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Improved Oil Recovery Through Development of Gum-based Relative Permeability Modifier

Block the Water and not the Revenue

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***Abstract*— Oil and Gas production from reservoirs are often accompanied by a huge amount of water production. Excessive water production is one of the common problems faced by the petroleum companies worldwide. Water Handling costs are high. Estimates range from 5 to more than 50 cents per barrel of water. In a well producing with 80% Water-Cut, cost of handling water can be as high as $4 per barrel of oil produced. Polymers and gels are being used with partial success over years to control water production. They form a system of Relative Permeability Modifier. The basic goal of an RPM is to reduce a completed interval's relative permeability to water much more than to oil and/or gas, which would reduce water-handling problems and lost oil production. Selection of an RPM for a given well treatment depends on reservoir conditions such as the Temperature, Salinity, Hardness and pH of the water with which the gelant was originally made. The objective of this paper is to discuss the advent of gum-based Relative Permeability Modifier (RPM) that can work with better efficiency in Water Control Operations.**

Keywords—Water Control; Water-Cut; Relative Permeability; Disproportionate Permeability Reduction (DPR) ; Gums; Polymers; Relative Permeability Modifier (RPM);

I. INTRODUCTION

Apart from increasing the production cost to the operating company, excess of water produced with the oil brings about the other problems like migration of fines into the wellbore and their subsequent production, production of sand and imminent collapse of formation, increased tendency of corrosion of tubular and down-hole components and scale formation. On an average, about three barrels of water are believably produced as a by-product for one barrel of oil [1]. This has become even more pronounced with the advent of Extended Reach Drilling (ERD) and Multilateral Wells. Often these wells pass through multiple conductive fractures, faults and high permeable streaks connecting the wellbore to under laying aquifer or injection water front and the mobility advantage results in high water production. Water affects every stage of oilfield life. Starting from Exploration where the Oil-Water Contact (OWC) plays a pivotal role in determining the Original Oil-in-Place (OOIP), through Development, Production and finally to Abandonment. Oil producers are always looking to maximise their revenue at minimum costs possible. To cater to this optimisation requirement of the operators, a number of water control techniques have emerged and are in use in the oil and gas industry. This paper explores and discusses the pros and cons and also suggests certain remedial innovations in the purview of Chemical Water Control Methods that are either under development or are being used at the industrial level with partial success.

Delimiting this discussion on the broad perspective of Water Shut-off, Chemical Water Shut-off includes development and application of certain polymers and gels that could control water production by forming a system of Relative Permeability Modifiers (RPMs). RPMs work by reducing the relative permeability to water, in a completed interval, much more than that to oil. This phenomenon of reducing the relative permeability of one phase with respect to another is known as Disproportionate Permeability Reduction (DPR) and this feature of RPM Polymers put them at an advantage over the conventional cement plugging that completely blocks off the zone that has to be treated.

On the downside, a number of factors prevail that limit usage on a commercially viable and industrial scale. Selection of an RPM for a given well treatment depends on reservoir conditions such as the Temperature, Salinity, Hardness and pH of the water with which the gelant was originally made. Other parameters also include salinity of the formation water, permeability of the target zone and the lithology of the formation. A large number of gelling systems are available for this Improved Oil Recovery application. They are sorted on the basis of traits of hydrophilicity, cross-linking capacity, high temperature resistance and non-toxicity. The traditionally used RPM gels pose the difficulty of gelation kinetics control and further the penetration of treating fluids could be short if the rock offers high buffer capacity. Other problems relate with the thermal stability of the RPM formulations. They indeed turn out to be effective at temperatures below 75ºC, but at higher temperatures, they tend to fail in terms of their capacity to form effective cross-links. The gels also compromise with their integrity show shorter cessation periods at the conditions of high temperatures in the well. In addition, their response to salinity of formation waters also becomes questionable on varying occasions. The carboxylate groups are generated as a result of thermal analysis of these gels and they additionally cross-link the system with divalent cations. The process of over-crosslinking results in expulsion of water from the gel-structure. This phenomenon is known as Gel Syneresis and it greatly shrinks the volume of the structure.

II. MECHANISMS OF DISPROPORTIONATE PERMEABILITY REDUCTION

Most gel and polymer systems used in the industry are placed in the near well bore region before the cross-linking takes place. After injection of the polymer system in the matrix of the target zone, the components react and form a three-dimensional polymer structure. Referred to as gel, this three-dimensional structure can reduce or completely block the flow of water through the porous medium.

In order to suggest remedies to the problems faced in the efficient functioning of Relative Permeability Modifier, it becomes imperative to understand the mechanism that the formulation incorporates to generate the desired outcome. There have been a considerably large number of previous studies conducted on understanding the behaviour of these RPMs. It could be shown that the Disproportionate Permeability Reduction was not caused by simple hysteresis of relative permeabilities. Also the phenomenon did not depend on the length of the core sample. Gravity and Lubrication did not show significant effects and also the shrinking and swelling of the gel could not suffice to be the causal factors (Liang and Seright, 2000). All of these phenomena were observed in core experiments using constant-rate drive and constant-pressure drive. [3]

This paper focusses on some of the key mechanisms largely supported as being promising explanations of the Disproportionate Permeability Reduction (DPR). The models could be enlisted as:-

i. Wall-Effect Model (Zaitoun et. al. 1998)
ii. Gel-Droplet Model (Nilsson et. al. 1998)
iii. Combined Model (Liang and Seright, 2000)

(i) Wall-Effect Model
Wall-Effect Model was postulated by *Zaitoun et. al.*[4] Theories of this model ascribed the whole phenomenon of Disproportionate Permeability Reduction to the wall effects of the adsorbed polymer on the walls of the pore space. In a strongly water-wet rock, residual oil droplets tend to accumulate at the centre of the pore and this can significantly reduce the effective width of the water channels during the course of Waterflooding. Therefore, for a given thickness of an adsorbed polymer layer, the permeability reduction for water during waterflooding is greater than that for oil during oilflooding. On a similar token, if the adsorbed layer on the pore walls is either a polymer or a water-based gel, the wall-effect model could explain why some water-based gels exhibit disproportionate permeability reduction in strongly water-wet cores (Fig. 1).
For an oil-wet system, the model proposed that the gel could pounce on the discontinuous wettability feature by anchoring on to the water-wet portion of the rock surface. The layer of polymer covering the oil-wet surface would then spread on to the surface shifting the wettability of the system in favour of being water-wet. Thus, the polymer system could reduce the relative permeability to water more than that to oil. Based on a careful study of Capillary Pressure and Relative Permeability Characteristics before and after the gel treatment, *Zaitoun et. al.* concluded that that the adsorbed polymer layer was responsible for the Disproportionate Permeability Reduction in both the oil-wet and the water-wet cores.

However, going by this theory, there should be no effects of DPR in a strongly oil-wet core. However, this effect was observed to be more pronounced in a strongly oil-wet core (Fig. 2). This anomaly could not be explain using the Wall-Effect Model. Based on these findings, it was concluded that the Wall-Effect Model could hold accountable for Disproportionate Permeability Reduction only if the gelant is prepared from or matches the wetting phase (Liang and Seright, 2000).

(ii) Gel-Droplet Model
Gel-Droplet Model was conceptualised by *Nilsson et. al.*[5] to account for Disproportionate Permeability Reduction if the gelant is not prepared from or not matches the wetting phase. This model assumes the formation of the gel-droplet at the centre of the pore causing more restriction to the flow of the wetting phase than to the flow of the non-wetting phase. Prior to the gel treatment, the only restriction to the flow of the water through the pore is the thin film of the oil on the walls of the pore. However, in contrast, oil flowing through the pore throat is restricted by the accumulation of water droplet at the centre of the pore.
Once the gel is placed, the gel droplet being the non-wetting phase accumulates at the centre of the pore. The volume fraction of the pore available to oil flow remains the same as before treatment. However, the presence of the gel droplet significantly reduces the volume fraction of the pore available to water flow (Fig 3). Given that the only restriction to the flow of water before the gel treatment was only because of the thin film of oil on the surface of the pore wall, the gel can reduce permeability to water without affecting permeability to oil. Of course, if the gel droplet is larger than the residual water droplet, the permeability to oil will be reduced. Also, the disproportionate permeability reduction should diminish when the size of the gel droplet falls below that of the residual water droplet.
According to this model, results could be unfavourable if the treatment is performed on a strongly water-wet rock. The applied gelant would completely block the pores by encapsulating the residual water droplets thereby reducing the effective permeability to both oil and water (Fig. 4).

(iii) Combined Model
Reviewing the above models, it could well be summarized to decide the precise application of the correct model in the correct scenarios. The Disproportionate Permeability Reduction can be explained using the Wall-Effect Model if the gelant is prepared from or matches the wetting phase. In contrast, when the gelant is prepared from or matches the non-wetting phase, the Gel-Droplet Model explains the Disproportionate Permeability Reduction. In a combined model, we simply assume that the individual models apply for the appropriate circumstances. In particular, the wall-effect model applies for water-based gels in water-wet cores or for oil-based gels in oil-wet cores. The droplet model applies for water-based gels in oil-wet cores or for oil-based gels in water-wet cores. **T**he ratios, F_{rrw}/F_{rro}, or F_{rro}/F_{rrw} could be used to quantify Disproportionate

Permeability Reduction. Higher ratios indicate more pronounced effect of the gel treatment.

In addition, it is also observed that maintaining high residual oil saturations in the oil zone to be treated by the gel could also reduce damage to oil productivity.[6] Also to a certain extent, increase in pressure drawdown after the gel treatment could reduce damage to oil productivity without increasing water production.[7]

III. SOLUTION THROUGH IMPLEMENTATION OF ALTERNATIVE RPM

This paper attempts to find the possible solutions in the hands of substitution of the conventional polymer gel materials with gum-forming polymers. These polymers could well be sustained at higher temperatures and possess a greater water absorption capacity. Materials like Alginic Acid, an anionic polysaccharide can form a viscous gum by binding with water. It is capable of absorbing water up to 200-300 times its weight[8]. When this base compound is augmented with high-temperature organic cross-linking agents, can enhance the thermal stability of the formulation helping to maintain the integrity of the RPM up to temperatures above 150˚C.[9] Both Primary and Secondary cross-linkers could be used in conjunction to establish the determined benchmarks of the formulation. The use of Alginic Acids as an intermittent pharmaceutical component may accountably vouch for its environmental benignity.

Liquid hydrocarbons are known to solidify when emulsified with the Alginic Acid or any water soluble salt of Alginic Acid. Liquid hydrocarbons disperse as tiny droplets (discontinuous/external phase) in the solidified structure of Alginic Acid (continuous/internal phase)[10].

In review of this circumstance, the paper also proposes the application of a specific slush molding compound. Using Thermoplastic Urethane (TPU) mixed with certain suitable additives can help substantially in absorbing water up to 4oo times its weight.[11] The resin powder has an average particle diameter in the range of 70-300µ and is capable of melting at 200-300°C. Thermoplastic Urethane (TPU) polymers are highly resistant to oil and grease and this could provide a favourable point of egregiousness as the DPR agent would repel the oil and interact only with the water below the OWC[12]. The overall reagent is known to be innocuous from the perspective of toxicity as TPU based polymers are extensively used in pharmaceuticals designed for children below 10 years of age and also in Endoscopy in medical science.

IV. CONCLUSION

Hence, on an overall, Water Control techniques involving application of Relative Permeability Modifiers can indeed revolutionise the oilfield economics o an operating company. If the prevalent limitations associated with relative permeability modifiers could be eliminated, the discussed technology can indeed prove to be a state-of-the-art tool towards controlling influx of bad water. Some of the major challenges faced by the RPM polymer and gel systems happen to be Thermal Stability, Chemical Interaction with the Reservoir Fluids, Environmental Benignity and the Economics of the Water Control Project. The proponed remedies in this paper are hoped to counter or mitigate the challenges associated with Water Control via Disproportionate Permeability Reduction.

NOMENCLATURE

RPM = Relative Permeability Modifier

ERD = Extended Reach Drilling
OWC = Oil-Water Contact
DPR = Disproportionate Permeability Reduction
F_{rro} = Oil Residual Resistance Factor (oil mobility before gel treatment divided by oil mobility after gel treatment)
F_{rrw} = Water Residual Resistance Factor (water mobility before gel treatment divided by water mobility after gel treatment)
TPU = Thermoplastic Urethane

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REFERENCES

[1] Bill, Bailey. Crabtree, Mike. Tyrie, Jeb. and Roodhart, Leo., Water Control, Oilfield Review, Schlumberger (2000).
[2] Karmakar, G.P. and Chakraborty, Chandrima, Improved Oil Recovery Using Polymeric Gelants, Indian Journal of Chemical Technology (2006), Volume 13, pp. 162-167
[3] Liang, J. and Seright, R.S., Wall-Effect/Gel Droplet Model of Disproportionate Permeability Reduction, paper SPE 59344, SPE/DOE Improved Oil Recovery Symposium (2000), Tulsa, Oklahoma, USA
[4] Zaitoun, A., Bertin, H. and Lasseux, D., Two-Phase Flow Property Modifications by Polymer Adsorption, paper SPE 39631, SPE/DOE Improved Oil Recovery Symposium (1998), Tulsa, Oklahoma, USA
[5] Nilsson, S., Stavland, A. and Jonsbraten, H.C., Mechanistic Study of Disproportionate Permeability Reduction, paper SPE 39635, SPE/DOE Improved Oil Recovery Symposium (1998), Tulsa, Oklahoma, USA
[6] Lake, L.W., Enhanced Oil Recovery, Prentice Hall, Englewood Cliffs, New Jersey (1989), pp. 62-77.
[7] Seright, R.S., Improved Methods for Water Shut-off, Final Technical Progress Report (US DOE Report DOE/PC/91008-14), US DOE Contract DE-AC22-94PC91008, BDM-Oklahoma Subcontract GS4560330 (October, 1998), pp. 59-69.
[8] Article on Alginic Acid, Wikipedia
[9] Moradi-Araghi, Ahmad, A Review of Thermally Stable Gels for Fluid Diverison Journal of Petroleum Science and Engineering, Elsevier (2000), Volume 26, Issue 1, pp. 1-10
[10] Fischer, Karl A., Washington DC and Hecht, Otto F., Recovery of Liquid from Solidified Fuel, Sept. 16, 1952, Philadelphia, PA., United States Patent Office, S. No. 2610952
[11] Article on Thermoplastic Urethane, Wikipedia
[12] Fujibayashi, Shinya, Nishioka, Shogo, Maruyama Daichi, Nomura, Akira, Sanyo Chemical Industries, Japan, Powdered resin composition for slush molding and molded product, US 8034883 B2, US Patents
[13] Ghosh, B., Bemani, A.S., Wahaibi, Y.M., Hadrami, H., Boukadi, Fathi H., Development of a novel chemical water shut-off method for fractured reservoirs: Laboratory development and verification through core flow experiments, Journal of Petroleum Science and Engineering, 96-97, Elsevier (2012), pp. 176-184

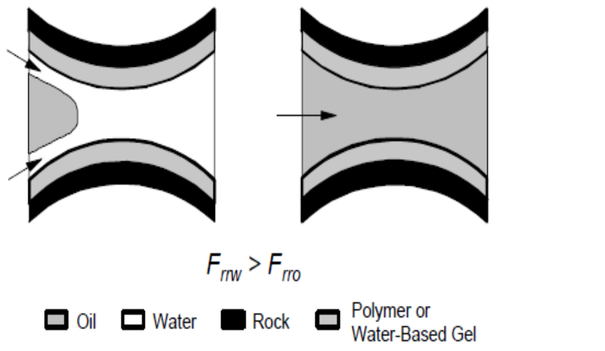

Figure 1 Wall-Effect Model proposed by *Zaitoun et. al.*

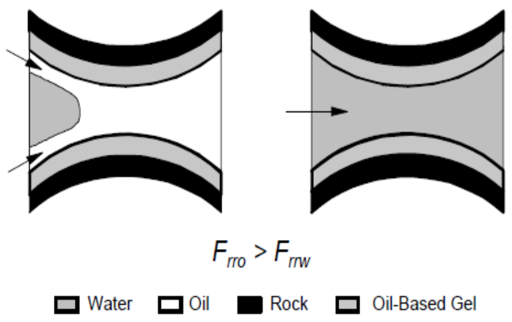

Figure 2 Wall-Effect Model proposed by *Zaitoun et. al.*

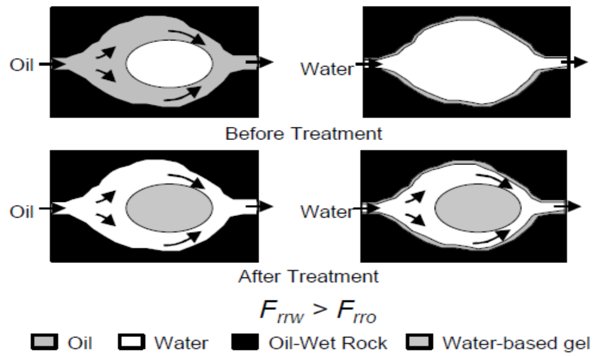

Figure 3 Gel-Droplet Model inspired by Nilsson et. al**.**

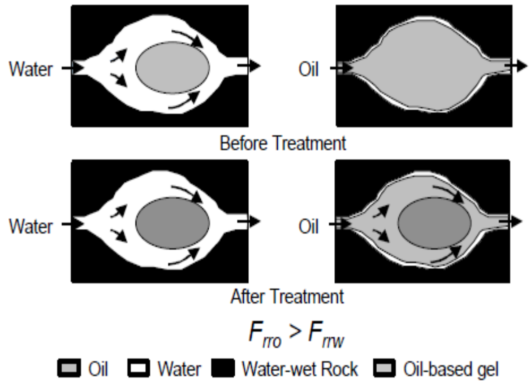

Figure 4 Gel-Droplet Model inspired by *Nilsson et. al.*