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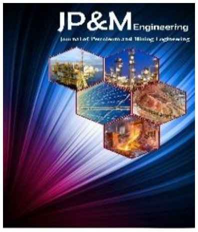

Using Anionic Surfactants for Increasing the Displacement Factor in Jaribee Formation of Dero Oil Field

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Abstract

In this research, a lab study was conducted on the process of injection Of Surfactant Dodecyl benzene Sodium Sulfonate [Wetconat-P1220EH (DDBSCa)] into a lab prepared matrix model consists of Marble that physically simulates the reservoir properties of Jaribee producing formation in Dero oil field. An injecting operation of the said surfactant was applied on the rock model using The Following Volumetric ratios (15, 30 and 50% PV), then the injection was continued at each ratio using the displacement liquid until the Volumetric ratio 250%PV in order to guarantee an efficient displacement . Through the results of the displacement processes, the change of the following factors in relation with the ratio of the injected liquid to the volume of the pores of the model was studied O.F.D: oil displacement factor, W: water percentage in the produced liquid, and Ra: recoverability. represents the ratio of the produced oil volume at every injecting process to the accumulating volume of the injected liquid in the same stage. Ra=V_O/V_T . To compare the efficiency of displacement using the said surfactant with the efficiency of water injection (currently applied in Dero field), the model was prepared for water injection (Water flooding) by cleansing by kerosene and water, then dried and re-saturated with oil. A comparison between the change of the aforementioned factors of water injection and surfactant injection was graphically performed . The results of the graphical comparison of both injecting methods implied an obvious increase of (O.F.D) and (Ra) factors when injecting the surfactant at all studied injection ratios than that of the water injection.

Keywords

Recoverability;Water Percentage ; oil Displacement factor; Anionic Surfactant ; interfacial tension; Sweep Efficiency; Mutual Solubility

Introduction

Due to the recent increasing in global demand on oil, researches and oil studies tend to recover formation residual oil left in place after first and second oil recovery. One of the applied methods was surfactant injection; however, although the idea of using surfactants appeared in 1927, it wasn't as popular as the other methods of oil enhanced recovery. Since then, several projects adopting this method were implemented, many of which were very successful where others were not. It became a matter of fact that the high salinity of formation water or water associated with oil in the pores, in addition to the high temperature of the reservoir are considered inhibiting factors of the surfactants.

Surfactant injection has the following advantages:

- Easy to apply, meaning it doesn't require a lot of sophisticated surface equipment other EOR methods do such as the injection of (CO_2, vapor, etc..).
- High safety factor.
- Can be applied during all stages of the field production, in addition to its Screening criteria is flexibility, So that makes this method applicable on variety of oil fields with varied characteristics.
- Can be applied alongside with the widespread water injection method.

Research objective

The main objective of this research is to study the possibility of increasing the oil displacement factor in Jaribee formation of Dero oil field through surfactant injection. In this field, water injection is used as one of EOR methods. Water injection in Jaribee formation started in 1993 and irregularly continued with low averages (30 m3/day) until 1996 when it became (100 m3/day). During 1998, other injecting wells were added that let the daily injecting average to become (300 m3/day). By 2005 the daily injecting average became (500 m3/day).

From all above, we can conclude that the annual water volume injected was (77752 m3), and the accumulated volume (658857 m3) versus an accumulating liquid production of (10703x106 m3) which represents a small percent no greater than (38.5%). form the other hand the comparison of the critical conditions of applying surfactant injection method

Table 1 comparison between the screening criteria of applying surfactant injecting method and the reservoir parameters of Dero field.

Reservoir parameters of Dero field	The Screening Criteria to apply this method
$API = 35.1$	$API > 25$
μ (formation)=4.5 C.P	$\mu < 30 C.P$
$S_o = 65\%$	$S_o > 30\%$
$K = 89.6 (mD)$	$K > 10 mD$
$Depth = 600\ m$	$Depth < 2400 m$
$T = 33\,°C$	$Temperature < 79\,°C$
$h = 4.55\ m$	$h > 3m$
Producing formation: Carbonate	Carbonate and sandstone reservoirs

with the reservoir parameters of Dero field, presented in table (1), revealed a complete identification that encourages studying the potential of using this method in the said field alongside with the water injection that is currently applied. Suing these both methods will enhance the sweep efficiency.

consequently, increase the oil recovery factor better than using water injection alone. In addition, the (PH) in Dero field is about (PH=8.5) which is very suitable for surfactant injection (the lost amount by adsorption is minimum, no precipitation and maximum efficiency).

Litho-stratigraphic description of Jaribee formation:

Depending on the detailed stratigraphic and depositional petrographic study of the cores taken from this formation, it can be divided into the following four intervals: The first interval (JE1): the rocks of this interval consist of micrite-calcite-carbonate, while micrite-dolomite is less abundant. It also contains knots of anhydrate in addition to crystals of pyrite. Thickness of this interval ranges from (39 m) in Dero6 well and (33.5 m) in Dero15 well.

The second interval (JE2): the rocks of this interval consist of calcite rocks of bio-micro-sparite, in addition to dolomite and dikes of anhydrate. Thickness of this interval is (20 m) in Dero8 well and (12 m) in Dero18 well. The third interval (JE3): a (2 m) layer of anhydrate. The fourth interval (JE4): consists of calcite biomicrite rocks, sometimes biomicrosparite. Thickness of this interval is (28 m) in Dero5 well and (23.5 m) in Dero2&6 wells.

Petrographic and depositional properties of Jaribee formation:

Three intervals from bottom to top can be distinguished: Interval A: represents (JE1): consists of micrite carbonate rocks. Microscopic calcite forms (70%) of the total rock volume. Reservoir properties of the studied rocks are medium. Porosity (10-15%), pore size (0.02-0.8 mm). few vertical millimeter-size cracks can be noticed. Interval B: represents (JE2): consists of calcite-micosparitic rocks. It consists of microsparitic calcite, sometimes micrite between (50-60%) of the calcitic rock. Porosity (15-25%) has the size of (0.02-1.5 mm) with the presence of cavities up to (9 mm). Interval C: represents (JE3): (2-4 m) anhydrate layer with poor reservoir properties with no existence of any oil shows. Interval D: represents (JE4): its rocks consist of micritic-calcite to dolomite-microsparite. Micrite and microsparitic rocks form (50-80%) of the total rock volume. Reservoir properties of this interval are generally poor in the upper section and good in the lower section.

Reference Study

WittonT.Adams showed in his study about anionic surfactants injection in the carbonate reservoirs of western Texas where third production operations of oil is complicated due to very low permeability accompanied with high hardiness and salinity of formation water, showed the possibility of chemical injecting in the low-permeable carbonate reservoirs. [1]

Anita,K.Mohanty showed that anionic surfactants can alter wet ability of calcite surface in moderate water-wetted conditions better than cationic surfactants. He also showed that all carbonate surfaces (calcite rock, dolomite, marble and calcite) have a similar behavior regarding wet ability alternation with anionic surfactants. Form the other hand, they also showed that adsorption of sulfonic surfactants can be significantly decreased by adding (Na2CO3 or NaOH) that alter Zeta Energy of calcite into negative value. [2]

P.D.Berger referred in his study to developing a new anionic surfactant that can be used in very low concentration to achieve an extremely low interfacial tension of calcite and sandy rocks. These surfactants can be used in polymer injection, surfactant injection, ASP injection and as additives in water injection. He also referred that these new surfactants are distinguished from the classic surfactant in the following properties: low concentration levels, salinity Resistant, and decreasing corrosion and crusty salty depositions. [3]

AlainZaitoun,PaulBerger also showed developing a new anionic surfactant highly soluble in high saline water and in the same time achieves low interfacial tension. [4]

A.Seethepalli,B.Adibhatla showed that decreasing or restraining adsorption of sulfonates can be significantly performed by adding alkaline. [5]

W.Xu, S.C.Ayirala concluded that the influence of chemical surfactants on surface tension (oil/water) and wet ability of (crude oil-formation water-rock) systems in the reservoir conditions are very important in the EOR. They found through their research(measuring surface reactions resulted from surfactants in reservoir conditions) that surface tension (oil/water) is function to oil composition and temperature, and showed low connection with pressure. They also concluded that altering wet ability by surfactants can result in enhanced oil recovery through decreasing capillary pressure and adhesive forces. [6]

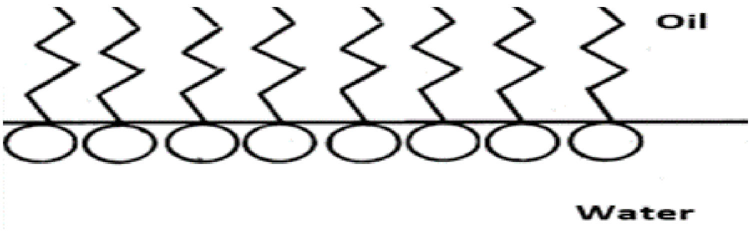


Figure 1 Distribustion of hydrophilic and hydrophobic parts of surfactant micelles at oil/water contact.

In their research about evaluation of lingosulfonates as an adsorbed material to be sacrificed (lost) during surfactant injection, Hong,S.A,Bac,J.H referred that the lost amount of surfactant can be significantly decreased (more than 50%) if an initial treatment by lignosulfonate wash is done. [7]

Researcher Marc Baviere showed in his study about olefin sulfonate (AOS) behavior in high temperature and high hardiness as a surfactant in EOR that this sulfonate group gives important results especially at high temperatures and salinity, in addition to the chemical stability of this kind of Sulfonates. [8]

Glinsmann,GilbertR referred to the possibility of designing anionic-surfactant injecting systems to generate in place multiphase-micro-emulsions as a result to mixing it with residual oil in the reservoir. Efficiency of this process depends on the properties of the generated micro-emulsions and associated phases. [9]

Chiang, Michael Y showed in their research “Alcohol influence on the movement of surfactant mass through contact surfaces (oil/water)” the important proposed role of alcohol in decreasing viscosity between surfaces and activating consolidating of oil blocks in pores, which in turn leads to the conclusion that achieving very low surface tension at the (oil/surfactant solution) contact is surprisingly supported by existence of Iso-butanol what caused more oil production. [10]

Arshad,A.Harwell proposed in their study a new chemical EOR process in order to enhance the efficiency of volume sweep in reservoirs. The proposed process is different from the traditional surfactant injection process. In these new processes, a series of surfactants is injected into the reservoir, provided the last injected material has a higher chromatographic speed from the precedent injected materials. [11]

V.M,Ziegler conducted lab researches about injecting some surfactants into high-temperature formations. Standard being used to choose the surfactant suitable to this high-temperature applications includes: thermal stability and surface activity. Several injection operations of surfactants work at thermal interval of (200-300 oF) were performed to study the effects of several variables on tertiary recovery. These variables include: volume of the initial washing batch, volume of the surfactant batch, concentration of surfactant, field temperature, sample material and mobility control. Evaluation of field performance indicated an increase of oil recovery of (8-32%) when using surfactants with vapor. [12]

Physical principle of surfactant injection:

It is known that formation fluids (oil, water and gas) distributed within the reservoir according to its physical properties when contact with rock. Surface phenomena occur at the surfaces separating these fluids and rocks and between these fluids itself. These phenomena occur from the interchangeable forces between fluid molecules or between fluid molecules and rock. These forces contribute in keeping a considerable amount of oil unrecoverable.

Injecting surfactants into the formation weaken these forces causing residual amounts of oil to release due to the mutual solubility of surfactant micelles originated from the dual polar nature of these micelles (the part soluble in water and the one that is soluble in oil). The hydrophilic part dissolves in water where the hydrophobic part dissolves in oil and that boosts storing (accumulating) surfactant onto two-liquid contact or between liquid and gas or between liquid and solid body. Figure (1) shows distribution of hydrophilic and hydrophobic parts of surfactant micelles at oil/water contact.

Surfactants when injected into formation have the ability of:

- Decreasing surface tension at oil/gas contacts.
- Decreasing surface tension at oil/water contacts.
- Decreasing surface tension and altering wetting angle of oil on contact with rock.

The previous combined changes lead to increasing the produced oil which in turn reflects positively on oil recovery factor. [13]

Surfactant Types:

- Cationic surfactants.
- Anionic surfactants.

- Non ionic surfactants;
- Amphoteric (Aniocationic) surfactants.
- Phlorocarbon surfactants.

Anionic surfactants are the subject of this research.

Anionic surfactants:

Anionic surfactants are compounds soluble in water and form negative surfactants. The in-water soluble group has a negative charge, and this charge is balanced by M+ Cation like sodium as it is shown in figure (3).

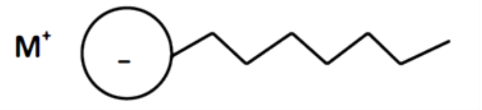


Figure 3 simple mono micelle of anionic surfactant

Anionic surfactants are distinct in having a low adsorption on the rock surface plus it is abundant and relatively cheap. It is used widely in EOR. Table (2) shows some types of these surfactants. [13]

In general, these anionic surfactants are:
-Sulfates(R-OSO3).
-Sulfonates (R-(SO3)).
-Phosphates (R-OPO3).
-Phosphonates (R-(PO3)).
Where:
R: hydrocarbon part able to dissolve in oil.
Some of the common uses of anionic surfactants include:
Cleaning agents.
Demulsifiers.

Table 3 Formulas and codes of some anionic surfactants

Code of the surfactant	Detailed formula	Molar Mass (g)	Kraft Temperature (°C)
OBSNa	$C_8H_{17}C_6H_4.SO_3Na$	292.38	18
DBSNa	$C_{10}H_{21}C_6H_4SO_3Na$	320.36	29
4DBSNa	C_3H_7	348	18
8HBSNa	CH. $C_6H_4.SO_3Na$	404	>20
5DPEBSNa	C_8H_{17}	376	16

Table 2 Commercial name of some types of anionic surfactants

Commercial name	Appearance	Code of the surfactant
Wetconic1298soft	Tender viscous liquid	DDBSA
Wetconic1298hard	Solid	DDBSA
Wetconat1238slurry	Thin-mud texture	DDBSNa
Wetconat1223H	Solid	DDBSNa
Wetconat1223L	Tender viscous liquid	DDBSNa
Wetconat-P1220EH	High-viscous liquid	DDBSCa

Table 4 physical properties of DDSNA surfactant

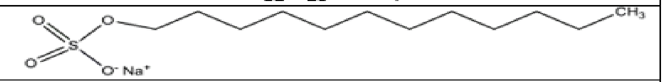
SUR 1	Dodecyl sodium Sulfate (DDSNa)
Formula	$C_{12}H_{25}NaO_4S$
Detailed Formula	
Appearance	Wight powder
Molecular weight	M=288.38 (gr/mol)
Solubility(20°C)	100 (gr/L)

Table 5 physical properties of Dodecy benzene calcium Slfonate surfactant

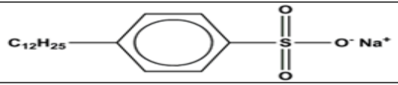
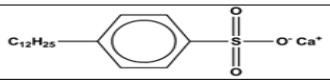
SUR 3	Dodecyl Benzene Sodium Sulfonate
Formula	DDBSNa
Trade name	Wetconate 1223L
Detailed Formula	
Appearance	Viscose Gel
Solubility in water water(20c)	High

Table 6 physical properties of Dodecy benzene sodium Slfonate surfactant

SUR 2	Dodecyl benzene calcium Sulfonate (DDBSCa)
Formula	DDBSCa
Detailed Formula	
Appearance	High viscose Liquid
Trade name	Wetconate P1220EH
Solubility in water water(20c) (20 oC)	High
Viscosity (25 o C)	16500 C.P
Surface Tension (25 o)	27.5 mN/M
PH (5%)	7
Active Content	60%

Lab Study

In order to choose the best type of surfactant that gives minimum surface tension at minimum concentration, the study was conducted on the following types of surfactants:

- Dodecyl sodium Sulfate (DDSNa);
- Dodecyl benzene calcium Sulfonate DDBSCa (WetconatP1220EH);
- Dodecyl benzene sodium Sulfonate DDBSNa (Wetconat1223L).

Physical properties of the mentioned surfactants are shown in the tables [14].

The Lab study included the following basic stages :

Firstly : studying the relation between IFT (interfacial tension) and the concentration Cs of the studied surfactants.

This study aims to choose the anionic surfactant that achieves minimum IFT at oil contact at minimum concentration through determination of the critical micelles concentration of all chosen surfactants.

- Proposed Surfactants concentrations for studying are: (0.01 - 0.03 - 0.05 - 0.1- 0.2- 0.3 % wt).
- Prepared volumes for each type (500 ml), volume needed for measurement (30 ml).
- Interfacial tension measuring device: KRUSS K-10 connected to heat-programmed water bath.

All measurements were carried out at formation temperature(33Co). Results are presented in the following tables and figures:

Table 7 summary of measuring results of the studied surfactants.

C.M.C %wt	IFT_{min} mN/M	Surfactant Type
0.05	1.1	SUR 1 (DDSNa)
0.05	0.2	SUR2 (DDBSCa) Wetconate P1220EH
0.05	0.2	SUR 3 (DDBSNa)wetconat1223L

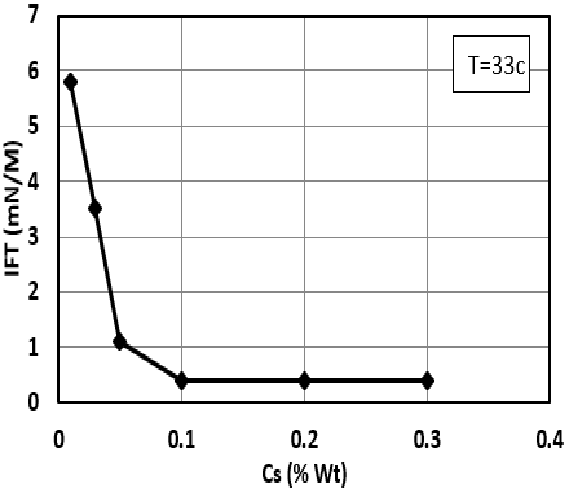


Figure 4 change of IFT at oil contact by relation with Cs concentration of DDSNA surfactant

Results

It can be noticed from the reached results that the minimum concentration where IFT is minimum is (0.05 %wt), hence, results of measuring IFT of the chosen surfactants can be summarized in the following table:

Basis should be taken into consideration when choosing the suitable surfactant are:

- It should achieve minimum IFT at minimum concentration. [15].
- Rock charge should be compatible with the type of the used surfactant. [15].
- It should be considered that number of carbon atoms in the straight series are at least 8. It's favorable to have types with branched series. [15].
- Formation temperature should be higher than Kraft's temperature of the surfactant. [15].

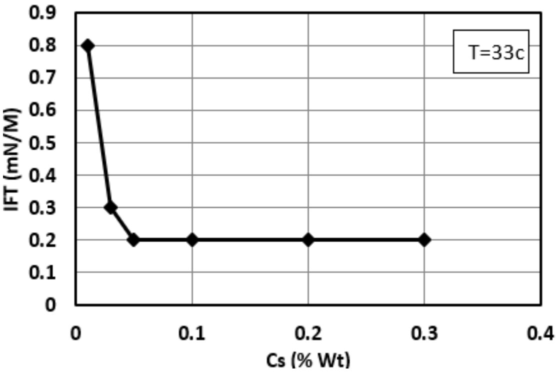


Figure 5 change of IFT at oil contact by relation with Cs concentration of DDBSCa surfactant

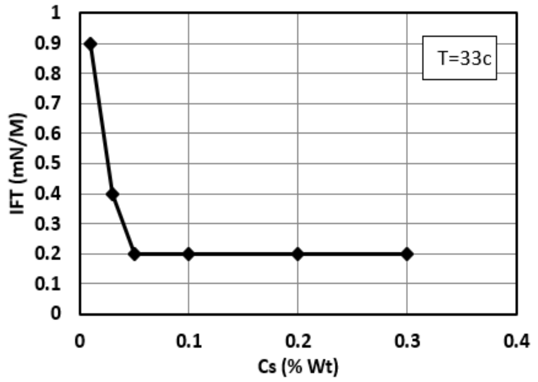


Figure 6 change of IFT at oil contact by relation with Cs concentration of DDBNa surfactant

From studying of the results presented in the above table, we found that:

- Sur3, Sur2 show minimum IFT at minimum concentration, while Sur1 gives IFT Equal (1.1 mN/M) at the same concentration.
- All chosen surfactants are anionic and are compatible with the charge of the studied rock.
- All chosen surfactants have more than 8 atoms of carbon.

Table 8 IFT measuring results of surfactants types at different concentrations.

IFT(sur$_3$) (mN/M)	IFT(sur$_2$) (mN/M)	IFT(sur$_1$) (mN/M)	Cs %wt
0.9	0.8	5.8	0.01
0.4	0.3	3.5	0.03
0.2	0.2	1.1	0.05
0.2	0.2	0.4	0.1
0.2	0.2	0.4	0.2
0.2	0.2	0.4	0.3

- Temperature of the studied formation (Jaribee formation) is higher than Kraft's temperature for all chosen surfactants. Formation temperature is (33 oC) while Kraft's temperature of the studied surfactants is bout (29 ^{o}C).

From all above, we find that (Sur2-Sur3) types are nominated to chose one of them to study, however, SUR2(DDBSCa) was chosen rather than SUR3(DDBSNa) in order to avoid any charge exchange (between Calcium charge forming reservoir rock in Dero field and the Sodium charge in the structure of DDBSNa surfactant).

Secondly : preparation of rock model that physically simulates Jaribee producing formation of Dero field:

Preparation of this rock model was explained in my previous research published in Petroleum and Mining Journal in 2016 under the title of "Effect of ASP Chemical Flooding Efficiency On Displacement Factor and Water Percentage After Exhaustion of Water Flooding Efficiency in DERO Field"

As a reminder, the model consists of a mix of marble grains with the following ratios and dimensions: 89 %wt of marble grains with dimensions of µM 63<(Marble)<µM 75. 11 %wt of marble grains with dimensions of µM 75<(Marble)<µM150.

Thirdly: Rock model preparation for displacement process:

Includes the following procedures:

- Emptying the model from air.
- Saturating the model with Kerosene.
- 3Drying the model of Kerosene.
- Saturating the model with water to form connect water.
- Displacing free water out of the model.
- Saturating the model once again with Kerosene.

All these stages were explained in the said previous research.

Fourth: Preparation of formation oil sample:

It is known that formation oil has a specific density, viscosity and surface tension; therefore, during lab experiments and displacement processes, dead oil taken from the field shouldn't be used. It is necessary to prepare an oil sample that has the same properties of oil at the formation conditions. According to the previous study I concluded that the ideal percent of Kerosene should be added to the surface sample of oil of Dero field to achieve a viscosity compatible with that of Dero oil at formation conditions is: Ck=19.5% vol.

Fifth: saturating the model with oil:

This process is performed using the pump illustrated in the following figure:

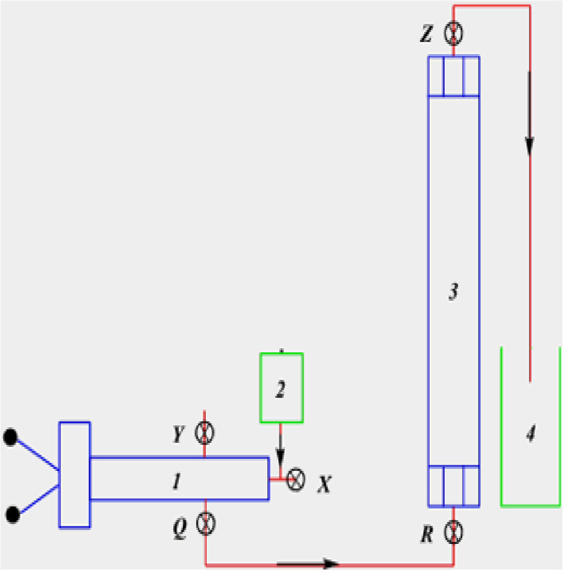


Figure 7 diagram shows the device for saturating model with oil.

The Parts:
Q: Oil pump to model connecting valve.
Y: Oil pump to Station connecting valve.
1: Oil pump.
X: Pump cylinder filling valve;
2: Container connected to the pump cylinder.
R: Model lower valve.
3: The model.
Z: Model upper valve.
4: Container to receive displaced oil and water.

Sixth: Displacement Process:

Includes:

- Surfactant injection which is the subject of this research.
- Water injection after rehabilitation of the model (Cleansing by Kerosene and water, drying and re-saturating with oil). The purpose of this process is to compare its results with the results of surfactant injection.

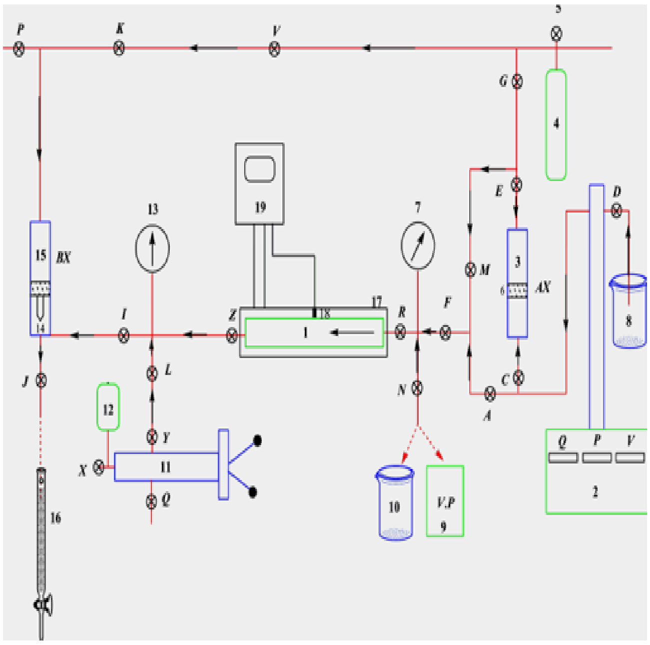


Figure 8 diagram of injection and displacement station.

Work procedures:

1. Putting the model in the heating device.
2. Connecting valves (R and Z) to the model.
3. Connecting the heat sensor by contacting the model and setting its temperature at (33 oC) (temperature of the studied field) using a heating-control device connected with electrical heater within the heating device.
4. Filling the hinder needle valve cylinder (BX) with oil.
5. Valves (V and K) are opened for pressure increase up to the pressure of the are cylinder (4).
6. Cylinder (BX) pressure is calibrated until equals the formation pressure (45 atm) by opening valve (P) to vent the excessive air (the reading on the left large pressure gauge).Valve (J) is opened rapidly to discharge the excessive amount of oil where the needle of the valve closes automatically, then valve (J) closes again.
7. Cylinder (AX) is filled with the active material that wanted to be injected plus the displacing water (active material is above the piston while water is under it).
8. Valve(N)is closed and pressure is increased until the required pressure by implementing the following procedures on the pump's panel: (A→45→Inter→Run).
9. Reading on the pump is recorded (reading V1).
10. Valve (R) is open then injection process of the active material starts. The active material passes through the opened valves (E, M, F and R) whereas valve (A) is closed.

Table 9 results of surfactant injection by (15% PV)

Remarks	R.a	W (%)	O.D.F (%)	Vw (ml)	Vo (ml)	V_T (ml)	Vx (ml)	V_A (ml)	Vpv (%)
T=33 °C ΔP=3 atm P1=45 atm P2=42 atm Q=65.38 ml/Hour Total Pv=112.8 cm^3 C_S=0.05% Wt	1	0	15	0	16.9	16.9	16.92	16.92	**15**
	1	0	30	0	33.8	33.8	16.92	33.84	30
	0.68	31.9	34.0	18	38.4	56.4	22.56	56.4	50
	0.38	61.8	38.1	69.8	43.0	112.8	56.4	112.8	100
	0.26	73.9	39.0	125.1	44.1	169.2	56.4	169.2	150
	0.20	80.4	39.2	181.4	44.2	225.6	56.4	225.6	200
	0.16	84.2	39.3	237.6	44.4	282	56.4	282	250

Table 10 results of surfactant injection by (30% PV)

Remarks	R.a	W (%)	O.D.F (%)	Vw (ml)	Vo (ml)	V_T (ml)	Vx (ml)	V_A (ml)	Vpv (%)
T=33 °C ΔP=3 atm P1=45 atm P2=42 atm Q=65.38 ml/Hour Total Pv=112.8 cm^3 C_S=0.05 % Wt	1	0	15	0	16.9	-	-	-	**30**
	1	0	30	0	33.8	33.8	33.84	33.84	
	0.77	22.8	38.6	12.9	43.5	56.4	22.56	56.4	50
	0.42	57.4	42.5	64.8	48.0	112.8	56.4	112.8	100
	0.29	71	43.4	120.2	49	169.2	56.4	169.2	150
	0.22	78	43.9	176	49.6	225.6	56.4	225.6	200
	0.17	82.3	44.1	232.2	49.8	282	56.4	282	250

Table 11 results of surfactant injection by (50% PV)

Remarks	R.a	W (%)	O.D.F (%)	Vw (ml)	Vo (ml)	V_T (ml)	Vx (ml)	V_A (ml)	Vpv (%)
T=33 °C ΔP=3 atm P1=45 atm P2=42 atm Q=65.38 ml/Hour Total Pv=112.8 cm^3 C_S=0.05 % Wt	1	0	15	0	16.9	-	-	-	**50**
	1	0	30	0	33.8	-	-	-	
	0.85	15.4	42.3	8.7	47.7	56.4	56.4	56.4	
	0.47	53	47.1	59.7	53.1	112.8	56.4	112.8	100
	0.32	68.5	47.3	115.9	53.3	169.2	56.4	169.2	150
	0.24	76.3	47.4	172.1	53.5	225.6	56.4	225.6	200
	0.19	81	47.5	228.4	53.6	282	56.4	282	250

11. When finished with active material injection with the required volume, reading (V2) is taken and valve (R) is closed.
12. Valve (M) is closed and valve (A) is opened until exit of water through valve (N) that opens.
13. When closing valve (N), pump pressure increases to (45 atm), then reading (V1) is taken which is (reading of start of displacement liquid injection). Valve (R) is then closed.
14. When displacing water injection is finished, valve (A) is closed and reading (V2) is taken at the pump (reading of injection end), where (V2-V1) is the volume of injected water (displacement liquid).
15. Process of injecting displacing liquid is repeated until reaching the ratio of total injected volume (displacing liquid + surfactant solution) equals (250%) of porous volume of the model;
16. At the end of each injecting process (15-30-50-100-150-200-250)%PV, volume of oil and water resulted from the displacement process exited through valve (J) and accumulated in a millimeter-scaled cylinder are measured.

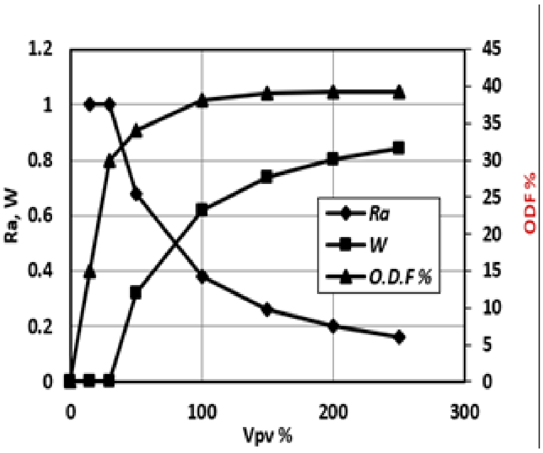


Figure 9 change of O.D.F, R.a and W by relation of Vpv% (when injecting 15% PV of surfactant).

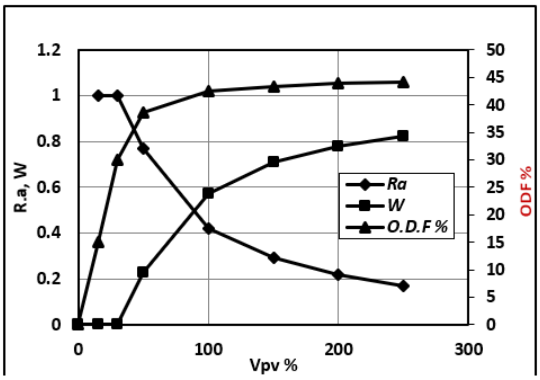


Figure 10 change of O.D.F, R.a and W by relation of Vpv% (when injecting 30% PV of surfactant).

Clarification of symbols used in the previous table and figures:

Vpv: ratio of injected liquid volume to the pores volume (%).

V_A: amount of the relative volume of the injected liquid (ml).

Vx: volume of the injected liquid in each stage (ml).

ΔV: volume of the injected liquid in every single stage (V2-V1) (ml).

V_T: accumulated volume of the injected liquid (ml).

Vo: accumulated volume of the produced oil (ml).

Vw: accumulated volume of water produced with oil (ml).

O.D.F: oil displacement factor (%).

W: percentage of water in the produced liquid (oil + water) ($W\%=V_w/V_T .100$).

R.a: proposed factor (recoverability) represents the ratio between accumulated volume of produced oil in every injecting process and the accumulated volume of the injected liquid in the same stage (ml/ml): ($Ra = \frac{V_O}{V_T}$).

P1: model inlet pressure (45 atm) equals the average formation pressure of Dero oil field.

P2: model outlet pressure (42 atm) equals the average bottom-hole pressure of the producing wells.

Q: average of fluid injection into the model (65.38ml/hour). It's determined to be compatible with the inlet and outlet pressure of the model.

Total PV: pores volume of the model saturated with oil (112.8 cm^3).

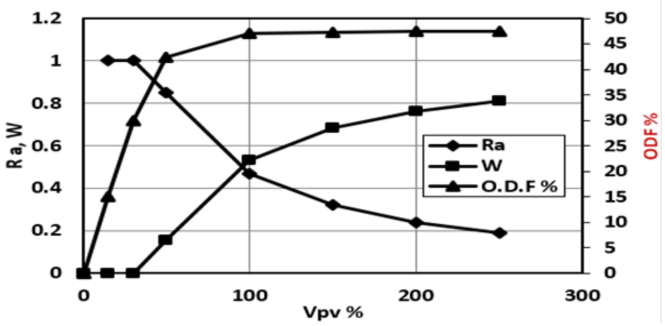


Figure 11 change of O.D.F, R.a and W by relation of Vpv% (when injecting 50% PV of surfactant).

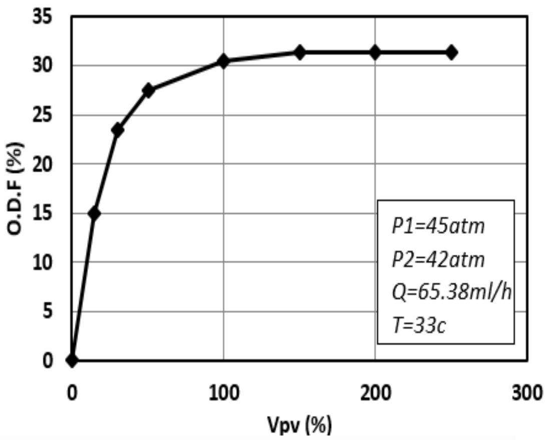


Figure 12 change of O.D.F by relation of Vpv% (water flooding).

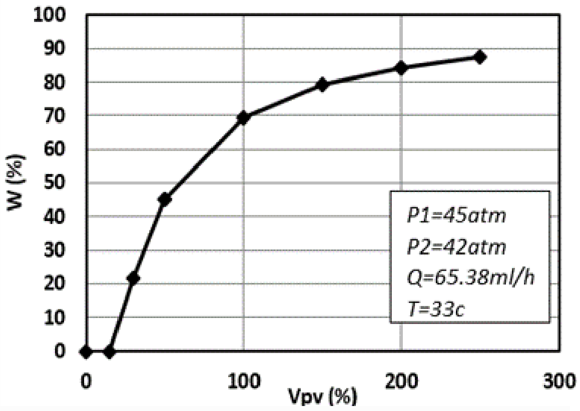


Figure 13 change of W by relation of Vpv% (water flooding).

Table 12 results of water injection at different ratios of pores volume.

R.a	W (%)	O.D.F (%)	Vw (ml)	Vo (ml)	V_T (ml)	V2 (ml)	V1 (ml)	Vx (ml)	V_A (ml)	Vpv (%)
1	0	14.9	0	16.9	16.9	85.78	102.7	16.92	16.92	15
0.78	21.5	23.5	7.3	26.5	33.8	74.26	91.18	16.92	33.84	30
0.55	45	27.4	25.4	31	56.4	51.7	74.26	22.56	56.4	50
0.30	69.4	30.5	78.4	34.5	112.9	46.2	102.6	56.4	112.8	100
0.2	79.1	31.3	133.9	35.3	169.2	37.24	93.64	56.4	169.2	150
0.15	84.3	31.3	190.3	35.3	225.6	45.4	101.8	56.4	225.6	200
0.12	87.4	31.3	247.7	35.3	282	45.64	102.04	56.4	282	250

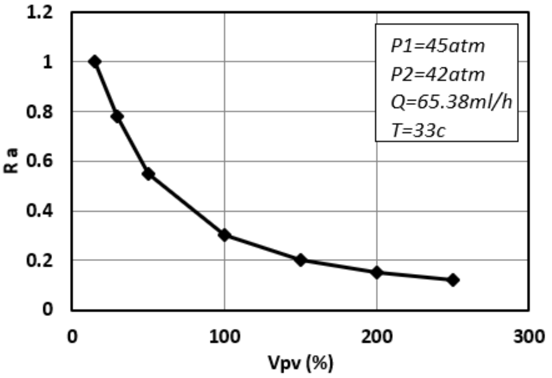


Figure 14 change of R.a by relation of Vpv% (water flooding).

Comparison between the efficiency of surfactant injection and water flooding:

The following figures show a comparison between the efficiency of both methods in regards to (O.D.F, R.a and W) at all the studied injection ratios:

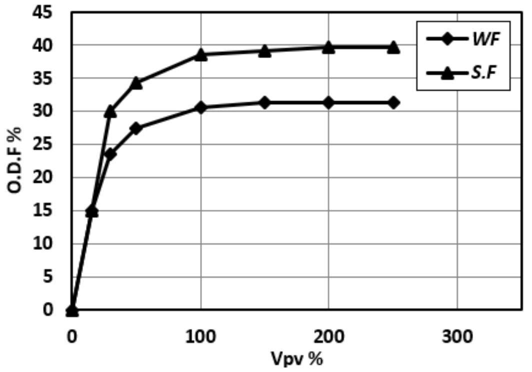


Figure 15 comparing O.D.F change by relation with Vpv% of both methods (when injecting 15% PV of surfactant)

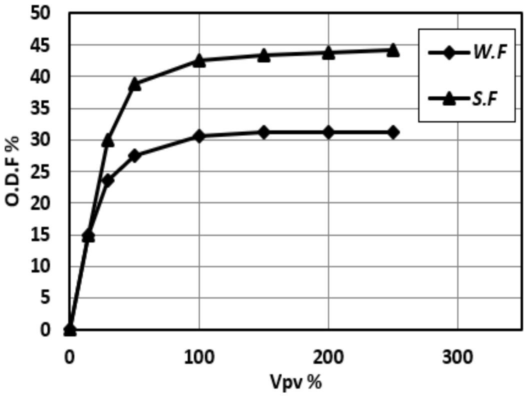


Figure 16 O.D.F change by relation with Vpv% of both methods (when injecting 30% PV of surfactant)

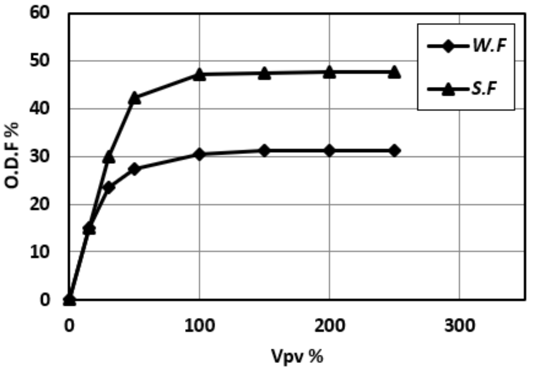


Figure 17 comparing O.D.F change by relation with Vpv% of both methods (when injecting 50% PV of surfactant)

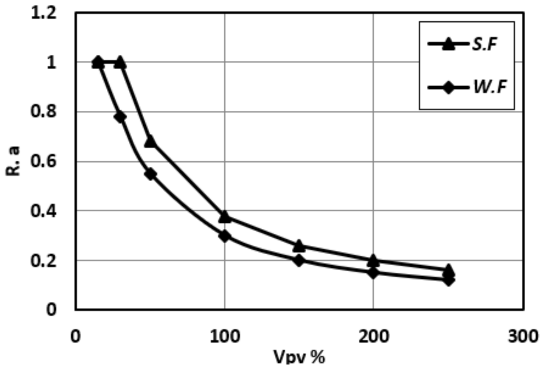


Figure 18 comparing R.a change by relation with Vpv% of both methods (when injecting 15% PV of surfactant)

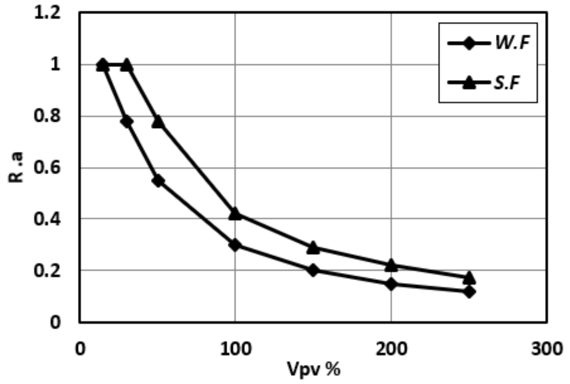


Figure 19 comparing R.a change by relation with Vpv% of both methods (when injecting 30% PV of surfactant)

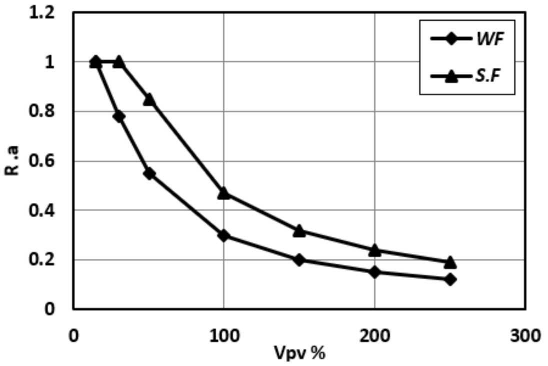


Figure 20 comparing R.a change by relation with Vpv% of both methods (when injecting 50% PV of surfactant)

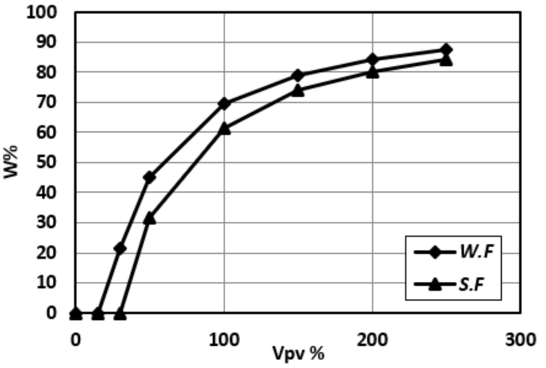


Figure 21 comparing W change by relation with Vpv% of both methods (when injecting 15% PV of surfactant)

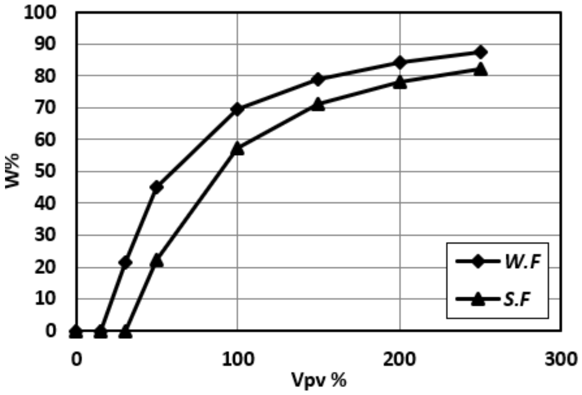


Figure 22 comparing W change by relation with Vpv% of both methods (when injecting 30% PV of surfactant)

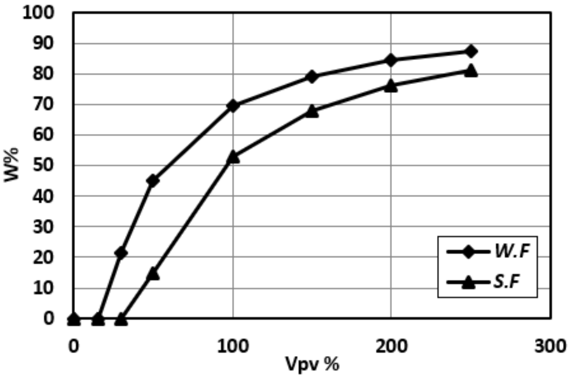


Figure 23 comparing W change by relation with Vpv% of both methods (when injecting 50% PV of surfactant)

Discussion of the Results

- At all studied injecting ratios of surfactant (15, 30 and 50)%PV we notice an obvious and significant increase of the displacement factor (O.D.F) (bigger than of water flooding) until reaching the ratio of injected liquid volume (surfactant + displacement liquid) to the volume of pores of (100%). After this ratio and until reaching (250%) of the injected liquid (surfactant + displacement liquid) we notice the increase of O.D.F continues but in lower pace while it remains steady in the process of water flooding.
- For the factor R.a, we notice that its value stay steady until the ratio of (35%), then it starts to decrease. In water flooding however, the value of R.a starts to decrease after the ratio of (15%). Comparing the values of R.a factor between the both methods of injection (when injection ratio is fixed) we find that this factor has a bigger value when injecting surfactant than that when injecting water;
- Regarding the results of the change of water ratio in the produced liquid, it is noticeable that when injecting surfactant, this ratio is zero until the percent of circa (35%). After that, the ratio of water produced with oil starts to increase while the ratio of water within the produced liquid during water flooding increases as of the ratio of (15%). With notice that the ratio of water produced

with oil during surfactant injection is less than that during water flooding.

- All above can be explained due to the important and active role of the surfactant depending on its influence on the oil displacement process through the model according the following mechanisms:
- Decreasing interfacial tension between oil and water which contributes in releasing residual oil within the pores of the model and increases its motility which in turn contributes in the increase of displacement factor more than that in water flooding;
- Increasing the capillary number NC , $N_c = \frac{V.\mu}{\sigma}$. The increase of NC leads to the increase of displacement factor by decreasing (σ) between oil and surfactant solution which contributes in displacing residual oil in the model efficiently;
- Wet ability alteration. Surfactant Injection contributes in alteration of wet ability from oil-wet ability to water-wet ability as surface electrical charges and vandervals forces affect properties of oil wet ability which in turn leads to the increase of the produced oil and to increase oil relative permeability of the model on the account of its water relative permeability. That in turn leads the ratio of produced water with oil when surfactant injection is lower than that when water flooding.

Conclusions and recommendations

- According to the positive lab results reached in this study, surfactant injection method can be accredited as a method to increase oil displacement factor in Dero field.
- We suggest applying this method on mini model (pilot) in the studied field and monitoring the outcome of this process in the field. If encouraging results reached, then this method can be applied on the entire field;
- This method can be applied alongside water flooding currently applied in the said field.
- Conducting further researches aiming to study the possibility of using other chemical injection methods such as: (Alkaline Flooding- MAP Flooding - MP Flooding – Emulsion Flooding) in order to increase the displacement factor.

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