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icse@bwu.edu.ly

Fractional Flow Curve Construction Using Buckley-Leverett Method: A Case Study of the Masrab Oilfield in Libya

Salma Addami Hasan, Oil & Gas Engineering Department, Bani-Waleed University, Libya, starsammo390@gmail.com
Elnori Elhaddad, Petroleum Engineering Department, Bani-Waleed University, Libya, norimab2014@gmail.com

Abstract: Understanding and accurately calculating fractional flow curves is crucial for effective reservoir management and enhanced oil recovery. Various approaches for calculating fractional flow curves exist, including mathematical models, which can obtain different results. The main objective of this paper is to calculate fractional flow curves using the Buckley-Leverett method for two wells, P06 and P07, in the Masrab Oilfield in Libya, utilizing Excel Program for analysis. The study employs core analysis data to ensure accurate calculations.The fractional flow curve of well P06 does not display an S shape according to the Buckley-Leverett method, indicating high residual oil saturation at approximately 0.46, thus classifying the Sarir reservoir as an oil-wet reservoir. Similarly, the fractional flow curve of well P07 does not display an S shape and shifts to the left, with residual oil saturation at about 0.299. Both wells show consistent results because they are part of the same reservoir (Sarir).The observed deviation from the expected S shape in the fractional flow curves shows significant changes in the rock and fluid properties of the reservoir. These changes require further investigations to understand their impact on oil recovery and to address the oil-wet issue effectively. Identifying and mitigating these changes is essential for optimizing oil production and ensuring sustainable reservoir management.This study highlights the importance of accurate fractional flow curve calculations for effective reservoir management and the need for ongoing research to adapt to changing reservoir conditions. Further investigations are required to understand the changes in rock and fluid properties and address the oil-wet issue, ultimately leading to improved strategies for enhanced oil recovery.

Keywords: Fractional Flow Curves, Mathematical Model, Oil-Wet Reservoir, Buckley-Leverett Method.

1. Introduction:

When the reservoir pressure gets too low, these artificial lift methods become impractical. Pressure maintenance is now necessary to build up reservoir pressure, a process known as secondary recovery, which involves using external sources to maintain reservoir pressure, such as water injection or gas injection [1]. If water injection (water flooding) is employed, large amounts of water will be generated with oil. Fractional flow curves are utilized to calculate these quantities (FW). Fractional flow curves represent the immiscible displacement of oil by water through a permeable porous media. Fractional flow curves provide parameters of water flooding project. Previously, Buckley–Leverett method known as (conventional equation), depending on fluid properties and core analysis data [2]. The method's results are accurate than correlations as curry's correlation [3]. Coring sample is difficult and challenges in some reservoirs such as offshore

reservoir and another have compromised data. In 2014 Fadairo Adesina et al, found mathematical model depending on production data, this method is quite challenging when fluid properties and special core analysis data is limited or compromised [4].

There are various approaches for obtaining fractional flow curves, including mathematical models and correlations. These methods provide different results. The primary objective of the paper is to identify the most effective mathematical method for obtaining fractional flow curves [5].

The technique of water injecting into a reservoir is to support formation water and maintain reservoir pressure in order to increase oil recovery, which is known as water injection. Water flooding is the most extensively used and successful oil recovery method. It has been discovered since 1880 [6].

Water-flooding process is the most successful and widely used process for several reasons including:

- Availability of water sources.
- Low cost of water injection in comparison to injecting other fluids.
- Injecting water into formation is difficult than injecting other fluids.

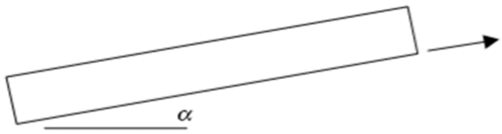
Water has a high displacement efficiency when compared to other fluids [7].

1.1 Buckley-Leverett Equation:

Buckley-Leverett equation describes an immiscible displacement process as: displacement of oil by water, in one dimensional reservoir.

Derivation of the fractional flow equation for a one-dimensional oil-water system:

Assume oil displacing water in dip angel α system:



The start point is Darcy´s equations:

$$q_o = -\frac{kk_{ro}A}{\mu_o}\left(\frac{\partial p_o}{\partial x} + \rho_o g \sin\propto\right) \qquad (1)$$

$$q_w = -\frac{kk_{rw}A}{\mu_w}\left(\frac{\partial p_w}{\partial x} + \rho_w g \sin\propto \qquad (2)$$

And replace the pressure of water by:

$$P_w = P_o - P_{cow} \qquad (3)$$

Therefore:

$$q_w = -\frac{kk_{rw}A}{\mu_w}\left[\frac{\partial (P_o - P_{cow})}{\partial x} + \rho_w g \sin\alpha\right] \qquad (4)$$

Rearranging the equations as following:

$$-q_o \frac{\mu_o}{kk_{ro}A} = \frac{\partial P_o}{\partial x} + \rho_o\, g \sin\alpha \qquad (5)$$

$$-q_w \frac{\mu_w}{kk_{rw}A} = \frac{\partial P_o}{\partial x} - \frac{\partial P_{cow}}{\partial x} + \rho_w\, g \sin\alpha \qquad (6)$$

By subtracting the first equation from the second equation, obtaining:

$$-\frac{1}{kA}\left[q_w \frac{\mu_w}{k_{rw}} - q_o \frac{\mu_o}{k_{ro}}\right] = -\frac{\partial P_{cow}}{\partial x} + \Delta\rho g \sin\alpha \qquad (7)$$

By replacing: 2

$$q = q_w + q_o \qquad (8)$$

$$f_w = \frac{q_w}{q} \qquad (9)$$

We obtain the following equation for the water fraction flow:

$$f_w = \frac{1 + \frac{kk_{ro}A}{q\mu_o}\left[\frac{\partial P_{cow}}{\partial x} - \Delta\rho g \sin\alpha\right]}{1 + \frac{k_{ro}\,\mu_w}{\mu_o\, k_{rw}}} \qquad (10)$$

By negligible capillary pressure effect, for the simplest case of horizontal flow, the equation constricts to:

$$f_w = \frac{1}{1 + \frac{k_{ro}\,\mu_w}{\mu_o\, k_{rw}}} \qquad (11)$$

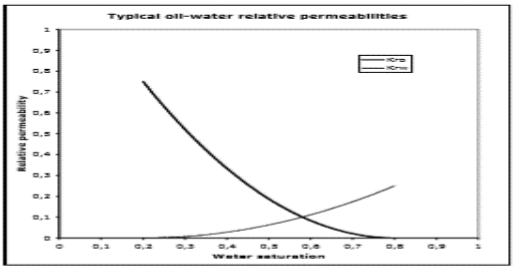


Figure 1: Typical Oil-Water Relative Permeability [2].

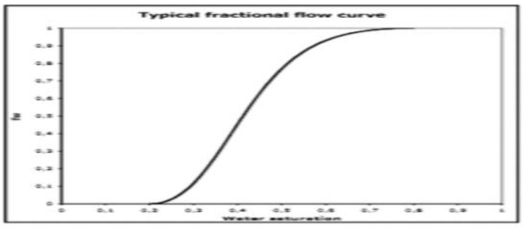


Figure 2: Typical Fractional flow curve [2].

In 2017, Edwin. T.J and Hamed. H, found that the saturation profile appreciable affected by three factors: porosity, permeability and injection rate, and neglected the end effect of capillary pressure, due to the limitation of the simulator, as a results, it hasn't appreciable effect towards the length of core. The main results of this study is:

1) Porosity & permeability are proportional with induced error.

2) Induced error inversely proportional with injection rate.

3) The core length does not show regarded effect in terms of capillary pressure. It is important to know the influence of factors such as permeability and porosity on saturation profile to understand the error in fractional flow estimations, when results inaccurate [8,9].

In 2017, Abdul Jamil N and Shigeo H, evaluated and compared the effect of fractional flow and relative permeability of heavy oil and Kerosene during recovery in a petroleum reservoir. During enhancing oil recovery there are several problems, one of challenging problems is Water fingering, and evaluate the amount of oil recovery from a petroleum reservoir. Therefore, the analyze of fractional flow and relative permeability of heavy oil and Kerosene is important to understand and to solve these problems. So, they use the conventional (Buckley-Leverett) method to calculate water-flooding performance **. وصلنا هنا**

Shifting of the fractional flow curve to the right or left has important consequences regarding the efficiency of the oil displacement process by water in the reservoir. This shift reflects changes in the physical properties of the fluids and rocks in the reservoir, such as viscosity and saturation ratio.

1. **Shifting of the Fractional Flow Curve to the Right:**

Increased Water Viscosity: If the fractional flow curve shifts to the right, it indicates that the water viscosity has increased or the viscosity ratio has decreased. In this case, water has a greater ability to displace oil more effectively.

Improved Displacement Efficiency: A shift to the right indicates an improvement in displacement efficiency. This means that a change in the water flow fraction quickly leads to a change in the oil flow fraction, reflecting higher efficiency in the displacement process.

Relative Permeability: Increased relative permeability of water at the same pressure leads to a shift of the curve to the right.

2. Shifting of the Fractional Flow Curve to the Left

Increased Oil Viscosity: If the fractional flow curve shifts to the left, it indicates that the oil viscosity has increased or the viscosity ratio has decreased. In this case, water has a lower ability to displace oil effectively.

Reduced Displacement Efficiency: A shift to the left indicates a reduction in displacement efficiency. This means that a change in the water flow fraction slowly leads to a change in the oil flow fraction, reflecting lower efficiency in the displacement process.

Relative Permeability: Decreased relative permeability of water at the same pressure leads to a shift of the curve to the left Fig (3).

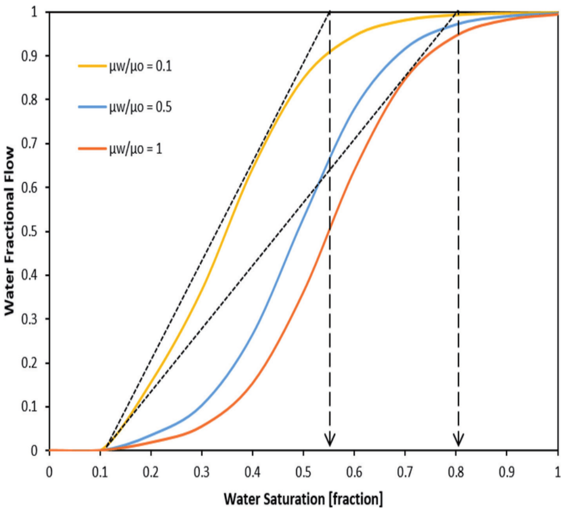


Figure 3: shows the Effect of viscosity ratio on the fractional flow curve [10].

2. THE METHODOLOGY:

2.1 Masrab Field:

The Masrab Field is situated in Concession 59E and was discovered in October 1961 with the drilling of the first well, known as Well P01. During its development, 10 wells were drilled in the 1960s, 5 wells in the 1970s, and 21 wells in the 1980s, totaling 36 wells to date. The Masrab Field contains three oil reservoirs: Lidam, Etla-Sarir, and Eocene. The primary reservoirs are Lidam and Etla-Sarir. Well P06, drilled in 1967, produces oil at a rate of 2540 BOPD from the Sarir sandstone, with initial reservoir pressure and temperature recorded at 4886 psig and 240°F, respectively. The proposed integrated Geoscience-Reservoir Engineering and Black Oil Simulation Study will focus solely on the Lidam and Etla-Sarir reservoirs.

2.2 The wells under study

2.2.1 Well P06:

From January to April 1967, the well was drilled to a depth of 10,882 feet. It was then completed in the Sarir formation (between 10,204 and 10,212 feet) in June 1967.

The well has been producing oil since July 1978. By March 2003, the total production was 2.78 MM SCF of gas, 4,137 M STB of oil, and 1.86 M bbl of water.

2.2.2Well P07:

In April 1967, a well was drilled to a depth of 10,714 feet and was completed in the Sarir formation (between 10,169 and 10,197 feet) on June 21, 1967. The well has been producing oil since July 1978.

In December 2000, total production amounted to 2.9 MMM SCF of gas, 4.709 MM STB of oil, and 152 M bbl of water.

2.3 Project Data:

Table 1: Masrab Field Data:

EOR Method	Water Injection
Injection Start Date	Sep, 1989
Initial Reservoir Pressure, psi	4879
Bubble Point Pressure, psi	2891
Gas Oil Ratio, SCF/STB	780
Pore Volume, MMbbl	1029.5
Area of the Reservoir, acres	10104
Average Net Pay zone thickness, ft	15.8

Table 2: Rocks Properties of Field:

Average Porosity, %	17.2
Average Permeability, md	30
Initial Water Saturation, %	30
Compressibility Factor, 1/psi	2.49E-05
s_{orw}, %	30

Table 3: Fluid Properties of Field:

Oil Density, g/cc	0.6056
Water Density, g/cc	1.17
Oil Viscosity, cp	0.3549
Water Viscosity, cp	0.4467
Oil Formation Volume Factor, bbl/STB	1.45

2.4 Procedures:

This study was conducted on the Masrab oil field to construct fractional flow curves. The methodology of this paper is outlined below:

1. Collect required data of Masrab field from Alwaha Company.
2. Use Excel program as a software.
3. Input data of equation of (Buckly-Leverett).
4. Calculate fractional flow curve by Buckly-Leverett equation for two wells.

3. RESULTS& DISCUSSION:

3.1 Buckley-Leverett Equation:

3.1.1 Well P 06:

S_w	k_{ro}	k_{rw}	k_{ro}/k_{rw}	μ_w	μ_o	μ_w/μ_o	f_w
0.262							0
0.324	0.06	0.005	12	0.4467	0.3549	1.258664	0.062096
0.367	0.026	0.009	2.888889	0.4467	0.3549	1.258664	0.215697
0.381	0.013	0.011	1.181818	0.4467	0.3549	1.258664	0.402008
0.434	0.007	0.016	0.4375	0.4467	0.3549	1.258664	0.644884
0.476	0.004	0.022	0.181818	0.4467	0.3549	1.258664	0.81377
0.533	0.001	0.031	0.032258	0.4467	0.3549	1.258664	0.960982

Table 4: Results of well P 06 by use Buckly-Leverett equation.

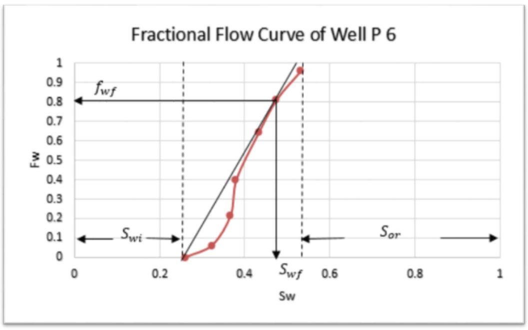


Figure 4: Fractional flow curve of well P 06 by use Buckly-Leveratt equation.

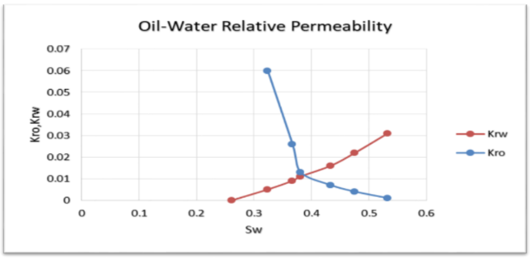


Figure 5: Oil- water relative permeability of well P 06.

3.1.2 Well P 07:

S_w	k_{ro}	k_{rw}	k_{ro}/k_{rw}	μ_w	μ_o	μ_w/μ_o	f_w
0.21	0.381	0.009	42.33333	0.4467	0.3549	1.258664	0.018422
0.248	0.223	0.023	9.695652	0.4467	0.3549	1.258664	0.075737
0.307	0.122	0.05	2.44	0.4467	0.3549	1.258664	0.245631
0.402	0.055	0.107	0.514019	0.4467	0.3549	1.258664	0.607173
0.443	0.037	0.136	0.272059	0.4467	0.3549	1.258664	0.744917
0.492	0.021	0.174	0.12069	0.4467	0.3549	1.258664	0.868125
0.543	0.012	0.215	0.055814	0.4467	0.3549	1.258664	0.93436
0.583	0.006	0.251	0.023904	0.4467	0.3549	1.258664	0.970791
0.607	0.004	0.272	0.014706	0.4467	0.3549	1.258664	0.981827
0.634	0.003	0.288	0.010417	0.4467	0.3549	1.258664	0.987059
0.655	0.002	0.293	0.006826	0.4467	0.3549	1.258664	0.991482
0.701	0	0.303	0	0.4467	0.3549	1.258664	1

Table 5: Results of well P 07 by use Buckly-Leverett equation.

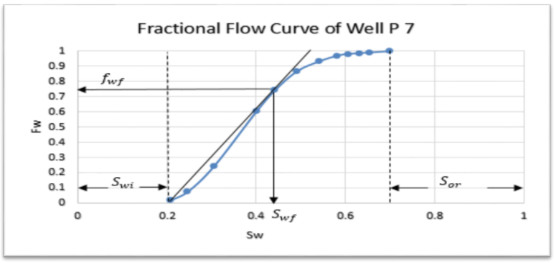


Figure 6: Fractional flow curve of well P 07 by use Buckly-Leverett equation.

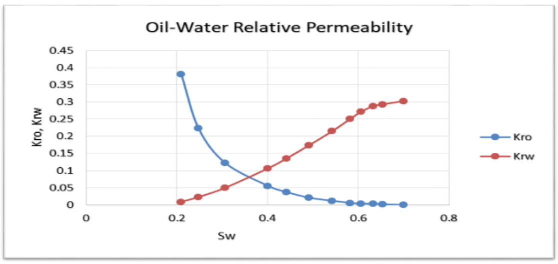


Figure 7: Oil-water relative permeability of well P 07.

Figures (4) and (5) illustrate the fractional flow curve and relative permeability for well

P06. The fractional flow curve of well P06 does not display the typical S shape predicted by the Buckley-Leverett method. Instead, it shows a linear behavior, which is unusual and indicative of specific reservoir characteristics. The intersection between the oil and water relative permeability curves occurs at a water saturation point of less than 0.5, indicating a high residual oil saturation of approximately (0.467).

This high residual oil saturation suggests that the Sarir reservoir is an oil-wet reservoir. In oil-wet reservoirs, the rock surfaces are preferentially coated with oil, requiring improving oil mobility but also to significant amounts of residual oil being left behind after primary and secondary recovery extraction processes. This characteristic implies that traditional water-flooding techniques may not be as effective, and enhanced oil recovery (EOR) methods, such as chemical flooding, hot water injection or surfactant injection, might be required to improve oil recovery.

Well P07

Figures (6) and (7) illustrate the fractional flow curve and relative permeability for well P07. Similar to well P06, the fractional flow curve for well P07 does not exhibit the typical S shape. However, it also shows a shift to the left, which further deviates from the expected model behavior. The intersection point between the oil and water relative permeability curves occurs at a water saturation point of less than 0.5, with a residual oil saturation of about 0.299.

The lower residual oil saturation in well P07 compared to well P06 suggests some variability within the reservoir. While both wells are located in the same Sarir reservoir, the differences in their specific locations, rock properties, and fluid compositions can lead to variations in their behavior. These variations are evident in the observed fractional flow curves and relative permeability characteristics.

The lack of matching between the results from wells P06 and P07 highlights the complexity and heterogeneity of reservoir systems. Factors such as reservoir heterogeneity, variations in rock and fluid properties, and differences in well completion designs, production histories, and operating practices can all contribute to the observed differences. These results emphasize the importance of considering multiple factors when analyzing and interpreting reservoir data.

Implications for Reservoir Management:

The identification of high residual oil saturations and the non-typical behavior of the fractional flow curves indicate that the Sarir reservoir is oil-wet. This characteristic requires the consideration of alternative EOR methods to improve oil recovery. Traditional water flooding may not be sufficient, and techniques such as chemical flooding, Hot water injection or surfactant injection should be evaluated and potentially implemented.

4. Conclusion

In conclusion, despite differences in behavior observed between wells P06 and P07 in the Masrab oil field, it's noteworthy that both wells are situated in an oil-wet reservoir. This common characteristic suggests that the reservoir's inherent properties, specifically its oil-wet nature, play a significant role in influencing fluid displacement behavior. However, variations in reservoir heterogeneity, fluid properties, reservoir conditions, and operational factors contribute to the lack of matching results between the two wells. These results emphasize the importance of considering multiple factors in reservoir analysis and highlight the need for detailed reservoir characterization and modeling. Moving forward, further investigation into the specific factors influencing the behavior of each well, coupled with continued refinement of reservoir modeling techniques, will be crucial for optimizing production strategies and maximizing recovery from the Masrab oil field.

Despite these challenges, investing the necessary effort and time in obtaining accurate parameters for the Buckley-Leverett equation is crucial for improving the accuracy of reservoir modeling and fluid flow predictions. By ensuring the reliability of input data and parameters, operators can enhance the effectiveness of the Buckley-Leverett method in evaluating reservoir performance, optimizing production strategies, and maximizing oil recovery.

5. Recommendations:

Based on the findings and conclusions drawn from the analysis of wells P06 and P07 in the Masrab oil field, several recommendations can be proposed:

1. Further Reservoir Characterization: Conduct detailed reservoir characterization studies to better understand the heterogeneity, fluid properties, and reservoir conditions within the oil-wet reservoir. This may involve additional well logging, core analysis, and reservoir simulation studies.

2. Integrated Reservoir Modeling: Develop integrated reservoir models that incorporate data from both wells P06 and P07, as well as other available data sources. These models should account for variations in reservoir properties and fluid behavior to provide more accurate predictions of reservoir performance.

3. Enhanced Well Testing: Conduct additional well testing and monitoring programs to gather more data on fluid flow behavior and reservoir dynamics. This may include pressure transient testing, interference testing between wells, and production logging to validate reservoir models and improve reservoir management practices.

4. Optimized Production Strategies: Based on the insights gained from reservoir characterization and modeling studies, develop optimized production strategies tailored to the specific characteristics of the oil-wet reservoir. This may involve adjusting production rates, well completion designs, and injection strategies to maximize oil recovery while minimizing operational risks.

5. Continued Monitoring and Evaluation: Implement a comprehensive monitoring and evaluation program to track reservoir performance over time and identify any changes or trends that may impact production. Regularly update reservoir models and production forecasts based on new data and insights gained from ongoing monitoring activities.

6. Investing the necessary effort and time in obtaining accurate parameters for the Buckley-Leverett equation is crucial for improving the accuracy of reservoir modeling and fluid flow predictions. By ensuring the reliability of input data and parameters, operators can enhance the effectiveness of the Buckley-Leverett method in evaluating reservoir performance, optimizing production strategies, and maximizing oil recovery.

By implementing these recommendations, operators can improve their understanding of the reservoir behavior, optimize production practices, and maximize oil recovery from the Masrab oil field.

Arabic section:

العنوان:

إنشاء منحنى التدفق الجزئي باستخدام طريقة باكلي-ليفيريت: دراسة حقلية لحقل مسرب النفطي في ليبيا

سالمة صالح محمود

جامعة بني وليد – كلية الهندسة – قسم هندسة النفط والغاز

النوري المبروك الحداد

جامعة بني وليد – كلية الهندسة – قسم هندسة النفط والغاز

الملخص:

الملخص: يُعَدُّ فهم وحساب منحنيات التدفق الجزئي بدقة أمرًا حيويًا لإدارة المكامن بشكل فعال وتعزيز استخراج النفط. توجد طرق مختلفة لحساب منحنيات التدفق الجزئي، بما في ذلك النماذج الرياضية التي يمكن أن تُسفِر عن نتائج مختلفة. الهدف الرئيسي من هذه الورقة هو حساب منحنيات التدفق الجزئي باستخدام طريقة باكلي-ليفيريت لبئرين، P06 وP07، في حقل مسرب النفطي في ليبيا، باستخدام برنامج إكسل للتحليل. تعتمد الدراسة على بيانات تحليل اللب لضمان دقة الحسابات. لا يظهر منحنى التدفق الجزئي لبئر P06 شكلاً على هيئة S وفقًا لطريقة باكلي-ليفيريت، مما يشير إلى ارتفاع التشبع بالنفط المتبقي ليصل إلى حوالي 0.46، وبالتالي يصنيف مكمن السرير كمكمن مبلل بالنفط. وبالمثل، لا يظهر منحنى التدفق الجزئي لبئر P07 شكلاً على هيئة S وينزاح إلى اليسار، حيث يصل التشبع بالنفط المتبقي إلى حوالي 0.299. تُظهِر كلا البئرين نتائج متشابهة لأن البئرين من نفس المكمن (السرير). يُظهِر الانحراف الملحوظ عن الشكل المتوقع لمنحنيات التدفق الجزئي تغييرات كبيرة في خصائص الصخور والسوائل في المكمن. تتطلب هذه التغييرات مزيدًا من الدراسات لفهم تأثيرها على استخراج النفط ومعالجة مشكلة تبلل النفط بالصخر بشكل فعال. يُعَدُّ تحديد ومعالجة هذه التغييرات أمرًا ضروريًا لتحسين إنتاج النفط وضمان إدارة مستدامة للمكامن. تسلط هذه الدراسة الضوء على أهمية الحسابات الدقيقة لمنحنيات التدفق الجزئي لإدارة المكامن بشكل فعال، والحاجة إلى البحث المستمر للتكيف مع الظروف المتغيرة للمكامن. تتطلب دراسات اضافية لفهم التغيرات في خصائص الصخور والسوائل ومعالجة مشكلة تبلل الصخر بالنفط، مما يؤدي في النهاية إلى تحسين استراتيجيات تعزيز استخراج النفط.

الكلمات المفتاحية: منحنيات التدفق الكسري، نموذج رياضي، مكمن رطب بالزيت، طريقة باكلي-ليفيريت.

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