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The Effectiveness of Polyacrylamide Gel Polymer in Shutting off Water Production in Niger Delta Reservoirs.

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ABSTRACT : *Produced water associated with petroleum production has been a huge problem in the petroleum industry over the years, especially in matured fields. High water productions reduces crude oil production as well as contribute to many operational problems such as fines production, increased rate of equipment corrosion, increased tendency for emulsion and the formation of scales. Several studies have shown polymer as a better option for shutting off water in reservoirs because they possess a good potential for reducing reservoir permeability to water, thereby making them effective in maximizing reservoir recovery. This study experimentally investigated the efficiency of a polymer gel (formulated from polyacrylamide polymer, chromium acetate and thiourea) in plugging water channels in the reservoir. Six (6) core samples from three (3) different reservoirs in the Niger Delta were analyzed. The results showed that the polymer gel solution developed in this study had a water control impact averaging over 89% at 90oC for the 6 core samples. It was concluded that this developed polymer will work effectively as a water control agent for reservoirs in Niger Delta.*

KEYWORDS *Water shutoff, Polyacrylamide gel, Niger Delta, Permeability, Cross-linker, Reservoir.*

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I. INTRODUCTION AND BACKGROUND

The high cost of lifting, handling, separation and disposal of large amount of produced water threatens the economic viability and most times lead to an early abandonment of several fields/production wells, reduced rates of production, low oil recovery and increased environmental concerns (Bailey et al, 2000). Fig. 1 below shows a summary of water produced globally between years 2000 and 2005 in the petroleum industry. Water production within the Shell petroleum group increased from 2.2 million barrels per day in 1990 to more than 6.3 million barrels per day in 2004 (Van Eijden et al., 2004). According to Mohammed et al. (1998), 81% of water was cut from some of the wells of Saudi Aramco which were produced in a large carbonate reservoir in Saudi Arabia. Total E&P also made a report for its wells in Al Khalij filed in Qatar; water cut was over 75% (Pradie et al., 2007). BP also reported a water cut of 80% for its wells in Ust Vakh field (Guerra et al., 2007).

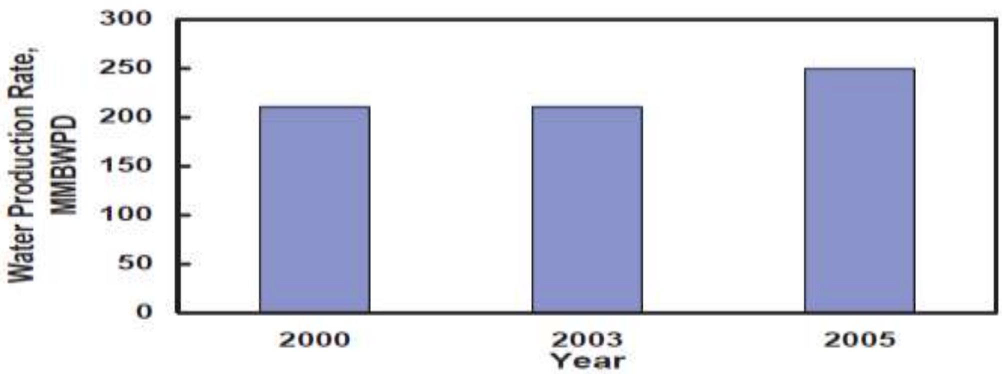

Fig. 1 Global water production data (Bailey et al., 2000)

Water being the most abundant fluid can be indispensable particularly when it sustains reservoir pressure which enhances good reservoir management but becomes a nuisance when it mars productive performance and affects the overall operational economics of the Reservoir (Joseph et al, 2010). It is important to lower the rate of water production from our reservoirs because this will get rid of the extra costs of handling water production during oil production. Water production which sets a good precedence for sand production is one the worst production problems, as it creates a huge problem in disposing and coordinating the logistics involved. It contributes to other operational problems such as fines production, increased rate of equipment corrosion, increased tendency for emulsion and the formation of scales. Water production reduces the ultimate recovery of a reservoir by reducing its sweep efficiency. A high water cut ultimately reduces the economic life of the reservoir. Gel polymer treatment which could be seen as an Improved Oil Recovery (IOR) technique can be used to ensure a higher oil production rate and a lower water production rate provided all the necessary factors are being considered together with a proper selection method. A polymer that is soluble in water and a cross-linker are the usual components dissolved in water to form a polymer gel system. It may be very difficult to completely hinder the flow of water. In such situations, there are other chemical treatments that can be used to tactically reduce the permeability to water more than that to oil (Zaitoun and Kohler, 1998; Sydansk and Seright, 2007). Polymer gels have the following advantages over mechanical methods and cementing: they have a greater penetration property; and the plugs can be removed unlike permanent plugs developed as a result of physical cementing (Simjoo et al, 2007).

Seikh and Mahto (2013) highlighted the negative effects of producing excess water and the benefits of adequately controlling excess production of water. They experimentally developed a polymer gel system using partially hydrolysed polyacrylamide polymer and inorganic (chromium acetate and thiourea) cross-linkers. They injected their developed polymer gel into Berea core samples and core analysis was done to ascertain the effectiveness of the developed polymer gel in controlling excess water production. They concluded that the developed polymer gel was effective in controlling water production from the reservoir as it reduced the permeability to water by 94.25%. Sun and Bai (2017) carried out a comprehensive review of water shut off methods for horizontal wells. They carried out a case study analysis to determine the best water shutoff method for open hole completion, cased hole completion and perforated liner completion. They concluded that mechanical methods are more expensive and that the correction depth is usually a big challenge. The further said that both the chemical and the mechanical methods can be utilized in open hole or cased hole completion in horizontal wells while for slotted liner and sand screen completion, water shutoff can only be done by chemical treatment. Anderson et al., (2000) talked about some well and reservoir characteristics that cause a high WOR and discussed some chemical (gel) treatments necessary in reducing water production from reservoirs. They highlighted four (4) gel treatment parameters that are very critical in achieving a successful gel treatment. They are: viscosity at the time of injection, nature of phase, density and setup time. They also highlighted some case study wells where chemical treatment effectively reduced water production and enhanced oil production. They concluded that gel treatment can be highly effective, both technically and economically, provided the product possesses the required characteristics relative to the well's deficiencies. Kuzmichonok and Asghari (2007) carried out an experimental study to evaluate polymer gel performance in water shutoff while injecting brine and the polymer gel simultaneously instead of the common practice of first injecting gel before injecting the brine. They carried out experiments to verify how residual oil affects the characteristics of polymer gel. They went with the assumption that, studying the gel behaviour under multiphase flow conditions may result in a clearer understanding of the principles behind the Disproportionate Permeability Reduction (DPR) effect in porous carbonate media. They concluded that rock permeability to oil was greatly reduced in the absence of residual oil saturation compared to that of brine during both the continuous and simultaneous injections and that during the simultaneous injection of oil and water in the presence of residual oil saturation, the DPR effect did not come to play on all the experiment steps. Simjo et al., (2009) conducted an experimental study to ascertain the effectiveness of a copolymer of acrylamide-sodium acrylate cross-linked with chromium acetate for water shutoff operations in a fractured carbonate rock. The results of their experimental analysis showed that the polymer gel made with a high saline formation water was stable at 850C (high temperature condition) for up to 4 days. They also observed that presence of formation water resulted in more cross-linking of the polymer chains. They concluded that the polymer gel was very effective in water shutoff operations as it reduced the fracture conductivity by four orders of magnitude. Purkable and Summers (1988) designed a testing programme to help in identifying the best polymer gel for various applications in the field. They proposed the use of beaker test for a rapid screening of the polymer gels while core flooding tests were proposed for the selection of the final polymer gel system. They carried out experimental analysis on 15 commercially available polyacrylamide polymers gelled with Cr(III) cross linker in a thick multi-zone reservoir. They utilized the Plackett-Burman screening design which they used a standard statistical software for the analysis. After their series of experiments the following conclusions were drawn: producing constant gels at reservoir condition requires a low level of polymer hydrolysis; the pH of the polymer gel solution in the buffered field brine greatly affects the characteristics of gel; the two polymer gels (Allied colloids Alcoflood 935L and American Cyanamid Cyangel 150) that were selected to undergo coreflood analysis proved to be very effective in water shutoff operations as they both reduced the rock permeability to water by at least 97% after 50 days of static aging at reservoir conditions.

This research paper is aimed at ascertaining the effectiveness of polymer gels in reducing rock permeability to water, hence obtaining its (polymer gel) efficiency in shutting off water production from reservoirs in the Niger Delta.

II. MATERIALS AND METHOD

The following materials were used in carrying out this experiment: Polyacrylamide polymer powder; Chromium acetate; Thiourea; Sodium chloride; Calcium chloride; Hydrochloric acid; Sodium hydroxide; Sodium thiosulphate; Distilled water; pH Meter; Thermometer Density Bottle; U-tube viscometer; Liquid Permeameter; Weighing scale; Core samples; Beaker; Conical flask; Magnetic stirrer; Electrical heating system.
The experimental method focused on the suitability of the polymer gel for water shutoff operations in Niger delta reservoirs by effectively reducing the rock permeability to water.

Consider a porous medium treated with a gelant. After that, the core is shut-in to allow for a 3-D gel structure gelant to be formed. When brine flow is attempted through the core, it will compress the porous medium and gel. Since, there will be no flow initiated through the core; the brine saturation will remain zero. When the critical pressure is reached, the gel yield and allows microflow through the gel and the porous medium. Core flow studies were done to ascertain the effectiveness of the formulated polymer gel as a water shutoff agent. Six (6) core samples (sandstones) from three (3) different locations in the Niger Delta were analyzed. The three locations are Reservoir 1, Reservoir 2 and Reservoir 3. Table 1 below displays the core samples dimensions.

Table 1 Dimensions of the core samples

Core Sample	Location	Weight of plug sample, grams	Length of plug sample, cm	Diameter of Plug, cm	C-sectional Area of plug, cm2
A1	Reservoir 1	101.30	6.286	3.303	8.569
A2	Reservoir 1	92.15	6.119	3.264	8.367
B1	Reservoir 2	109.45	6.080	3.205	8.068
B2	Reservoir 2	95.80	5.944	3.175	7.917
C1	Reservoir 3	75.73	5.826	3.255	8.321
C2	Reservoir 3	91.08	6.148	3.251	8.301

The composition of the polymer gel solution used for the water shutoff study is shown in Table 2 below.

Table 2 Gelant composition used for the gelation studies in Niger Delta core samples

Component	Composition	Unit
Brine Concentration	30000	ppm
Viscosity	0.9651	cp
Polyacrylamide Concentration	15000	ppm
Chromium Acetate	4000	ppm
thiourea	4000	ppm
pH	7.4	-
Polymer:crosslinker	20:1	Ratio
Simulated temperature	90	oC

The following experimental procedures were carried out to ascertain the effectiveness of the formulated polymer in shutting off water:

1. 30000ppm brine was prepared and viscosity obtained.
2. After the respective core conditioning, they were individually flooded with the prepared brine in the core holder.
3. The pressure differential between the forward and the backward flow were recorded from the differential gauge on the permeameter.
4. The Permeability of the core samples were respectively estimated using Darcy's equation (shown in Equation 1) and base permeability established for each of the core sample.
5. 15000ppm polymer gel and 4000 ppm cross linker were respectively prepared with Brine.
6. The prepared polymer gel solution was mixed with the prepared cross linker solution.
7. The prepared gel solution was used to treat the core samples while allowing a six (6) day aging time in order to give enough time for gelling of the solution under simulated reservoir temperature of about 90oC.

8. Brine was again injected into the treated core samples respectively and their respective permeability values obtained.

The Permeameter is the instrument that was used in estimating the permeability of the core samples. It measures the pressure differential across the core sample which is then plugged into the Darcy's equation to estimate permeability.

The Darcy's equation is shown in Equation 1 below:

$$K = \frac{q\mu L}{A\Delta P} \quad 1$$

Where; K is the Permeability in Darcy, q is the flow rate in cc/sec, µ is the viscosity in cp, L is the length in cm, A is the cross sectional area in cm2, and ΔP is the pressure differential in atm.

The pressure differential was in in.H2O but was converted and recorded in atm by multiplying our read off figures by 2.46 X 10-3.

The flow rate was in percentage with 100% representing 1.5cc/sec.

The canon U-tube viscometer was used in combination with the density bottle to measure the fluid viscosity. Dynamic viscosity was estimated to be 0.9651 cp.

III. RESULTS AND DISCUSSION

Two (2) samples each from three (3) different reservoirs were used for the analysis. The base permeability of the different core samples were obtained by flowing brine through the core samples in the core holder. Then, the formulated gel was injected into the core samples until a uniform distribution was attained. The core samples were then shut in for some time to allow for a proper in-situ curing of the gel. Finally, brine was passed through the polymer treated core samples under constant flow conditions to analyse the blocking efficiency of the gel. The reservoir rock permeability which was the basic property used in examining the water shutoff efficiency of the gel was measured using the liquid permeameter.

Table 3 shows the result summary obtained for sample A1 from Reservoir 1 in Niger Delta. It was observed that after treating the core sample with the polymer gel solution, the permeability reduced by over 92%. Table 4 shows the result summary for core sample A2 from Reservoir 1 in Niger Delta. It was observed that after treating the core sample with the polymer gel solution, the permeability reduced by over 90%. This is an indication that polyacrylamide polymer cross-linked with chromium acetate and thiourea is very effective in shutting off water production in Reservoir 1 in Niger Delta. Table 5 shows the result summary for core sample B1 from Reservoir 2 in Niger Delta. It was observed that after treating the core sample with the polymer gel solution, the permeability reduced by over 87%. Table 6 gives the result summary for core sample B2 from Reservoir 2 in Niger Delta. It was observed that after treating the core sample with the polymer gel solution, the permeability reduced by over 86%. This is an indication that polyacrylamide polymer cross-linked with chromium acetate and thiourea is very effective in shutting off water production in Reservoir 2 in Niger Delta. Table 7 gives the result summary for core sample C1 from Reservoir 3 in Niger Delta. It was observed that after treating the core sample with the polymer gel solution, the permeability reduced by over 89%. Table 8 gives the result summary for core sample C2 from Reservoir 3 in Niger Delta. It was observed that after treating the core sample with the polymer gel solution, the permeability reduced by over 88%. This is an indication that polyacrylamide polymer cross-linked with chromium acetate and thiourea is very effective in shutting off water production in Reservoir 3 in Niger Delta.

In all three (3) reservoirs, a total of six (6) core samples were analyzed. The analysis confirms that the gel formulated from a mixture of polyacrylamide and chromium acetate is quite effective in shutting off water. The polymer gel solution developed has a water control impact averaging over 89% at 90oC. This developed polymer will work effectively as a water control agent for reservoirs in Niger Delta.

Table 3 Effect of polyacrylamide gel on core sample A1 from Niger Delta

Parameter	Estimated Value	Unit
Base Permeability	785.47	mD
Gel treated permeability	60.70	mD
Reduction in permeability	92.27	%
Reduction factor	12.94	-

Table 4 Effect of polyacrylamide gel on core sample A2 from Niger Delta

Parameter	Estimated Value	Unit
Base Permeability	843.6	mD
Gel treated permeability	78.42	mD
Reduction in permeability	90.70	%
Reduction factor	10.76	-

Table 5 Effect of polyacrylamide gel on core sample B1 from Niger Delta

Parameter	Estimated Value	Unit
Base Permeability	661.979	mD
Gel treated permeability	85.90	mD
Reduction in permeability	87.02	%
Reduction factor	7.706	-

Table 6 Effect of polyacrylamide gel on core sample B2 from Niger Delta

Parameter	Estimated Value	Unit
Base Permeability	597.19	mD
Gel treated permeability	79.33	mD
Reduction in permeability	86.72	%
Reduction factor	7.528	-

Table 7 Effect of polyacrylamide gel on core sample C1 from Niger Delta

Parameter	Estimated Value	Unit
Base Permeability	722.851	mD
Gel treated permeability	76.7865	mD
Reduction in permeability	89.377	%
Reduction factor	9.413	-

Table 8 Effect of polyacrylamide gel on core sample C2 from Niger Delta

Parameter	Estimated Value	Unit
Base Permeability	691.817	mD
Gel treated permeability	76.5842	mD
Reduction in permeability	88.93	%
Reduction factor	9.03	-

IV. CONCLUSION

In this paper, the water blocking ability of polyacrylamide polymer cross-linked with chromium acetate/thiourea for 3 Reservoirs in Niger Delta was investigated. Based on the experimental and mathematical analysis carried on the formulated polymer gel system, it was concluded that the polyacrylamide-chromium acetate/thiourea polymer gel solution can effectively plug off water channels in Niger Delta reservoirs, and can therefore be used for water shutoff jobs in Niger Delta.

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APPENDIX

Analysis of core sample A1 (Reservoir 1)

From the experiment, the base permeability was gotten as shown below:
The permeameter was set at a flow rate, q = 10%
But recall from the method section that 100% from the permeameter represents 1.5 cc/sec
Therefore, q at 10% = 0.1 X 1.5cc/sec = 0.15cc/sec
Pressure differential read from the differential gauge, ΔP = 55 in H_20
But recall that 1 in H_20 = 2.46 X 10^{-3}atm
Hence, 55 in H_20 = 55 X 2.46 X 10^{-3} = 0.1352 atm
Putting all these into Equation 1

$$K = \frac{0.15 \times 0.9651 \times 6.286}{8.569 \times 0.1352} = 0.7855D$$

But 1D = 1000mD
0.7855D = 785.47mD.
After treating the core sample A1 with the polymer gel solution, the pressure differential read off from the two manual gauges ΔP = 1.75 atm. Therefore,

$$K = \frac{0.15 \times 0.9651 \times 6.286}{8.569 \times 1.75} = 0.0607\,Darcy$$

K = 60.70mD

Analysis of core sample A2 (Reservoir 1)

From the experiment, the base permeability was gotten as shown below:
The permeameter was set at a flow rate, q = 10%
But recall from the method section that 100% from the permeameter represents 1.5 cc/sec
Therefore, q at 10% = 0.1 X 1.5cc/sec = 0.15cc/sec
Pressure differential read from the differential gauge, ΔP = 51 in H_20
But recall that 1 in H_20 = 2.46 X 10^{-3}atm
Hence, 51 in H_20 = 51 X 2.46 X 10^{-3} = 0.1255 atm
Putting all these into Equation 1

$$K = \frac{0.15 \times 0.9651 \times 6.119}{8.367 \times 0.1255} = 0.8436\,Darcy$$

But 1 Darcy = 1000mD
0.8436 Darcy = 843.6 mD.
After treating core sample A2 with the polymer gel solution, the pressure differential read off from the two manual gauges ΔP = 1.35 atm. Therefore, the polymer gel solution treated permeability was gotten as:

$$K = \frac{0.15 \times 0.9651 \times 6.119}{8.367 \times 1.35} = 0.07842\,Darcy$$

K = 78.42 mD

Analysis of core sample B1 (Reservoir 2)

From the experiment, the base permeability was gotten as shown below:
The permeameter was set at a flow rate, q = 10%

But recall from the method section that 100% from the permeameter represents 1.5 cc/sec
Therefore, q at 10% = 0.10 X 1.5cc/sec = 0.15cc/sec
Pressure differential read from the differential gauge, ΔP = 67 in H_20
But recall that 1 in H_20 = 2.46 X 10^{-3}atm
Hence, 67 in H_20 = 67 X 2.46 X 10^{-3} = 0.1648 atm
Putting all these into Equation 1

$$K = \frac{0.15 \times 0.9651 \times 6.08}{8.068 \times 0.1648} = 0.661979\,Darcy$$

But 1 Darcy = 1000mD
0.661979 Darcy = 661.979 mD.
After treating core sample B1 with the polymer gel solution, the pressure differential read off from the two manual gauges, ΔP = 1.27 atm. Therefore, the polymer gel solution treated permeability was gotten as:

$$K = \frac{0.15 \times 0.9651 \times 6.08}{8.068 \times 1.27} = 0.0859\,Darcy$$

K = 85.90 mD

Analysis of core sample B2 (Reservoir 2)
From the experiment, the base permeability was gotten as shown below:
The permeameter was set at a flow rate, q = 10%
But recall from the method section that 100% from the permeameter represents 1.5 cc/sec
Therefore, q at 10% = 0.10 X 1.5cc/sec = 0.15cc/sec
Pressure differential read from the differential gauge, ΔP = 74 in H_20
But recall that 1 in H_20 = 2.46 X 10^{-3}atm
Hence, 74 in H_20 = 74 X 2.46 X 10^{-3} = 0.1820 atm
Putting all these into Equation 1

$$K = \frac{0.15 \times 0.9651 \times 5.944}{7.917 \times 0.1820} = 0.59719\,Darcy$$

But 1 Darcy = 1000mD
0.59719 Darcy = 597.19 mD.
After treating core sample B2 with the polymer gel solution, the pressure differential read off from the two manual gauges, ΔP = 1.37 atm. Therefore, the polymer gel solution treated permeability was gotten as:

$$K = \frac{0.15 \times 0.9651 \times 5.944}{7.917 \times 1.37} = 0.07933\,Darcy$$

K = 79.33 mD

Analysis of core sample C1 (Reservoir 3)
From the experiment, the base permeability was gotten as shown below:
The permeameter was set at a flow rate, q = 10%
But recall from the method section that 100% from the permeameter represents 1.5 cc/sec
Therefore, q at 10% = 0.10 X 1.5cc/sec = 0.15cc/sec
Pressure differential read from the differential gauge, ΔP = 57 in H_20
But recall that 1 in H_20 = 2.46 X 10^{-3}atm
Hence, 57 in H_20 = 57 X 2.46 X 10^{-3} = 0.14022 atm
Putting all these into Equation 1

$$K = \frac{0.15 \times 0.9651 \times 5.826}{8.321 \times 0.14022} = 0.722851\,Darcy$$

But 1 Darcy = 1000mD

0.722851 Darcy = 722.851 mD.

After treating core sample C1 with the polymer gel solution, the pressure differential read off from the two manual gauges, ΔP = 1.32 atm. Therefore, the polymer gel solution treated permeability was gotten as:

$$K = \frac{0.15 \times 0.9651 \times 5.826}{8.321 \times 1.32} = 0.0767865 Darcy$$

K = 76.7865 mD

Analysis of core sample C2 (Reservoir 3)

From the experiment, the base permeability was gotten as shown below:

The permeameter was set at a flow rate, q = 10%

But recall from the method section that 100% from the permeameter represents 1.5 cc/sec

Therefore, q at 10% = 0.10 X 1.5cc/sec = 0.15cc/sec

Pressure differential read from the differential gauge, ΔP = 63 in H_20

But recall that 1 in H_20 = 2.46 X 10^{-3}atm

Hence, 63 in H_20 = 63 X 2.46 X 10^{-3} = 0.15498 atm

Putting all these into Equation 1

$$K = \frac{0.15 \times 0.9651 \times 6.148}{8.301 \times 0.15498} = 0.691817 Darcy$$

But 1 Darcy = 1000mD

0.691817 Darcy = 691.817 mD.

After treating core sample C2 with the polymer gel solution, the pressure differential read off from the two manual gauges, ΔP = 1.40 atm. Therefore, the polymer gel solution treated permeability was gotten as:

$$K = \frac{0.15 \times 0.9651 \times 6.148}{8.301 \times 1.40} = 0.0765842 Darcy$$

K = 76.5842 mD

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