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Application of Demulsification as a Water Shut-Off Technique for Production Optimization in Oil Wells

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Abstract

Water from surrounding aquifers and injector wells encroach, and eventually breakthrough into the wellbore as oil production progresses. Water plays a very vital role in the production of oil through pressure maintenance and production support. However, when produced alongside the oil, it costs a lot to separate, treat, and dispose it. This prompted the need for developing appropriate and effective water shut off methods. In this study, a model is developed for determining the volume of water that can be displaced from an oil-water emulsion using a demulsifier, which when combined with a downhole oil-water separator will greatly reduce the volume of water travelling up the wellbore and thereby minimizing hydrostatic pressure losses. Results shows that there is significant drop in the volume of water produced from the wells due to the application of demulsifiers which translates to a reduction in hydrostatic pressure losses.

1. Introduction

Broadly speaking, hydrocarbons are produced from underground rocks where they are accumulated as field, trap, or pool. Water produced from hydrocarbon reservoirs are products of aquifers where they exist as natural water drive or used as water floods. Water production becomes a serious problem when its rates exceed economic limits, water by-pass oil, and a large volume of recoverable oil is left behind in the reservoir [1]. Water from surrounding aquifers and injector wells encroach, and eventually breakthrough into the wellbore as oil production progresses. The concept of water cycle (the invasion of water into production tubing and surface production facilities, followed by its eventual separation, treatment, and reuse or disposal) emanates from the breakthrough of water during oil production [1]. Uneconomic water production from oil reservoirs is a major challenge faced by many production companies. Some statistics revealed that over seven barrels of water are produced with every barrel of oil averagely, in the U.S alone [2]. High water production is a common problem petroleum production companies around the world struggle with. This problem is a common signature of old wells, albeit it can also occur in newly developed wells [3]. Excessive water production creates ample economic challenges for production companies. Notable among such problems is the shortening of the lifespan of the well. Early water breakthrough, and an eventual increase in water production result in increase in the weight of the fluid column in the well [4]. Increase in the weight of the fluid column in the well results in an increase in hydrostatic pressure losses, these losses cause an increase in the operating cost of production by creating the need for artificial lift systems to counteract these losses. Another major problem associated with high water production is the high cost of handling produced water. Significant fractions of the operating expenses go into the separation, treatment, and disposal of produced water. For instance, Thomas et al. [5] remarked that about $1 billion is spent on handling produced water yearly in Alberta, Canada.

Water plays a very vital role in the production of oil through pressure maintenance and production support. However, when produced alongside the oil, it costs a lot to separate, treat, and dispose it. This prompted the need for developing appropriate and effective water shut off methods. There are two major categories of water shut off methods. They include chemical [6, 7] and mechanical methods [4, 9, 10].

1.2 Overview of Demulsification and Demulsifiers

Since crude-oil coexists, and is co-produced with water, emulsification is a common phenomenon in the oil and gas industry. Since oil and water are immiscible, the interface between the liquids gets agitated during movement giving rise to emulsions. Consequently, demulsification with the use of an effective and efficient demulsifier is very essential [11].

Demulsification is commonly carried out majorly with chemical demulsifiers. Other methods such as filtration and centrifugal action are also used to break emulsions. Alsabagh et al [12] explained that the success of demulsification is hinged upon the breaking of the interface between the liquids by an agent. Two major categories of factors affect demulsification. The first set of factors are those resulting from the properties of the continuous phase. Such properties include viscosity, density, and asphaltenes content. The other category of factors depends on the structural modification the molecules the demulsifier has undergone [11].

Demulsification is carried out with the use of demulsifiers. Demulsifiers are surface-acting agents. They generate intense pressures at the oil and water interphase. Generally, commercial demulsifiers are surfactants of polyoxyethylene and polypropylene compounds [13]. The objective of this study is to highlight how demulsification can be used as a technique for reducing the water produced from oil wells.

1.2 Types of Demulsifiers

Different crude oil samples respond differently to demulsifiers. Hence, each crude oil sample has a suitable demulsifier type [14]. This explains why there are different types of demulsifiers. However, generally, the demulsifiers used in oil fields are products of the polymerization of surfactants. They are generally copolymers ethylene oxide; propylene oxide; ethoxylated phenols; nonyphenols and alcohols and amines [15].

It is a fact that light crude-oil samples generally contain between 5% and 20%of W/O emulsions per volume. This means that a hundred barrels of oil could contain as much as twenty barrels of water. Note that the water from the emulsion is different from the produced water that comes out with the oil. There has not been any study on how demulsification can be adopted as a water reduction method. However, the properties and mode of operation of demulsifier makes them look good as water shut off tools. This is the major focus of this study i.e developing a methodology for the deployment of demulsification for water shut-off operations.

1.3 Application of Demulsification in Water Shut-Off Operations

There are several publications with extensive details on the role of demulsification in crude-oil treatment. The target of many of the existing literature is the use of demulsifiers in the treatment of oil samples prior to shipping and refining. However, there has been no direct mention or review of the role of demulsification in reduction of produced water, which is the target of this current study. This study aims at showcasing the application of demulsification in reducing the amount of water produced from wells.

This study is based on a deep knowledge and extensive review of the nature and potentials of demulsifiers. Moreover, the significant presence of emulsion in many crude oil samples makes it right to infer those emulsions contribute significantly to the volume of produced water. Hence, this study will draw the attention of oil producers to identifying demulsifictaion as a water reduction method. This will mean introducing demulsifiers to near wellbore and wellbore regions primarily, to separate water-in-oil emulsions. Worthy of note is the fact that, like many other water shut-off operations, the method introduced in this study will work better in alliance with some other water reduction techniques (especially the downhole oil-water separator (DOWS)).

By breaking off a significant number of emulsions in the crude oil stream inside a well with the DOWS technology in place, a corresponding amount of water will go into the lower water sink. This study is aimed at drawing more attention to the application of demulsifiers in reducing the water produced from oil wells.

In treating emulsions during production, the demulsifier solution is poured into the well from the wellhead. To apply demulsifier for water production reduction, the wellbore is saturated with solutions of the demulsifier shortly before production commences. Also, a valve through which the demulsifier can be introduced to the fluid stream close to the production zone can be introduced. This way, as fluids flow into the well from the reservoir, emulsions are broken off in the well, significant volumes of water are trapped back in the well, and more oil gets produced.

Based on the mechanism of operation of this proposed technique, there will be an accumulation of water at the well bottom of conventionally completed wells. However, this technique will give greater results in wells where downhole oil-water separator (DOWS) is in place. In wells with DOWS completion, the demulsifier is introduced to the well close to the upper oil section. The demulsifier breaks the emulsion in the oil stream, and the displaced water flows down to the lower water sink.

Moreover, this technique is also achievable in a well with the downhole water sink. Like what happens in the DOWS completion, the demulsifier solution is introduced close to the oil zone. The emulsions in the oil stream are broken off, and the unwanted water is displaced to the base under the influence of gravity. Then, the displaced water is collected by the water sink.

From the foregoing, and as mentioned earlier, this method is not intended to work as a stand-alone approach. Contrarily, it was designed to help optimize the performance and result generated from some other known methods of water reduction.

2. Methodology

2.1 Model Development

This work is a modification of the experimental study by Ohia and Raji [16] on the use of demulsifiers on crude oil samples in Niger Delta. Similar reservoir and fluid data as those used in the referenced study were adopted in this study. Also, the same demulsifiers as those used in the root model were used in this study to develop a model for estimating the water reduction capacity of the demulsifier. The developed model was used to calculate the expected amount of water removable from the well.

It is important to reiterate that the target of this study is the amount of water, in form of emulsion, displaced from oil. This is different from the free layer of water produced alongside the oil.

2.3 Governing Conditions

For the sake of this study, we adopt oil with the following fluid properties.

0.85 Specific gravity

35 degrees API

5.25% water-in-oil emulsion per volume of liquid

2.4 Properties of Demulsifier Used

Data and information about two different demulsifiers was considered in this study, in line with the root study. The demulsifiers used are phenol and diethylene glycol (DEG).

The properties of these demulsifiers are expressed in Table 1.

Table 1: Properties of the demulsifiers used

Demulsifier/Properties	Phenol	Di-ethylene glycol
Molecular formula	C_6H_6O	$C_4H_{10}O_3$
Physical properties	Transparent crystalline solid	Colorless liquid
Density	1.07g/cc	1.118g/cc
Melting point	40.5°C	-10.45°C
Boiling point	181.7°C	244.5°C
Displacement potential	32%	57%

To calculate the amount of water-in-oil emulsion displaced from a crude-oil sample, we define the following:

The displacement potential of the demulsifier ($D_{potential}$) which is expressed as the ratio of volume of water (V_{w-in-o}) displaced from an emulsion to the initial volume of oil and emulsion (V_{oil}).

$$D_{potential} = \frac{V_{w-in-o}}{V_{oil}} \quad (1)$$

Based on a study by Adeyanju and Oyekunle [17], the displacement potential of phenol is 32% volume, and that of di-ethylene glycol is 57%. These values are adopted in this study.

1. Amount of emulsion in oil ($V_{\%,emulsion}$): From literature, most light crude oil contains between 5% and 20% by volume of emulsion [18, 19]. For this study, 15% by volume was adopted according to Ohia and Raji [16].
2. Volume of oil produced in a day (Q_{liquid})

Hence, the amount of water displaced ($V_{water,displaced}$) from a water-in-oil emulsion is calculated as:

$$V_{water,displaced} = D_{potential} \ x \ V_{\%,emulsion} \ x \ Q_{water} \quad (2)$$

This correlation will be applied in calculating the amount of water separable from crude-oil samples from a water producing well.

3. Results and Discussion

Table 2: Summary of gross liquid and net water production from well when phenol is used as demulsifier

Oil volume (STB)	Water volume (STB)	Volume of liquid (STB)	% Volume of emulsion	Efficiency of demulsifier	V of water displaced	% vol of emulsion in produced liquid	Volume of produced water after treatment
3155.285958	1470	4625.285958	0.15	0.32	70.56	4.767272813	1399.44
4917.904585	1558	6475.904585	0.15	0.32	74.784	3.60876225	1483.216
9966.262164	1600	11566.26216	0.15	0.32	76.8	2.07500052	1523.2
8611.628447	1475	10086.62845	0.15	0.32	70.8	2.193498067	1404.2
8108.080697	2693	10801.0807	0.15	0.32	129.264	3.739903546	2563.736
6785.823497	3746	10531.8235	0.15	0.32	179.808	5.335258421	3566.192
2994.156696	6513	9507.156696	0.15	0.32	312.624	10.27594297	6200.376
147.379617	8437	8584.379617	0.15	0.32	404.976	14.74247478	8032.024
4504.500034	9162	13666.50003	0.15	0.32	439.776	10.05597627	8722.224
5239.218248	10174	15413.21825	0.15	0.32	488.352	9.901241749	9685.648
6836.827066	11033	17869.82707	0.15	0.32	529.584	9.261141666	10503.416
11279.47731	10040	21319.47731	0.15	0.32	481.92	7.063963051	9558.08
7172.791617	15579	22751.79162	0.15	0.32	747.792	10.27105926	14831.208
4061.234669	16578	20639.23467	0.15	0.32	795.744	12.04841187	15782.256
2480.537527	16249	18729.53753	0.15	0.32	779.952	13.01340194	15469.048
5919.188212	15722	21641.18821	0.15	0.32	754.656	10.89727596	14967.344
6647.079939	16566	23213.07994	0.15	0.32	795.168	10.70474063	15770.832
3303.884384	18295	21598.88438	0.15	0.32	878.16	12.70551734	17416.84
187.661568	18431	18618.66157	0.15	0.32	884.688	14.84881171	17546.312
3177	19262	22439	0.15	0.32	924.576	12.87624226	18337.424
7109	17720	24829	0.15	0.32	850.56	10.70522373	16869.44
6780	19597	26377	0.15	0.32	940.656	11.1443682	18656.344
4849	23441	28290	0.15	0.32	1125.168	12.42895016	22315.832
2058	19817	21875	0.15	0.32	951.216	13.5888	18865.784
2009	22177	24186	0.15	0.32	1064.496	13.75403126	21112.504
3448	22197	25645	0.15	0.32	1065.456	12.9832326	21131.544
3125	22094	25219	0.15	0.32	1060.512	13.14128237	21033.488
126	19438	19564	0.15	0.32	933.024	14.90339399	18504.976
252	20927	21179	0.15	0.32	1004.496	14.82152132	19922.504
378	19875	20253	0.15	0.32	954	14.72004148	18921
3125	21887	25012	0.15	0.32	1050.576	13.12589957	20836.424
3218	24047	27265	0.15	0.32	1154.256	13.22959839	22892.744
4025.49105	23240	27265.49105	0.15	0.32	1115.52	12.78539232	22124.48
4372.044576	24085	28457.04458	0.15	0.32	1156.08	12.69545047	22928.92

3971.085257	23498	27469.08526	0.15	0.32	1127.904	12.83151575	22370.096
3492.645681	22566	26058.64568	0.15	0.32	1083.168	12.98954689	21482.832
1673.78638	24738	26411.78638	0.15	0.32	1187.424	14.04940941	23550.576
1805.212094	24465	26270.21209	0.15	0.32	1174.32	13.9692439	23290.68
2720.182608	21876	24596.18261	0.15	0.32	1050.048	13.34109464	20825.952
3574.567236	20875	24449.56724	0.15	0.32	1002	12.80697515	19873
4957.3152	25752	30709.3152	0.15	0.32	1236.096	12.57859374	24515.904
3895.210418	24206	28101.21042	0.15	0.32	1161.888	12.92079574	23044.112
2840.895155	22497	25337.89515	0.15	0.32	1079.856	13.31819387	21417.144
6749.977293	20670	27419.97729	0.15	0.32	992.16	11.30744919	19677.84
7406	20173	27579	0.15	0.32	968.304	10.97193517	19204.696
23391	23115	46506	0.15	0.32	1109.52	7.455489614	22005.48
25286	23170	48456	0.15	0.32	1112.16	7.172486379	22057.84
33707	23406	57113	0.15	0.32	1123.488	6.147286957	22282.512

Table 3: Summary of gross liquid and net water production from well when di-ethylene glycol (DEG) is used as demulsifier

Oil volume (STB)	Water volume (STB)	Volume of liquid (STB)	% Volume of emulsion	Efficiency of demulsifier	V of water displaced	% vol of emulsion in produced liquid	Volume of produced water after treatment
3155.285958	1470	4625.285958	0.15	0.57	125.685	4.767272813	1344.315
4917.904585	1558	6475.904585	0.15	0.57	133.209	3.60876225	1424.791
9966.262164	1600	11566.26216	0.15	0.57	136.8	2.07500052	1463.2
8611.628447	1475	10086.62845	0.15	0.57	126.1125	2.193498067	1348.8875
8108.080697	2693	10801.0807	0.15	0.57	230.2515	3.739903546	2462.7485
6785.823497	3746	10531.8235	0.15	0.57	320.283	5.335258421	3425.717
2994.156696	6513	9507.156696	0.15	0.57	556.8615	10.27594297	5956.1385
147.379617	8437	8584.379617	0.15	0.57	721.3635	14.74247478	7715.6365
4504.500034	9162	13666.50003	0.15	0.57	783.351	10.05597627	8378.649
5239.218248	10174	15413.21825	0.15	0.57	869.877	9.901241749	9304.123
6836.827066	11033	17869.82707	0.15	0.57	943.3215	9.261141666	10089.6785
11279.47731	10040	21319.47731	0.15	0.57	858.42	7.063963051	9181.58
7172.791617	15579	22751.79162	0.15	0.57	1332.0045	10.27105926	14246.9955
4061.234669	16578	20639.23467	0.15	0.57	1417.419	12.04841187	15160.581
2480.537527	16249	18729.53753	0.15	0.57	1389.2895	13.01340194	14859.7105
5919.188212	15722	21641.18821	0.15	0.57	1344.231	10.89727596	14377.769
6647.079939	16566	23213.07994	0.15	0.57	1416.393	10.70474063	15149.607
3303.884384	18295	21598.88438	0.15	0.57	1564.2225	12.70551734	16730.7775
187.661568	18431	18618.66157	0.15	0.57	1575.8505	14.84881171	16855.1495
3177	19262	22439	0.15	0.57	1646.901	12.87624226	17615.099
7109	17720	24829	0.15	0.57	1515.06	10.70522373	16204.94
6780	19597	26377	0.15	0.57	1675.5435	11.1443682	17921.4565
4849	23441	28290	0.15	0.57	2004.2055	12.42895016	21436.7945
2058	19817	21875	0.15	0.57	1694.3535	13.5888	18122.6465
2009	22177	24186	0.15	0.57	1896.1335	13.75403126	20280.8665
3448	22197	25645	0.15	0.57	1897.8435	12.9832326	20299.1565
3125	22094	25219	0.15	0.57	1889.037	13.14128237	20204.963

126	19438	19564	0.15	0.57	1661.949	14.90339399	17776.051
252	20927	21179	0.15	0.57	1789.2585	14.82152132	19137.7415
378	19875	20253	0.15	0.57	1699.3125	14.72004148	18175.6875
3125	21887	25012	0.15	0.57	1871.3385	13.12589957	20015.6615
3218	24047	27265	0.15	0.57	2056.0185	13.22959839	21990.9815
4025.49105	23240	27265.49105	0.15	0.57	1987.02	12.78539232	21252.98
4372.044576	24085	28457.04458	0.15	0.57	2059.2675	12.69545047	22025.7325
3971.085257	23498	27469.08526	0.15	0.57	2009.079	12.83151575	21488.921
3492.645681	22566	26058.64568	0.15	0.57	1929.393	12.98954689	20636.607
1673.78638	24738	26411.78638	0.15	0.57	2115.099	14.04940941	22622.901
1805.212094	24465	26270.21209	0.15	0.57	2091.7575	13.9692439	22373.2425
2720.182608	21876	24596.18261	0.15	0.57	1870.398	13.34109464	20005.602
3574.567236	20875	24449.56724	0.15	0.57	1784.8125	12.80697515	19090.1875
4957.3152	25752	30709.3152	0.15	0.57	2201.796	12.57859374	23550.204
3895.210418	24206	28101.21042	0.15	0.57	2069.613	12.92079574	22136.387
2840.895155	22497	25337.89515	0.15	0.57	1923.4935	13.31819387	20573.5065
6749.977293	20670	27419.97729	0.15	0.57	1767.285	11.30744919	18902.715
7406	20173	27579	0.15	0.57	1724.7915	10.97193517	18448.2085
23391	23115	46506	0.15	0.57	1976.3325	7.455489614	21138.6675
25286	23170	48456	0.15	0.57	1981.035	7.172486379	21188.965
33707	23406	57113	0.15	0.57	2001.213	6.147286957	21404.787
42660	23772	66432	0.15	0.57	2032.506	5.367593931	21739.494
37923	24047	61970	0.15	0.57	2056.0185	5.820639019	21990.9815

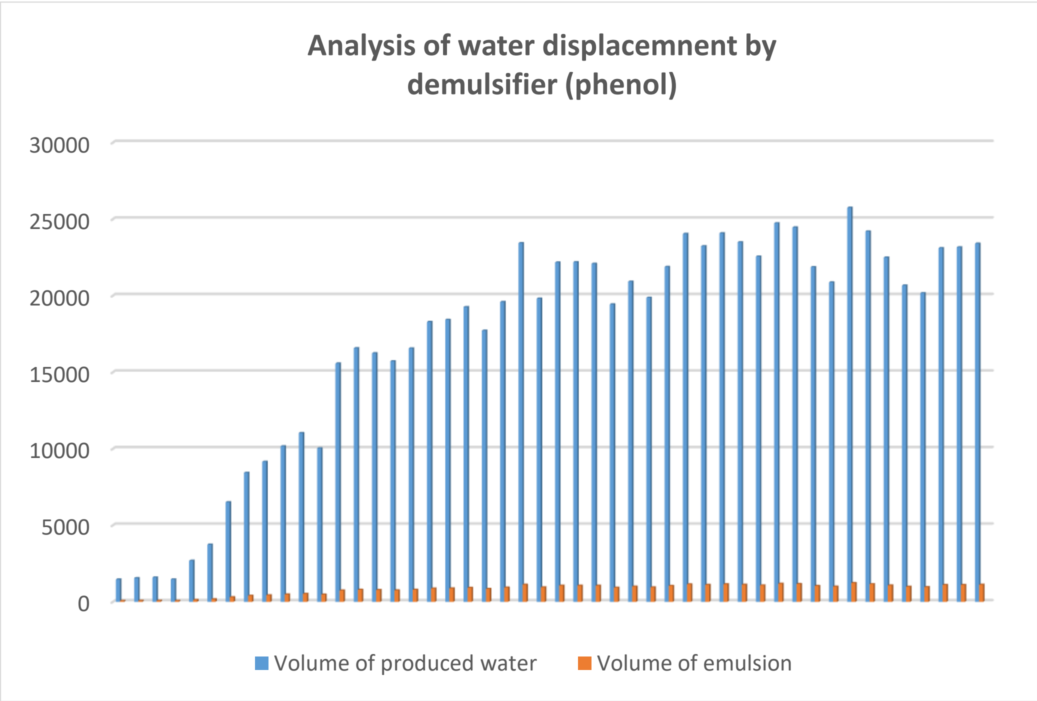

Figure 1: Chart showing how much of the produced water from the well is from emulsion (with phenol as demulsifier).

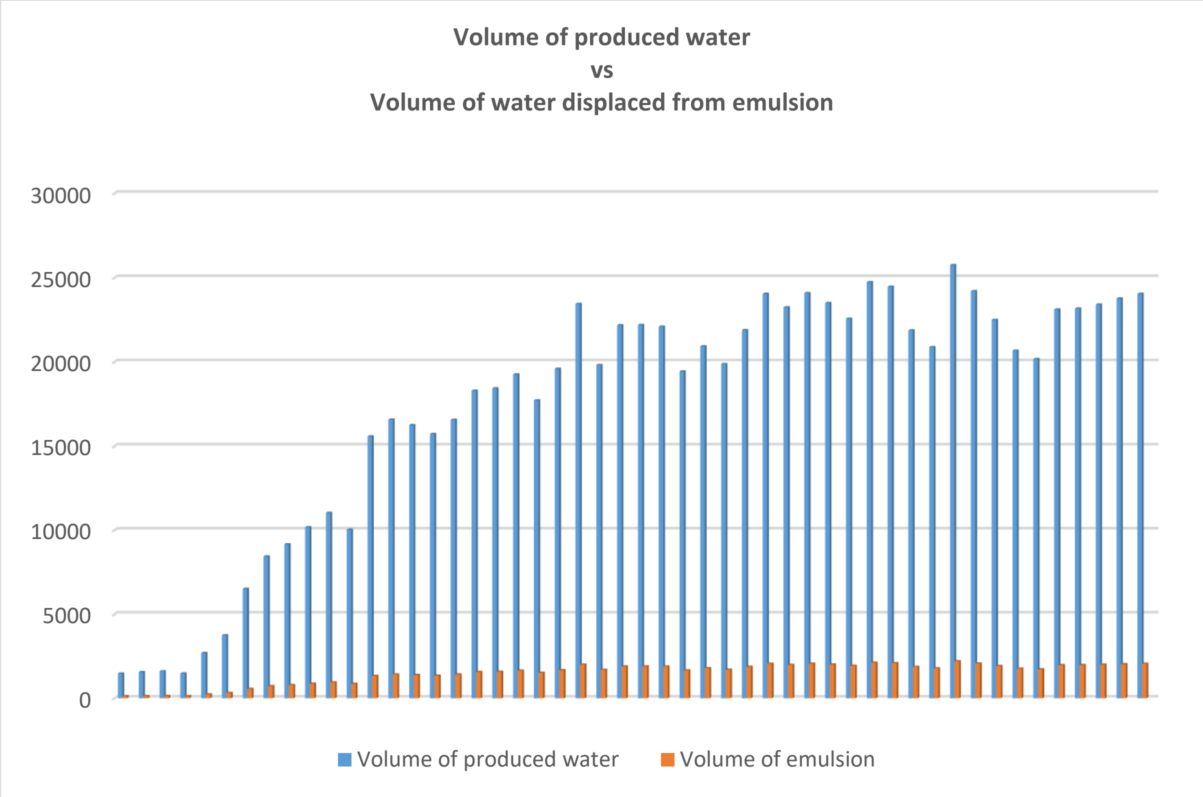

Figure 2: Chart showing how much of the produced water from the well is from emulsion (with DEG as demulsifier).

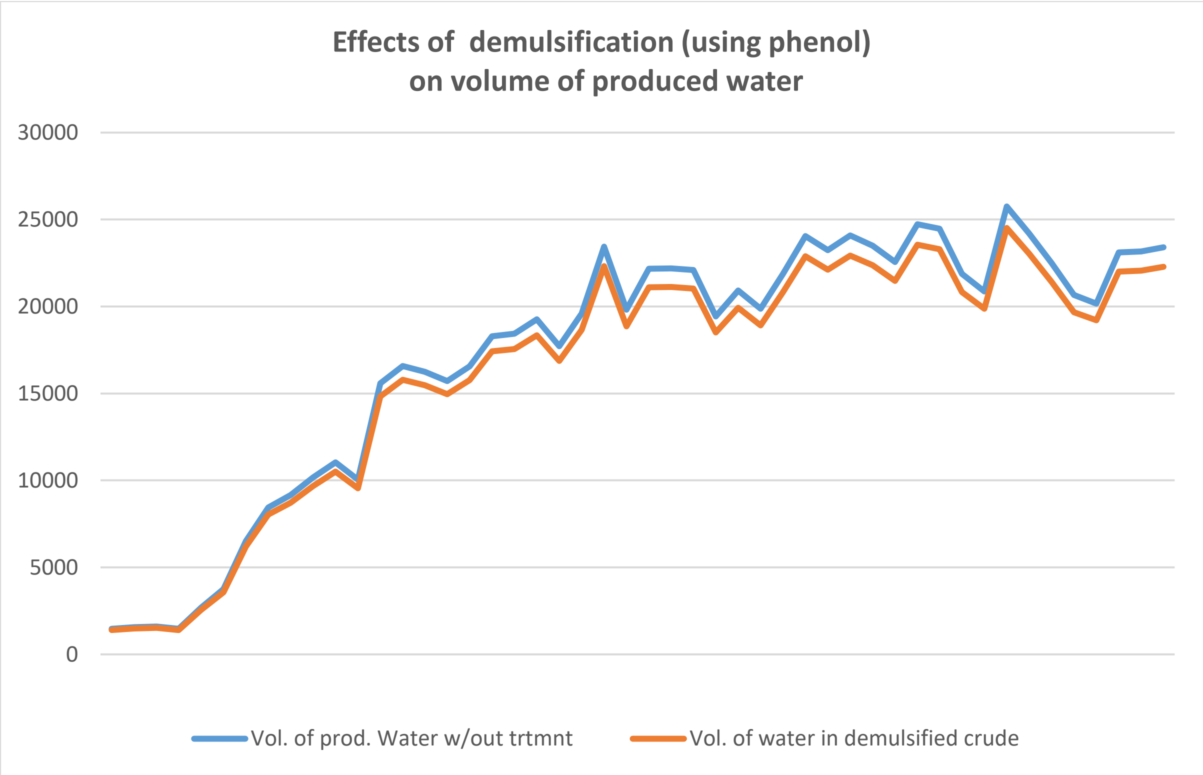

Figure 3: Analysis of produced water volumes before and after demulsification (using phenol)

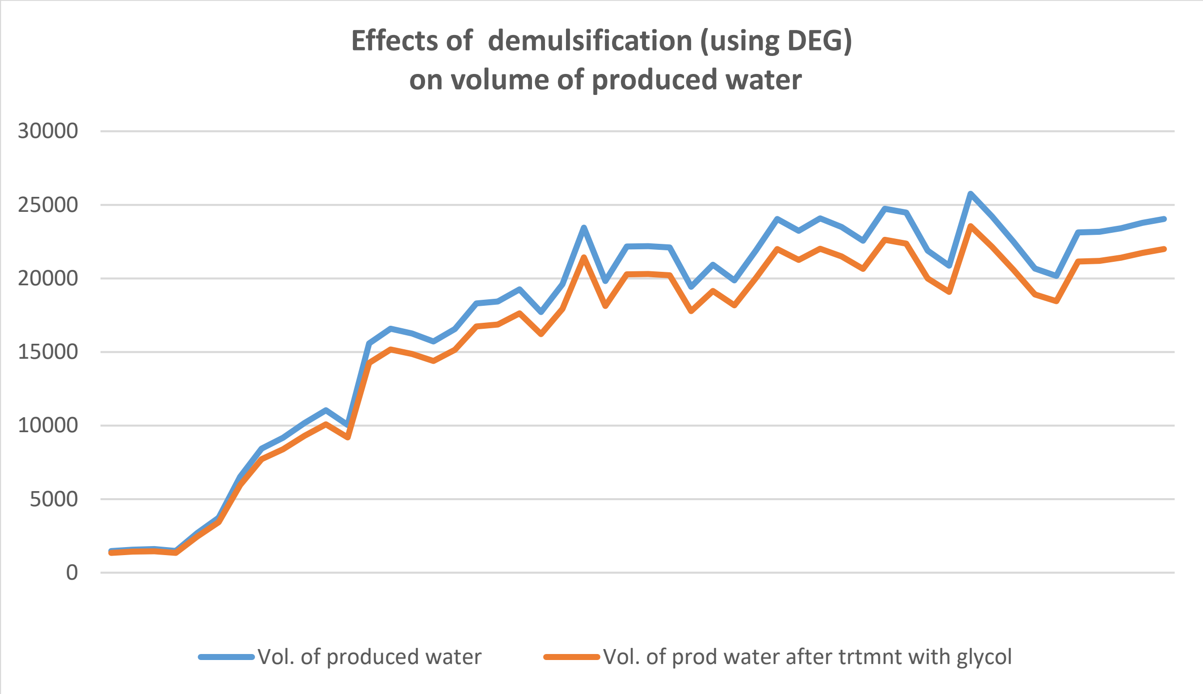

Figure 4: Analysis of produced water volumes before and after demulsification (using di-ethylene glycol).

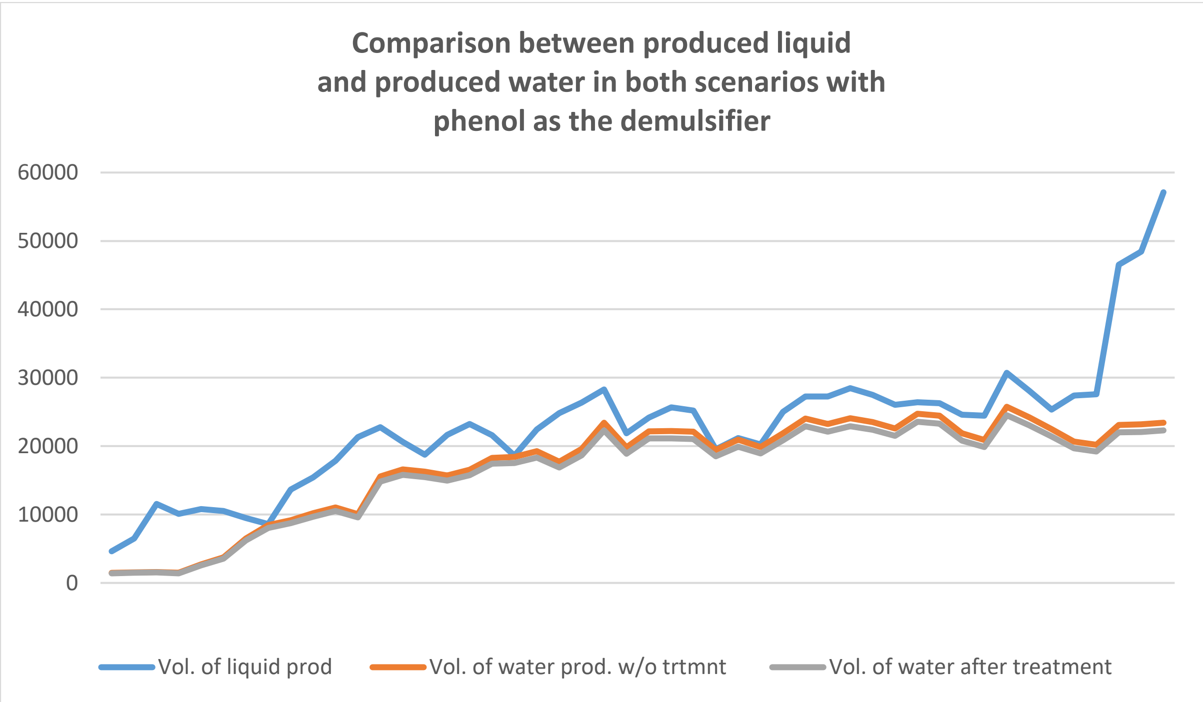

Figure 5: Chart showing the volume of water produced after demulsifying with phenol

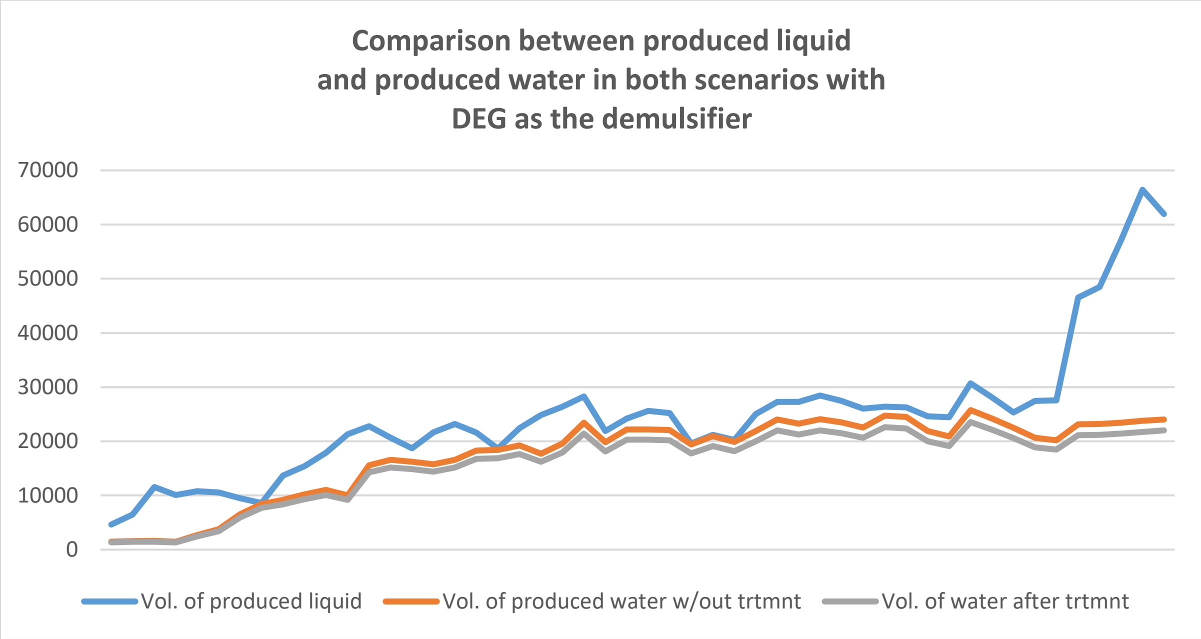

Figure 6: Chart showing the volume of water produced after demulsifying with DEG

The potentials of demulsifiers in reducing the amount of water produced in oil production fields have been established. Figures 1 to 6 highlight how the volume of liquid reduces upon introduction of demulsifiers. It is important to reiterate that two major factors influence the outcomes of demulsification. One of them is the amount of emulsion to be displaced. The other and more important factor is the efficiency (or potential) of the demulsifier. In this study, very mild values of both variables were used. However, results still show significant drops in the volume of water produced from the well.

From the foregoing, it is obvious that large volumes of water will be separated from oil downhole. This will greatly reduce the amount of water produced at the surface. However, if a suitable technology is not designed for this, a secondary problem may generate. Possible problem that may arise from this is rise in backpressure at the bottomhole as water will over time fill up the tubing and create a problem for oil passage.

This proposed approach will work best in wells with downhole oil water separator (DOWS) and downhole water sink (DWS) installed. In such systems, as the water is separated from the liquid stream downhole, it goes straight down to the column prepared for water. This way, there will be no buildup of water in wellbore and near wellbore areas.

3. Conclusion

A correlation for estimating the potential of demulsification in water shut off operation was developed for this study. This correlation was tested with production data from a field with high water production problem. With this, it was shown that demulsification can be applied in water shut-off operations.

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