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Constructing the Fractional Flow Curve for the Masrab Oilfield Using Production Data: A Case Study in Libya

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ABSTRACT

This study focuses on evaluating the flow performance of oil and water in the Masrab oilfield, Libya, using production data. The main goal is to apply the production data method to calculate fractional flow curves, which are essential for optimizing production strategies in mature oilfield. The analysis was conducted using Excel software, which facilitated efficient calculations and plotting of the fractional flow curves. The results reveal that the field is oil-wet, a condition that has a direct impact on oil recovery efficiency. Oil wet reservoirs tend to have lower recovery rates, as water does not easily displace oil from the rock surfaces, leading to challenges in maximizing oil extraction. The production data method used in this study proved to be more accurate and practical for field applications compared to traditional methods like the Buckley-Leverett approach. Furthermore, this approach was shown to be more cost-effective and time-efficient, particularly in environments where core sampling or extensive fluid property data is difficult to obtain. The study highlights the importance of using real-time production data to assess reservoir performance, especially in challenging conditions where conventional methods may not be feasible. Based on the results, it is recommended that the production data approach be preferred in oil-wet reservoirs like Masrab, as it offers significant advantages in terms of improving oil recovery and optimizing field operations. This approach provides a more practical and accessible solution for enhancing reservoir management and increasing long-term production efficiency.

1 Introduction

Oil-wet reservoirs, such as the Masrab field, present unique challenges for water flooding. In oil-wet conditions, the rock surface prefers to retain oil, making it more difficult to displace oil with water injection (Morrow, 1990).

As a result, oil recovery efficiency tends to be lower compared to water-wet reservoirs. The displacement patterns in oil-wet systems are complex, with capillary forces and wettability playing crucial roles in fluid movement (Abbas, et al., 2015; Anderson, 1986). The concept of fractional flow is essential for predicting fluid displacement and recovery in petroleum reservoirs. It plays a critical role in understanding how oil and water phases flow during water-flooding operations, a common secondary recovery process used to maintain reservoir pressure and enhance oil recovery. The fractional flow curve represents the proportion of each phase in the total flow rate, making it essential for managing reservoir performance and optimizing production, (Yang, 2009).

The Masrab oilfield in Libya is a mature reservoir facing challenges such as water breakthrough and reduced oil recovery efficiency. Understanding the relationship between water cut and oil recovery is essential for improving production strategies and mitigating water encroachment, which can significantly reduce oil recovery if not properly managed.
By analyzing production data and applying fractional flow principles, engineers can generate curves that highlight water-oil displacement efficiency, predict

water breakthrough, and optimize the overall performance of the field (Marvin, 2023; Kida et al., 2023), Fig.(1).

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

$$f_w = \frac{1}{1+\frac{k_{ro}\,\mu_w}{\mu_o\,k_{rw}}} \qquad \text{(Eq 2)}$$

The next equation is for calculating the fractional flow using production data and exhibits how changes in pressure and saturation influence the fractional flow of water. By analyzing pressure variations in the reservoir, it provides insights into the behavior of water and oil flow, aiding in more informed decisions for optimizing production strategies (Fadairo et al., 2014).

$$f_w = \frac{Kdp - \frac{V_p\,dS_w}{\beta_w\ dp}[1-\frac{S_w\,d\beta_w}{\beta_w\ dp}]}{Kdp - \frac{V_p\,dS_w}{\beta_w\ dp}\left[1-\frac{S_w\,d\beta_w}{\beta_w\ dp}\right] + OIIP - \frac{V_p dS_o}{\beta_o\ dp}(1-\frac{S_o\,d\beta_o}{\beta_o\,dS_o})} \qquad \text{(Eq 3)}$$

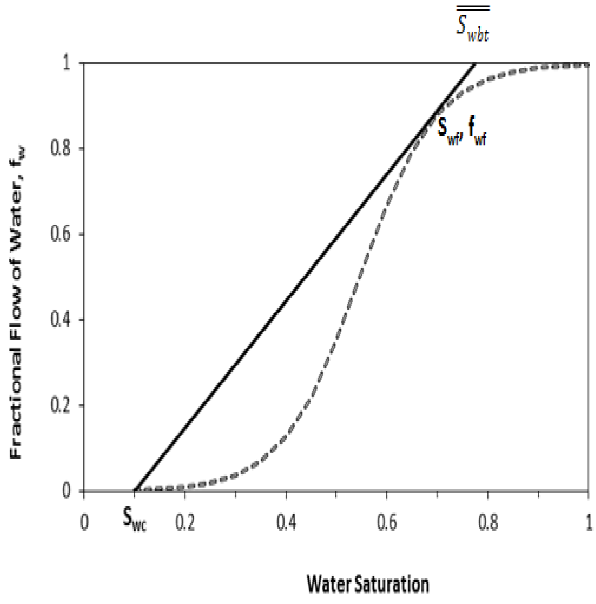


Figure 1: Fractional Flow Curve from Buckley and Leverett (1942).

In recent years, advancements in production monitoring and reservoir simulation technologies have allowed real-time data acquisition and the continuous adjustment of recovery models based on changing reservoir conditions (Karami et al., 2014).

This study focuses on constructing fractional flow curves for the Masrab field using a production data approach to identify the most accurate method for optimizing water-flooding approaches and improving oil recovery, Fig. (2).

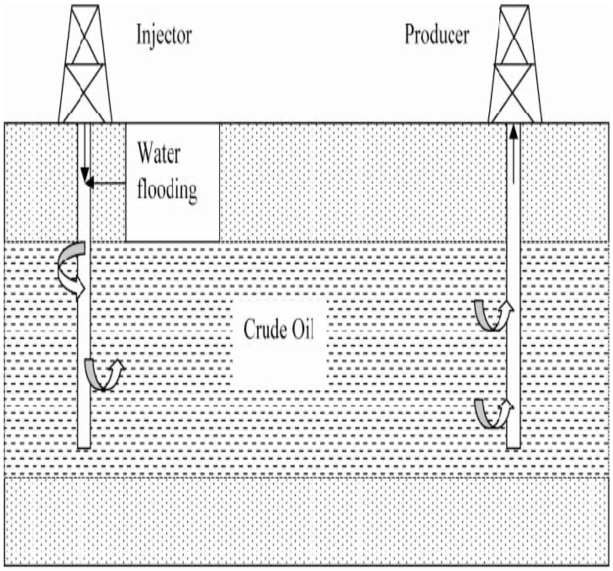


Figure 2: Water-flooding process showing injector and producer wells (Adeniyi et al., 2008).

2 Materials and Methods

2.1 Masrab Oilfield Overview:

The Masrab field, discovered in 1961, contains three main oil reservoirs: Lidam, Etla-Sarir, and Eocene, with Lidam and Etla-Sarir being the primary producers with a significant number completed in these two reservoirs. Waterflooding was introduced in 1989 to maintain reservoir pressure above the bubble-point pressure, with several wells converted into water injectors, (Masrab Oil Field,Libya)..https://www.gem.wiki/Masrab_Oil_Field_(Libya). (Tables1, 2, and 3).

The production data approach calculates fractional flow using the actual production rates of oil and water from the field. This method provides an alternative means of analyzing flow behavior based on observed field data rather than relying on theoretical core analysis, (Adesina, et al., 2014; Al-Jasmi, et al., 2013).

2.2 Study 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 the 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 the 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

2.3 Procedures:

This study was conducted on the oilfield to calculate the fractional flow curve using the production data equation. The methodology for this work is outlined as follows:

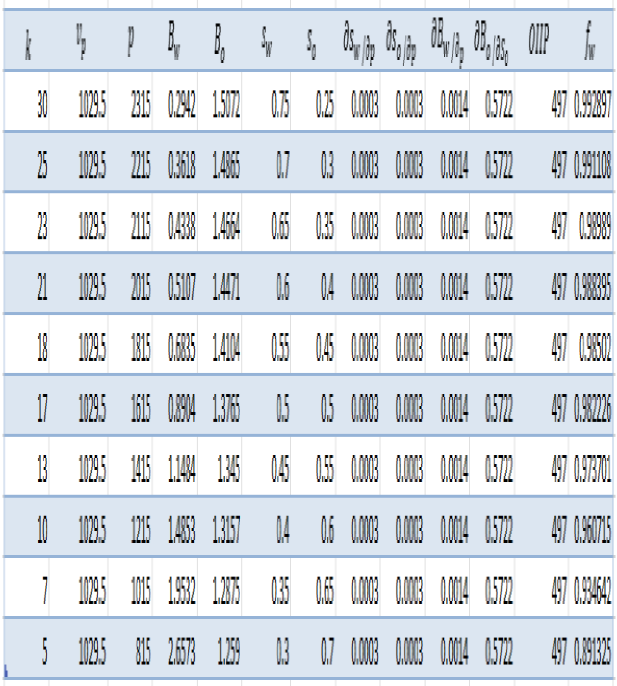
1. Collect the necessary data for the Masrab field from Alwaha Oil Company.
2. Use Excel software to analyze the relevant equations.
3. Input the production data into the equation.
4. Calculate the fractional flow curve using the production data equation.
5. Analyze and interpret the results to confirm whether the reservoir is oil-wet or water-wet.

3 Results

3.1 Production Data Analysis:

The production-database approach, applied to the whole field, confirmed that the reservoir is oil-wet. The fractional flow curve generated from the production data deviated from the typical S-shape seen in water-wet reservoirs, displaying a leftward shift instead. This method proved to be more accurate, efficient, and timesaving than the Buckley-Leverett approach, particularly in scenarios where obtaining core samples is challenging, (Addami & Elhaddad, 2024; Aghahoseini, et al., 2023).

3.2 Production data Equation:



k	V_p	p	B_w	B_o	S_w	S_o	$\partial S_w/\partial p$	$\partial S_o/\partial p$	$\partial B_w/\partial_p$	$\partial B_o/\partial S_o$	$OIIP$	f_w
30	1029.5	2315	0.2942	1.5072	0.75	0.25	0.0003	0.0003	0.0014	0.5722	497	0.992897
25	1029.5	2215	0.3618	1.4865	0.7	0.3	0.0003	0.0003	0.0014	0.5722	497	0.991108
23	1029.5	2115	0.4338	1.4664	0.65	0.35	0.0003	0.0003	0.0014	0.5722	497	0.98989
21	1029.5	2015	0.5107	1.4471	0.6	0.4	0.0003	0.0003	0.0014	0.5722	497	0.988395
18	1029.5	1815	0.6835	1.4104	0.55	0.45	0.0003	0.0003	0.0014	0.5722	497	0.98502
17	1029.5	1615	0.8904	1.3765	0.5	0.5	0.0003	0.0003	0.0014	0.5722	497	0.982226
13	1029.5	1415	1.1484	1.345	0.45	0.55	0.0003	0.0003	0.0014	0.5722	497	0.973701
10	1029.5	1215	1.4853	1.3157	0.4	0.6	0.0003	0.0003	0.0014	0.5722	497	0.960715
7	1029.5	1015	1.9532	1.2875	0.35	0.65	0.0003	0.0003	0.0014	0.5722	497	0.934642
5	1029.5	815	2.6573	1.259	0.3	0.7	0.0003	0.0003	0.0014	0.5722	497	0.891325

Table 4: Results of Production Data Equation.

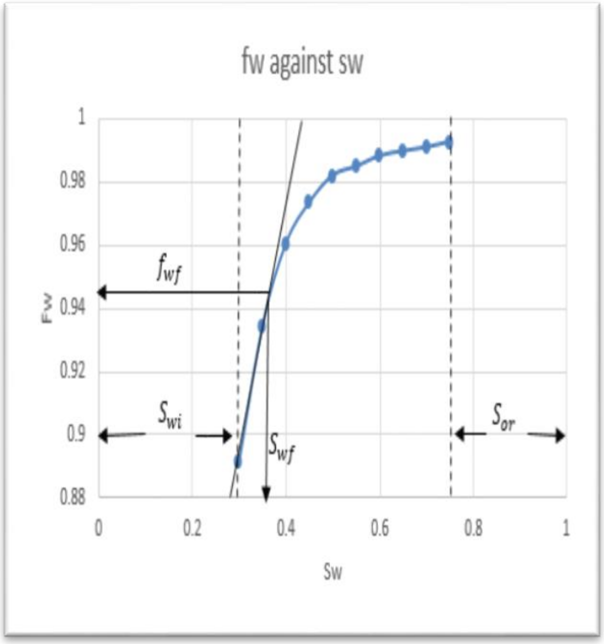


Figure 3: Fractional flow curve of Masrab field by using Production Data Equation.

Figure 3. Presents the fractional flow curve for the Masrab field generated using the production data equation. This approach was applied to the field as a whole, rather than individual wells. The results indicate that the field is oil-wet, as the fractional flow curve does not exhibit the typical S-shape and instead shifts to the left. The production data approach is more accurate, less labor-intensive, cost-effective, and time-efficient.

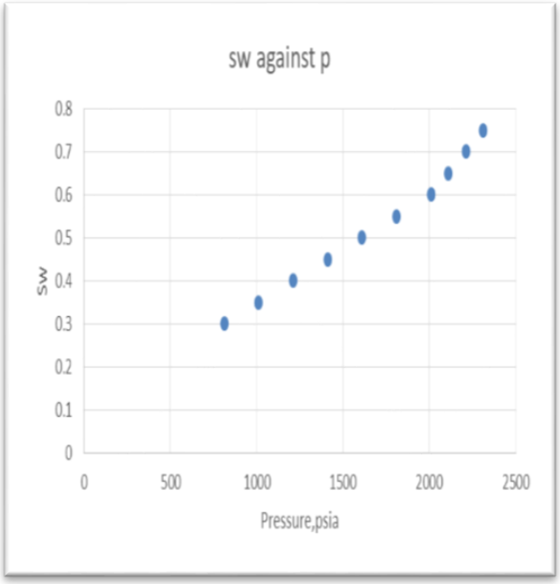


Figure 4: Water saturation against pressure.

Figure 4. Illustrates the relationship between water saturation and pressure, clearly demonstrating how pressure depends on water saturation. Tangents were drawn at various points to calculate $\frac{d\,S_w}{dP}$, which is low at high pressures and high at low pressures. The figure indicates that pressure drops as water saturation declines.

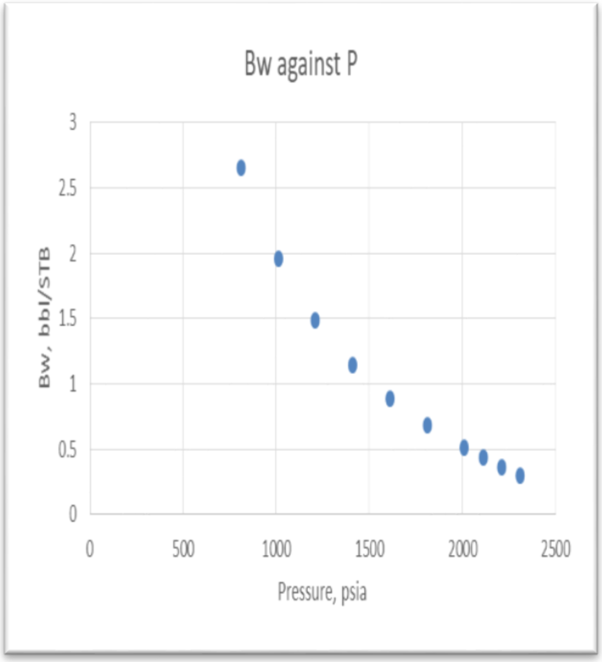


Figure 5: Water FVF against pressure.

Figure 5. Illustrates the relationship between the water formation volume factor and reservoir pressure. As the reservoir pressure reduces below the initial pressure P_i, the water volume factor rises due to the expansion of water.

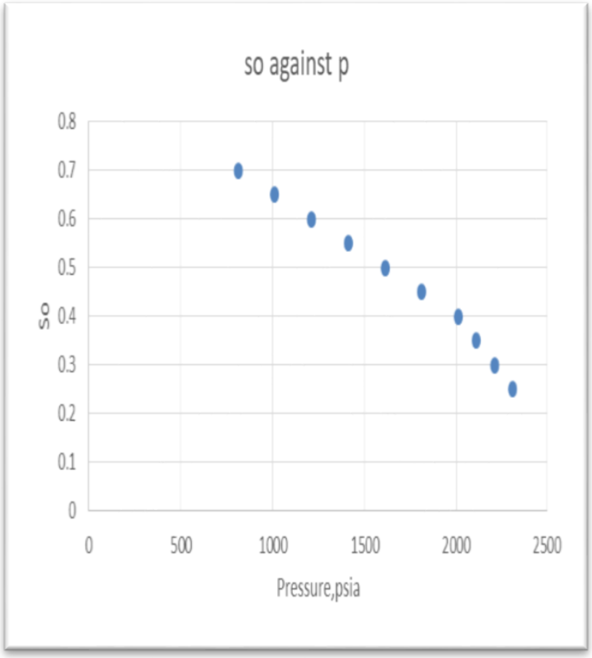


Figure 6: Oil saturation against pressure.

Figure 6: Illustrates the relationship between oil saturation and pressure. As the pressure decreases, oil saturation increases linearly, with two distinct slopes: a smaller slope at higher-pressure ranges and a steeper slope at lower pressure ranges.

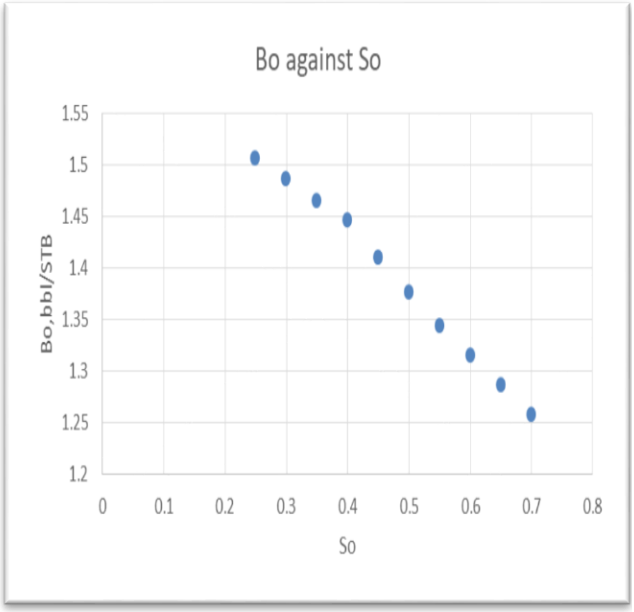


Figure 7: Oil FVF against oil saturation.

Figure 7: Illustrates the relationship between the oil formation volume factor and oil saturation. Below bubble point pressure (P_b), oil saturation decreases due to oil shrinkage, while the oil formation volume factor (B_O) shows a slight increase.

4 Discussion

The results of this study highlight the significance of using production data to construct fractional flow curves for the Masrab oilfield. These results provide valuable insights into reservoir behavior and suggest practical approaches for optimizing oil recovery in oil-wet reservoirs.

One key observation is the deviation of the fractional flow curve from the typical S-shape observed in water-wet reservoirs. This deviation confirms the oil-wet nature of the Masrab field, where water struggles to effectively displace oil due to the preferential retention of oil on the rock surfaces. This has a profound impact on recovery efficiency, as it necessitates tailored strategies to maximize production.

The production data approach demonstrated several advantages over traditional methods like the Buckley-Leverett model. It is not only more accurate but also more practical, particularly in environments where obtaining core samples or extensive fluid property data is challenging. This makes it a valuable tool for engineers working in similar fields where conventional methods may fall short.

Additionally, the relationships between water saturation, pressure, and oil saturation underline the importance of monitoring these parameters in real-time to anticipate and address challenges such as water breakthrough. Figures 4, 5, and 6 provide a clear understanding of how pressure fluctuations impacts fluid distribution, guiding decisions on injection and production strategies.

Ultimately, this study emphasizes the necessity of leveraging field-specific data to enhance reservoir management. By focusing on the unique characteristics of oil-wet reservoirs, the production data method offers a cost-effective and efficient means to improve long-term recovery and ensure sustainable field operations.

5 Conclusions

The Reservoir is Oil-Wet: This means that the rock surfaces in the reservoir have a higher wettability for oil compared to water. In oil-wet reservoirs, oil tends to stick to the rock surfaces, while water is non-wetting. This property affects how fluids (oil and water) flow through the reservoir.

Changes in Rock and Fluid Properties : The rock and fluid properties have changed، leading to a phenomenon called water fingering where water moves toward the wells. Water fingering can disrupt oil production by allowing water to flow more freely into the production wells, which can lower oil recovery and efficiency.

Solving the Problem: To address water fingering، you need to either reduce the mobility of water (make it less likely to flow) or reduce interfacial tension (the force between oil and water). Both approaches can help control water movement and improve oil production.

Water-Wet Reservoir for Better Oil Recovery: For improved oil recovery، the reservoir should ideally be water-wet، meaning the rock surfaces would attract water more than oil. In water-wet reservoirs, oil can flow more freely because it does not stick as much to the rock surfaces.

Production Data Approach: The production data approach used in this analysis is more accurate, less labor-intensive, cost-effective, and time-efficient compared to other methods like core sampling or laboratory testing. This method saves time and effort in diagnosing reservoir conditions.

Need for Further Investigation : However, more investigations are needed to fully understand the changes in the reservoir's rock and fluid properties. These investigations would help diagnose the cause of the oil-wet condition and help determine the best course of action to solve the problem and enhance oil recovery.

The conclusion emphasizes the need for more investigations to understand why the reservoir has become oil-wet and how to effectively solve water fingering and improve oil recovery using a more efficient and accurate production data approach, (Ghaffarkhah, A., et. al.,2023).

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Conflict of interest: The authors hereby declare that there are no conflicts of interest associated with the publication of this research. We confirm that the research was conducted without any financial or personal interests that could have influenced the results or interpretations presented in this paper.

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