Polymer Injection for Water Production Control through Permeability Alteration in Fractured Reservoir

E. Bedaiwi, B. D. Al-Anazi, A. F. Al-Anazi and A. M. Paiaman

ORIGINAL SCIENTIFIC PAPER

Water production is one of the major technical, environmental, and economical problems associated with oil and gas production. Water production can limit the productive life of the oil and gas wells and can cause several problems including corrosion of tubular, fines migration, and hydrostatic loading. Produced water represents the largest waste stream associated with oil and gas production. Therefore, it is of importance to alleviate the effects of water production.

Conventionally, water production can be avoided by adopting new drilling practices such as drilling horizontal, deviated or infill wells. Different well completion designs also offers a mean to manage water production through selectively perforate dry zones, placing a liner or installing down hole flow separation equipment. Moreover, chemical treatment arises as one of the promising water-shut-off techniques through polymer flooding.

The proposed chemical technique examines two types of treatment, polymer/gel flooding, and cement squeeze. Water treatment process was carried out through permeability alteration principle. The permeability modification technique was tested using cores that simulate a Berea sandstone reservoir that is characterized by presences of channels.

The result shows that a permeability reduction from 4 500 mD to approximately 15 mD using polymer/gel and cement was successfully achieved. It was also concluded that polymer gel allows practical field applications for it its ease of preparation, storage, transport, pumping, cleaning after treatment, and need for normal injection wellhead pressure. The study also shows the applicability of the technique in a heterogeneous reservoirs dominated by channels and fractures.

Key words: polymer gel flooding, cement squeeze, water production, permeability, fractured reservoir

1. INTRODUCTION

Water shut-off is defined as any operation that hinders water to reach and enter the production wells. Water production is one of the major technical, environmental, and economical problems associated with oil and gas production. Water production not only limits the productive life of the oil and gas wells but also causes several problems including corrosion of tubular, fines migration, and hydrostatic loading. Produced water represents the largest waste stream associated with oil and gas production. Moreover, the production of large amount of water results in (a) the need for more complex water–oil separation (b) rapid corrosion of well equipments (c) rapid decline in hydrocarbon recovery and (d) ultimately, premature abandonment of the well while others use chemical to manage unwanted water production. In many cases, innovative water-control technology can lead to significant cost reduction and improved oil production.

Water shut-off without seriously damaging hydrocarbon productive zones by maximizing permeability reduction in water–source pathways, while minimizing permeability reduction in hydrocarbon zones is the target for oil and gas operators. In mature fields, oil and gas wells suffer from high water production during hydrocarbon recovery. High water production represents a serious threat to the quality of the environment due to water disposal, and is a growing concern in the petroleum industry. Today, a full range of solutions is available for virtually any type of produced water challenge. A variety of techniques and tools is available to appropriately analyze well bore and reservoir characteristics. Most importantly, diagnosing the problem so as to determine which treatment will provide the best overall technical and economical solution.

The current study presents a chemical-based water control technique in oil and gas wells and the methodology for identification and resolving the source of water production problem. It also presents some water control applications in the world and especially in Saudi Arabia and Arab-gulf area are mentioned to know the type of the problems and their solutions.[11, 13, 16]

2. SOURCES OF WATER PRODUCTION

Moawad[9] showed the mechanisms by which water can arrive at a production as (a) water coning, (b) global increase of the water oil contact, (c) water arrives through a high permeability layer, and (d) water arrives through one or more fractures that connect the aquifer to the well, see Figures (1,2,3 and 4). Gawish[7] has added (e) the casing failure or the leak behind the casing due to a weak cement layer or the channelling behind the casing and (f) the perforation in the aquifer and (g) barrier breakdown (shale) during stimulation.

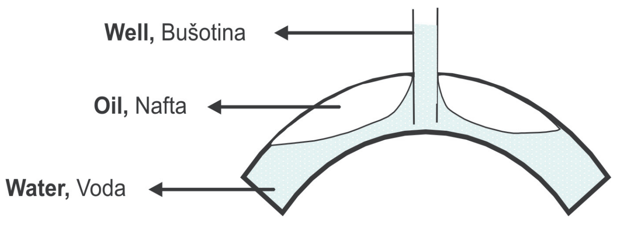

Fig. 1. Water coning[9]
Sl. 1. Vodeni konus[9]

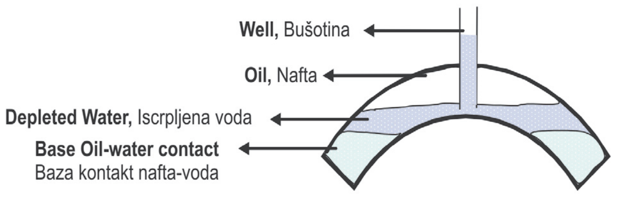

Fig. 2. Depletion of reservoir pressure causes an increase in water oil contact[9]
Sl. 2. Iscrpljenje tlaka ležišta uzrokuje porast kontakta voda nafta[9]

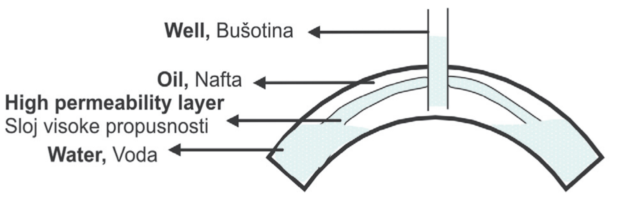

Fig. 3. Water arrives through a high permeability layer[9]
Sl. 3. Voda dolazi kroz sloj visoke propusnosti[9]

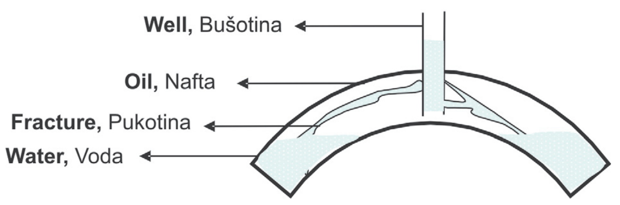

Fig. 4. Water arrives through one or more fractures that connect the aquifer with the well[9]
Sl. 4. Voda dolazi kroz jednu ili više pukotina koje povezuju vodonosni sloj s bušotinom[9]

Normally, the different permeability zones, presence of channels and fractures are the reasons for reservoir heterogeneity. In most carbonate reservoirs, natural fractures and vugs provide an easy way for water to move toward production wells. Also, reservoirs with strong bottom water drive are subjected to water breakthrough which reduces oil production as the water moves into the bottom of the perforated interval.

Numerous technologies have been developed to control unwanted water production. In order to design an effective solution, the nature of the water production must be known. The flow of water to the wellbore can occur through two types of paths. In the first type, the water usually flows to the wellbore through a separate path from that of the hydrocarbons. In this case, reducing water production increases oil and gas production rates and improves recovery efficiency. This type of water production should be the primary candidate for water control treatments. The second type of water production is water that is co-produced with oil usually later in the life of a water flood. However, controlling water production will result in corresponding reduction in oil production.[17]

2.1. Main Causes of Water Production [17,15,7,3]

1. Mechanical problems

Casing problems such as holes from corrosion, wear, excessive pressure, or formation deformation contribute to casing leaks. Often casing leaks occur where there is no cement behind the casing. Casing leak results in unwanted entry of water and unexpected rise in water production. In addition, the water entry in the wellbore can cause damage to the producing formation due to fluid invasion.

2. Completion related problems

The common completion related problems are channel behind casing, completion into or close to water zone, and fracturing out of zone. Channels behind casing can result from poor cement-casing or cement-formation bonds. Channels behind casing can develop throughout the life of a well, but are most likely to occur immediately after the well is completed or stimulated.

3. Fracturing out of zone

When wells are hydraulically fractured, the fracture often breaks into water zones. In such cases, coning through hydraulic fracture can result in substantial increase in water production. In addition, stimulation treatments can cause barriers breakdown near the wellbore as mentioned.

4. Reservoir depletion

Water production is an expected consequence of oil or gas production. There is very little that can be done to reduce water production in a depleted reservoir. Generally at the later stages of production the focus of water control will shift from preventing water production to reducing cost of produced water.

3. WATER SHUT-OFF TECHNIQUES

Water shut-off is defined as any operation that hinders water to reach and enter production wells. There exist countless number of techniques such as polymer and polymer/gel injection, different types of gel systems, organic/metallic cross linkers, and a combined between them, mechanical solution, cement plug solution and other hundreds of different mechanical and chemical methods for water shut-off.

3.1. Well configuration and well completions

The number of injection and production wells required to produce a field suggests the approach of selecting the optimum pattern and spacing. Different well pattern models, including line-drive, five, seven and nine spot, normal or inverted, could be developed for different well spacing under different well and reservoir conditions.[9]

Designing optimal well configuration, completions and replacements using new technologies starting with drilling techniques until the reservoir simulation, has the capability to increase oil recovery and reduce water production. The strategies of drilling and completion options are numerous. Some of the basic concepts are:

(a) Drilling a vertical well with open or cased and perforated completion either production or injection well;

(b) Drilling a horizontal and/or deviated well, or perhaps multilateral wells;

(c) Extending the use of an old well by re-perforating new productive zones.

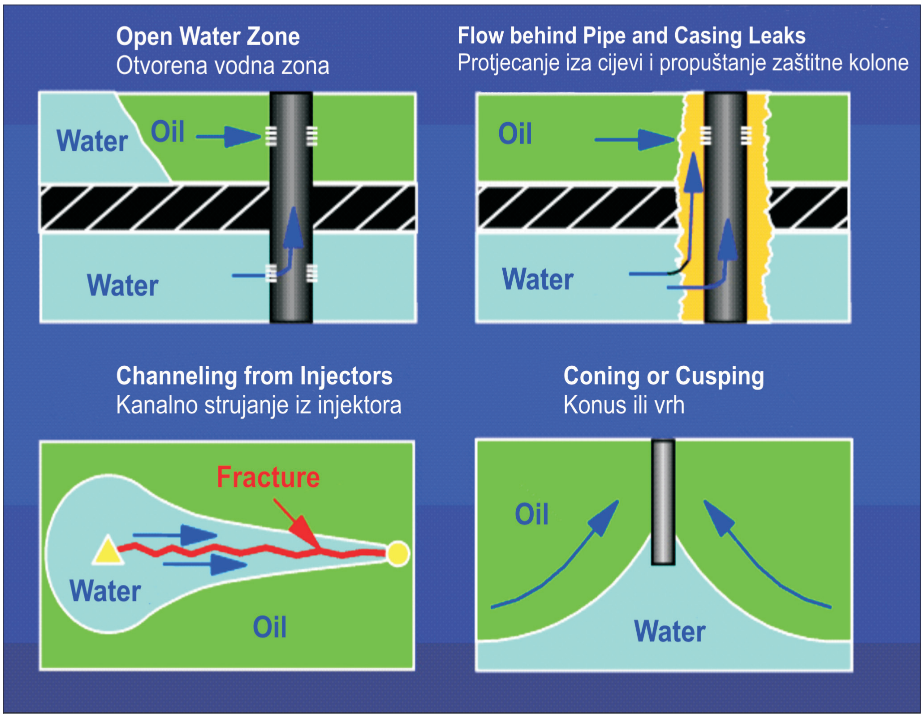

Fig. 5. Examples of water sources[17]
Sl. 5. Primjeri izvora vode[17]

3.2. Mechanical solution

In many near wellbore problems, such as casing leaks, flow behind casing, rising bottom water and watered out layers without crossflow, and in the case of bottom water beginning to dominate the fluid production, the perforations are sealed-off with a cement-squeeze, packer or plug. The well is re-perforated above the sealed zone, and oil production is resumed. This process is continued untill the entire pay zone has been watered out. This method is one of the easiest ways to control water coning.[4, 9]

3.3. Mechanical and cement treatment

Using squeeze cement alone is not sufficient. This is attributed to the fact that the size of the standard cement particles restricts the penetration of the cement into channels, fractures and high permeable zones, only about 30% success is reported.

The easiest method to control water coning when bottom water begins to dominate the fluid production is to seal off the perforations with a cement-squeeze, packer or plug. The well is then re-perforated above the sealed zone, and oil production is resumed. This process is continued until the entire pay zone has been watered out. However, these techniques require separated and easily identifiable oil and gas producing zones. Where possible, mechanical zone isolation by cement squeezes or plugging type gels can be the easiest way to shut off water coning from watered out layers. Very often excessive water-cuts can be reduced by re-completing the well or by placing mechanical devices to isolate the water producing zones. These solutions however, are expensive and can cause in micro-layered formations, the loss of volumes of hydrocarbons.[4, 7]

3.4. Chemical solution

Chemical treatments require accurate fluid placement, and including polymer/gel injection, different types of gel systems, organic cross linkers, metallic cross-linkers and combined between them as means of improving flooding efficiency are needed in heterogeneous reservoirs to reduce water production and improve oil recovery.[4,9]

4. POLYMER FLOODING TREATMENT

Polymer flooding (Chemical Enhanced Oil Recovery; EOR) is a very important method for improving the water flooding sweep efficiency to increase oil recovery and reduce water production. It can yield a significant increase in percentage recovery by reducing the water production and improving the recovery when compared to the conventional water flooding in certain reservoirs.[9]

4.1. Polymer types

There are two basic categories of polymers which are used in the field applications; biopolymers and synthetic polymers. Biopolymers include xanthan gums,

Table 1. A comparison between different polymers after Loetsch[9]

Type	Advantages	Disadvantages
PAA: Polyacrylamide (Partially hydrolyzed)	- high yield in normal water - high injectivity	- not salt resistance - shear sensitivity - O_2 sensitivity
Hydroxyethylcellulose (HEC)	- well soluble - resistance salt	- pH sensitivity - Fe^{+3} sensitivity - low temperature resistance - no structure viscosity
Biopolysaccharide (Xanthan, Scleroglucan)	- high yield in salt water - shear stable - temperature stable - low adsorption value	- problem of injection - bacteria sensitivity - O_2 sensitivity - high cost
Co- and Terpolymers	- well soluble - salt resistance - temperature stable - shear stable	- O_2 sensitivity - high cost

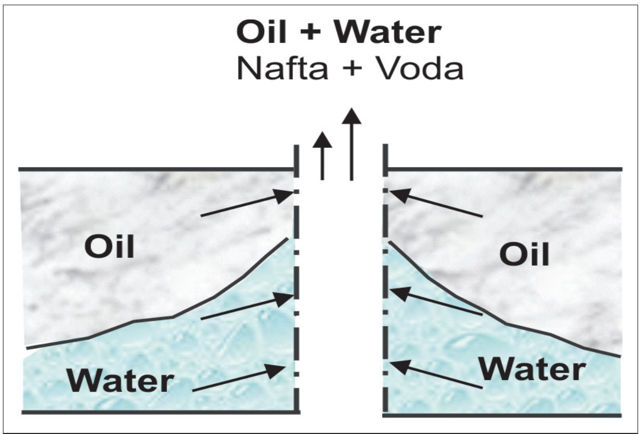

Fig. 6. Water coning before polymer treatment[9]
Sl. 6. Formiranje vodenog konusa prije tretmana polimerom[9]

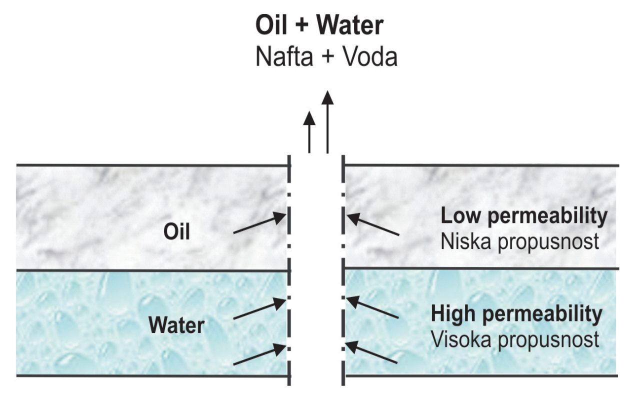

Fig. 8. Profile correction by polymer in heterogeneous reservoirs before treatment[9]
Sl. 8. Korekcija profila polimerom u heterogenim ležištima prije tretmana[9]

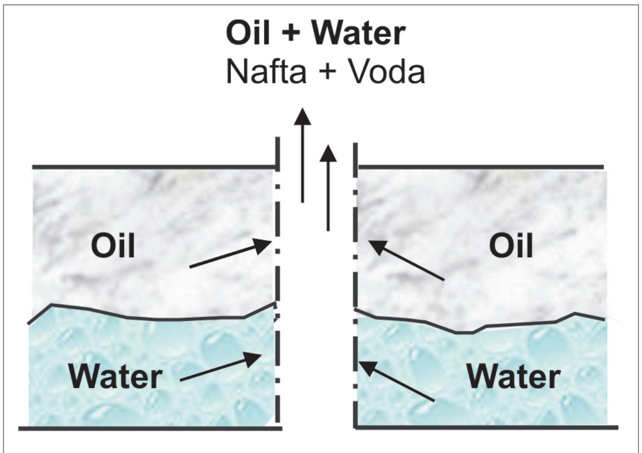

Fig. 7. Water coning after polymer treatment[9]
Sl. 7. Formiranje vodenog konusa nakon tretmana polimerom[9]

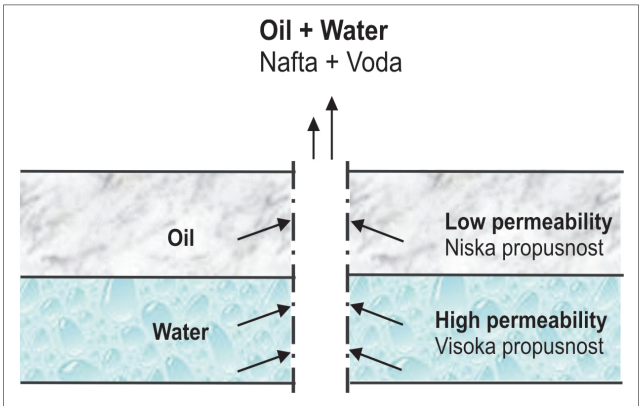

Fig. 9. Profile correction by polymer in heterogeneous reservoirs after treatment[9]
Sl. 9. Korekcija profila polimerom u heterogenim ležištima nakon tretmana[9]

hydroxyethyl cellulose, glucan, and guar gum, all of high molecular weight, obtained from the fermentation of natural substances rich in glucides. Synthetic polymers include high molecular weight partially hydrolysed polyacrylamides (HPAMs); copolymers of acrylamide and terpolymers.[9]

A comparison between advantages and disadvantages for polyacrylamide, hydroxyethylcellulose, biopolysaccharide, co- and terpolymers is listed in Table 1, see Figures (6, 7, 8 and 9).

5. FIELD EXAMPLES

5.1. Water shut-off results in high permeability zones in Saudi Arabia[1]

Production Wells in one of Saudi Aramco oil fields was reported to produce under flowing conditions with pressure support provided by a peripheral water flood. As the water flood matures, water breakthrough occurs in the lower zones of the oil wells and production rates decline. In this case, extensive work has been done by Saudi Aramco to reduce water cycling and increase oil rates in one area of the field. The field results from 49 bottom water shut-off jobs during the last 6 years and the success in reducing water production and increasing oil rates by the different methods are compared and presented in the same reference[1]. The techniques were carried out during workover and/or wireline jobs.

5.2. Water shut-off in high angle wellbore in Ghawar field[3]

The Hawiyah area of the Ghawar field produces from the Arab-D reservoir. This reservoir consists of four zones that have different permeabilities, is highly fractured and faulted, is in hydraulic communication through fault planes and vertical fractures. The field is under pressure maintenance using seawater injection from the flanks. The field is being developed by drilling highly deviated and horizontal wells. Many of these wells died right after drilling or after a short period of production due to excessive water production from high flow intervals. This case describes the successful application of rigless water shut-off in highly deviated well bores using inflatable plugs set by coiled tubing and with cement placed on the top to reduce excessive water production. This technique was successfully employed to reduce water production and revive dead wells in Hawiyah area of the Ghawar field.

5.3. Water production in the South Umm Gudair field, in Kuwait[5]

The producing history of the South Umm Gudair Field (SUG) is characterized by increasing water cuts and increasing decline rates. Several different conventional techniques were applied to mitigate the effects of water encroachment. While some earlier applications were seem to be promising, later applications were often marginal. Consequently, horizontal sidetracking was introduced in the SUG field. A total of 15 horizontal sidetracks were performed from 1999 to 2004, resulting in both increase in oil production and reduction in water cut.

5.4. Water shut-off job using two new polymer systems in Wafra Ratawi field, Kuwait[5]

With the introduction of water injection in the Wafra Ratawi Oolite reservoir, in the Partitioned Neutral Zone of Saudi Arabia and Kuwait, water production was reported especially after drilling horizontal wells. An economical method to reduce this unwanted water influx was needed. The process was complicated in the horizontal open hole producing wells. A cost-effective water control method of temporarily protecting the producing horizontal section was needed to protect the potential oil producing zone for future post-treatment production.

5.5. Water shut-off system by using gel-cement in a Syrian field[6]

Water production in the North east of Syria has increased significantly in recent years. As a result costs per barrel of oil have increased and the field production is currently constrained by the facilities capacity. The gel that is used as 'mix water' of the cement will be squeezed into the matrix creating a shallow matrix shut off. The cement will remain in the perforation tunnel as a rigid seal. This system showed superior shut off performance in the laboratory compared to normal cement squeeze techniques. Selective perforation of the hydrocarbon zones will resume oil production. The shut off zones can be re-opened later in the well's life when artificial lift has been installed. In the first field trial 84 meters of perforations (gross) were squeezed of with gel-cement in a single attempt. After re-perforation of the top and the middle zone, the well was produced at a strongly reduced water cut, i.e. 25-33% compared to 60-62% before the treatment, and an increased oil production of 477 m^3/d (3 000 bbl/d) compared to 159 m^3/d (1 000 bbl/d) before the treatment was noticed. The oil production declined to 318 m^3/d (2 000 bbl/d) over a year as the water cut gradually increased to 56%.

6. CEMENT AND POLYMER GEL EXPERIMENT

This study will present a cement and polymer gel application for water shut-off. Berea Sandstone cores that are dominated by channels and other cores absent of channels were used to demonstrate the proposed methodology. The experiment is explained in the following sections.

6.1. Slurry preparation

A propeller type mixing device is commonly used to prepare well cement slurries. The mixer is operated at 4 000 rpm for 15 seconds during which all of the cement solids should be added to the mix water, followed by 35 seconds at 12 000 rpm. Variations in mixing procedures can alter the resultant slurry properties. The disadvantage of this procedure is that the foam is not present under simulated high-pressure field conditions. Recently, some pressurized testing methods were described by Rozieres and Ferriere.

Table 2. The properties of the Berea Sandstone cores

Properties	Berea Sandstone I	Berea Sandstone II
L	11.236 cm	9.874 cm
d	4.978 cm	5.08 cm
A	19.46 cm^2	20.2 cm^2
v_b	218.67 cm^3	200 cm^3
ω_{dry}	429.7 cm^3	398.1 cm
ω_{sat}	472.3 gm	433.8 gm
v_p	42.6 gm	35.7 gm
Φ	19.5%	17.85%
k	131 mD	131 mD
$k_{with\ channel}$	4 415 mD	4 415 mD

Table 3. Permeability of Berea Sandstone I and II

Δp psi	Δp atm	p.v. injected cm³	p.v. injected %	q cm³/min	k mD
2.69	0.1830	110	2.58	2.5	131.4688
2.7	0.1837	122.5	2.88	2.5	130.9819
2.69	0.1830	135	3.17	2.5	131.4688
2.69	0.1830	147.5	3.46	2.5	131.4688

Table 4. Permeability of Berea Sandstone I and II with channels

Δp psi	Δp atm	p.v. injected cm³	p.v. injected %	q cm³/min	k mD
0.1	0.007	6.25	0.15	3.125	4 420.638
0.1	0.007	12.5	0.29	3.125	4 420.638
0.11	0.007	18.75	0.44	3.125	4 018.762
0.1	0.007	25	0.59	3.125	4 420.638
0.1	0.007	31.25	0.73	3.125	4 420.638
0.1	0.007	37.5	0.88	3.125	4 420.638
0.1	0.007	43.75	1.03	3.125	4 420.638
0.11	0.007	50	1.17	3.125	4 018.762
0.11	0.007	56.25	1.32	3.125	4 018.762
0.11	0.007	62.5	1.47	3.125	4 018.762
0.11	0.007	68.75	1.61	3.125	4 018.762
0.1	0.007	75	1.76	3.125	4 420.638
0.1	0.007	81.25	1.91	3.125	4 420.638
0.1	0.007	87.5	2.05	3.125	4 420.638
0.1	0.007	93.75	2.20	3.125	4 420.638
0.1	0.007	100	2.35	3.125	4 420.638
0.1	0.007	106.25	2.49	3.125	4 420.638
0.1	0.007	112.5	2.64	3.125	4 420.638
0.1	0.007	118.75	2.79	3.125	4 420.638
0.1	0.007	125	2.93	3.125	4 420.638
0.1	0.007	131.25	3.08	3.125	4 420.638
0.1	0.007	137.5	3.23	3.125	4 420.638
0.1	0.007	143.75	3.37	3.125	4 420.638
0.1	0.007	150	3.52	3.125	4 420.638
0.1	0.007	156.25	3.67	3.125	4 420.638
0.1	0.007	168.75	3.81	3.125	4 420.638

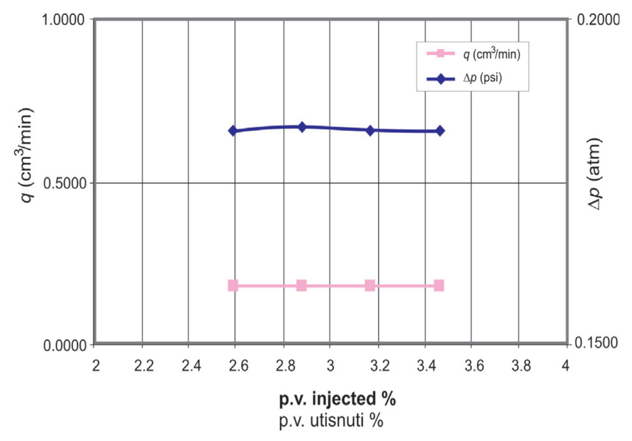

Fig. 10. Relation between injected pore volume vs. difference pressure and flow rate for Berea Sandstone I and II
Sl. 10. Odnos između utisnutog pornog volumena i razlike tlaka i kapaciteta protjecanja za Berea pješčenjak I i II

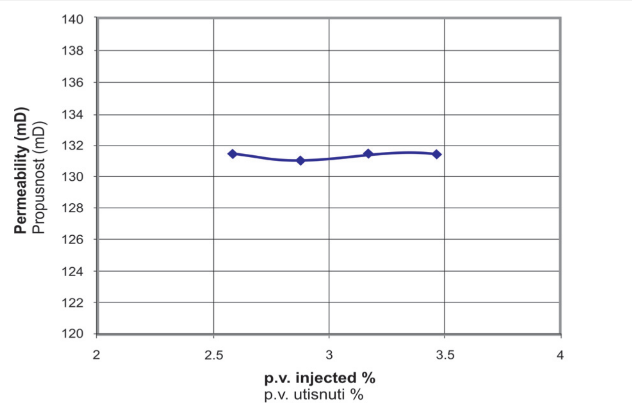

Fig. 11. Relation between injected pore volume vs. permeability for Berea Sandstone I and II
Sl. 11. Odnos između utisnutog pornog volumena i propusnosti Berea pješčenjaka I i II

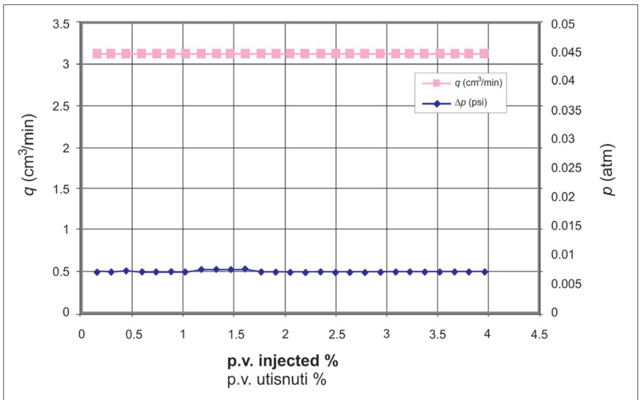

Fig. 12. Relation between injected pore volume pressure difference and flow rate for Berea Sandstone I and II with channels
Sl. 12. Odnos između razlika tlaka utisnutog pornog volumena i kapaciteta protjecanja za Berea pješčenjak I i II

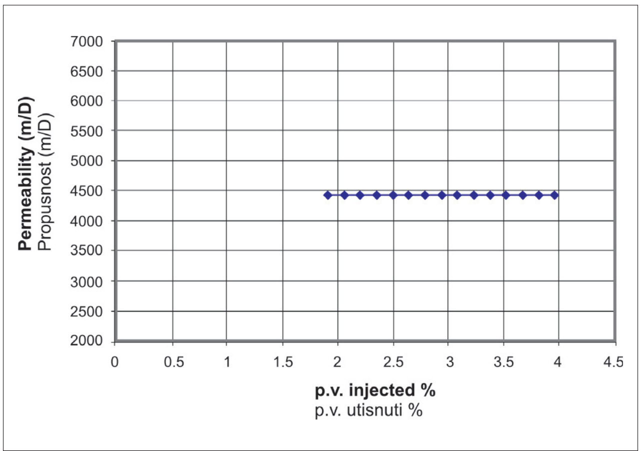

Fig. 13. Relation between injected pore volume vs. permeability for Berea Sandstone I and II with channels
Sl. 13. Utisnuti porni volumen u odnosu na propusnost Berea pješčenjake I i II s kanalima

Design of the polymer gel for treatment Berea Sandstone I

Material	Quantities, g
Polymer 5%	16.5 From polymer solution (15%)
Distilled Water	32
Cross-linker 5 000	1.5 From X-Linker solution with (11.5%)

6.2. Thickening time

Thickening time tests are designed to determine the length of time in which cement slurry remains in a pumpable fluid state under simulated wellbore conditions of pressure and temperature. The test slurry is evaluated in a pressurized consistometer. The end of a thickening time test is defined when the cement slurry reaches a consistency of 100 Bc, however 70 Bc is generally considered to be the maximum pumpable consistency. The (Bc) Bearden units are a dimensionless quantity that measures the pumpability of the cement ranges from 0 to 100. Temperature and pressure affect measured thickening time.

6.3. Compressive strength

An estimation of compressive strength from ultrasonic velocity is a recent development. The Ultrasonic Cement Analyzer (UCA) measures the sonic travel time of ultrasonic energy through a cement sample as it cures under simulated wellbore and reservoir conditions of temperature and pressure. The ultrasonic velocity directly measures the bulk compressibility of the sample. Compressive strength measurements are designed to furnish some indication of the ability of set cement to provide zonal isolation.

Table 5. Permeability of Berea Sandstone I after treatment by polymer gel

Δp psi	Δp atm	p.v. injected cm^3	p.v. injected %	q cm^3/min	k (mD)
33	2.245	17	0.40	3.4	14.57
32.68	2.223	34	0.80	3.4	14.72
32.9	2.238	51	1.20	3.4	14.62
32.6	2.218	68	1.60	3.4	14.75
32.78	2.230	85	2.00	3.4	14.67
32.88	2.237	102	2.39	3.4	14.63
32.66	2.222	119	2.79	3.4	14.73
33	2.245	136	3.19	3.4	14.57
32.28	2.196	153	3.59	3.4	14.90
33	2.245	170	3.99	3.4	14.57
37.03	2.519	192.5	4.52	4.5	17.19
37.34	2.540	215	5.05	4.5	17.05
37.72	2.566	237.5	5.58	4.5	16.88
37.4	2.544	260	6.10	4.5	17.02
38	2.585	282.5	6.63	4.5	16.75
37.8	2.571	305	7.16	4.5	16.84

Table 6. Permeability of Berea Sandstone I after one month

Δp psi	Δp atm	p.v. injected cm^3	p.v. injected %	q cm^3/min	k *(mD)*
34.35	2.34	17.5	0.411	3.5	14.41
34.3	2.33	35	0.822	3.5	14.43
34	2.31	52.5	1.232	3.5	14.56
33.92	2.31	70	1.643	3.5	14.60
33.87	2.30	87.5	2.054	3.5	14.62
34.2	2.33	105	2.465	3.5	14.48
39.3	2.67	129	3.028	4.8	17.28
39.78	2.71	153	3.592	4.8	17.07
39.38	2.68	177	4.155	4.8	17.24
39.44	2.68	201	4.718	4.8	17.22
39.25	2.67	225	5.282	4.8	17.30
39.32	2.67	249	5.845	4.8	17.27
33	2.24	266.5	6.256	3.5	15.00
33.42	2.27	284	6.667	3.5	14.81
33.7	2.29	301.5	7.077	3.5	14.69
33.7	2.29	319	7.488	3.5	14.69
33.8	2.30	336.5	7.899	3.5	14.65

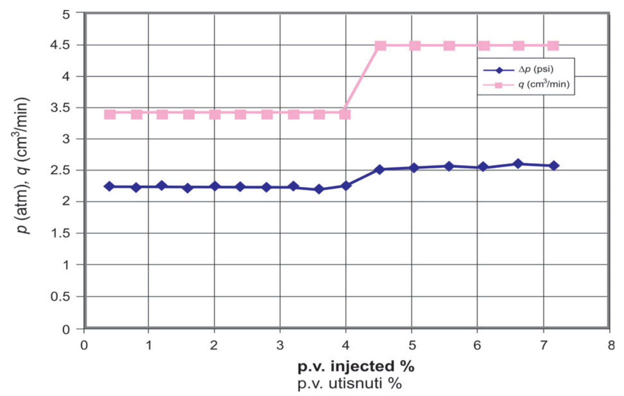

Fig. 14. Relation between injected pore volume vs. pressure difference and flow rate for Berea Sandstone I after treatment by polymer gel
Sl. 14. Odnos između utisnutog pornog volumena i razlike tlaka i kapaciteta protjecanja za Berea pješčenjak I nakon obrade s polimernim gelom

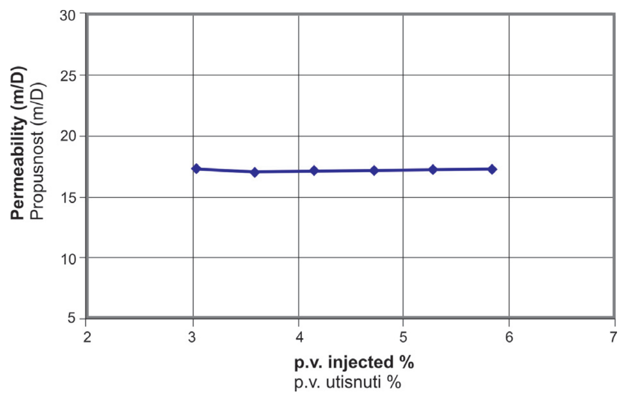

Fig. 17. Relation between injected pore volume vs. permeability for Berea Sandstone I after treatment by polymer gel after one month
Sl. 17. Utisnuti porni volumen u odnosu na propusnost Berea pješčenjaka I poslije obrade polimernim gelom, nakon mjesec dana

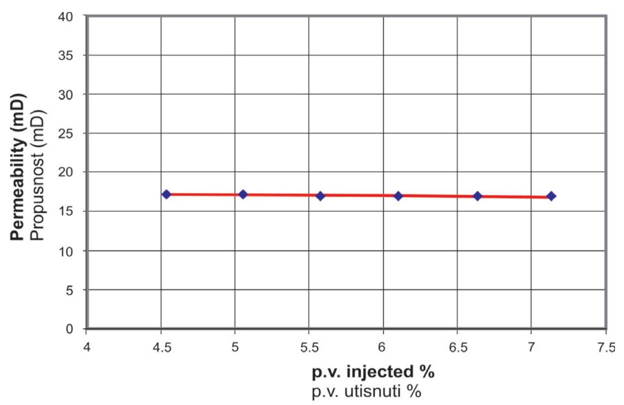

Fig. 15. Relation between injected pore volume vs. permeability for Berea Sandstone I after treatment by polymer gel
Sl. 15. Odnos između utisnutog pornog volumena i propusnosti Berea pješčenjaka I nakon obrade s polimernim gelom

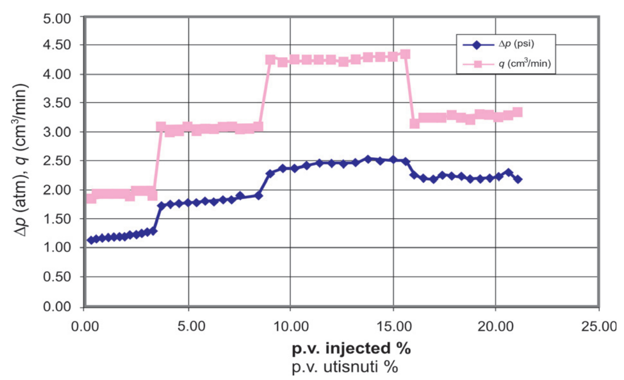

Fig. 18. Relation between injected pore volume vs. pressure difference and flow rate for Berea Sandstone I after treatment by cement squeeze
Sl. 18. Odnos između utisnutog pornog volumena i diferencijalnog tlaka i kapaciteta protjecanja za Berea pješčenjak I, poslije obrade cementacijom pod visokim tlakom

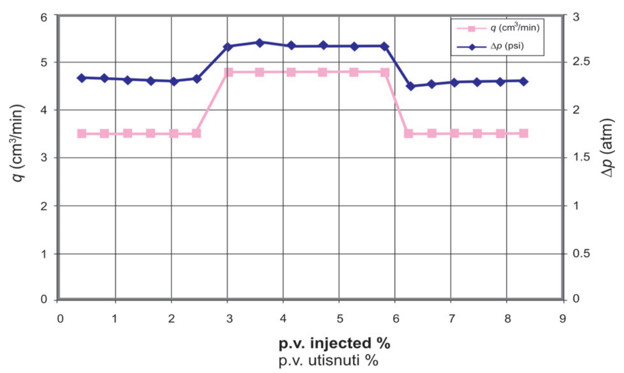

Fig. 16. Relation between injected pore volume vs. pressure difference and flow rate for Berea Sandstone I after one month
Sl. 16. Utisnuti porni volumen u odnosu na razliku tlaka i kapaciteta protjecanja za Berea pješčenjak I nakon mjesec dana

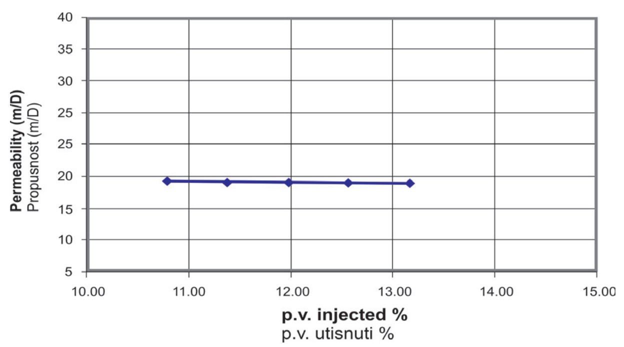

Fig. 19. Relation between injected pore volume vs. permeability for Berea Sandstone II after treatment by cement squeeze
Sl. 19. Odnos između utisnutog pornog volumena i propusnisti Berea pješčenjaka II poslije tretmana cementacijom pod visokim tlakom

Design of the Cement Slurry for Treatment Berea Sandstone II.

Table 7. Permeability of Berea Sandstone II after treatment by cement squeeze

Δp psi	Δp atm	p.v. injected cm^3	p.v. injected %	q cm^3/min	k (mD)
16.75	1.14	9.25	0.26	1.85	13.23
17.12	1.16	19.00	0.53	1.95	13.64
17.20	1.17	28.75	0.81	1.95	13.58
17.40	1.18	38.50	1.08	1.95	13.42
17.60	1.20	48.25	1.35	1.95	13.27
17.60	1.20	58.00	1.62	1.95	13.27
17.64	1.20	67.75	1.90	1.95	13.24
18.11	1.23	77.25	2.16	1.90	12.56
18.00	1.22	87.25	2.44	2.00	13.31
18.54	1.26	97.25	2.72	2.00	12.92
18.87	1.28	107.25	3.00	2.00	12.69
19.07	1.30	116.75	3.27	1.90	11.93
25.50	1.73	132.25	3.70	3.10	14.56
25.75	1.75	147.25	4.12	3.00	13.95
26.00	1.77	162.25	4.54	3.00	13.82
26.29	1.79	177.75	4.98	3.10	14.12
26.17	1.78	192.75	5.40	3.00	13.73
26.60	1.81	208.00	5.83	3.05	13.73
26.38	1.79	223.25	6.25	3.05	13.85
27.02	1.84	238.75	6.69	3.10	13.74
26.97	1.83	254.25	7.12	3.10	13.77
28.02	1.91	269.50	7.55	3.05	13.04
27.80	1.89	284.75	7.98	3.05	13.14
28.15	1.91	300.25	8.41	3.10	13.19
33.62	2.29	321.50	9.01	4.25	15.14
34.86	2.37	342.50	9.59	4.20	14.43
34.86	2.37	363.75	10.19	4.25	14.60
35.70	2.43	385.00	10.78	4.25	14.26
36.25	2.47	406.25	11.38	4.25	14.04
36.31	2.47	427.50	11.97	4.25	14.02
36.06	2.45	448.50	12.56	4.20	13.95
36.42	2.48	469.75	13.16	4.25	13.98
37.29	2.54	491.25	13.76	4.30	13.81
36.82	2.50	512.75	14.36	4.30	13.99
37.17	2.53	534.25	14.96	4.30	13.85
36.76	2.50	556.00	15.57	4.35	14.17
33.26	2.26	571.75	16.02	3.15	11.34
32.40	2.20	588.00	16.47	3.25	12.01
32.25	2.19	604.25	16.93	3.25	12.07
33.16	2.26	620.50	17.38	3.25	11.74
32.99	2.24	637.00	17.84	3.30	11.98
32.87	2.24	653.25	18.30	3.25	11.84
32.21	2.19	669.25	18.75	3.20	11.90
32.17	2.19	685.75	19.21	3.30	12.28
32.37	2.20	702.25	19.67	3.30	12.21
32.88	2.24	718.50	20.13	3.25	11.84
33.91	2.31	735.00	20.59	3.30	11.65
32.15	2.19	751.75	21.06	3.35	12.48

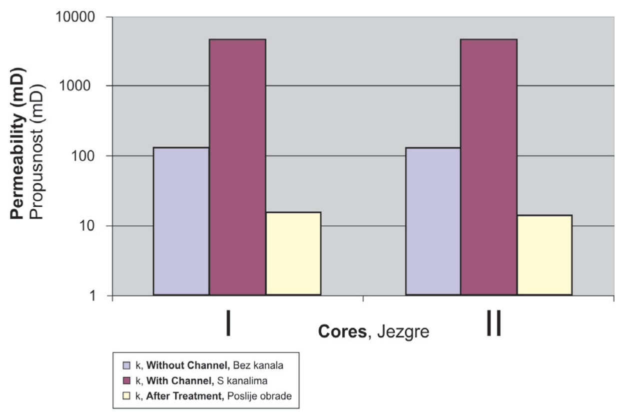

Fig. 20. Permeability comparison using cement and polymer/gel of the core samples
Sl. 20. Usporedba propusnosti uzoraka jezgre kod korištenja cementa i polimernog gela

7. PROCEDURE OF THE EXPERIMENT

The principle equipment used in this study consisted of flooding apparatus. The effect of the polymer gel and cement on water shut-off was investigated using core sample saturated with water (3% NaCl). However, to achieve the objective of this study the following laboratory procedures were established:

1. The petrophysical of the core samples were determined using core flow apparatus as shown in Table 2.
2. The core sample was evacuated using vacuum pump and was saturated with brine.
3. The core sample was placed in the core holder with rubber sleeve around, at confining pressure was applied with manual pump (500 psi/34 atm).
4. The core permeability was then calculated at constant injection flow rate by recording the pressure drop between the inlet and outlet sides using Darcy equation.
5. The base permeability of the core samples was approximately by 131 mD and values at different flow rates were recorded as illustrated in Figures 10 and 11.
6. The permeability of the core samples with channels reached approximately 4 400 mD at constant flow rate of 3.2 of cm^3/min as shown in Figures 7 and 8.
7. The permeability of core sample I decreased to 15 mD after it has been treated by polymer/gel as shown in Figure 10.
8. Th cement squeeze in the channels showed a decrease in permeability to approximately 14 mD as can be seen in Figure 19.

8. CONCLUSION

1. Both cement and polymer/gel has shown a decrease in effective permeability from 4 500 mD to approximately 15 mD.
2. Polymer/gel was observed to be easy for pumping and cleaning after treatment.
3. Polymer/gel has shown lower injection pressure compared to cement injection.
4. Polymer/gel can be injected deeper into fractures and channels compared to cement slurry.
5. Polymer/gel has advantageous feature over cement by breaking down inside the oil zone.

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Authors:

Emad Bedaiwi, *Completion & Stimulation Field Engineer, BJ Services Arabia Ltd.*, EBedaiwi@bjservices.ae

Bandar Duraya Al-Anazi, *Research Assistant ,King Abdulaziz City for Science & Technology*, bandar.alanazi@gmail.com

Ammal Fannoush Al-Anazi, *Saudi Aramco Ammal.*, anazi@aramcoservices.com

Abouzar Mirzaei Paiaman, *Sharif University of Technology*, Mirzaei1986@gmail.com