 SL, vol.10, no.1, pp.49-57, 2013

# Study and Application of Waterflood Reservoir Protection Technology in Developing Low Permeability Reservoirs

**Shuo Zhang[1], Guan-Cheng Jiang[1], Le Wang[1], Hai-Tao Guo[2], Jin Hai-feng[2], Dian-Gang Bai[2], Cong-Yue Shi[2]**

**Abstract:** Developing low and extra-low permeability reservoirs becomes more and more important to the sustainable energy development in China and waterflood development is the common development mode. But with the oilfield development, water injection well has also exposed some questions gradually, such as the injection pressure increases, water injection rate decreases and so on. We proposed a new reservoir protection technology by adding new anti-swelling agent NTW-1 and fluorocarbon surfactant FCS-08 in the injection water. NTW-1 has good anti-swelling ability and FCS-08 could change rock surface to neutral wetting. After successful field application in ShengLi oilfield in china, water injection pressure reduced by 21.7%, daily water-injection rate increased by 31.8%. it is proved that the new reservoir protection technology has well reservoir protection effect which has good decompression and augmented injection function.

**Keywords:** water injection reservoir protection, augmented injection, rock surface property, low permeability, wetting.

## Nomenclature

| | |
|---|---|
| $S_w$ | the bound water saturation, % |
| $K_{rso}$ | the oil phase relative penetration (displaced by treated injection water) |
| $K_{rsw}$ | the water phase relative penetration (displaced by treated injection water) |
| $K_{rw}$ | the water phase relative penetration (displaced by untreated injection water) |
| $K_{ro}$ | the oil phase relative penetration (displaced by untreated injection water) |

[1] State Key Laboratory of Petroleum Resources and Prospecting, China University of Petroleum, Beijing, 102249, China.
[2] Tan Hai development company, China National Petroleum Corporation, Tian Jin 300289, China.

## 1 Introduction

Low and extra low permeability reservoirs characterized by the high argillaceous cement content, high capillary pressure, tiny pore throat, complicated structures, serious heterogeneity, large oil-gas flow resistance and so on [Jiang (2011)]. As the water flooding continues, the water injection well pressure increases quickly, water injection rate decreases and injection water is deficient, at the same time, hydration swelling happens, water blocking damage and jamin effect occur [Adeniyi et al. (2008); Pang et al. (2010); Yu et al. (2010)]. Conventional acidification deblocking does not have remarkable results, and the valid period is short (some water injection well valid periods are just one month) [Chen et al. (2007)]. Besides, conventional techniques are nanometer polysilicon material decompression and augmented injection technique, nanomaterials and surfactant combination technique, wetting alteration technique of the condensate gas reservoir and so on.

In order to enhance the liquid liquidity of the reservoir, measures of anti-swelling and changing the rock surface wetting are taken [A. L. er al. (2005); M.Robin er al. (2001); D. Han et al. (2001); F. L. et al. (2007)]. Neutral wetting is benefit for decompression and augmented injection during waterflood. [Adetola et al. (2005); Wu et al. (2011); Hirasaki et al. (2004)]. New anti-swelling agent NTW-1 is synthesized and has excellent anti-swelling property. New fluorocarbon surfactant FCS-08 is synthesized which could enhance the hydrophobic and oleophobic property of the rock surface and reduce the oil-water interfacial tension. 3% NTW-1 and 1% FCS-08 are added into the injection water. The new injection reservoir protection technology could change the injection water property and rock surface wetting, which could attain the aim of decompression and augmented injection.

## 2 Materials and Approaches

### *2.1 Instruments and materials*

X-ray diffractometer, contact angle measurement apparatus, electric blender, centrifuge tube, heater, four-neck flask, high speed mixer, beaker, condenser tube, thermometer, thermostat water bath cauldron, catheter, test tube, SEM, EDX, fourier transform infrared spectrometer, shear emulsifying machine.

NTW-1,FCS-08, kcl, FSJ-03 (produced by Dongsheng company, Beijing, China), GD-09 (produced by Liequan company, ShangHai, China), triethanolamine methyl ammonium chloride (TMAC, produced by M-I company, dongying, china), Polygnlactomannas (PG, produced by Rhone-Ponlene company,France), cl-vinylformamide (CV, produced by Ciba company, shanghai, china), $NaHCO_3$, fluorine-containing monomers, montmorillonite, bentonite, injection water in Shengli oilfield, kerosene, nitrogen, OP-10, tween-80.

### 2.2 Experiment methods

#### 2.2.1 Synthesis of NTW-1

Acrylamide, cationic monomer and water are added into a 4-neck boiling flask equipped with blender, thermometer, Condenser pipe and funnel. when water-bath reaches 75°, drip the ammonium persulfate and coupling agent respectively. The polymerization time is 4 hours and the pH value is adjusted to 7, and then NTW-1 is formed

#### 2.2.2 Synthesis of FCS-08

By adding the fluoroacrylate monomer, acrylate monomers and anionic surfactant into 170mL deionized water, a mixture that would be make into homogeneous emulsion was formatted. Transferred the emulsion into a four-neck flask equipped with electric mixer, condensing tubes, nitrogen import device and water-bath of 80°, dripped the initiator twice respectively. The polymerization time is 3 hours and the pH value is adjusted to neutral, and the fluoroacrylate polymer FCS-08 is formed.

### 2.3 Anti-swelling test

The anti-swelling property of NTW-1 is tested. First, optimize the best concentration using the X-ray diffractometer, evaluate the anti-swelling effect under the condition of formation temperature; Second, measure the anti-swelling height. We select the suitable anti-swelling agent based on the anti-swelling height.

(1) Compound the anti-swelling agents into solutions with different density, then mix the solutions with montmorillonite and have complete reaction respectively. Measure the interplanar distance $d_0$ of the montmorillonite using the X-ray diffractometer , $d_0$ is the shorter, and the anti-swelling effect of the sample is the better.

(2) Put bentonite into centrifuge tubes with the same weight, then add the anti-swelling agents, kerosene and injection water with the same weight respectively(test the three samples at every measurement). Rock the centrifuge and exhaust the gas, let the kerosene pre-expanse for 2 hours under the condition of 80°. Measure the bentonite volume $V_0$ in the kerosene, the bentonite volume $V_1$ in the the clay stabilizer solution and the bentonite volume $V_2$ in the injection water.

(3) Calculate the anti-swelling rate H:

$$H = \frac{V_2 - V_1}{V_2 - V_0} \times 100\%.$$

H is the less and the anti-swelling effect of the anti-swelling agent is the better.

### *2.4 Wetting reversal property*

Clean and dry the nature core slice, then immerse the core slices in FCS-08 solution (2%) for two hours and dried naturally. Measure the contact angles of different solutions.

### *2.5 Permeability damage rate*

3%NTW-1 and 1% FCS-08 are added into the injection water. Measure the permeabilities of the cores after injecting different pore volume multiples. The nature cores are derived from S29 strata in well LAI113-1 of Shengli Oilfield in china. The permeability damage rate of the core is calculated after injecting different pore volume multiples.

### *2.6 Oil-water Relative Permeability*

Oil-water relative permeability tests are taken by the untreated injection water and treated water respectively.

## 3 Results and Discussion

### *3.1 The anti-swelling property*

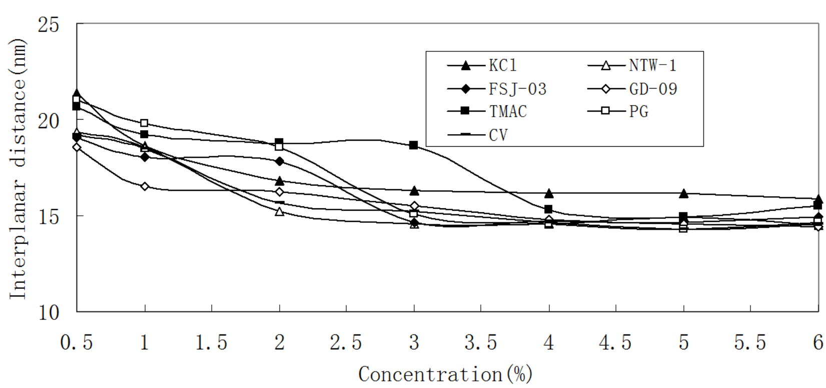


Figure 1: The influence of the anti-swelling agent density to interplanar distance.

Figure 1 shows that, the inorganic salt clay stabilizer KCl has the worst anti-swelling effect, other six clay stabilizer could decrease the interplanar distance $d_0$

of the montmorillonite by (3∼5)%. The fittest density of NTW-1 and is 3%, the fittest density of TMAC is 5%, the fittest density of GD-09, PG and CV is 4%.

The anti-swelling rate of NTW-1 is 93%, which has well anti-swelling property. After being treated under the condition 130°. The anti-swelling property of NTW-1 has little change which could adapt to the formation temperature (102.7° ∼125.4°).

### *3.2 Wetting reversal property*

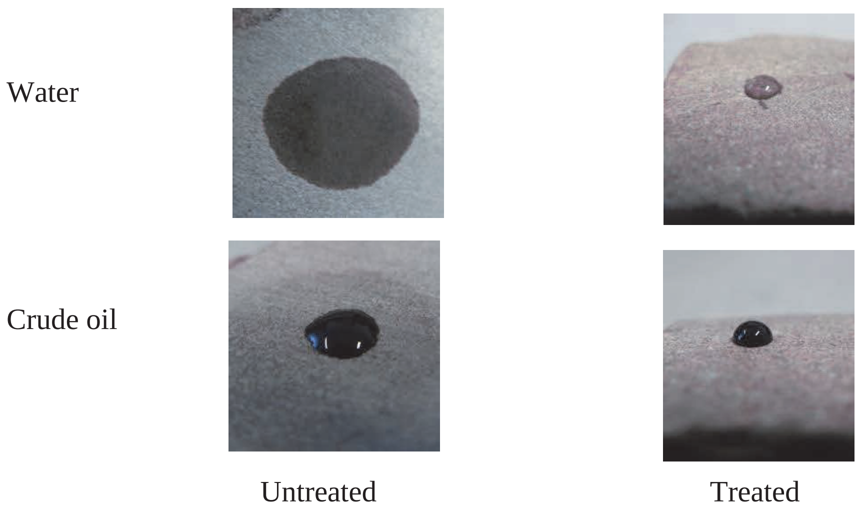


Figure 2: Contact Angle.

Figure 2 shows that, the contact angles of the rock surface and the liquid become bigger after the core treated by FCS-08. The contact angle of water and the core surface increases from 2.2° to 65.5°, the contact angle of crude oil and the core surface increases from 35.35° to 85.7°. It is concluded that FCS-08 has quite well wetting reversal function which could increase the hydrophobic and oleophobic property of the core surface and have good wetting reversal ability.

### *3.3 Surface and interfacial tension*

Figure 3 shows that the surface tension of FCS-08 with different concentration. When the concentration is zero, the surface tension is 68.9mN/m. When the mass concentration is 600mg/L, the surface tension of FCS-08 solution is 35.3mN/m and reaches the lowest. The interfacial tension of the oil and FCS-08 (600mg/L) solution is 0.257mN/L. Low interfacial tension could avoid the happening of water block, Jamin effect and other damages.

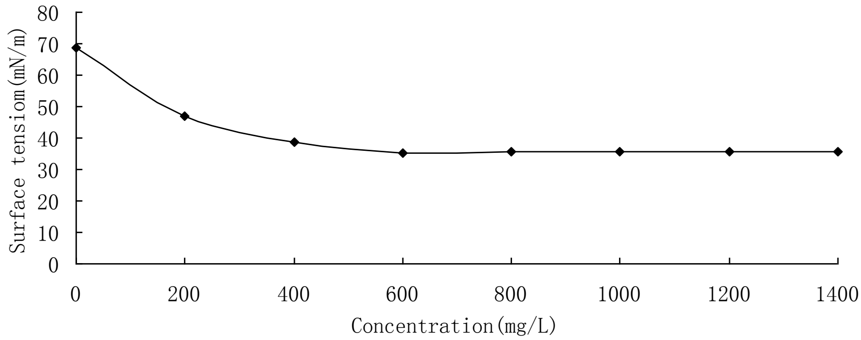


Figure 3: The influence of mass concentration to surface tension.

### *3.4 Permeability damage rate*

Figure 4 is the ratios of the treated core permeability and natural core after injecting different pore volume multiples. The injection water is treated by adding 3% NTW-1 and 1% FCS-08. Figure 4 shows that permeability damage rate of the core injected by the untreated water decreases quickly when the pore volume multiple increases, but, the permeability damage rate of the core treated by the treated water decreases slowly when the pore volume multiple increases. The reason is that the treated injection water has well anti-swelling, water lock prevention and wetting reverse effect which could decrease the core damage caused by the injection water on a large scale.

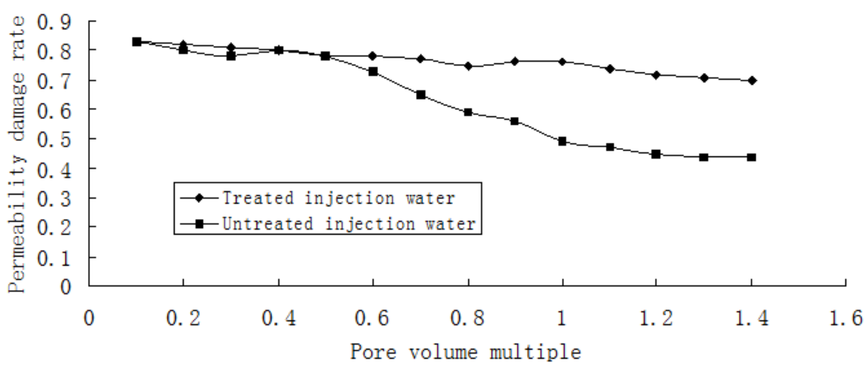


Figure 4: Permeability damage rate of the cores.

### 3.5 Oil-water Relative Permeability

Figure 5 indicates the changes of the relative permeability. When the core is displaced by untreated water, the residual oil saturation is 40.6%, the bound water saturation at the equivalent permeability point is 51.8% and the range of the oil water two-phase flow is narrow. When the core is displaced by treated water, the residual oil saturation is 31.3%, the bound water saturation at the equivalent permeability point is 55.2% and the range of the oil water two-phase flow is broader than the one displaced by untreated water. The oil-water equivalent permeability point moves to the right, which proves that the water phase relative penetration has improved. After the test it is proved that NTW-1 and FCS-08 could improve the water phase penetration and the water absorbing ability of the core.

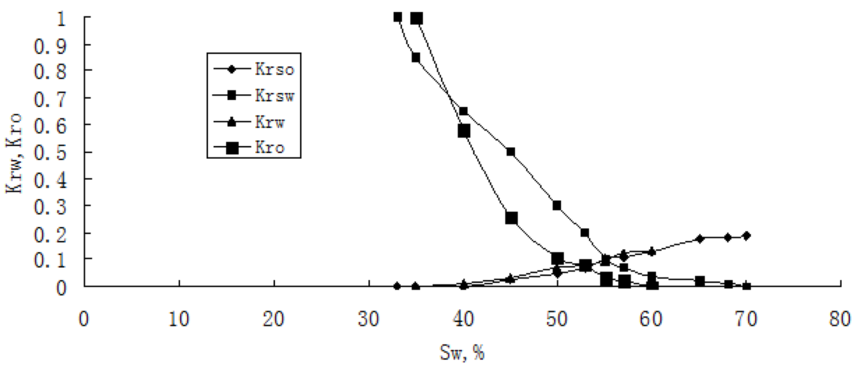

Figure 5: Oil-water Relative Permeability.

### 3.6 Field test

We had the field test in LAI-113 Well in ShengLi Oilfield in china. The reservoir porosity distributes from 9.7% to 22.3%, the average porosity is 17.9%; the reservoir permeability distributes from $1.6\times10^{-3}$ $\mu$m$^2$ to $27.6\times10^{-3}$ $\mu$m$^2$, the average permeability is $8.7\times10^{-3}\mu$m$^2$. The formation in LAI-113 Well is low porosity and low permeability reservoir.

In order to prevent the water sensitivity damage, 3% NTW-1 and 1% FCS-08 are added in the injection water for anti-emulsification treatment. By using the technology, water injection pressure reduced by 21.7%, daily water-injection rate increased by 31.8% and fluid production rate increased from 3.8t/d to 6.1t/d. This demonstrated that the new water injection technology gained good effect in reservoir protection.

## 4 Conclusions

(1) NTW-1 has well anti-swelling effect and FCS-08 could change rock surface to neutral wetting, the contact angle of the crude oil and the rock surface increases from 35.35°to 85.7°.

(2) The new waterflooding reservoir protection technology has the advantages of anti-swelling, oil displacement, water block removing and other merits.

(3) After the field test, it is proved that new waterflooding reservoir protection technology could improve the daily water-injection rate and daily fluid production rate, which could provide enough formation energy and meet the need of decompression and augmented injection.

**Acknowledgement:** This study is supported by Basic Research on Drilling & Completion of Critical Wells for Oil & Gas (Project NO. 51221003); the National Science and Technology Major Project (Project NO.2011ZX05050) and the National Science Fund (Project NO.51074173).

## Reference

**Adetola, L.; Ogunberu, Muhammad, A.** (2005): The role of wetting in petroleum recovery. *Petroleum Science and Technology,* vol. 23, no. 2, pp. 169-188.

**Adeniyi, O. D.; Nwalor, J. U.; Ako, C. T.** (2008): A review on waterflooding problems in Nigeria's crude oil production. *Journal Of Dispersion Science and technology,* vol. 29, no. 3, pp. 362-365.

**Chen, X.; Wang, Y.; Zhang, D.** (2007): Acidification de-blocking technology in low permeability sandstone reservoir. *Oil-gasfield surface engineering,* vol. 26, no. 5, pp. 23-26.

**Han, D.; Shen, P. P.** (2001): Principle and Application of Surfactant Oil Displacement. *Petroleum Industry Press: Beijing,* vol.1, pp.24.

**Hirasaki, G.; Zhang, D. L.** (2004): Surface chemistry of oil recovery from fractured, oil-wet, carbonate formations. *SPE Journal,* vol. 9, no. 2, pp. 151-162.

**Jiang, G. C.; Li, Y. Y.; Xu, W. X. et al.** (2011): Study and application of formation protection drilling-in completion fluid indeveloping low and wxtra low permeability reservoirs. *Mechanical industrial and manufacturing engineering*, pp. 405-409.

**Ogunberu, A. L.; Ayub, M.** (2005): The role of wettability in petroleum recovery. *Petroleum Science and Technology,* vol. 23, no. 2, pp. 169-188.

**Pang, Z. X.; Liu, H. Q.; Liu, X. L.** (2010): Characteristics of formation damage and variations of reservoir properties during stream injection in heavy oil Reservoir.

*Petroleum Science and Technology,* vol. 28, no. 5, pp. 477-493.

**Robin, M.** (2001): Interfacial phenomena: Reservoir wettability in oil recovery. *Oil & Gas Science and Technology Y-Revue De L Institut Francais Du Petrole,* vol 56, no. 1, pp. 55-62.

**Wu, S.; Firoozabadi, A.** (2011): Effects of firing and chemical treatments on berea permeability and wetting. *Energy & Fuels,* vol. 25, no. 1, pp. 197-207.

**Yu, Q.; Jiang, H.; Zhao, C.** (2010): Study of interfacial tension between oil and surfactant polymer flooding. *Petroleum Science and Technology,* vol. 28, no. 18, pp. 1846-1854.

**Zhao, F. L.** (2007): Oilfield Chemical. *China University of Petroleum Press: Dongying,* vol.1, pp.112.