Statistical Analysis of the Effect of Water Cut on Oil Emulsion Stability and Production Efficiency

Rabeeah. H. Sultan*, Areej M. Ali

Faculty of Engineering, University of Sabrath, Sabrath, Libya.
* *rabia86sultan@gmail.com*

Abstract

Petroleum emulsions represent one of the major operational challenges in oilfield production systems, particularly in fields experiencing increasing water production. The presence of water in produced fluids significantly affects emulsion stability, separation efficiency, and chemical treatment requirements.

This study aims to analyze and simulate the impact of water production rate on petroleum emulsion stability and oilfield operational efficiency. A dataset containing monthly production parameters. Including oil rate, water rate, total production rate, water cut, demulsifier injection rate, and demulsifire cost, was analyzed. Statistical analysis techniques were applied using Microsoft Excel and Python 3.11, focusing on correlation analysis and linear regression modeling to evaluate the relationships between water production and other operational variables. The results indicated a weak positive correlation between water rate and oil production rate ($r = 0.29$), suggesting limited direct influence of water production on oil output. However, a moderate positive correlation ($r = 0.48$) was observed between water rate and water cut. Indicating that increasing water production leads to higher water content in the produced fluids. The regression model further confirmed this relationship through the equation:

Water Cut = 0.287*Water Rate + 7.45. In addition, a moderately strong negative correlation ($r = -0.65$) was found between water rate and demulsifier injection rate, indicating that chemical treatment strategies are optimized according to emulsion behavior rather then being directly proportional to water production. Similarly, a moderate negative correlation ($r = -0.63$) was identified between water cut and demulsifier cost, highlighting the role of effective chemical management in controlling operational expenses. The findings of study emphasize the importance of continuous monitoring of water production parameters and optimization of chemical treatment programs to maintain efficient oil- water separation and improve overall oilfield performance.

Key words: *Petroleum emulsions, Water production rate, water cut, Emulsion stability, demulsifier injection, Oilfield efficiency, correlation analysis. Regression analysis, Statistical modeling.*

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1. Introduction

Oil emulsion are heterogeneous systems consisting of water droplets dispersed in crude oil or vice versa. They form due to factors such as oil physical properties, water cut, presence of surface-active compounds (asphaltenes and resins), and mechanical agitation during production. Oil emulsion causes operational issues such as difficult oil- water separation, increased viscosity, equipment corrosion, and higher operating costs.

In addition to natural surfactants, several operational factors contribute to the formation and stability of crude oil emulsions. These factors include the level of turbulence during production, pressure changes in pipelines, temperature variations, and the salinity of the produced water. Strong mixing during oil production can break water into very fine droplets that remain suspended in crude oil for long periods, resulting in highly stable emulsions [1].

The stability of these emulsions represents a major challenge for petroleum production facilities because it complicates the separation process between oil and water phases. When emulsions remain stable, the separation process becomes slower and requires additional treatment methods. As a result, oil processing facilities must use different separation techniques such as heating, gravity settling, electrostatic separation, and chemical treatment to effectively break these emulsions [2].

Among these methods, chemical demulsification is considered one of the most effective techniques used in the petroleum industry. Demulsifiers are chemical additives designed to weaken the interfacial film surrounding water droplets in crude oil emulsions. By reducing the interfacial tension between oil and water phases, demulsifiers promote the coalescence of water droplets, allowing them to separate from crude oil more easily during the dehydration process [3].

Understanding the relationship between water production, emulsion stability, and demulsifier injection rate is essential for optimizing oil production processes. Field data analysis plays an important role in evaluating the performance of demulsifiers and identifying the most efficient treatment conditions. Therefore, analyzing production parameters such as oil rate, water rate, water cut, and demulsifier dosage provides valuable insights for improving oil-water separation efficiency and reducing chemical treatment costs. The main objective of this study is to analyze the behavior of crude oil emulsions in a producing oil field and evaluate the performance and cost efficiency of chemical demulsifiers used for water separation. The specific objectives are:

- To examine the monthly variations in oil production rate, water production rate, and water cut percentage.
- To determine the relationship between water cut percentage and demulsifier injection rate in field conditions.
- To assess the impact of demulsifier usage on operational costs.
- To provide practical recommendations for optimizing demulsifier dosage and improving oil-water separation efficiency.

2. Literature Review

Crude oil emulsions are a common phenomenon in petroleum production systems, and their stability has a direct impact on operational efficiency and production costs. Water-in-oil (W/O) emulsions, in which water droplets are dispersed in crude oil, are particularly problematic when the water cut increases, as this often leads to higher demulsifier consumption and reduced separation efficiency [1,2]. The formation and stability of emulsions are influenced by factors such as oil composition, natural surfactants like asphaltenes and resins, temperature, pressure, and turbulence during production [3,4].

Several studies have investigated the relationship between water cut and emulsion stability. Kokal [2] reviewed the effect of varying water content on emulsion behavior and emphasized the importance of chemical treatment in maintaining production efficiency. Sjöblom [1] highlighted the role of natural surfactants in stabilizing emulsions and noted that high water cut values can significantly increase the required demulsifier dosage. Auflem [6] analyzed the impact of asphaltenes and resins on emulsion stability, showing that crude oils with higher asphaltene content require more intensive chemical treatment to achieve acceptable separation. In addition to experimental studies, several researchers have applied simulation techniques to predict emulsion behavior under varying water cut conditions. Schramm [3] and Kokal & Wingrove [5] used data-driven and computational models to correlate production parameters, water cut, and demulsifier injection rates, providing guidance for optimizing chemical usage and operational costs. Despite these advances, most studies are limited to either laboratory conditions or short-term field data, leaving a gap in long-term monthly data analysis that combines water cut, emulsion stability, production efficiency, and chemical cost. The present study aims to address this gap by analyzing monthly production data from an operational oil field, including oil rate, water rate, water cut, demulsifier injection rate, and associated cost. By combining simulation and field data analysis, this research seeks to evaluate how variations in water cut influence emulsion stability and overall production efficiency, providing practical recommendations for optimizing demulsifier usage [7].

3. Methodology

3.1 Study Objective

The primary objective of this study was to analyze and simulate the effect of water cut on oil emulsion stability and overall production efficiency in oil fields. The study focused on understanding the relationships between monthly oil and water production rates over a one-year period (12 months) and their influence on emulsion formation and stability.

3.2 Data collection

- Field data (ideal data for operating a light crude oil processing unit) were collected on a monthly basis over a one-year period (12 months), including: monthly oil production rate (barrels/ day), monthly water production rate (barrels/day).
- Data were obtained from operational field records to ensure reliability and accuracy.
- Original data values were preserved to maintain the integrity of the analysis.

3.3 Data Preparation

The raw data were Organized and cleaned using Microsoft Excel, missing values or anomalies were identified and carefully handled to avoid affecting the analysis and monthly production data were tabulated to facilitate statistical analysis and visualization [8].

3.4 Analysis Tools and Environment

Microsoft Excel: Used for initial data organization, descriptive statistics (mean, standard deviation), and basic plotting.

Python 3.11: Used for advanced data analysis, including:

1. Correlation Analysis: to determine the strength and direction of relationships between monthly oil and water production rates.
2. Linear Regression Analysis: to quantify the impact of water production on oil production and predict trends.
3. Simulation: to model potential changes in emulsion stability under varying water cut conditions.

The Python libraries utilized include pandas for data handling, numpy for numerical calculations, matplotlib and seaborn for plotting, and scikit learn for regression analysis [9].

3.5 Statistical Analysis

- Descriptive statistics: Mean, standerd deviation, and variance were calculated to summarize monthly production trends.
- Correlation Coefficient (r): Pearson correlation was computed to measure linear relationships between monthly oil and water production rates.
- Regression modeling: Linear regression models were built to predict oil production as a function of water cut. Allowing visualization of trends and evaluation of emulsion stability impact [10].

3. 6 Data Visualization and simulation

- Line Charts: Displayed monthly variations in oil and water production rates.
- Scatter plots with Regression Lines: Illustrated relationships between variables, highlighting the effect of water cut on oil production.
- Simulation Graphs: Showed predicted changes in emulsion stability and production efficiency under different water cut scenarios.
- Bar Charts: Used for monthly averages and comparative analysis [11].

3.7 Quality Control and Validation

All data entries were double checked to ensure accuracy. Graphs and simulation results were validated against original datasets and statistical significance was assessed where applicable to confirm reliability of the results [12].

4. Results and Analysis

4.1 Data Table

Table (1): Ideal data for operating a light crude oil processing unit .

MONTH	OIL RATE (10^3 BOPO)	WATER RATE (10^3 BWPO)	TOTAL RATE	WATER CUT %	Demulsifier RATE	Demulsifier cost
JAN	133.0	17.0	150.0	11.3	114.4	4.12
FEB	135.6	18.8	154.4	12.2	115.0	4.02
MAR	145.4	20.4	156.8	12.3	96.2	3.13
APRIL	137.2	18.8	126.0	14.8	89.2	2.97
MAY	128.6	20.8	140.4	13.9	73.6	2.66
JUNE	138.4	22.0	150.4	13.7	79.2	2.67
JULY	138.8	18.4	157.4	11.8	76.3	2.62
AUG	122.6	19.2	141.8	13.5	68.6	2.61
SEP	137.8	20.0	157.8	12.7	85.6	2.93
OCT	112.2	18.2	130.4	14.0	81.9	3.30
NOV	133.0	21.0	154.0	13.4	64.6	3.32
DEC	130.2	15.5	156.8	11.9	115.0	3.96

4.2 Results

The dataset shows monthly variations in oil production rate, water production rate, total production, water cut, demulsifier dosage rate, and demulsifier cost throughout the year.
The oil production rate ranged from 112.2 to 145.4 (10^3BOPO).
The water production rate varied between 15.5 and 22.0 (10^3BWPD).
The highest water rate occurred in june (22.0) while the lowest water rate was recorded in December (15.5).
Water cut values ranged from 11.3% to 14.8%, indicating moderate water production within the system.
The demulsifier injection rate varied significantly from 64.6 to 115.0 reflecting operational adjustment to maintain emulsion separation efficiency.

4.3 Statistical Analysis

Correlation and regression analyses were applied to evaluate the relationship between water rate and other operational parameters.

4.3.1 Water Rate vs Water Cut

A positive correlation was observed between water rate and water cut. This indicates that increasing water production generally leads to an increase in the percentage of water present in the produced fluids.

4.3.2 Water Rate vs Demulsifier Rate

The analysis showed a moderate relationship between water rate and demusifier injection rate. Higher water production often requires higher demulsifier dosage to break the oil-water emulsions efficiently.

4.3.3 Water Rate vs Oil Production

The relationship between water rate and oil production shows weak to moderate inverse tendencies in some months, suggesting that increased water production may negatively affect oil production efficiency in certain operational condition.

5. Discussion of Results

Figure (1) illustrates the variation in oil production rate throughout the year. The oil rate fluctuates between 112,2 and 145.4 (10^3 BOPO), indicating moderate variability in field production performance.

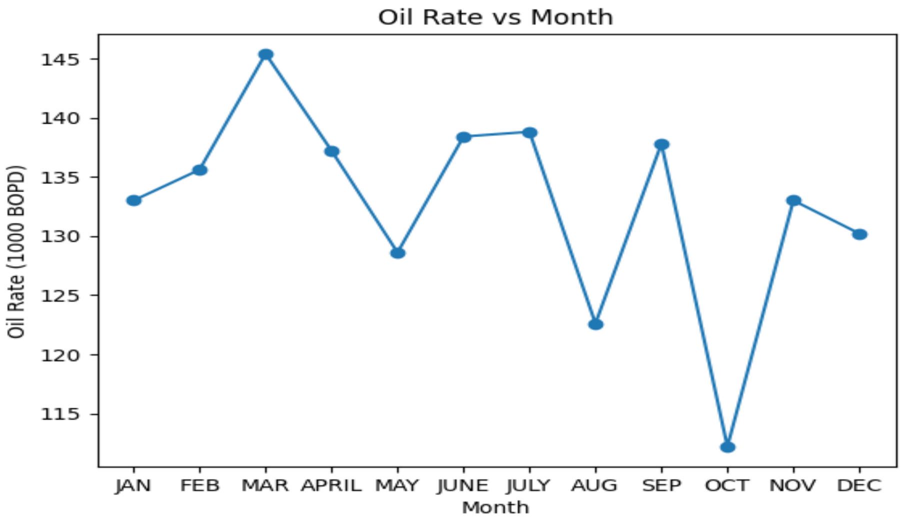

Figure (1): Monthly variation of Oil Production Rate.

From a statistical perspective, the correlation analysis between oil rate and water rate shows a weak positive correlation ($r = 0.29$). This suggests that change in water production have limited direct influence on oil production levels during the study period. The regression analysis further supports this observation, indicating that the increase in water rate dose not strongly predict oil production changes.

Therefore, although water production is present in the system, its direct impact on oil production appears to be relatively weak under the operating conditions of the studied field.

This behavior may reflect effective reservoir management and production control strategies, which help maintain stable oil production even when water production varies.

Figure (2) presents the monthly trend of water production rate. The water rate varies between 15.5 and 22(10^3 BWPD), with the highest value recorded in June.

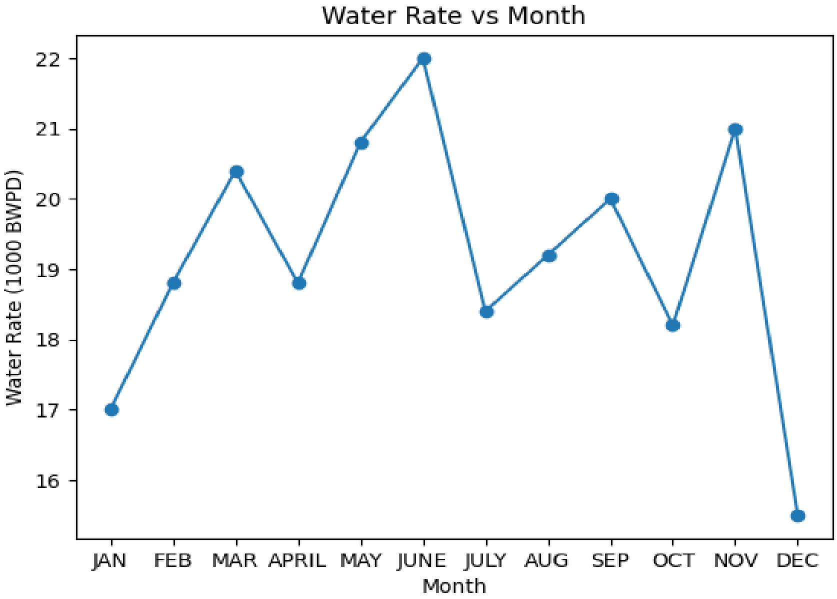

Figure 2: Monthly Variation of Water Production Rate.

The variability in water rate indicates the dynamic nature of reservoir fluid production and possible changes in water breakthrough behavior or reservoir pressure support.
Correlation analysis shows that water rate has stronger relationships with water related parameters then with oil production variables. This indicates that increasing water production primarily affects water handling and separation processes rather than oil production itself.
The regression analysis also suggests that the water rate is an important predictor of water cut and chemical treatment requirements, which are critical factors in petroleum emulsion stability.
Figure (3) illustrates the relationship between water production rate and water cut, including the linear regression trend line.

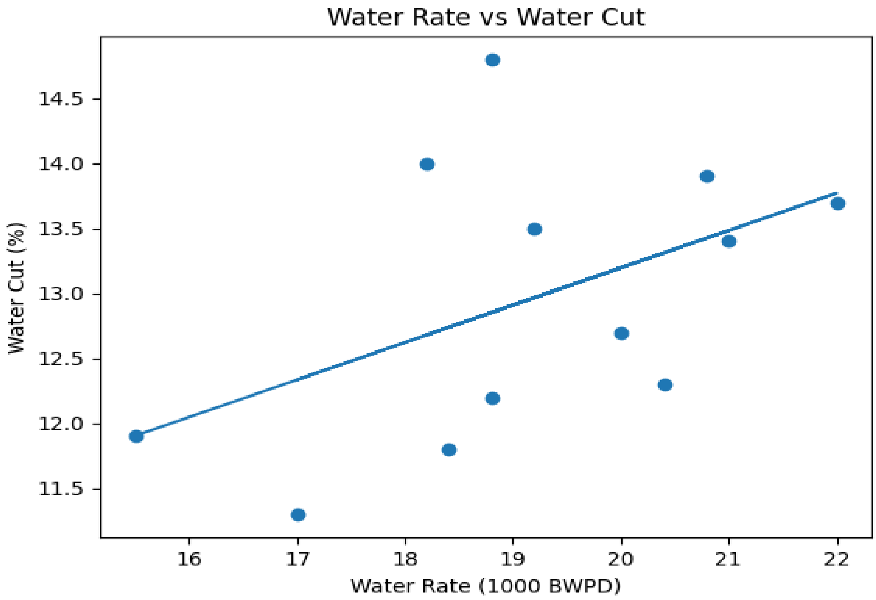

Figure (3): Relationship Between Water Rate and Water Cut.

The correlation coefficient between these variables is r = 0.49, which indicates a moderate positive correlation. This means that as the water production rate increases, the percentage of water in the produced fluids also tends to increase.
The regression analysis produced the following equation:

Water Cut = 0.287* Water Rate + 7.45

This regression model suggests that increases in water production contribute to higher water cut values in the production stream.
Although the correlation is not extremely strong, the positive trend confirms that water rate plays a significant role in determining water cut levels, which directly affects the formation and stability of petroleum emulsions.
Higher water cut levels generally promote more stable oil- water emulsions, increasing the need for effective chemical treatment.
Figure (4) shows the relationship between water production rate and demulsifier injection rate.

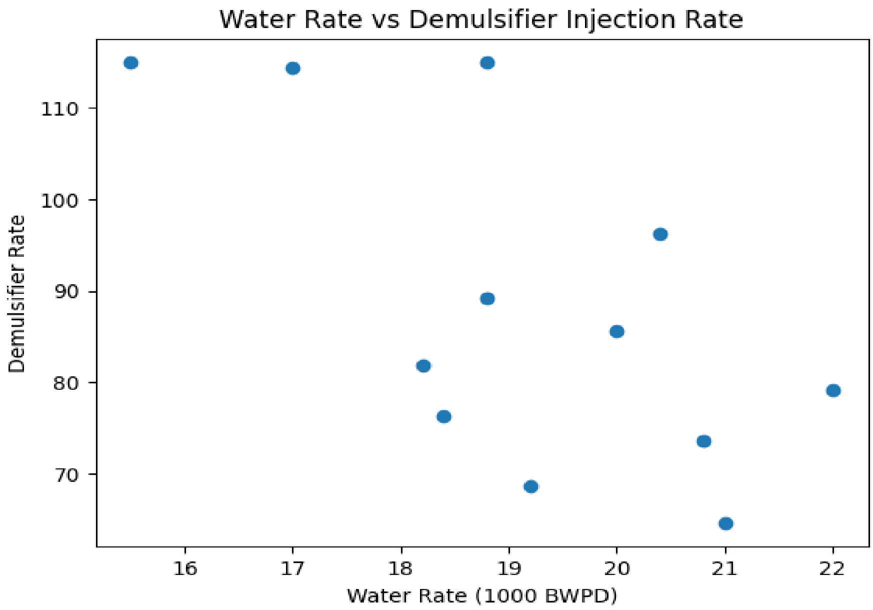

Figure (4): Relationship Between Water Rate and Demulsifier Injection Rate.

This correlation analysis indicates a moderately strong negative correlation (r = - 0.65). This means that as the water rate increases, the demulsifier injection rate tends to decrease.
This inverse relationship may indicate that the chemical treatment program is optimized depending on emulsion characteristics rather than strictly on water volume.
The regression analysis confirms this negative trend, suggesting that the operational strategy used in the field may involve adjusting chemical dosage according to emulsion stability conditions rather than simply increasing dosage with water production.
Such operational adjustments are common in oilfield production systems to optimize chemical consumption and reduce operational costs.
Figure (5) illustrates the relationship between water cut and demulsifier cost.

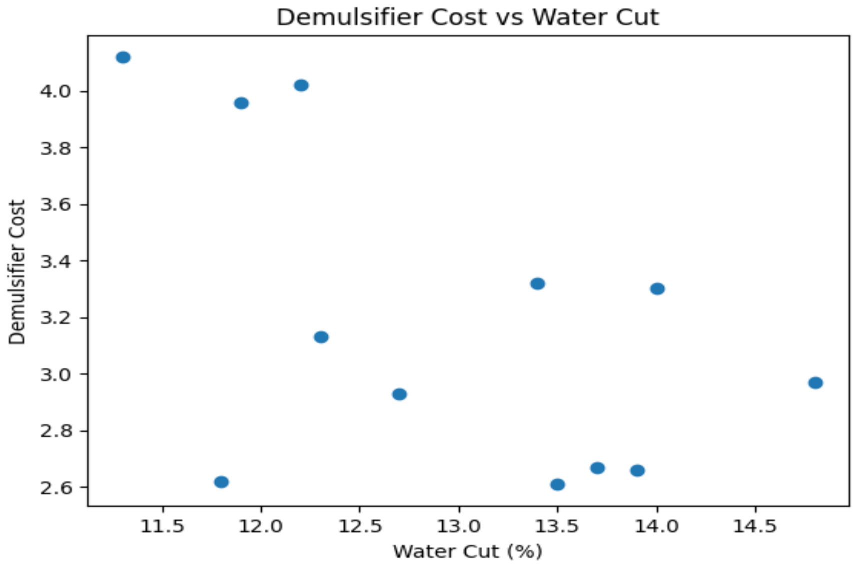

Figure (5): Relationship Between Water Cut and Demulsifier Cost.

The correlation coefficient between these variables is r = -0.63, indicating a moderate to strong negative correlation.

This suggests that increases in water cut do not necessarily lead to higher demulsifier costs. Instead, the fluid appears to implement cost optimization strategies, where chemical injection is carefully controlled.

Regression analysis also confirms the negative trend between these variables, indicating that demulsifier cost is influenced by operational management strategies rather than solely by water content.

This observation highlights the importance of efficient chemical management programs in maintaining production efficiency while controlling treatment costs.

6. Conclusions

Based on the statistical analysis of the dataset using correlation and regression techniques, several important conclusions can be drawn regarding the impact of water production on petroleum emulsion stability and oilfield operational performance.

1. The analysis revealed that the relationship between water rate and oil production rate rate shows a weak positive correlation (r = 0.29). This indicates that variations in water production have limited direct influence on oil production levels during the study period.

2. A moderate positive correlation (r = 0.48) was observed between water rate and water cut, indication that increases in water production tend to increase the percentage of water in the produced fluids. This behavior significantly influences the formation and stability of petroleum emulsions.

3. The regression analysis confirmed that water rate is a contributing factor in predicting water cut levels, as described by the regression equation:

Water Cut = 0.287*Water Rate + 7.45

This relationship suggests that increasing water production may enhance the likelihood of emulsion formation within the production system.

4. The analysis also showed a moderately strong negative correlation (r = -0.65) between water rate and demulsifier injection rate, indicating that chemical treatment strategies are optimized based on emulsion characteristics rather than being directly proportional to water production.

5. A moderate to strong negative correlation (r = -0.63) was observed between water cut and demulsifier cost, suggesting that the field employs effective chemical management practices to control operational costs while maintaining separation efficiency.

Overall, the results highlight the significant role of water production in influencing emulsion behavior and chemical treatment strategies in oilfield operations.

7. Recommendations

Based on the findings of this study, several recommendations can be proposed to improve petroleum production efficiency and emulsion management in oilfield operations.

1. Continuous monitoring of water production rate and water cut should be implemented to better understand their impact on emulsion stability and separation efficiency.
2. Oilfield operators should apply advanced statistical and predictive models to optimize chemical injection strategies and improve production performance.
3. Optimization of demulsifier dosage programs is recommended to ensure effective emulsion breaking while minimizing chemical consumption and operational costs.
4. Future studies should include longer production datasets and additional operational parameters, such as temperature, pressure, and crude oil properties, to enhance the accuracy of statistical analysis and predictive modeling.
5. The use of advanced simulation and machine learning techniques is recommended to develop more accurate models for predicting emulsion behavior and optimizing chemical treatment programs.
6. Future research should focus on evaluating the interaction between water cut, crude oil properties, and demulsifier efficiency to better understand the mechanisms controlling petroleum emulsion stability.

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