Numerical Simulation of Alkaline – Surfactant – Polymer Flooding for Enhanced Oil Recovery

Ong Shen Chien, Sami Abdelrahman Musa, Elhassan Mostafa Abdallah

Abstract: Chemical enhanced oil recovery (EOR), has drawn increasing interest and identified as an effective enhanced oil recovery method. Despite the collapse of oil prices since 2014, operators still see ASP flooding as opportunities for increasing recovery factors from known oil accumulations. The simulation has been carried out on a 3-dimensional homogeneous synthetic model using Schlumberger's Eclipse software. Waterflooding act as primary case has a recovery of 47%. Simulation involved compised of ASP Formulation Development. Key results showed that Single chemical flooding gives recovery range of 50-60%. Concentration for cost effective surfactant-polymer (SP), alkaline-polymer (AP) and alkaline-surfactant (AS) coupled has been determined gives presentable recovery range from 58% to 72% at reduced cost. Concentration of ASP flooding optimized to 20 lb/stb alkaline, 5 lb/stb surfactant and 1 lb/stb polymer, gives optimized recovery of 81% from 47% waterflooding

Keywords: Enhanced oil recovery (EOR), ASP flooding, Schlumberger's Eclipse software

I. INTRODUCTION

Inferable from the wastefulness of ordinary essential and auxiliary recuperation techniques to yield above 20% - 40% of the OOIP as steady oil, the requirement for EOR to recoup a higher extent of OOIP has winding up increasingly critical. Soluble – surfactant - polymer (ASP) flooding is a mix procedure which upgraded oil recuperation by diminishing IFT, expanding fine number, improving infinitesimal uprooting proficiency, enhancing portability proportion and expanding plainly visible range productivity. The principle oil dislodging components of ASP flooding are decreasing interfacial strain (IFT) among oil and water. The response among antacid and corrosive part in oil which creates in-situ surfactant to diminish IFT which builds narrow number (Nc) and lower remaining oil immersion. Oil with decrease of IFT by surfactant decline its slender power enable it to go through modest pore throats. It has diverse impact on cracked repository, which imbibition of water present where solid hairlike weight is expected to achieve high uprooting proficiency. Polymer in ASP surge permit portability control. The infusion of polymer builds the consistency of dislodging liquid which at that point decline its portability proportion. Portability proportion is characterized as the versatility of dislodging liquid to portability of uprooted liquid. Furthermore, controlling the versatility enable compelling porousness to diminish which at that point expand clearing volume, bringing about increasingly ideal portability proportion. Antacid diminish synthetic misfortunes. The adsorption misfortunes of surfactant and polymer onto shake surface can be diminished by infusing soluble base, which are sodium hydroxide, sodium hydrogen carbonate and natural acids go about as saponifiable segments. It is finished by expanding the stone surface's negative charge thickness. Expansion of soluble base outcomes in high pH because of disintegration in the watery stage. Surfactant adsorption will be decreased at high pH. Sulfonates can be retained on dirt surfaces on account of electrostatic cooperations. At high pH, the adsorption of sulfonates diminished on the grounds that at high pH strong surfaces require negative charge that offer ascent to substantial repugnance species. A definitive objective of EOR forms is to build by and large oil dislodging productivity, which covers minute and naturally visible relocation.

The commitments of every compound to the ASP framework is sub-partitioned into couple of flooding technique: soluble polymer flooding (AP), antacid surfactant flooding (AS) and surfactant-polymer flooding (SP). Soluble just flooding regularly unfeasible as huge measure of basic is required to accomplish low IFT because of utilization by particle trade, disintegration and precipitation forms. Gooey fingering couldn't be overwhelmed by soluble alone. Work by Sheng J [1] indicate high soluble fixation decreased the consistency of a polymer arrangement. Sodium particles would kill carboxyl gatherings. Consequently, the frightful powers among carboxyl gatherings are protected and the polymer ties are looped up [2]. Actually, expansion of NaOH builds the hydrolysis of polyacrylamide, which presents negative charges on the foundation of polymer chain which increment the thickness of polymer to slight degree [3]. The simultaneousness of these two checking forms decides the general impacts of soluble base on the thickness of polymer arrangements. Sheng et al. [4] mentioned the objective facts that the expansion of polymer could increment or decline IFT. the blended arrangement of Na2CO3 with HPAM has bring down IFT than NaOH with HPAM given same basic focus. Creator additionally performed infusion through blend of antacid and polymer flooding can have three varieties: (1) soluble infusion pursued by polymer infusion (A/P), (2) polymer infusion pursued by basic infusion (P/An), and (3) basic with polymer co-infusion (A P).

Revised Manuscript Received on February 05 2019.

Ong Shen Chien, Faculty of Engineering, Technology & Built Environment, UCSI University, No. 1, Jalan Menara Gading, UCSI Heights (Taman Connaught), Cheras 56000 Kuala Lumpur, Malaysia

Sami Abdelrahman Musa, Faculty of Engineering, Technology & Built Environment, UCSI University, No. 1, Jalan Menara Gading, UCSI Heights (Taman Connaught), Cheras 56000 Kuala Lumpur, Malaysia

Elhassan Mostafa Abdallah, Faculty of Engineering, Technology & Built Environment, UCSI University, No. 1, Jalan Menara Gading, UCSI Heights (Taman Connaught), Cheras 56000 Kuala Lumpur, Malaysia

Recuperation from third infusion mode is the most elevated.

In Sheng J. [4], antacid demonstrated to decreases surfactant adsorption. High antacid fixation lead to increment in ionic quality, it ends up less demanding for the inverse charged particles to enter the adsorption layer from dispersion layer. Static electric shock between shake surface and surfactant ends up more fragile which makes less demanding for surfactant to adsorb on shake surfaces, along these lines increment adsorption. At the point when anionic surfactant focus expands, ASP framework thickness diminished because of electric shield impact. Liu et al. [5] added surfactant to the basic arrangement brings about decreasing the oil/water IFT. The surfactant was dissolvable in both the fluid arrangement and the supply oil however increasingly solvent in the previous.

Different reenactment works has been accounted for in regards to numerical Simulation of Alkali/Surfactant/Polymer Flooding [6-10]. Subsequently in this work, ASP flooding as open doors for expanding recuperation factors from known oil collections was finished. The reenactment has been completed on a 3-dimensional homogeneous engineered display utilizing Schlumberger's Eclipse programming.

II. METHODOLOGY

Model Initialization

Schlumberger's Eclipse software will be used to execute all simulation experiments which distributed to five sections in this project. Synthetic model of dimension 1500 feet, 1500 feet and 40 feet in I, J and K directions set to 30x30x1 grids. There were 2 wells: injector and producer which were placed in grid number (1, 1, 1) and (30, 30, 1) respectively. This synthetic model is used to perform ASP simulation experiment for section 1,2 and 3. The standard condition reservoir has the properties defined in Table 1.

Table. 1 Synthetic Model Properties

Parameter		Parameter	
Reservoir Pressure	4007 PSIA	Reservoir Fluid type	Black Oil
Reservoir Temperature	120oF	S.G Oil	0.833
Viscosity of Oil	5 cP	Number of fluids	2
Viscosity of Water	0.5 cP	Horizontal permeability	50 mD
Porosity	30%	Vertical permeability	5 mD
Datum Depth	4000 ft	Simulation start date	1-Jan-1993
Water compressibility	3.03x10-6 psia-1	Sro	0.3
Rock compressibility	3x10-4 psia-1	Srw	0.25
Density of oil	52 lb/ft3	Number of grids	900
Density of water	64 lb/ft3	Oil API	38.37o
Density of gas	0.044 lb/ft3	STOIIP	3.76 MMSTB

Synthetic reservoir in figure 1 with 120 feet thickness will be used in simulation experiments under section 4 and 5, STOIIP increases from 3,763,871 STB to 11,291,614 STB to give a greater complexity and closer proximity to actual reservoir.

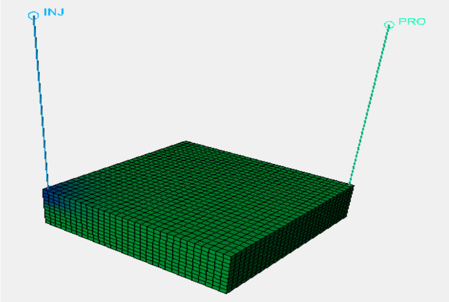

Fig. 1 Upgraded Synthetic Model used for section 4 and 5

Alkaline Model & Properties

The soluble reproduction show initiated by ALKALINE watchword in the RUNSPEC segment. The soluble just exist in water stage as including focus in the water injector where the centralization of antacid set by WALKALIN watchword under SCHEDULE area. At first, grouping of all synthetic substances will be set as zero for base case. ALSURFST catchphrase is the primary property that shown the water-oil surface pressure multipliers as a component of antacid focus. This impact of basic can likewise be joined with impact of surfactant by changing the W/O IFT. ALSURFST in Table 2 and Table 3 is utilized for this undertaking. It is shown that W/O IFT decline as antacid fixation increment. The isotherm adsorption can be determined utilizing the look-into table of adsorbed antacid as an element of basic fixation utilizing the ALKADS catchphrase.

Table. 2 W/O IFT multiplier as a function of alkaline concentration

Alkaline Concentration (lb/stb)	W/O IFT multiplier
0.0	1.0
1.0	0.5
2.0	0.1
5.0	0.01

Published By:
Blue Eyes Intelligence Engineering & Sciences Publication

Table. 3 Adsorb alkaline as a function of alkaline concentration

Alkaline Concentration (lb/stb)	Adsorbed Alkaline on rock (lb/lb)
0.0	0.0000
1.0	0.0001
5.0	0.0002

The antacid can likewise decrease the adsorption of both surfactant and polymer on the stone surface. This is displayed by altering the mass of adsorbed surfactant or polymer. Table 4 demonstrates polymer and surfactant adsorption multiplier.

Table. 4 Polymer and surfactant adsorption multiplier as a function of alkaline concentration

Alkaline Concentration (lb/stb)	Polymer Adsorption Multiplier	Surfactant Adsorption Multiplier
0.0	1.0	1.0000
1.0	0.9	0.9995
2.0	0.8	0.9950
5.0	0.7	0.5000

Surfactant Model & Properties

The surfactant flooding choice is enacted by utilizing SURFACT watchword in RUNSPEC segment. The surfactant is expected to exist just in the water stage, and the contribution to the repository is determined as a fixation at a water injector. In this way, the dissemination of infused surfactant is displayed by settling a protection condition for surfactant inside the water stage.. The grouping of infused surfactant is control by WSURFACT under SCHEDULE area. SURFST supplies tables of water-oil surface pressure as an element of surfactant focus in the water. Table 5 indicates W/O IFT as a component of surfactant.

Table. 5 Polymer and surfactant adsorption multiplier as a function of alkaline concentration

Surfactant Concentration (lb/stb)	W/O IFT (lb/in)
0.0	0.05
0.5	$1x10^{-3}$
1.0	$0.5x10^{-3}$
2.0	$1x10^{-4}$
5.0	$1x10^{-4}$

The adsorption of surfactant relies upon the measure of surfactant fixation around the stone surface. Provided by SURFADS while surfactant desorption from shake is actuated by SURFROCK when every framework square follows the adsorption isotherm as surfactant focus falls. Table 6 demonstrates the surfactant adsorption as a component of surfactant focus. Most unrefined petroleum contains waxes which can accelerate amid cooling and cause understood issues, for example, statement in pipelines, fouling in refineries and creation gear. The stop opposition properties of unrefined oils are characterized by the accompanying parameters, the wax appearance temperature (WAT): the temperature at which unmistakable wax crystallization happens. It relies upon the fixation and sub-atomic load of the waxes and the synthetic idea of the non-waxy piece of the raw petroleum. Next, the wax precipitation temperature/pour point (WPT/PP): as the temperature falls, precious stone development proceeds and at the same time the measure of accelerated waxes increments. A grid is gotten prompting the hardening of the substantial raw petroleum at the pour point. WAT is normally decided utilizing the ASTM D2500 strategy but there is no explicit standard methodology for WAT. Past research [7] has considered on the wax precipitation from North Sea rough oils by utilizing distinctive test procedures, for example, cross polarization microscopy, differential filtering calorimeter (DSC) and viscometer. Nonetheless, cross polarization microscopy will be supplanted to ASTM D2500 strategy. Subsequently, in this work, it was chosen to embrace a relative report on wax assurance by these couple of strategies.

Table. 6 Surfactant adsorption as a function of surfactant concentration (SURFADS keyword)

Surfactant Concentration (lb/stb)	Surfactant Adsorption on Rock (lb/lb)
0.0	0.0000
0.5	0.0005
1.0	0.0010
2.0	0.0020
5.0	0.0030

Polymer Model & Properties

Polymer show initiated by the catchphrase POLYMER in the RUNSPEC area. The measure of polymer infused is relies upon the focus, indicate by WPOLYMER under SCHEDULE segment. TLMIXPAR actuated by '1' permit blending parameter in displaying the level of isolation. between the water and the infused polymer arrangement. The consistency of polymer is indicate utilizing PLYVISC while adsorption by PLYADS in Table 7 and Table 8 as needs be. Desorption impacts as the slug passes is enacted.

Table. 7 Polymer adsorption as a function of polymer concentration

Polymer Concentration. lb/stb	Polymer adsorption on rock (lb/lb)
0.0	0.000
0.1	0.001
0.5	0.005
1.0	0.008

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

Table. 8 Water Viscosity Multiplier as a Function of Polymer Concentration

Polymer concentration, lb/stb	Water Viscosity multiplier
0.0	1.0
0.1	3.0
0.5	5.0
0.8	9.0
1.0	10.0

III. RESULT AND DISCUSSION

The recovery of 47% obtained for water flooding base case after 2800 days. The highest oil production rate occurs as early as 200 days, where oil rate reaches 1700 barrel per day, and decline from the day onwards to the end of simulation. The water cut reaches 89% after 2800 days as shown in Table 9.

Table. 9 Summary of result of ASP Formulation Development

Run No.	Type of CEOR	Chemical concentration			Total Recovery factor, %
		Ca (lb/stb)	Cs (lb/stb)	Cp (lb/stb)	
1	Polymer	-	-	3.5	58%
2	Alkaline	50	-	-	50%
3	Surfactant	-	30	-	58%
4	AP	50	-	3.5	61%
4.1	Optimized AP	30	-	0.8	58%
5	AS	50	30	-	74%
5.1	Optimized AS	20	5	-	72%
6	SP	-	5	3.5	66%
6.1	Optimized SP	-	5	1.5	60%
7	ASP	30	5	1	81%
8	Water flooding	-	-	-	47%

The concentration executed for each chemical EOR processes were identified as optimum for recovery after a series of different concentration simulated. Looking at 3 single compound flooding, the outcomes are demonstrated that all single concoction infusion needs change time to mirror the impact and it influences just a brief period before achieving achievement purpose of synthetic flooding and oil creation rate moves toward becoming decay again amid cycle 4 where just water is infused, after substance infusion period. Both surfactant and polymer flooding show promising execution as far as gradual recoverable oil. While compare the water cut profile of 3 chemical flooding, alkaline show almost no effect on water production reduction, while polymer mange to have the greatest reduction of water cut, but the water cut rises back during cycle 4, indicate that the polymer may not be suitable to be injected prior to pure water injection. Surfactant display good water production control by increase the oil production portion as polymer.

For dual chemical flooding, Initial concentration were obtained from the optimum concentration single chemical flooding. Optimized concentration were simulated based on optimization between chemical cost and recovery with much lower concentration.

Great contrast on adsorption in AP flooding from polymer flooding due to the contribution of alkaline. Presence of alkaline reduce adsorption of polymer on rock to 10% of original adsorption amount from $4.1x10^7$ lb to $2x10^6$ lb. A decline of curve at 2150 days shows adsorption reduce when polymer concentration isotherm reduce as desorption for polymer option is activated. Based on Figure 2, the existence alkaline solution notably reduces IFT among oil and water.

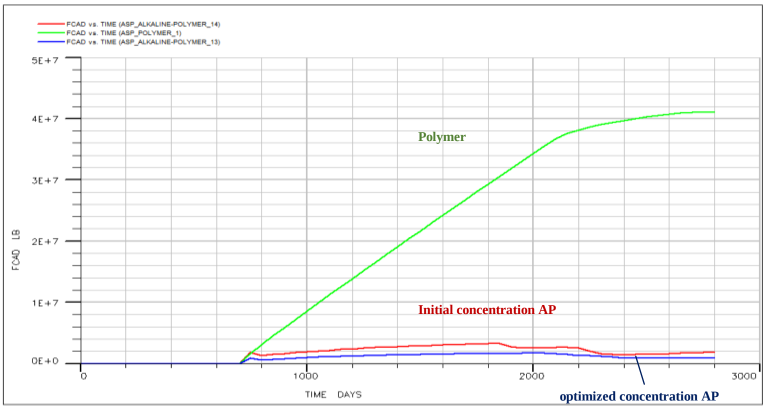

Fig. 2 Polymer adsorption profile between polymer flooding and AP flooding

The net impact of soluble base on the polymer arrangement consistency relies upon the general degree of these two components. What's more, antacid can lessen the adsorption of polymer on the stone surface, so improving the viability of the polymer drive.

The adsorption for AS system are less aggressive than surfactant flooding without the aid of alkaline. Compare to polymer adsorption, alkaline are less effective in reduce surfactant adsorption although both surfactant and polymer are able to reduce at least by halves by alkaline as shown in Figure 3.

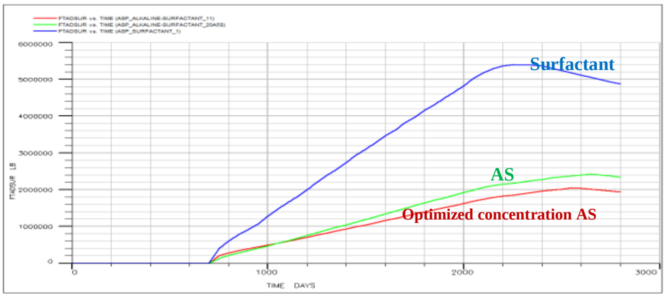

Fig. 3 Surfactant adsorption profile between surfactant flooding and AS flooding

Figure 4 and identify the recovery of SP flooding gives 66% is compare to surfactant flooding, polymer flooding and waterflooding with 58%, 58% and 47% respectively. The highest recovery obtained in section 1 goes to ASP Flooding, with 81% recovery as shown in Figure 5. Compare to other dual-chemical flooding, ASP generate an approximate 20% increment recovery. The expansion of surfactant made basic flooding progressively effective in recuperating the water surge leftover oil. Polymer flooding was utilized for increment consistency of flooding arrangement which enhancing clear effectiveness in ASP framework. Including surfactant results diminishing consistency of HPAM by causes the shrinkage of sub-atomic chains of polymer and the decline of hydrodynamic span, coming about lower polymer arrangement thickness.

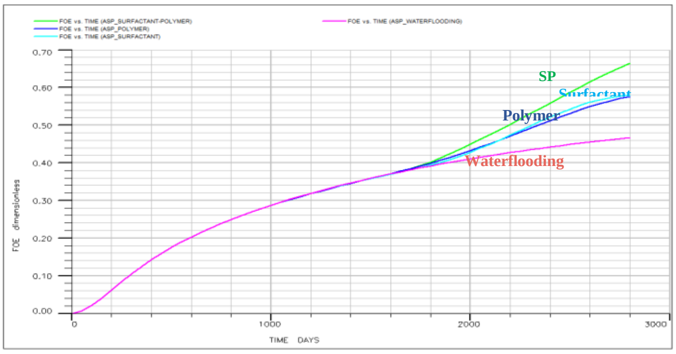

Fig. 4 Surfactant adsorption profile between surfactant flooding and SP

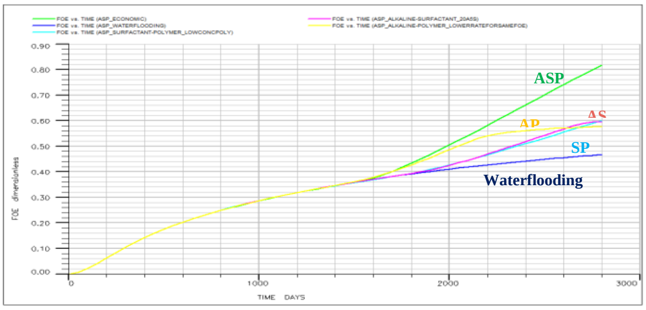

Fig. 5 Recovery factor profile of ASP flooding, AP flooding, AS flooding, SP flooding and water flooding base case

Figure 6 compare the water cut and oil production rate between ASP flooding and water flooding base case. Excellent water cut control seen 1400 days onwards. The water cut reduce from 77% to 30%. Even at cycle 4 where there is only pure water injected, the water cut remain constant as cycle 3. The outstanding water production control lead to great oil production. ASP inject at 700 days, however, due to large reservoir, the effect of incremental oil rate was seen about 650 days later, at day 1420, the oil production rises to highest 1500 barrel per day, the peak in 2400 days. As of the end of simulation at 2800 days, the difference of oil production rate is 1300 barrel per day.

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

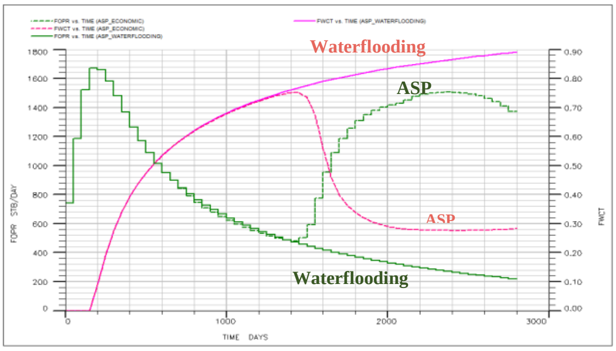

Fig. 6 Production rate profile of ASP flooding and water flooding

Economic studies show that polymer flooding and SP flooding are most expensive EOR method while AS flooding are promising EOR in low cost application in standard reservoir condition, with price lower than ASP flooding. Initial concentration AS flooding and optimized AS flooding gives total chemical cost of $3.32 and $2.59 per incremental oil barrel as shown in Table 10. The price gives an idea on EOR process' cost range and is dependence on reservoir condition and recoverable oil. The reservoir has a normal viscosity oil with 36oAPI, Hence, the polymer cold not contribute much.

Table. 10 Economic – Chemical cost per incremental barrel calculation for ASP Formulation Development

Run No.	Chemical EOR	Total Chemical Cost *(USD)*	Incremental Oil Production during CEOR *(STB)*	Total cost (USD)/Icremental Oil(STB)
1	Polymer	$13,720,000.00	1166800	$11.76
2	Alkaline	$7,000,000.00	865690	$8.09
3	Surfactant	$10,080,000.00	1166800	$8.64
4	AP*(initial conc)*	$12,880,000.00	1242077	$10.37
4.1	AP*(optimized conc)*	$10,080,000.00	1166800	$8.64
5	AS*(initial conc)*	$5,880,000.00	1769019	$3.32
5.1	AS*(optimized conc)*	$4,480,000.00	1731380	$ 2.59
6	SP*(initial conc)*	$15,400,000.00	1467909	$10.49
6.1	SP*(optimized conc)*	$7,560,000.00	1242077	$ 6.09
7	ASP	$9,800,000.00	2070129	$4.73

IV. CONCLUSION

Single chemical flooding gives recovery range of 50-60%. Concentration for cost effective surfactant-polymer (SP), alkaline-polymer (AP) and alkaline-surfactant (AS) coupled has been determined gives presentable recovery range from 58% to 72% at reduced cost. Concentration of ASP flooding optimized to 20 lb/stb alkaline, 5 lb/stb surfactant and 1 lb/stb polymer, gives optimized recovery of 81% from 47% waterflooding.

REFERENCES

1. J. Sheng, Modern Chemical Enhanced Oil Recovery: Theory and Practice (Gulf Professional Publishing, 2010).
2. M.S. Kamal, A.S. Sultan, U.A. Al-Mubaiyedh, and I.A. Hussein, Polym. Rev. 55, 491 (2015).
3. J. Sheng, Modern Chemical Enhanced Oil Recovery: Theory and Practice (Gulf Professional Publishing, 2010).
4. J.J. Sheng, Asia-Pacific J. Chem. Eng. 9, 471 (2014).
5. Q. Liu, M. Dong, S. Ma, and Y. Tu, Colloids Surfaces A Physicochem. Eng. Asp. 293, 63 (2007).
6. M. Delshad, C. Han, F.K. Veedu, and G.A. Pope, J. Pet. Sci. Eng. 108, 1 (2013).
7. A.A. Olajire, J. Pet. Sci. Eng. 135, 723 (2015).
8. S. Yuan, P. Yang, Z. Dai, and K. Shen, Int. Meet. Pet. Eng. 14 (1995).
9. Z. Lei, J. Song, and B. Zhu, SPE Reserv. Characterisation Simul. Conf. Exhib. 10 (2011).
10. R. Farajzadeh, A. Andrianov, R. Krastev, G.J. Hirasaki, and W.R. Rossen, Adv. Colloid Interface Sci. 183–184, 1 (2012).