meters, and the permeability is 620 millidarcies (Mahdi et al., 2021). The protective cover of the Hetref deposit, similar to neighboring oil-bearing areas, consists of a thick layer of greenish clay, marl (marl), chert, and barite anhydrite, with a thickness ranging from 60 to 70 meters (Of & Projects, 2014).
2. Alb Formation: This formation, divided into three parts: lower, middle, and upper, has its lower part composed of limestone and clay layers, and is considered productive in the interval (849-879) meters in the Ak Darya area (Brookfield & Hashmat, 2001) . The lower Alb layer has an overall thickness of about 200 meters, with an effective oil-saturated thickness of 5.7 meters. Its open porosity ranges from 2 to 15%, and permeability from 2 to 12 millidarcies, as shown in Table (2). The middle and upper parts of the Alb formation, with a combined thickness of 45 to 60 meters, consist of alternating layers of chert, marl, and clay (“Mineral Resources in Afghanistan,” 2000). This area is located on the southern flank of the Angout oil zone, and its industrial development has been confirmed by drilling 8 exploratory and production wells, with the Alb and Hetref formations proven to be productive. Based on regional data and laboratory analysis of sulfur, paraffin, and other hydrocarbons, the oil in the Alb and Hetref formations is characterized by high paraffin content, with the following proportions: paraffin (9.5) % in Alb and (10.2) %, sulfur (0.7) % and (2.88) %, respectively. The light fractions of oil in the Alb and Hetref formations are 57% and 32%, respectively. The asphalt content in the oil of the Alb formation is 4.2%, while in the Hetref formation it ranges from 12.3% to 21.9%. The kinematic viscosity of the fluids in the Alb and Hetref formations varies significantly, with the first being 6.3 centistokes and the second reaching up to 11.82 centistokes (Shroder et al., 2022).
3. **Materials and Methods**

This study employs a comprehensive approach to examine modern oil extraction techniques in the Ak Darya area, utilizing a combination of data collection and analysis methods outlined as follows:

Data Collection Methods

1. Library Research

In this method, credible printed sources such as books, scientific articles, encyclopedias, and specialized journals related to modern oil extraction techniques in the Ak Darya region were reviewed. The researcher visited these sources to identify relevant information, recording key data in note cards (fiches). Each fiche included source details such as title, author, publisher, publication date, and the extracted information. The collected data were systematically organized and categorized to facilitate analysis.

1. Field Survey

To gather empirical data, a structured questionnaire was developed comprising 12 closed questions with four multiple-choice options (mechanized pumping, water injection, gas injection, and (I don't know) and 2 open-ended questions allowing respondents to express their opinions freely. The questionnaires were distributed among oil and gas engineers, field engineers in the Ak Darya oil zone, officials from the Northern Oil and Gas Exploration Departments, members of the Afghan Gas Company in Jowzjan Province, and academic staff from relevant institutions. This facilitated the collection of expert insights and operational experiences regarding the application of modern extraction techniques in the area.

1. Population and Sampling

The statistical population consisted of all individuals and units involved in the oil industry within the Ak Darya region, totaling 115 participants. These included oil and gas engineers, regional engineers, officials from exploration departments, and academic staff—all sharing common professional attributes pertinent to the study's focus.

1. Data Analysis Procedures

Following data collection, initial data screening and cleaning were performed. The responses from questionnaires were coded systematically, and the data were entered into the SPSS statistical software package. Both quantitative (numerical) and qualitative (descriptive) analyses were conducted, including descriptive statistics, frequency distributions, and inferential tests as appropriate. The results were thoroughly analyzed and interpreted.

1. Validity and Reliability of Data Collection Tools

The questionnaires and data collection instruments were validated through expert review to ensure content validity. Reliability was assessed using appropriate statistical measures (such as Cronbach's alpha) to confirm the consistency and dependability of the instruments, ensuring that the data collected would produce accurate and trustworthy results.

Overall, this mixed-method approach combining library research and field surveys provides a comprehensive understanding of modern oil extraction techniques in the Ak Darya area, establishing a solid foundation for subsequent analysis and conclusions.

1. **Nature of Data Analysis**

The responses and data obtained through questionnaires are analyzed in both quantitative and qualitative formats. The first part involves analyzing numerical data related to closed questions, while the second part focuses on qualitative analysis of open-ended responses.



Figure1: Types of information analysis

**Quantitative Data Analysis**

In this section, the information and data from the first and second parts of the questionnaires, which include respondent characteristics and closed-ended questions, are analyzed. The third part, consisting of open-ended questions, will be analyzed qualitatively.

1. **Survey based on respondents' education level**



Figure 2: Respondents' education level

Another topic included in the first section of the questionnaire was the respondents' educational level. Among the 115 respondents, 44 individuals hold a master's degree. Additionally, 46 respondents, who constitute the majority, have a bachelor's degree. Furthermore, 16 respondents possess a postgraduate diploma.

Therefore, it can be concluded that the majority of respondents who provided answers to the questionnaires have a bachelor's or master's degree, while the remaining respondents have various educational levels, including postgraduate diplomas and higher education qualifications.

1. **Survey on the choice of oil extraction method in the Ak Darya oil field**

The review of modern methods of oil extraction and the selection of the most appropriate method for the Ak darya oil field, as mentioned above, has transformed the extraction of oil from the Amu Darya basin in northern Afghanistan into a comprehensive and debatable strategy by the Ministry of Mines and Petroleum for economic growth.

Over the past 20 years, oil extraction from mineral-rich areas in the country has involved contracts with several foreign companies. However, due to various factors, particularly the lack of knowledge about extraction methods from these areas, implementation has been slow, and some contracts have even been canceled.

In oil extraction, knowing the suitable method for each oil field is a fundamental condition, and the absence of an appropriate extraction technique represents a significant challenge to the operation of oil wells.



Figure 3: The distribution of opinions regarding the selection of the method for oil extraction in the Ak Darya oil field

Therefore, the first question included in this research questionnaire was to gather professional engineers' opinions regarding the selection of the most appropriate method for the Ak darya oil field. Participants in this study responded to this question, and the following results were obtained: out of 115 individuals, 91 (which is 79.1%) favored the mechanical pumping method, and 24 individuals (20.1%) preferred the water injection option as the suitable extraction method for the Ak darya oil field. As a result, considering the data collected, the majority of oil and gas engineers recommended the mechanical pumping method for the Ak darya oil field.

1. **Survey according to geological structure**

Regarding the geological structure of the Ak darya oil-bearing area, layers of different ages, from the Paleozoic to the Cenozoic, are present. The Sweit Guri stone in the dome-shaped part of Ak darya and the Sweit Shafa and Qashtegin sediments emerge at the surface. The dome-shaped part of Ak darya has a gentle dip, with the bedding planes inclined at angles ranging from 12 to 18 degrees. The industrial oil potential of this area was confirmed through exploratory borehole No. 1, where the production capacity was measured at 17.1 tons per day in the Heitref, Opt, and Alb formations. In total, eight exploratory and prospecting boreholes, with a combined depth of 1,153 meters, have been drilled to determine the extent of the Heitref, Opt, and Alb reservoirs and to obtain reservoir parameters. The presence of oil and gas has been confirmed with positive results, especially in the hydrocarbon industrial reservoirs.

For this reason, one of the questions in the Ak darya oil field questionnaire pertains to its geological structure, which features anticline folding. Which method would you recommend for this? The following responses were provided:



Figure 4: Selection of the method for extracting Ak Darya oil based on the geological structure.

Among the respondents to this question, 77 individuals (which is 67%) preferred the mechanical pumping method, while 38 individuals (33%) chose water injection as the suitable approach. As a result, considering the above information, the suitable extraction method for the Ak darya area, which has an anticline folding geological structure, has been selected as the mechanical pumping method.

1. **Analysis in terms of porosity and permeability**

Based on the results of laboratory (Core) investigations, the productive section or cross-section indicates that the porous rocks with permeability less than one Darcy retain up to 80% or more of the remaining water. As a result, effective permeability in these rocks is practically not observed, and consequently, the lower permeability limit is considered to be one Darcy. Based on the collected information and conducted research, the porosity of the rocks forming the productive layers is one of the fundamental parameters in oil extraction, significantly impacting the oil recovery process. The respondents' opinions regarding this matter, as presented in the questionnaire, are summarized in the following result Figure 5.



Figure 5: Selecting the appropriate extraction method based on the porosity of the rocks

Out of 115 respondents, 86 individuals (which accounts for 74.8) % favor the mechanized pumping method, while 19 respondents (16.5) % support water injection, and 4 respondents (3.5) % believe that gas injection is effective. Additionally, 6 respondents (5.2) % chose "I don’t know," citing the lack of porosity data for the rocks constituting the productive layers, and therefore refrained from expressing an opinion on the effectiveness of porosity in oil extraction in Ak darya.

Therefore, it can be concluded that more than 70% of the respondents to this question confirmed the effectiveness of the mechanized pumping method.

1. **Appropriate method according to the depth of the mine**

The fourth question of the questionnaire pertains to the choice of extraction method based on reservoir depth, which reflects the impact of reservoir depth and the thickness of oil-bearing layers.

The layers of the Ak darya field are primarily composed of gravel and olivine rocks, stabilized by wells numbered (1), (2), and (3). The thickness of the Hetref sediments in the Ak darya field varies from 135 to 145 meters. Its open porosity is 17%, the effective oil-saturated thickness is 5.6 meters, and the permeability is 620 millidarcies. The protective cover of the Hetref deposit, similar to adjacent oil-bearing areas, consists of thick greenish clay layers, marl, chert, and barite anhydrite, with a thickness ranging from 60 to 70 meters.

The lower Alb layer has an overall thickness of about 200 meters, with an effective oil-saturated thickness of 5.7 meters. Its open porosity ranges from 2% to 15%, and its permeability varies from 2 to 12 millidarcies.



Figure 6: The effectiveness of mine depth on oil extraction methods

As shown in the figure above, out of 115 respondents, 89 individuals selected the first option mechanized pumping. This indicates that the majority of respondents believe that oil extraction using the mechanized pumping method is effective in the shallow Ak darya oil field.

Meanwhile, 23 respondents (20) %considered water injection a suitable method for oil extraction in Ak darya. Only 1 respondent (0.9) % recommended gas injection for the oil-bearing area of Ak darya. In addition, 2 respondents (1.7) % refrained from expressing any opinion on this matter.

1. **The appropriate method of oil extraction considering the physical-chemical properties of fluid**

In the Ak Darya region, the physical and chemical properties of fluid hydrocarbons indicate that the oil contains high paraffin content (9.5-10.2) %, asphalt (4.2-21.9) %, and sulfur (0.7-2.88%)%. The dynamic viscosity in the Hethrif and Albeh formations is 11.82 and 6.3 centistokes, respectively. These characteristics necessitate the use of specialized methods such as vertical and horizontal drilling, along with thermal and chemical techniques, to achieve efficient and economical oil extraction in this area.



Figure 7: Suitable Method of Oil Extraction for the Ak darya Field Considering the Physical-Chemical Properties.

Regarding this, the respondents’ opinions were expressed as follows in the questionnaire: Out of 115 respondents, 90 individuals (which accounts for 78.3) % favor the mechanized pumping method for oil extraction in the Ak darya field, while 15 respondents (13) % support water injection. Meanwhile, 4 respondents (3.5) % believe that gas injection is ineffective for oil extraction in this area. Additionally, 6 respondents (5.2) % chose I don’t know and refrained from giving an opinion.

From this information, it can be concluded that over 78% of the respondents believe that the mechanized pumping method is the most effective extraction technique for the Ak darya oil field.

**Qualitative Data Analysis**

As mentioned in the data analysis section, the collected information in this study was analyzed using two approaches. The data obtained from closed-ended questions were previously analyzed quantitatively, while in this section, the data derived from open-ended questions are analyzed qualitatively to gain a deeper understanding of experts' perspectives and opinions regarding extraction methods and the hydrogeological features of the Ak darya field.

1. **Open-ended Question 1: Proposed Extraction Methods Based on Hydrogeological Characteristics**

In the questionnaire, respondents were asked to suggest suitable recovery methods for the Ak darya field considering the effective reservoir thickness. A variety of responses were received, many of which shared similarities. The most important responses can be summarized as follows:

Based on the results of drilled wells, the productive reservoirs in Cretaceous sediments consist of sandstone, claystone, and dense limestone layers, located at depths between 60 and 145 meters. These reservoirs have permeability around 1 to 4 millidarcies. Most respondents believed that, given these reservoirs are situated above the anticline fold structure, extracting oil via mechanical pumping is technically efficient.

Additionally, many noted that the thickness of the productive layers in the Ak darya field ranges between 60 and 145 meters, and considering the relatively limited volume of oil reserves, pumping methods are more economical and practical compared to other extraction techniques.

1. **Open-ended Question 2: Extraction Methods Based on Hydrogeological Features**

Respondents were asked to propose the most suitable extraction method based on the hydrogeological characteristics of the Ak darya field. Their opinions highlighted the following points:

The Ak darya oil field is located in the southeast part of the Karakum region and is fed by the Neogene recharge system. It lies within a large tectonic structure called the Toran Plate and is situated in the Orogen or Orogenic platform area, characterized by stratigraphic sequences from the Permian and Triassic periods to recent sediments.

Active neotectonic processes have complicated the relationships of recharge and discharge of the groundwater sources, leading to abnormal high and low pressures within the reservoir. Additionally, infiltrated waters from Neogene and anthropogenic periods have temporarily affected the Middle Mesozoic sediments.

The field is located along the southeastern development zone of the Dowlat Abad geological basin, and the watershed system in its foothill (semi-mountainous) areas is highly developed, with hydrochemical profiles indicating unique hydrogeological features of the region.

During exploratory drilling, hydrogeological properties of the Graft, Aptian, and Lower Albian units were studied. In tests related to the Aptian unit, the static groundwater level and pressure were measured at the wellhead, and water samples were collected from the well areas for chemical analysis.

In wells No. 2, 3, and 4, the entire thickness of the Graft sediments was penetrated, consisting of sandstone and claystone. Based on geophysical assessments and core samples, the thickness of this unit ranges from 150 to 170 meters, with permeable layers around 4 to 6 meters, considered effective reservoirs with high filtering properties. The production rate in well No. 5 reached 197 cubic meters per second.

The permeability characteristics of the productive layers vary with fluid flow, and uniform pressure was observed in the oil-water contact within the Graft unit, indicating that the contact between oil and water is approximately horizontal.

The chemical composition and type of groundwater in the lowest part of the Graft unit are predominantly sodium-bicarbonate with sulfate groups and slightly alkaline to neutral pH, confirming the infiltration of waters from recharge areas.

Comparing this unit with neighboring oil fields such as Angut and Kashqari shows that the Graft unit in Ak darya has higher salinity and salinity levels. The Ak darya reservoir is surrounded by sandstone with relatively suitable hydrochemical features, including the presence of hydrogen sulfide gas.

These qualitative analyses, based on field findings and laboratory results, contribute to a better understanding of the hydrogeological characteristics and the most appropriate extraction methods for the Ak darya field, aligning with the objectives of the research.

1. **Discussion**

The analysis of the data collected through questionnaires provides valuable insights into the preferences and perceptions of oil and gas engineers regarding oil extraction methods in the Ak Darya oil field. The predominance of respondents with higher education levels (bachelor’s and master’s degrees) suggests a well-informed participant pool, which lends credibility to the findings.

Quantitative results consistently indicate a strong preference for mechanical pumping methods across various geological and physical-chemical parameters. For instance, over 70% of respondents favored mechanized pumping based on the geological structure, porosity, permeability, reservoir depth, and fluid properties. This consensus aligns with the geological context of the Ak Darya field, characterized by anticline folding, moderate permeability, and relatively shallow reservoir depths. The respondents’ emphasis on the suitability of mechanical pumping in light of the reservoir’s physical and chemical properties underscores its perceived efficiency and cost-effectiveness.

Qualitative responses further reinforce these findings, with respondents highlighting the lithological composition, reservoir thickness, and hydrogeological conditions as reasons for favoring mechanized pumping. The identification of gravelly rocks, interbedded clay, and carbonate layers as productive collectors indicates a comprehensive understanding of the field’s geological and hydrogeological complexity. The acknowledgment of active neotectonic processes and groundwater dynamics also suggests awareness of the challenges posed by the region’s hydrogeological environment, which may influence extraction strategies.

The divergence of opinions regarding water and gas injection methods was relatively minor, with a clear majority advocating for mechanical pumping. This consensus may reflect the perceived limitations of alternative methods in the context of the specific reservoir characteristics, such as permeability and fluid composition, which favor mechanical rather than chemical or thermal techniques. Overall, the combination of quantitative and qualitative data points toward a strong professional consensus favoring mechanical pumping as the primary extraction method in the Ak Darya field. The respondents’ insights regarding geological, physical, and hydrogeological parameters provide a holistic understanding that supports this preference.

1. **Conclusion**

The comprehensive analysis of the questionnaire data demonstrates that oil and gas engineers predominantly favor the mechanized pumping method for extracting hydrocarbons from the Ak Darya oil field. This preference is justified by the field’s geological structure, characterized by anticline folding, moderate permeability, and relatively shallow reservoir depths, as well as the physical-chemical properties of the hydrocarbons present. Both quantitative responses and qualitative insights highlight the suitability, efficiency, and cost-effectiveness of mechanical pumping in this specific context.

Furthermore, the respondents’ emphasis on the lithological composition, reservoir thickness, hydrogeological conditions, and fluid properties underscores the importance of tailoring extraction techniques to the unique geological and hydrogeological environment of the field. While alternative methods such as water injection and gas injection are recognized, their perceived applicability appears limited based on the respondents’ expertise.

In summary, the findings suggest that the current geological and hydrochemical characteristics of the Ak Darya oil field favor the use of mechanical pumping techniques for optimal resource recovery. These insights can inform strategic planning, technological application, and further research aimed at enhancing oil extraction efficiency in similar geological settings.

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