Water Control Analysis on Production Enhancement along with Permeability Modification by Polymers

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Oil and gas production from the reservoirs are often accompanied by huge amount of water production which is the major problem faced in petroleum industry worldwide. Polymer gels have been successfully used for many years to control water production. Most methods involve crosslinking of partially hydrolyzed polyacrylamide-PHPA using organic or metallic crosslinkers. These polymer gels are formed in-situ under the reservoir condition which blocks the water producing zones thereby reducing the water production. This paper attempts to for the selection of suitable polymer and crosslinker concentration for Gandhar field in Cambay basin using gel study and core flooding analysis. Polymer is made gel using organic crosslinkers at stable reservoir temperature 90°C.

Key words: Water control, Permeability, polymers.

Water production is one of the major technical and economic issues throughout the world, which reduces expected production of oil/gas thereby affecting the life of the well. Given that the worldwide production of water is about 210 million bbls for every 75 million bbls of oil. Water handling cost is about 5 to 50% per barrel of water. If a well has water cut more than 80%, then the cost of handling of water is nearly $4 per barrel of oil[1].

Water production may occur in two ways. First is, water gets produced along with the oil that might be the result of water flooding. Measures taken to control this water production may inhibit oil production also. Second is, water gets produced from different zone which has high permeability or pressure gradient. Measures taken to avoid this

water production will actually increase the oil production rate. This thesis deals with the first method of water production and find out the best way to reduce the water production without affecting the oil production rate.

Due to increased water production, ultimate recovery of oil that has to be produced will be reduced, in turn reduce the life of the well. Water production not only reduces oil production but also causes corrosion, hydrostatic loading, and increased separation cost, premature abandonment of well and environmental issues concerned with water disposal.

In oil and gas industry many companies face this problem, once the oil well become mature. This is due to the fact that water saturation of near well bore increases thereby decreasing relative permeability of oil and increased relative permeability of water. Mechanical errors such as leaks from casing, tubing or packer, channeling behind the casing due to poor cementing or Completion errors like improper fracturing out of

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the productive zone, upward movement of oil water contact or reservoir related problems such as *coning*, high permeability streaks, *channeling-*including fractures between injector and producer well and fractures connecting water zone and well bore, poor sweep efficiency, gravity segregated layers, reservoir depletion. Etc., are the major causes of water production from the oil well[3].

Identification of the mechanism for excess water production is as important as the treatment design for combating water production. Diagnostic plot like Chan plot is very much helpful in this aspect. Log-log plot of WOR vs. time (Chan's plot) are helpful in identifying whether the mechanism is due to coning, channeling or near wellbore issues by the trend of the WOR and WOR' curves. Plots of WOR vs. cumulative oil production and oil rate decline curves will help us to identify the water treatment method that might be the best suited one to avoid the declining rate of oil. (Ref 5)

Several mechanical and chemical methods are available for water shut-off. However, the selection of treatment depends on the source of water production, well characteristics, and cost. Mechanical methods to minimize water production are cement squeeze, application of mechanical tools such as mechanical plug back tool or patchflex sleeve[4].Water shut-off treatments using chemical methods include injection of a gelling solution which is one of the most frequently used methods. Chemical methods are used for both water shut off and profile modification to reduce the water production. Polymer gel systems, rigid gel system, organic cross linkers, metallic cross linkers are some of the chemical techniques used for improving flooding efficiency and to reduce water production.

Gel polymer systems have a penetration property greater than the cement to provide a deeper barrier against the excess water. Also, plugging due to gel polymers can be removed unlike physical cement plugging which leads to a permanent plug in the porous media so that the residual oil cannot be produced from the treated region by cementing method after decreasing of excess water production.

Polymers are the compounds formed by the process of polymerization. Polymerization is the process of combining many small molecules (monomers) into larger molecules (polymers). Two categories of polymers are biopolymers that are fermented product of natural substances (eg. Xanthum gum) and Synthetic polymers are man-made substances (eg. Partially Hydrolysed Polyacrylamide-PHPA)

Cross linkers are the compounds used to link polymer molecules to form polymer gel. They can be covalent or ionic bond. Cross links are formed by chemical reactions that are initiated by heat, pressure, pH or radiation. Cross linkers are classified into metallic or organic cross linkers. Chromium is the most commonly used metallic cross-linker, where ionic bond is formed between the polymer and crosslinker, which is unstable at high temperature. Organically crosslinked polymers form covalent bonds that are highly stable at high temperatures. Organic crosslinkers used in this paper is Hexamine ($C_6H_{12}N_4$) and Hydroquinone ($C_6H_6O_2$)[2].

Gelant is the mixture of polymer and crosslinker enter into rock matrices, cracks and fractures. They decrease the permeability of the water by blocking the available conduit for water to flow into the well. In worldwide, polymer gels flooding techniques one of the promising method which not only reduces water production through reducing relative permeability of water, but also to accelerate oil production by increasing viscosity of water. (Ref 3).In this thesis, we use synthetic polymer and organic crosslinkers that has maximum stability and decreases the post injection problems.

Selection of a gel polymer system for a given well treatment strongly depends on reservoir conditions such as temperature, salinity, hardness and the pH of the water used for preparation of the gelant. Other parameters to be considered for the proper selection of a given gel polymer system include, permeability of the target zone, and the lithology of the formation.

Methodology

This paper includes gelation study and core flooding analysis to find out the concentrations of polymers and crosslinkers for the polymer gel formation and also core flood analysis to find out if this concentration is suitable enough to reduce the water production by decreasing the water permeability.

Gelation

Gel polymer systems are typically composed of a water soluble polymer and a crosslinking agent which are dissolved in water

known as gelant solution. After allowing sufficient time, the gelant sets into a semisolid mass, and behaves as flow diverting or blocking agent. Selection of a gel polymer system for a given well treatment strongly depends on reservoir conditions such as temperature, salinity, hardness and the pH of the water, permeability of the target zone and the lithology of the formation.
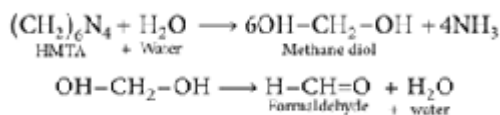
The gel strength codes were ranged from high flowing gels with barely any gel structure to rigid rubbery gels. Therefore, the gelation time is the period of time when change is no longer observed in the gel strength.

Initially the viscosity of the gelant will be very low and gel strength will be same as that of polymer solution. After few days, rate of gelling reaction is increased under the reservoir temperature. Thus, when the cross linking reaction takes place under high temperature, a 3-D polymer gel network is formed.

Gelation study involves preparation of gelant solution and find out the appropriate concentrations of polymer and crosslinker that can remain stable for longer duration at the reservoir temperature. Formation water solution is prepared by dissolving 1% of NaCl in the injection water. This water solution is used for making the polymer and croslinkers solutions. Different concentrations of PHPA(polymer), Hexamine and Hydroquinone (crosslinkers) are mixed with the injection water and stirred well using a beaker[8].

Chemical reaction for gel formation

In the initial step, hexamine hydrolyses to yield formaldehyde.

$$(CH_2)_6N_4 + H_2O \longrightarrow 6OH-CH_2-OH + 4NH_3$$
HMTA   + Water   Methane diol

$$OH-CH_2-OH \longrightarrow H-CH=O + H_2O$$
Formaldehyde + water

Formaldehyde produced from hexamine hydrolysis then reacts with hydroquinone to form a condensed structure known as 2,3,5,6 tetramethylolhydroquinone.
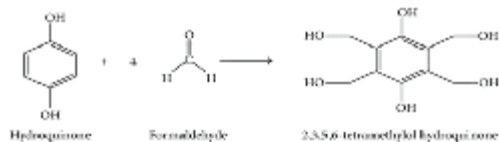
The condensed molecule formed then reacts with PHPA to form the 3-dimensional gel structure which helps in profile modification jobs

Crosslinking 3-D gel structure
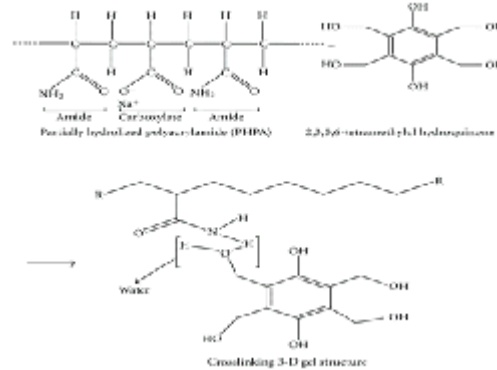
The above mechanism is made to happen by keeping the by keeping the different concentrations of polymer and crosslinkers into the oven that is set at reservoir temperature. With increase in temperature and time, the gelant forms the gel solution by above mechanism and the gel time and gel strength are noted down periodically to come up with the best concentrations of polymer and crosslinkers.
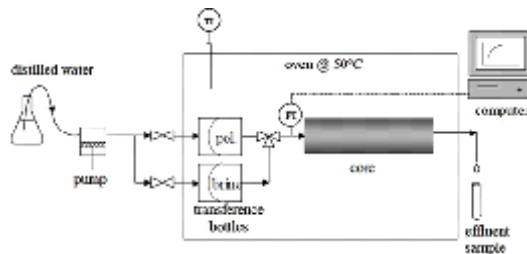
Core Apparatus

The objective of this study is to evaluate the effectiveness of oil injection around well bore on the cores shown in fig1. of reservoir in terms of permeability reduction. The residual resistance factor (Frr) which is obtained as the ratio of permeability before the treatment to permeability after treatment is calculated to determine the percentage change to phase permeability.

Residual Resistance Factor (F$_{rr}$)

In order to assess how far the polymer gel has been effective in preventing the flow of water, core flow studies can be carried out by simulating the bottom hole temperature condition. The core from the particular field of interest can be

used, impregnated with the polymer gel, followed by oil flooding and later brine. The residual resistance factor to brine flow can be calculated. Disproportionate permeability reduction occurs when the permeability to brine (formation water) after the polymer reduces by larger amount than the permeability to oil.

This often expresses in terms of Residual Resistance Factor (F_{rr}) for oil and brine.

The residual resistance factor for oil (F_{rro}) is defined as

$$(F_{rro}) = k_o/k_{og}$$

Similarly, the residual resistance factor for brine (F_{rr}) is defined as

$$(F_{rrw}) = k_w/k_{wg}$$

Where k_{og} and k_{wg} are the permeability to oil and water at endpoint saturation after gel treatment, and k_o and k_w are permeability to oil and water before treatment, at interstitial water saturation water saturation and residual oil saturation, respectively. Thus, disproportionate permeability reduction occurs when $(F_{rro}) < (F_{rrw})$.

RESULTS

Procedure

Core shown in table1. was saturated with water and stabilized at reservoir temperature in oven.

It was flooded with formation water followed by Oil with 5 Pore Volumes (PV). Pressure readings were observed during this process. Oil saturated in core has been displaced by injecting Polymer gel followed by river water. The same process has been repeated by injecting river water followed by polymer gel.

Table 1. Core Flow Studies: Core details

1	Sample no	G#
2	Length (cm)	7.344
3	Diameter (cm)	3.766
4	Pore Volume (cc)	12.506
5	Porosity (%)	15.29
6	Water/Oil Viscosity at 80ºC (cp)	0.4

Table 2. Gelation Study

Sample	Polymer (ppm)	Hexamine (ppm)	Hydroquinone (ppm)	Gel Time	Gel Strength
1.	2000	2000	3000	1-4 days NG	7-59 days FG
2.	3000	3000	4000	1-3 days NG	4-6 days VG
					7-59 days FG
3.	4000	3000	4000	1-6 days NG	7-59 days GFG
4.	5000	3000	4000	1-3 days NG	4-6 days VL
					7-59 days GFG
5.	4000	4000	3000	1-3 days NG	4-6 days FG
					7-14 days GFG
					15-16 days VGFG
					17-29 days GFG
					30-59 days FGb
6.	5000	4000	3000	1-3 days NG	4-29 days GFG
					30-59 days FGb

NG - No Gel, FG - Flexible Gel, GFG - Good Flexible Gel, VGFG- Very Good Flexible gel, GHG - Good Hard Gel, VGHG - Very Good Hard Gel, FGb - Flexible Gel breaking. VL- viscous liquid

Table 3. Core Data modifying Permmeability

Polymer concentration (ppm)	Hexamine concentration (ppm)	Hydroquinone concentration (ppm)	Permeability before treatment		Permeability after treatment		Frrw	Frro
			Kw	Ko	Kwg	Kog		
5000	3000	4000	1.4	1.13	0.07	0.16	21.7	7.0

Polymer gel for 5000ppm has been prepared shown in table 2.

Modification of Permeability have been observed in Table 3.

Permeability before polymer gel treatment job

K_w at S_{or} : 1.44 md

K_o at S_{wi} : 1.13md

K/K_w =1 before treatment

Permeability after polymer injection

K_{wg}: 0.07 md

K_{og}:0.16md

Frrw value for under stabilized condition= 21.7

Frro value for under stabilized condition= 7.0

Here Kwg<Kw i.e. permeability of water is reduced after polymer gel treatment.

CONCLUSIONS

Polymer gel was synthesized from partially hydrolyzed polyacrylamide using crossslinkers Hydroquinone and Hexamine for permeability modification for well X of Gandhar field in Cambay Basin under stable reservoir condition 90°c.

This done through Gelation study and core flooding Experiment in the laboratory using the core from well X and using the formation brine water for making gelant and water flooding in core flood experiment.Findings have been made are, concentrations of polymer and crosslinker considered to be suitable because it forms gel with less shut in time and also regains its gel strength for many days without breaking and from the core flooding experiment, considerable amount of reduction in permeability of water was observed with residual resistance factor for water is 21.7 which is more than 10.

Hence from the above study it is clear that the polymer and gel concentration has apparently succeeded in blocking the high permeable zones causing increased water production. Therefore the selected gelant concentration can be applied to the well X of Gandhar field in Cambay basin for profile modification job.

Further to this, during the course of our experiment, enormous visible growth of micro-organisms (fungal/algae/bacteria) was observed in the injection water. This waster was filtered using filter paper and no disinfectants were used while injecting into the core. Care must be taken while using the contaminated water, because some thermophiles are capable of thriving at high temperatures, that may also multiply and colonize in the reservoir that reduces the permeability of smaller pores which are available for oil to flow.

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