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ENHANCING THE SPONTANEOUS IMBIBITION PROCESS IN NATURALLY FRACTURED RESERVOIRS THROUGH WETTABILITY ALTERATION USING: NANOPARTICLES

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ABSTRACT

Naturally fractured reservoirs are characterized by having low-permeability matrix blocks surrounded with fractures of high hydraulic conductivity. Water flooding process in such reservoirs is successful if the matrix blocks holding the dominant fraction of the reservoir porosity, are able to imbibe the injected water (water-wet) and expel the oil into the fracture system and finally to the production well. This mechanism referred to as spontaneous imbibition of water into the matrix blocks is an efficient method to increase oil recovery from fractured reservoirs. However, most naturally fractured reservoir rocks are mixed- to oil-wet and do not imbibe the injected water, which translates into low-efficiency water flood recovery.

To enhance the spontaneous imbibitions process, low concentration of surfactants or lipophobic and hydrophilic polysilicon (LHP), is dissolved into the injected water to induce wetability alteration of the reservoir rock by changing the wetability of the rock toward a more water-wet state. This is the main subject of this study.

In conclusion, oil recovery can obviously be improved by flooding with hydrophilic nanometer powders by changing the wetability of the rock toward a more water-wet state as shown by the single block simulation model presented at this study. Since by flooding with hydrophilic nanometer powders permeability decline for the retention of nanoparticles in porous media ,it is suggested that an LHP concentration ranging from 2.0–3.0% percent by volume is preferable to enhance oil recovery.

INTRODUCTION

Most of the world's oil reservoirs are found in carbonate rocks, many of which contain fractures with high hydraulic conductivity surrounding low-permeability Matrix blocks. Evaluation of the wetting state for different reservoirs from all over the world indicates that most carbonate reservoirs seem to be mixed to oil-wet.

After the primary production period, water flooding is usually performed to recover more oil from reservoirs. However, water flooding recoveries are low from naturally fractured carbonate reservoirs, due in part to these reservoirs being mixed to oil-wet. In such reservoirs, production depends on spontaneous imbibitions of water to expel the oil from the matrix into the fracture system, but this is only efficient when the matrix blocks are water-wet. Wettability is an important parameter controlling the capillary pressure which is in turn the driving force for the spontaneous imbibition process. The imbibition process is also affected by many other factors including matrix permeability size and shape heterogeneity and boundary conditions. Fluid properties such as viscosities of the phases and interfacial tensions (IFT) also play a role in capillary imbibition recovery rate.

Naturally fractured reservoirs are good candidates for enhanced oil recovery (EOR) processes since the matrix part of the reservoir may contain a large amount of oil. Chemical EOR methods such as surfactant flood lipophobic and hydrophilic polysilicon (LHP) are used to improve the recovery from these reservoirs. Surfactants or (LHP) can act in several ways to enhance the oil production: lowering the IFT between residual oil and injected water, changing the wettability of the surface, forming emulsions, etc.

To enhance the spontaneous imbibitions process in fractured reservoirs in this study, surfactants or (LHP) are used as wettability alteration agents to modify the wettability of the reservoir rock.

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1. Wettability Concept

Wettability is defined as "the tendency of one fluid to spread on, or adhere to a solid surface in the presence of other immiscible fluids". The fluid with the higher affinity toward the solid surface is called the wetting phase, the other fluids called non-wetting. Wettability is a very important concept in oil recovery processes and has a strong impact on distribution, location and flow of oil and water in reservoir during production.

In a water-wet system, water will occupy the narrowest pores and will be present as a film on the pores wall while oil will reside as oil droplets in the middle of the pores. The reverse fluid distribution will exist in the case of an oil-wet reservoir (See Figure-1).

In Figure-2 we can see the effect of wettability on water flooding process.

2. Nanotechnology and EOR

2.1. Polysilicon Particles

Nanometer particles (from 1 to 100 nm) with many special physical effects and prepared in different ways have been used in recent years in chemical, ceramic, medical and other fields though no open reports are available on the application of nano powders to oil reservoir development by virtue of changing the wettability of reservoir rock through their adsorption on porous walls. Reported nanometer polysilicon materials that could change the wettability of porous surfaces. Polysilicon, of which SiO_2 is the main component, is obtained by adding an additive activated by γ-ray to form a kind of modified ultra- fine powder with particle size ranging from 10 to 500 nm. According to their surface wettability, polysilicon particles can be classified into three types: lipophobic and hydrophilic polysilicon (LHP), neutrally wettable polysilicon (NWP) and hydrophobic and lipophilic polysilicon (HLP). A simulation study was conducted in the present investigation show improved oil recovery by LHP flooding.

2.2. Mechanism of Improving Oil Recovery by LHP

When LHP is injected into a porous medium, four phenomena will occur: adsorption, desorption, blocking and transport. Inasmuch as LHP consists of Brownian particles with diameters less than1 μm, five kinds of energy –attractive potential energy of London-van der Waals, repulsion energy of electric double layers, Born repulsion, acid-base interaction, and hydrodynamic energy –are responsible for the interactions between LHP particles and pore walls. When the total energy is negative, attractive force is larger than repulsion between LHP particles and porous walls, leading to further adsorption of LHP. Otherwise, desorption of LHP from the porous walls will occur. Dynamic equilibrium between adsorption and desorption is controlled by the total energy between particles and porous walls. Blocking will take place if the diameter of LHP particles is larger than the size of the pore throat, or when several LHP particles smaller than the pore size gather together to block the pore throat. Transport of LHP particles in porous media is governed by diffusion and convection.

The four phenomena mentioned above have three important effects on the nature of seepage flow in reservoir rock. First, the hydrophobic pore walls will be changed into hydrophilic due to LHP adsorption, and consequently, the relative permeability of the oil phase (K_{ro}) increases, decreasing the resistance to oil flow, while at the same time, the relative permeability of the water phase (K_{rw}) decreases significantly. Second, oil in the small pores will be displaced due to LHP adsorption and wettability changes, and the effective pore diameters for oil flow in the porous medium may, in turn, be enlarged. Finally, the adsorption of LHP on the porous surface and blocking of the small pore throats may lead to reduction in porosity and absolute permeability (K) of the porous media. The first and second effects are favorable for improving oil recovery, but the last effect has an unfavorable effect on oil production due to decrease in absolute permeability. Successful well treatment is determined by improvement of effective permeability (K_o, i.e., KK_{ro}) of the oil-phase. As oil-wet reservoir rock can be changed into water-wet rock by LHP adsorption on porous walls, the relative permeability of the oil phase will increase, and the relative permeability of the water phase will decrease. Water-cut of the fluids produced from the oil well will, in turn, decline after a water break.

ANALYSIS AND MODELLING

Numerical Simulations

Statement of the Problem

In this chapter we explain the reservoir model, rock and fluid descriptions for the numerical simulations. We indicate the result of simulation to compare the flow efficiency of three-dimensional quarter of five-spot pattern reservoir model when the wettability of rock changes from oil wet to water wet in water flooding process. Black oil simulator Eclipse 100 software ver. 2009.1 was used in our simulations.

Reservoir Model Description

A three-dimensional quarter of five-spot pattern reservoir model was established as a base model for the simulation studies. Initial reservoir pressure is 4000 psia. The depth of the top of the reservoir is about 4000 ft. subsea. Mean reservoir thickness is 400 ft. The reservoir is assumed to be limited by four sealing faults in its boundaries. The average horizontal permeability is 20 md and average porosity is 0.20. The average vertical to horizontal permeability ratio is 0.2. Center point grid structure was used to model the geology. The initial and final oil distribution for oil wet and water wet and horizontal permeability distribution are shown in Figs.5,6,7 and 8 respectively. The model contains 20×20×20 grid blocks of which 8000 blocks are active. The X and Y dimensions of each grid block are 100 ft. The model is divided into 20 layers vertically and named 1 to 20 from top to bottom. The average thickness of the each layer is 20 ft. There is no water drive at the bottom of the oil zone and the brine in the reservoir is connate water. Water oil contact level is at 4390ft. subsea, while datum depth is at 4000ft.

Well Specifications

As one can observe in Fig.5 to 8, two wells are specified in this quarter of five-spot pattern reservoir model with their marginal position in order to obtain the best results showing the effect of different parameters. There are one producer and one injector wells. Well "I1" is located in grid (l, 1) and the well "P1" is in grid (20, 20). As employed here, both production and injection wells are completed only in Z direction; Oil production well should be completed at (20,20,1) up to (20,20,11and Water injection well should be completed at (1,1,11), up to (1,1,20). The control mode of the production well on bottom-hole pressure of is 1500 psia. The first control mode of the injection well should be sat on 2000 stb/d water injection rate from the start day, but its pressure should not exceed 7000psia.

It is also better to assign a pressure constraint for well bottom-hole pressure with a reasonable oil production rate to extend oil production time and improve oil recovery. But it must be mentioned that this pressure can't transfer the reservoir fluids to the surface without artificial lift. In all cases the maximum allowable injection pressure is set in such a way that does not exceed the highest pressure in PVT tables to ensure the tables are not extrapolated in the wells. The wellbore radius of both injection and production wells is 0.5 ft.

Reservoir Rock and Fluid Description

On the other hand, the initial reservoir pressure is 4000 psia. The relative permeability and capillary pressures data are shown below respectively.

Dimensions: 20* 20* 20
System: Oil & Water
Unit: Field
Start day of simulation: 1 'MAY' 2011 /
Equilibrium Region: 1
Delta X: 100 ft
Delta Y: 100 ft
Delay Z: 20 ft
Top of the first layer: 4000 ft
For all the cells:
Perm X: 20 md

Perm Y: 20 md
Perm Z: 2 md
Porosity: 0.2
Rock:
Pressure: 4000 psia
Cr: 0.3*10^(-6)

PVT for Water				
W-Phase Pressure	W- FVF	W-Compressibility	W-Viscosity	W-Viscosibility
3600	1.00341	3.00E-06	0.52341	0

Rock	
Pressure	R-Compressibility
4000.0	.30E-06

Density at surface condition		
Oil	Water	Gas
52	64	0.044

Equilibrium Condition		
Datum Depth	Pressure at Datum Depth	WOC
4000	4000	4390

Water-Oil Saturation Table **(water wet system)**			
Sw	Krw	Krow	Pcow
0.055	0	0.97	6.76
0.574	0	0.0782	1.22
0.6024	0.0024	0.0484	0.865
0.6283	0.008	0.0324	0.711
0.6599	0.037	0.0234	0.549
0.6849	0.069	0.0191	0.453
0.7078	0.109	0.0165	0.388
0.7284	0.14	0.0144	0.339
0.7507	0.178	0.012	0.291
0.7768	0.218	0.0101	0.251
0.8171	0.28	0.008	0.194
0.8385	0.309	0.0064	0.178
0.8595	0.343	0.0048	0.162
0.8833	0.386	0.0027	0.137
0.9039	0.431	0.0021	0.129
0.9249	0.495	0.0005	0.093
0.9387	0.56	0.0005	0.093
0.9585	0.7	0	0.085
0.97	0.91	0	0.076
1	0.97	0	0.03

Water-Oil Saturation Table **(OIL wet system)**			
Sw	Krw	Krow	Pcow
0.055	0	0.97	11.786
0.12	0.003	0.82	4.18
0.24	0.031	0.574	2.16
0.306	0.06	0.456	1.6
0.3535	0.088	0.379	1.32
0.4629	0.175	0.227	0.8
0.5548	0.273	0.128	0.57
0.5869	0.313	0.1	0.52
0.6152	0.351	0.078	0.47
0.6468	0.395	0.056	0.42
0.6746	0.395	0.056	0.42
0.7201	0.511	0.019	0.33
0.7531	0.568	0.008	0.31
0.7676	0.437	0.04	0.38
0.7965	0.648	0.001	0.26
0.812	0.678	0	0.24
1	0.99	0	0

PVT for the Dead Oil		
Oil Phase Pressure	Oil FVF	Oil Viscosity
400	1.012	1.16
1200	1.004	1.164
2000	0.996	1.167
2800	0.988	1.172
3600	0.9802	1.177
4400	0.9724	1.181
5200	0.9646	1.185
5600	0.9607	1.19

RESULTS AND DISCUSSION

Results obtained from water flooding of 3Dmodel show that more oil recovery can be produced from water wet system rather than oil wet system as shown in Figure-11and 12

CONCLUSIONS

(1)These are still lots of research work than can be done related to the study of wettability alteration using surfactants. Further work on the subject could include more fundamental studies such as characterization of the organic components in the crude oil which adsorb on the rock surface and are responsible for changing the wettability of rock surface to an oil-wet state. In addition, performing imbibition tests using the specific reservoir crude oil sample is very important to see the real interaction of the surfactant with rock surface in presence of crude oil sample. Also, one can investigate the effectiveness of Bolafrom surfactants in the case that wettability alteration is through the surfactant adsorption. Finding the optimum surfactant concentration for specific field conditions (reservoir type) can be done by performing imbibitions tests at surfactant concentrations below and above CMC of the specific surfactant.

(2) LHP can be adsorbed on pore walls and can give rise to blockage of pore throats, leading to change in wettability of sand rock surfaces.

(3) The mechanism for enhanced oil recovery consists of change of wettability of reservoir rock from hydrophobic to hydrophilic under the influence of adsorbed LHP.

(4) The results of numerical simulation show that porosity and permeability will decline due to retention of LHP during its transport in porous media.

(5) field oil recovery and total oil recovery can be enhanced obviously by flooding with LHP.

(6) LHP concentration of 2.0–3.0% percent by volume is suggested for improving oil recovery.

KEYWORDS
Wettability alteration, LHP, Spontaneous Imbibition, Simulation, Surfactant

Figure 1
Fluid distribution in (a) water-wet and (b) oil-wet rock

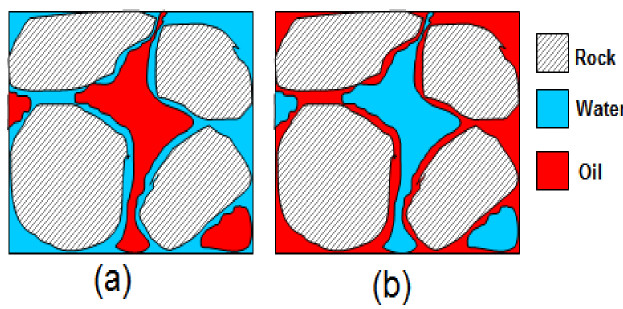
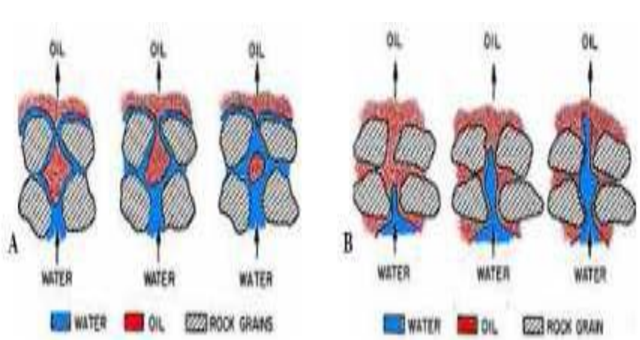


Figure 2
Wettability effect on water flooding (A) water-wet porous media (B) oil-wet porous media



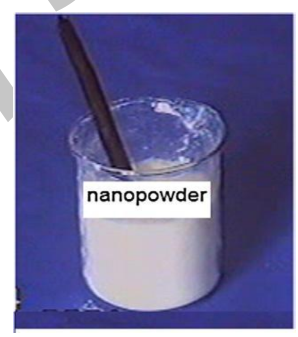


Figure 3
Nano powder in a beaker

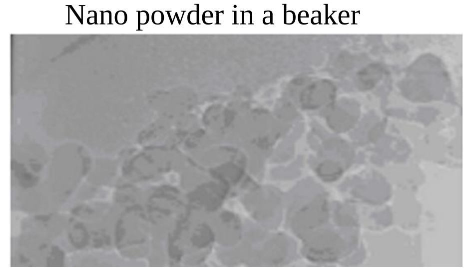


Figure 4
The image of polysilicon nano particles observed under TEM

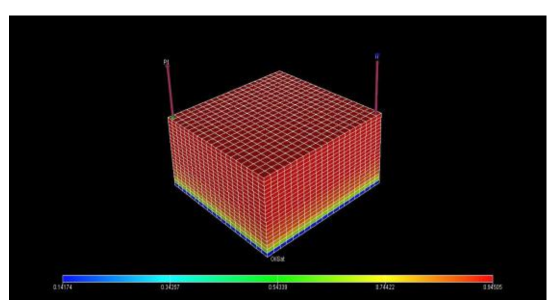


Figure 5
Initial oil saturation distribution of the model.

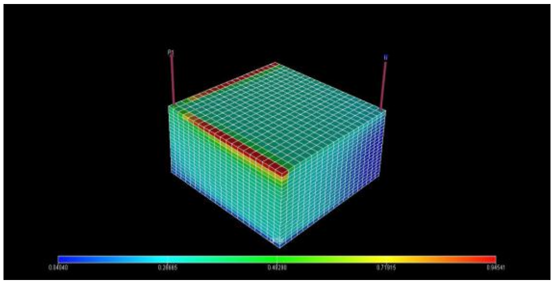


Figure 6
Final oil saturation distribution of the model
(water wet system)

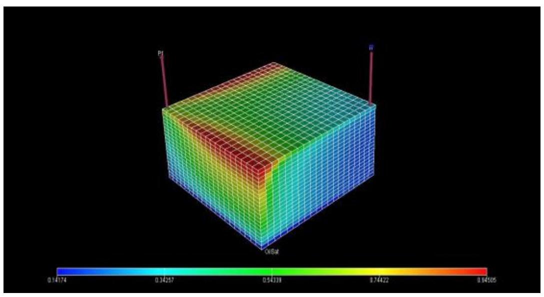


Figure 7
Final oil saturation distribution of the model
(oil wet system)

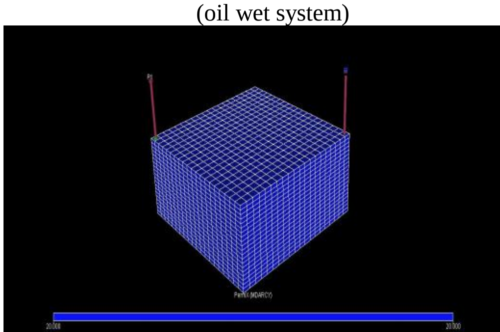
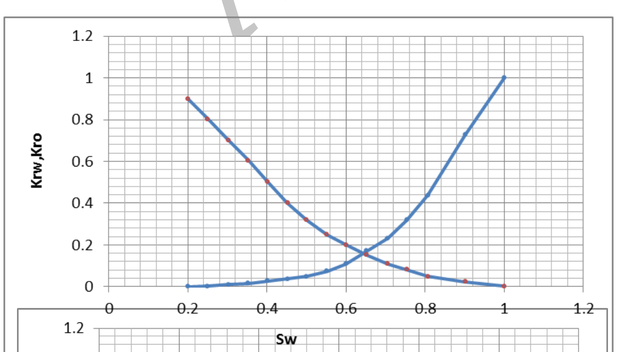


Figure 8
Permeability (KX) distribution of the model.



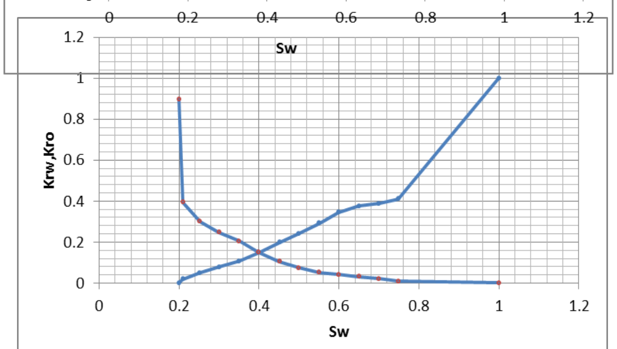


Figure 9
Relative permeability curve for water-wet system

Figure 10
Relative permeability curve for oil-wet system

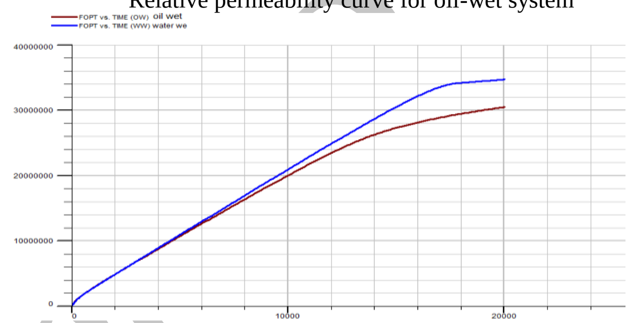
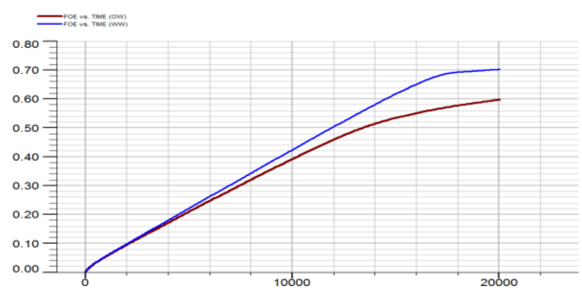


Figure 11
Effect of wettability alteration on field oil recovery (FOE vs. Time (day))

Figure 12



Effect of wettability alteration on total field oil production (FOPT vs. Time (day))

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