JP&M Engineering

Journal of Petroleum and Mining Engineering

The Economic Evaluation of the Efficiency of the ASP Chemical Flooding in DERO Field

Mosab Badr Aldin AlBredi
Syrian Private University (SPU) - Faculty of Petroleum Engineering- Syria
Mosab.afuniv@gmail.com

Abstract

In this research, economic evaluation of the efficiency of the ASP chemical flooding method applied on the oil-producing Jaribeh formation of DERO oil field was performed. The theoretical study firstly included complete explanation of objectives and justifications of the research, reference study related to the economic aspects of applying the mentioned method, overview of DERO oil field (lithostratigraphic, petrophysical, and depositional properties as well as reservoir indexes of Jaribeh reservoir in the mentioned oil field).The economic study however, included the following axes: Determination of sequence of chemical solutions and liquids proposed to be injected in the pilot area chosen for studying, determination of volumes of chemical solutions and liquids proposed to be injected in the pilot area, determination of the ideal batch of the ASP solution proposed to be injected in the pilot area, proposed scheme of the injection process, choosing a pilot in DERO field and determining its main reservoir characteristics, calculating volumes of chemical solution and liquids injected in the pilot area, calculating oil quantities expected to be produced from the pilot area as a result of applying the ASP flooding method, and calculating cost of chemical materials needed for the ASP flooding process in the pilot. As a result of this study, the additional quantity of oil produced by applying the ASP flooding method in the pilot was determined as well as the additional cost of an oil barrel resulted from using chemical materials in the mentioned flooding process that is (1.93 $/bbl).

Keywords

Oil displacement factor; Main slug; Mobility Buffer; Pilot; Chemical cost.

Introduction

ASP (Alkaline/Surfactant/Polymer) chemical flooding method is considered a modern technology of the chemical enhanced oil recovery. This method is a development of Polymer flooding, Alkaline flooding, and surfactant flooding. ASP method combines all advantages of all the mentioned flooding methods where we can benefit from the advantage of the presence of polymers, alkaline, and surfactants. ASP method currently receives significant attention regarding research and application.

The main objective of this research is to perform economic assessment of applying the ASP chemical flooding method in Jaribeh oil-producing formation. It is expected upon completing this research to determine the economic efficiency of applying this method and showing the increase that will occur on the price of one oil barrel produced from the mentioned oil field after applying this flooding method. As of 1993 and ever since, water flooding method has been used in DERO field as one of the secondary extraction method in order to support the formation pressure and increase the displacement efficiency. The annual quantities of injected water reached (77.752m3) until 2010 and (658.857 m3) as accumulative quantities versus (10703 x 106 m3) accumulative production of (oil and water) which forms a low percent not more than (38.5 %). Because DERO field has geological reserve of (17.064 x 106 m3) and recoverable reserve of (2.56 x 106 m3) against just (8.8 %) oil recovery, and since screening criteria of applying the ASP chemical flooding method is completely compatible with characteristics of DERO field regarding properties of formation fluids and reservoir indexes of producing Jaribeh formation in this field, therefore, it was decided to study the economic efficiency of applying this method and determining the additional cost on the oil barrel price resulted from applying this method. This additional cost is due to using chemical materials. In my pervious researches, I studied the displacement process using ASP solution consists of: [0.7 %wt NaOH (Alkaline) - 550 PPm Xanthan gum (Polymer) - 0.05 %wt DDBSNa (Surfactant)] on a rock model physically emulates oil-producing Jaribeh formation in the mentioned field. Through the displacement experiments, change of: ODF/Ra/W against (VPV) at different volumetric percents of ASP to the total volume of the rock-model pores was determined. Research results will be presented in the following sections.

The ODF index represents the oil displacement factor (in the displacement lab experiments) whereas, Ra index represents the ratio between oil volume in the produced liquid and the total volume of produced liquid (in the displacement lab experiments), while W index represents water percentage in the produced liquid (in the displacement lab experiments), (VPV) represents volumetric ratio of injected liquid (ASP, polymer ,water…) to the total volume of the rock-model pores (total Pores volume is 112.8 cm3).

Reference studies

In his experiment on injecting ASP solution in Cambridge field, Vargo and Turner [1] mentioned the success of this operation associated with the final increase of oil quantity up to (143,000 bbl) with cost of (2.42 $/bbl), showed that good mobility control is considered essential in the successful project, and indicated that detailed geological and petrophysical study of the reservoir as well as design of the lab fluid significantly enhance the probability of success. In addition, in a study conducted by Wyatt and Malcolm [2], the initial oil reserve of Minnelusa filed is estimated about 1 billion standard barrel, and the possible increase in the quantities of the produced oil that resulted from flooding by ASP solution in these fields is close to (130 x 106 bbl). This operation can be applied with an increase in the cost of producing one barrel ranges between (1.6-3.5 $/bb). Moreover, researchers Gu and Wang [3], through their experiments, showed that concentrations of polymers, surfactants, and alkaline remain high in the produced fluids when ASP method is applied, therefore, the successful study of these chemicals can dramatically reduce cost of this operation. Also, In a pilot experiment on injecting ASP solution in Daqing oil field, researchers Ang and Huabin [4] evaluated performance of the experiments by achieving the following results: Average of oil production increased in the experiment area from (36.7m3/day) to (91.5 m3/day), while percent of the produced oil decreased from (82.7%) to (59.7%). For the central well surrounded by injecting wells (reversed five spot system), average of the produced oil increased from (3.7 m3/day) to (27.1 m3/day) while percent of the produced water decreased from (87.9 %) to (45.8 %). Furthermore, researcher Protap [5] performed comprehensive lab studies on real cores in RFD institute related to ONGC company for evaluating efficiency of ASP flooding in Virage Indian field. Results of lab studies indicated increase of the oil recovery factor by (18 %) of the initial reservoir (OOIP) more than that of water flooding. Based on this encouraging result, a pilot experiment was designed (five-spot system) and (20 %PV) of ASP solution (1.5 %wt Alkaline, 0.2 %wt surfactant, and 800 ppm polymer) was injected. In addition, in the research for assessing ASP flooding process in Tanner field, published by researchers Pitts and Dowling [6] in which ASP solution consisting of (1 %wt NaOH , 0.1 %wt "ORS-41HF" surfactant, 1000 ppm "AlcoFlood" polymer) was injected, the oil recovery factor increased by (10 %) of the initial reserve (OOIP).In an another industrial experiment on ASP flooding, according to Fu and Guangzhi [7], in the central part of Xing2 of Daqing filed, the mentioned solution was injected in that part with (20 %PV). 19 producing wells showed response in oil displacement. Quantity of produced oil increased from (25 ton/day) to (148ton/day) associated with decrease in the produced water from (96.3%) to (69.9 %). Moreover, in their assessment of a lab pilot experiment for injecting ASP solution in Karmary field, Delshad and Xingiang [8] presented results of this experiment as follows: (24 %) increase in the oil recovery factor of the OOIP, and alkaline catalyst in the ASP solution partial consumption by undesired reactions with Calcium and other cations in the formation water as well as by cation exchange with shale. Also, in an experiment on ASP flooding in Godung field, according to Wang, Long, and Huanchen [9], oil production from the experimental project reached 20667.7 ton. The additional production of oil using this method in the central well (number7) reached 13.4% of the OOIP. Furthermore, Hernandez and Larry J [10] indicated that economic efficiency of applying ASP flooding method is based on a series of experiments including: compatibility between the fluids, thermal stability of the chemicals, auto-formation of the emulsions, interfacial tension (oil and ASP solution), and trapping chemicals in the porous medium. Moreover, results of injection cores taken from Salina offshore field showed that when injecting 30% PV of ASP solution followed by 30 %PV of polymer pushing solution, 24.6% recovery of the OOIP was obtained. Total oil recovery factor also reached 70.2 % of the OOIP. Also, Manrique [11] indicated that flooding reservoir cores taken from VLA field in Marakibo lake with ASP solution gave additional recovery between 22 % and 39 % of the initial reserve when injecting 30 %PV of the mentioned solution followed by 15 %PV of polymer solution. Moreover, in the pilot empirical test of flooding by ASP solution in Karmary field, as stated by Qi and Hongjun [12], 24 % recovery factor of the OOIP over all the test area was achieved. Oil recovery factor in the central well was just 25 %. In addition, the possibility of using four methods of enhanced recovery in Westkiehl was studied by Clark and Pitts [13] with methods including conventional water flooding, polymer flooding, polymer with alkaline flooding, and finally ASP flooding. Final oil recovery factor was (56%, 49 %, 46 %, 40 %) respectively. Furthermore, according to Hernandez and Chacon [14], in a test for tracking the injected chemical material to determine the efficiency of ASP flooding in Lagomar oil area of Venezuela, results showed that before injecting the solution, saturation with residual oil in VLA-1325 well was 31±3 %. However, after the ASP injection with 35 %PV followed by 15 %PV of polymer pushing solution, tracking tests showed that saturation with residual oil decreased to 16±3%. Also, in the pilot experiment on ASP flooding in Beiyiduanxi of China, Yang and Liao [15] stated that there was an increase in the oil recovery factor of (21.4%) more than that when flooding with water. In an extended field experiment in the mentioned area, percent of produced water from the producing wells decreased from 95 % when flooding with water to 54.4 % using ASP flooding. Oil recovery factor increased by 20.49 % of the initial reserve. Moreover, researchers YaunShiyi and Hau [16] classified factors affecting efficiency of ASP flooding to Geological factors, including unconformity of the formation (reservoir) and the ratio Kv/Kh. In the chemical injection, the increased ratio causes vertical flow and more spanning of volume of the displaced liquid, which is preferable for EOR operations, Physiochemical parameters, including interfacial tension, viscosity of the displacing liquid, adsorption of the chemicals, as well as Operational parameters, such as composition of the injected batch, concentration of the injected materials, volume of the injected batch, and injection rate.

Materials and Methods

Overview of DERO Oil Field [17]

1- Litho-stratigraphic Description of Jaribeh Oil-Producing Formation:

Depending on the study of the cores taken from this formation, Jaribeh can be divided into the following intervals:

- (JE1): Rocks of this interval consist of micrite-calcite-carbonate, while micrite-dolomite is less abundant. Rocks of this interval also contain knots of anhydrite in addition to crystals of pyrite. Thickness of this interval ranges from (39 m) in DERO-6 well and (33.5 m) in DERO-15 well.
- (JE2): Rocks of this interval consist of calcite rocks of bio-micro-sparite, in addition to dolomite and dikes of anhydrite. Thickness of this interval is (20 m) in DERO-8 well and (12 m) in DERO-18 well.
- (JE3): A (2 m) layer of anhydrite.
- (JE4): Consists of calcite biomicrite rocks, sometimes dolomitic. Thickness of this interval is (28 m) in DERO-5 well and (23.5m) in DERO-2&6 wells.

2- Petrographic and Depositional Characteristic of Jaribeh Formation:

Three intervals from bottom upwards can be distinguished:

- (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.
- (JE2): Consists of calcite-micosparitic rocks. It consists of microsparitic calcite, sometimes micrite between (50-60%) of the calcitic rock. Porosity (15-25%), pores size between (0.02-1.5 mm) with the presence of cavities up to (9 mm).
- (JE3): A (2-4 m) anhydrite layer with poor reservoir properties with absence of any oil shows.
- (JE4): Rocks of this interval 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.

The following figure represents structural map of Jaribeh formation in DERO field:

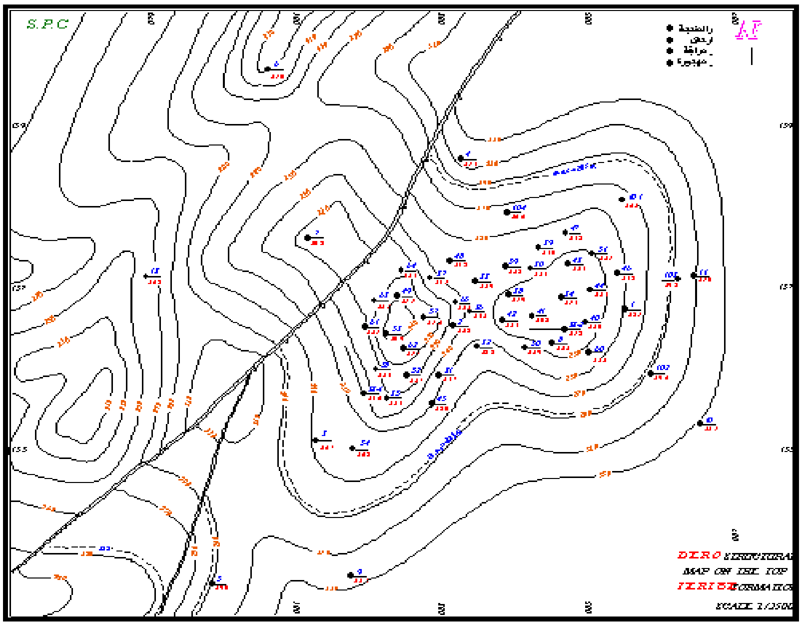

Figure 1 Structural map of DERO field (Jaribeh formation)

The following two figures show ratio of produced water and daily production rate in DERO oil wells:

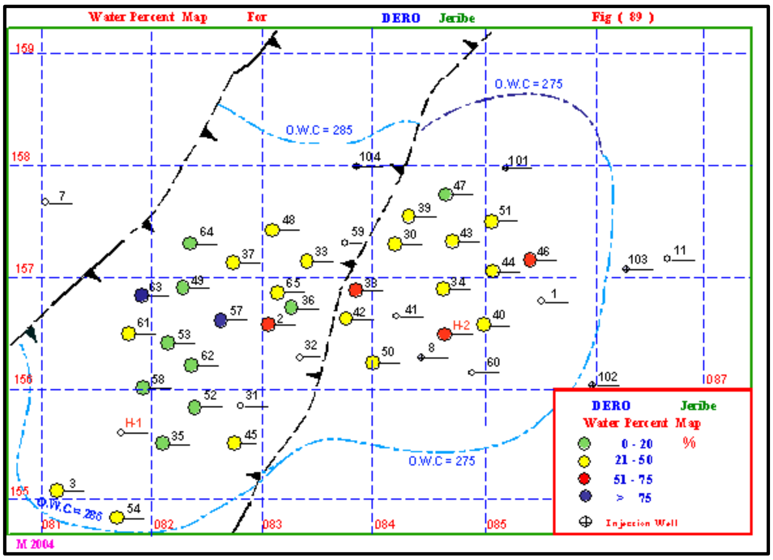

Figure 2 DERO wells Ratio of produced water

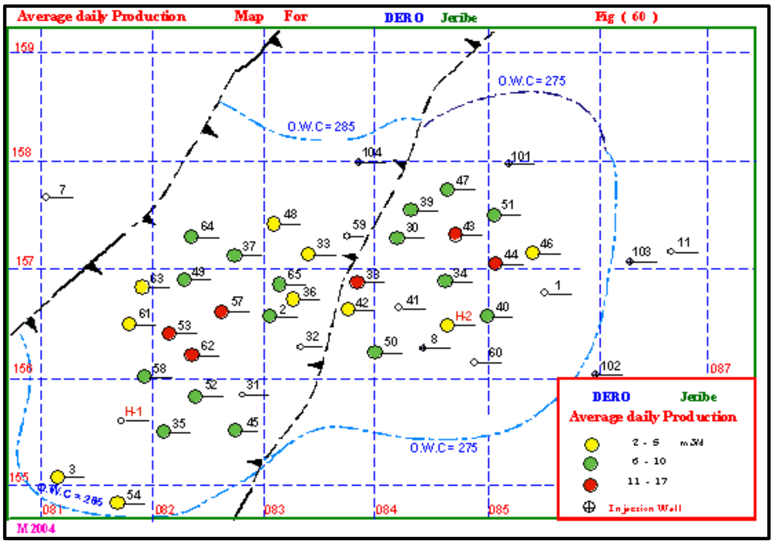

Figure 3 DERO Wells Daily production

3- Reservoir Indexes of DERO Oil Field: Presented in Table 1.

Table 1 Reservoir Indexes of DERO Oil Field

Formation	**Jeribeh**	**Transition**
Active thickness	4.55 m	
Average oil saturation	65 %	
API	35.1	
Oil viscosity at surface conditions	15.5 C.P	
Initial oil recovery	15 %	
Current oil recovery	8.8 %	
Recoverable reserve	$1.299 x 10^6$ m^3	$2.56 x 10^6$ m^3
Geological reserve	$8.662 x 10^6$ m^3	$17.064 x 10^6$ m^3
Current water ratio	34.5%	
Initial formation pressure	54 atm	
Current formation pressure	45.5 atm	
Formation temperature	33 °C	
Total number of wells	59	
Number of producing wells	34	
Number of operating wells	37	
Accumulative oil production	$1.507685 x 10^6$ m^3	
Residual reserve	$2.407 x 10^6$ m^3	
Density of wells network	91.4	
Rate of Yearly suction	2.2 %	
Rate of depletion	58.9 %	

Formation description	Fractured cavernous porous carbonates rock
Formation depth	600 m

Main Axes of the Study: Materials and Methods

1. **Determination of The Proposed Sequence of Chemical Solutions and Liquids Injection Into The Pilot Chosen For Study:**

   Proposed Sequence:

   a) Main slug: Main ASP solution batch.

   b) Mobility buffer: Batch of polymer solution for controlling mobility of the main batch.

   c) Fresh water: Fresh water batch for protecting the polymer batch and the ASP solution batch from the effect of displacement liquid salinity that is finally injected.

   d) Cashe water: Displacement liquid.

   Pre-flush of the formation can also be done before injecting the ASP solution to decrease its salinity.

2. **Determination of Volume of The Chemical Solutions And Liquids Proposed to be Injected Into The Pilot Area, including**:

   a) Main slug: Batch of ASP injection solution (determination of the optimum volume of this batch will be explained in the following article).

   b) Mobility buffer: Batch of polymer solution for controlling the mobility. Proposed volume of this batch is (15 %PV).

   c) Fresh water: This batch is proposed to be injected with volume (5 %PV) (injecting this batch is optional in the case of using Xanthan-gum polymer in the composition of the ASP injecting solution).

   d) Cashewater: Injecting the displacement liquid is continued after injecting the fresh water batch with a total volume of these both batches of (100 %PV).

3. **Determination of The Optimum Volume of The ASP Solution Batch Proposed to be Injected in The Pilot Area**:

   Determination of this optimum volume though lab displacement experiments is basically related to achieving the following indexes:

- Maximum oil displacement factor (ODF).
- Maximum ratio of oil in the produced liquid (Ra).
- Minimum water pecentage in the produced liquid (W).

Therefore, determination of the optimum volume of the ASP solution batch will be based on results of displacement processes I carried out in the lab displacement experiments as per the following steps:

1. Relation between (ODF, Ra, and W) and V_{PV}, which represents volumetric ratio of injected liquid volume to pores volume is charted at all volumetric ratios of the injected ASP solution.
2. Values of (ODF, Ra, and W) are compared at all volumetric ratios of the injected ASP solution.
3. The Ratio that leads to the maximum value of (ODF, Ra) factors in addition to the minimum value of (W) is chosen.

ASP solution was injected into rock model emulated Jaribeh producing formation of DERO field at formation temperature and pressure. This solution consisted of:

(0.7 %wt NaOH, 550 ppm Xanthan gum, and 0.05 %wt DDBSNa).

ASP solution was injected with the following volumetric ratios:(15, 30, 50 %PV). each of which followed by injecting (15 %PV) of the polymer solution to control the mobility and 5%PV of fresh water .Finally, the displacement liquid (water) was injected until completion of the total injected volumetric ratio (250 %PV). According to that, change of (ODF, Ra, and W) was studied in relation with (V_{PV}) at all the mentioned injected ratios.

Results of injection processes are presented in Tables 2, 3, and 4, along with graphical presenations in Figures 4, 5, and 6 in the results section.

4. Proposed Schematic of The Injection Process: (Refer to the results section).

5. Choosing A Pilot in DERO Field and Determination of Its Main Reservoir Characteristics:

A reverse four-point-injecting-system model was chosen. This model is a triangle. Three production wells (D2, D50, and D60) are located at each head of this triangle. D80 injecting well is located within this pilot as shown on DERO structural map. Indexes of these production wells are presented in Table 5, the pilot position in DERO field is presented in Figure 8, and characteristics of the pilot chosen for the study are presented in the Table 6 in the results section.

6. Calculating Volumes of Chemical Solutions And Liquids Injected in The Pilot Area: (Refer to the results section)

7. Calculating Oil Quantities Expected to Produce From the Pilot Area When ASP Flooding is Applied: (Refer to the results section)

8. Calculating cost of chemical materials required for injecting the ASP solution into the pilot: (Refer to the results section)

Results

- **Results of injection processes:**

Table 2 Results of injecting (15% PV) of the ASP solution

Vpv (%)	Vo (cm^3)	Vw (cm^3)	ODF (%)	W (%)	Ra
15	16.9	0	15	0	1
30	33.8	0	30	0	1
50	52.4	4	46.5	7	0.92
100	58.5	54.3	51.9	48.1	0.51
150	59	110.2	52.3	65.1	0.34
200	59.4	166.2	52.7	73.6	0.26
250	59.6	222.4	52.9	78.8	0.21

Table 3 Results of injecting (30% PV) of the ASP solution.

Vpv (%)	Vo (cm^3)	Vw (cm^3)	ODF (%)	W (%)	Ra
15	16.9	0	15	0	1
30	33.8	0	30	0	1
50	52.0	4.4	48.1	1.7	0.92
100	66.1	46.7	58.6	41.7	0.58
150	66.5	102.7	59.0	60.7	0.39
200	67.1	158.5	59.5	70.2	0.29
250	67.4	214.6	59.8	76	0.24

Table 4 Results of injecting (50% PV) of the ASP solution

Vpv (%)	Vo (cm^3)	Vw (cm^3)	ODF (%)	W (%)	Ra
15	16.9	0	15	0	1
30	33.8	0	30	0	1
50	55.8	0.6	49.5	1	0.99
100	77.5	35.3	68.7	31.2	0.68
150	78.8	90.4	69.9	53.4	0.46
200	79.4	146.2	70.4	64.8	0.35
250	80	202	71.0	71.6	0.28

Where:

V_O: accumulative volume of the produced oil.

V_W: accumulative volume of the produced water.

Above results are graphically presented in the Figures 4, 5, and 6:

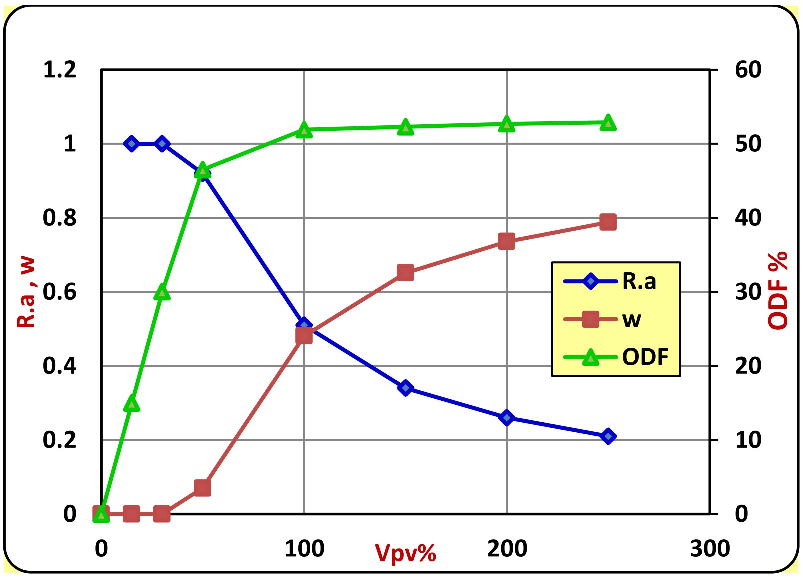

Figure 4 Change of ODF, Ra, and W in relation with V_{PV}%

when (15% PV) of the ASP solution is injected

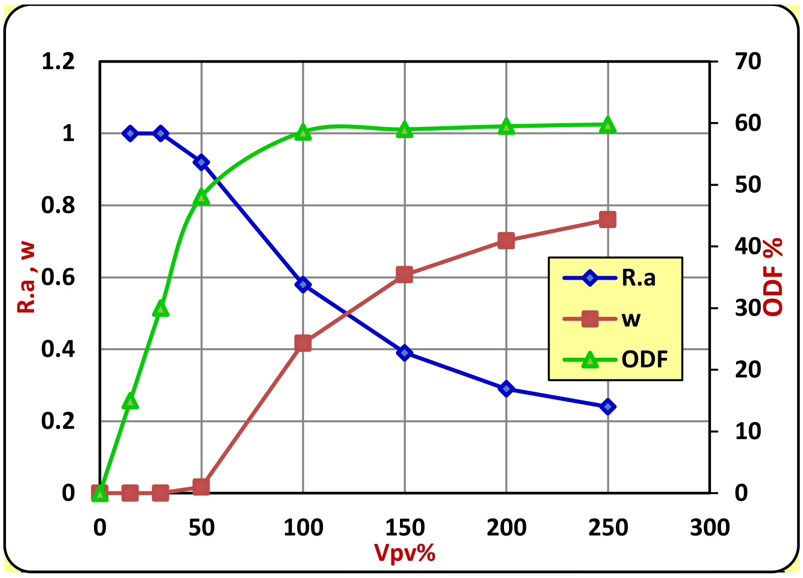

Figure 5 Change of ODF, Ra, and W in relation with V_{PV}%

When (30% PV) of the ASP solution is injected

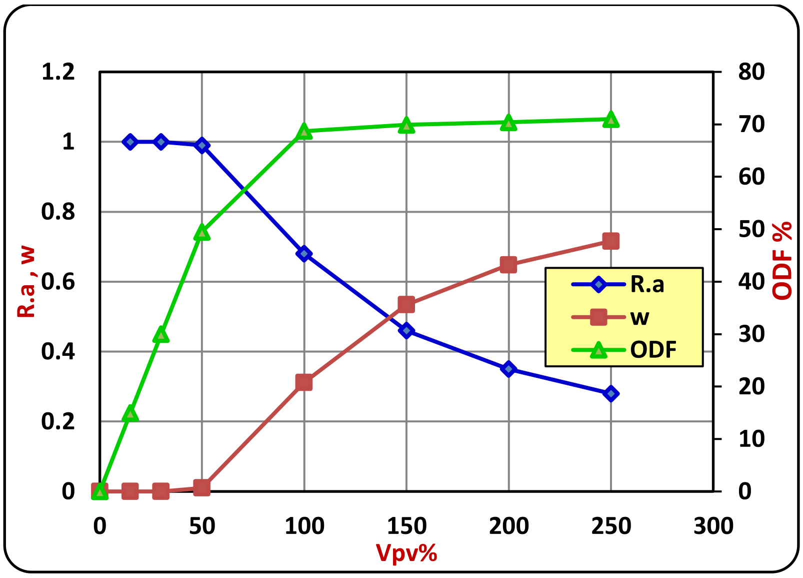

Figure 6 Change of ODF, Ra, and W in relation with V_{PV}%

When (50% PV) of the ASP solution is injected.

It is clear from the above figures that minimum volume of the ASP solution batch that meets the aforementioned indexes is (30% PV), while the maximum volume of this batch that meets these indexes is (50%PV) meaning that optimum volume of this batch ranges between (30-50% PV.

- **Proposed Schematic of the Injection Process:**

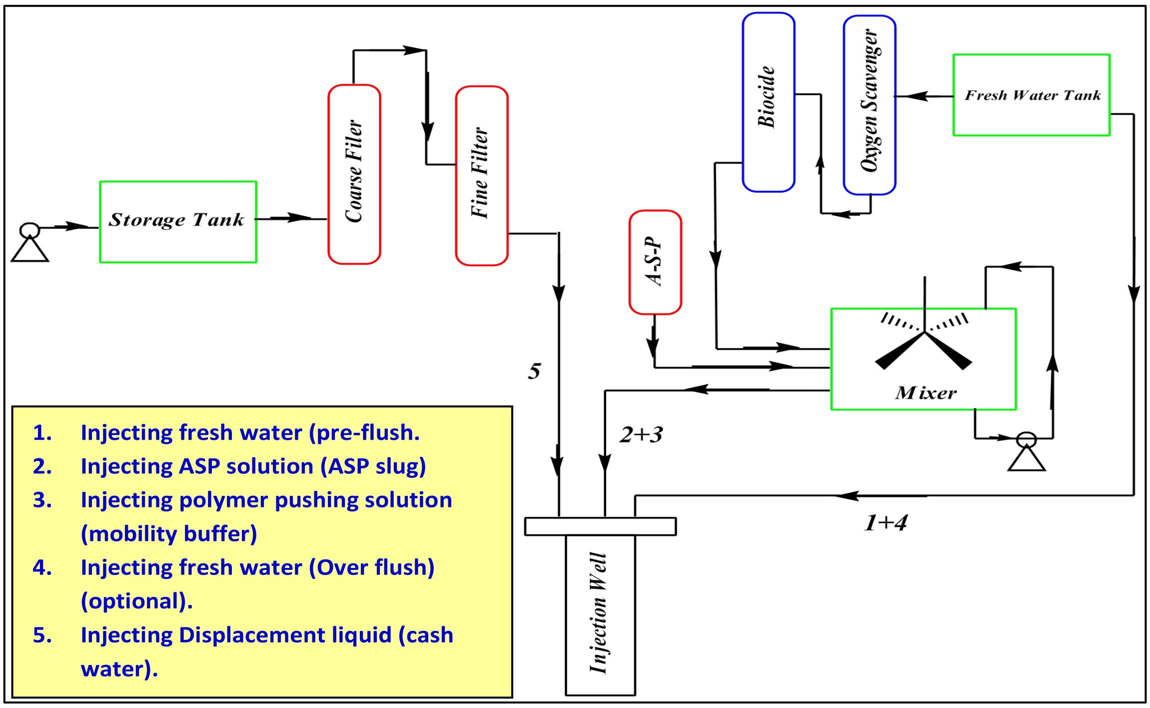

Figure 7 Proposed and Simplified Scheme of Surface Equipment Needed for ASP Flooding Operation

Water used as displacement liquid must be passed though two types of course and fine filters in order to eliminate any solid impurities. Fresh water and water are used for preparation of the ASP injection solution ;However, they must be treated with Biocide and scavenger oxygen especially when Xanthan gum polymer is used in the composition of the ASP solution in order to avoid any biological degradation and to eliminate the effect of oxygen on polymer efficiency used in the preparation of the solution or that used for controlling mobility after injecting the ASP solution.

- **Chosen Pilot in DERO Field and Its Main Reservoir Characteristics:**

Table 5 Production indexes of wells located within the studied pilot

Well	Q_o m3/day	Q_w m3/day	Q_T m3/day	W %
D2	2.8	5.2	8	65
D60	1.8	3.2	6	64
D50	4.02	1.98	5	33

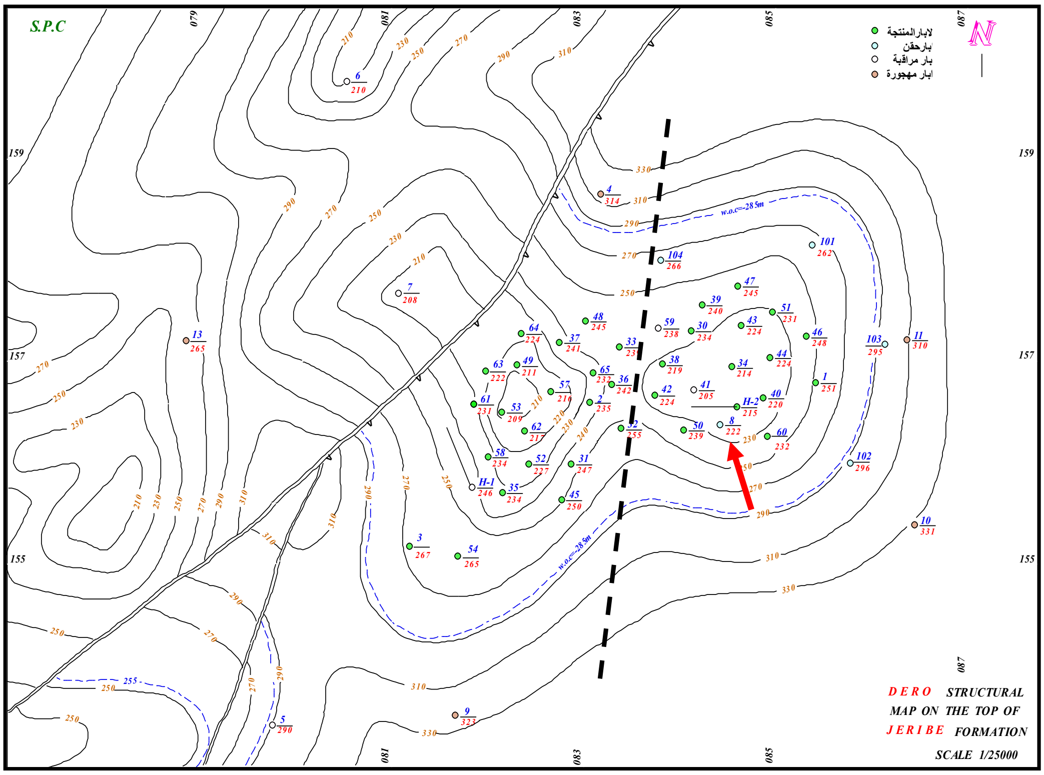

Figure 8 The Pilot Position in DERO Field

Table 6 Characteristics of The Studied Pilot in DERO Field

Distance between wells	D50 -D60 = 900 m D2-D60=425 m D2-D50 = 675 m
Average depth of the reservoir (producing formation)	576 m
Average porosity of the reservoir calculated from cores	25.43%
Pilot area	135000 m^2
volume of water daily injected into D8 injection well	100 m^3
Temperature of reservoir within the pilot	33 ^oC
Oil saturation	65%
Volume of oil within the pilot (pores volume)	F.h.m.So=135000x4.5x0.254x 0.65 = 100298m^3
Average effective thickness of the reservoir	4.5 m

- **Volume Calculations of Chemical Solutions and Liquids Injected in The Pilot Area:**

- Volume of the ASP solution (main slug) (when 50% PV injection ratio is chosen):
  $V_{Maine\ slug} = 0.5x100298=50149\ m^3$
- Volume of polymer solution behind the main batch (Mobility buffer):

  $V_{mobility\ buffer} = 0.15 \times 100298$

  $=15044.7\ m^3$
- Volume of fresh water behind the front of polymer solution (fresh water) that is a part of the displacement liquid:
  $V_{fresh\ water} =0.05x100298=5014.9\ m^3$
- Volume of the displacement liquid batch (cashe water):

  $V_{Cashewater} =0.95x100298=95283.1\ m^3$
- Total volume of all injected liquids and solutions:
  $V_{ToTal} =165491.7\ m^3$

- **Oil Quantities Calculations Expected to be Produced from the Pilot Area when ASP Flooding is Applied:**

Quantity of oil expected to be produced from the pilot when injecting ASP solution:

$Q_o =0.71 \times 100298= 71211.5\ m^3$

PS: The number (0.71) mentioned in tables (4 and 6) represents final oil recovery factor when injecting (50% PV) of ASP solution.

- **Cost Calculations of Chemical Materials Required for Injecting the ASP Solution into the Pilot:**

First: Cost of alkali used for preparing the ASP solution:

- Quantity of alkali needed for preparing (50149 m^3) of the ASP solution is (351043 Kg).
- Price of (1 Kg) of NaOH is: (0.8 $).
- Price of alkali needed to prepare (50149 m^3) of the ASP solution is: (280,834 $).

Second: Cost of the surfactant used to prepare the ASP solution:

- Main quantity of the surfactant needed to prepare (50149 m^3) of the ASP solution is (25074.5 Kg).
- Additional quantity of the surfactant needed to compensate the quantity lost by adsorption is (3259.6 Kg) for (50149 m^3) of the ASP solution
- Total quantity of the surfactant is: (28334.1 Kg).
- Price of (1 Kg) of the (DDBSNa) surfactant is: (2.04 $).
- Price of total quantity of the surfactant is: (57,801.56 $).

Third: Cost of the polymer used to prepare the ASP solution:

- Main quantity of the polymer needed to prepare (50149 m^3) of the ASP solution is (27581.9 Kg).
- Additional quantity of the polymer to compensate the quantity lost by adsorption is (2507.45 Kg) to prepare (50149 m^3) of the ASP solution.
- Total quantity of the polymer is: (30089.35 Kg).
- Price of (1 Kg) of the (Xanthan-gum) polymer is: (8.4 $).
- Price of total quantity of the polymer is: (252750.54 $).

Fourth: Cost of the polymer used to prepare the polymer pushing solution:

- Quantity of the polymer needed to prepare (15044.7 m^3) of the polymer pushing solution is (8274.5 Kg).
- Price of (1Kg) of the (Xanthan-gum) polymer is: (8.4 $).
- Price of polymer needed to prepare (15044.7m^3) of the polymer, pushing solution is: (69505.8 $).

Fifth: Cost of chemical materials needed for treating water used to prepare the ASP solution:

- Quantity of the Oxygen-Scavenger material (oxygen-removing material) needed to treat (50149 m^3) of the ASP solution is (401.19 liter).
- Price of (1 liter) of this material is: (0.517 $).
- Price of the total quantity: (207.4 $).
- Quantity of the Beocide1 (Antibacterial material) needed treat (50149 m^3) of the ASP solution is (6519 liter).
- Price of (1liter) of this material is: (2.65 $).
- Price of the total quantity: (17275 $).

Conclusions

- Total cost of the chemicals is: (678374 $).
- Total quantity of oil produced from the pilot when injecting ASP is: (71211.5 m^3).
- Total volumes of liquids injected during application of ASP flooding include:
  1. Volume of the ASP solution (main slug).
  2. Volume of polymer solution behind the main batch (mobility buffer).
  3. Volume of fresh water batch behind the polymer solution, which is a part of the displacement liquid volume.
  4. Volume of the displacement volume (cashe water).

Sum of the above volumes needed to perform the ASP flooding is (165491.7 m^3) as mentioned above.

Since the daily injection rate in the D8 injection well located within the pilot is (100m^3/day),therefore, if the mentioned total volume (165491.7m^3) was just water, this total volume will produce oil from injecting water into D8 well equals to: $1654.917\ m^3 \times 8.62 =14265.38\ m^3$.

PS.Number(8.62)represents accumulative daily produced quantities of oil from wells (D2, D50, and D60) when injecting (100 m^3/day) of water in D8 injecting well as in Table 2.

- Additional quantity of produced oil added to the quantity of oil produced from the pilot though water flooding is:
  $71211.5m^3$-$14265.38m^3$
  =$56946.12m^3$
  =358151.6bbl
- Current average price of oil barrel (March, 2019) is: (60 $/bbl).
- Price of the additional quantity of produced oil resulted from ASP flooding is: (21489096 $).
- Price of oil quantity produced though water flooding is only: (5383162 $).
- Additional revenue: (16105934 $).
- Additional cost of oil barrel from using chemical materials when flooding with the ASP is: (1.93 $/bbl).

Recommendations

Depending on the encouraging result reached upon this economical study, ASP flooding, as a method of chemical enhanced oil recovery, can be adopted to increase oil recovery factor of DERO field.

We suggest applying this method on a pilot in the studied field and monitoring the outcome of this field experiment. If effective results are reached, using this method can be generalized on the entire area of this field especially water flooding is currently applied in this field. We also suggest conducting additional researches to study the possibility of using other chemical flooding methods such as: (MAPF flooding, MPF flooding, Emulsion flooding, and Alkaline flooding) to increase oil recovery factor of DERO field or in other fields that have characteristics identical with critical criteria to apply these methods.

Funding sources

This research received no external funding.

Conflicts of interest

There are no conflicts to declare.

References

[1] JayVargo,JimTurner"Alkaline/ Surfactant/Polymer Flooding Of The Cambridge Minnelusa Field" SPE 2000.
[2] Wyatt,Malcolm"Alkaline/Surfactant/ Polymer Technology Potential of the Minnelusa Trend, Powder River Basin" SPE 1995.
[3] WeiWang, YonganGu" Detection and Reuse Of Produced Chemicals in Alkaline/Surfactant/Polymer Floods" SPE 2003.
[4] GauShutAng,LiHuabin"Alkaline/ Surfactant/Polymer Pilot Performance of the West Central Saertu, Daqing Oil Field" SPE 1996.
[5] MahendraProtap"Field Implementation of Alkaline/Surfactant/Polymer (ASP) Flooding: Amaiden Effort in India" SPE 2004.
[6] M.J.Pitts,P.dowling"Alkaline/ Surfactant/PolymerFlood of the Tanner Field" SPE 2006.
[7] Li Hong Fu, Liao Guangzhi " Alkaline/Surfactant/Polymer(ASP) Commercial Flooding Test In Central Xing2 Area Of Daqing Oil Field" SPE 2003.
[8] M.delshad,W.HanXingiang"Alkaline/ Surfactant/Polymer Flood Predictions for the Karmary Oil Field" SPE 1998.
[9] Wang, Chang Long, Li Huanchen "ApplicationandDeignOfAlkaline/ Surfactant/Polymer System to Close Well Spacing Pilot Gudong Oil Field" California 1997.
[10] Clara Hernandez, Larry J "ASP System Design for an Offshore Application in the La Salina Field" SPE 2001.
[11] ManriqueE"Alkaline/Surfactant/ Polymer at VLA Field in Maracaibo Lake" SPE 2000.
[12] Qiao Qi, Hongjun "The Pilot Test Of ASP Combination Flooding In Karamary Oil Field" SPE 2000.
[13] S.R.Clark, M.J.Pitts"DesignandApplication of an Alkaline/Surfactant/Polymer Recovery System to the West Kiehl Field" SPE 1993.
[14] Clara Hernandez, Larry Chacon "Single Well Chemical Tracer Test To Determine ASP Injection Efficiency At Lagomar VLA Area" SPE 2002.
[15] Xiaoming Yang, Guangzhi Liao "AnExtended Field Test Study On Alkaline/Surfactant/ Polymer Flooding In Beiyiduanxi Of Daqing Oil Field" SPE 2003.
[16] YaunShiyi,Yang Hau "Effects of Important Factors on Alkaline/Surfactant/Polymer Flooding" SPE 1998.
[17] Directorate of Hasakih fields “directorate of reservoir engineering directorate”, 2018