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Water Flooding for Variation of Petrophysical Properties in Zubair Reservoir/West Qurna Oil Field

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ABSTRACT

This paper illustrates a study on the damages of the petrophysical properties, in particular, the porosity and permeability as a result of the flooding of water in West Qurna field . Five core samples of sandstone were provided from the formation of Al-Zubair in West Qurna field at depths (3219-3246) meters by the South Oil Company. The plugs were sectioned, then cleaned and dried, after which the petrophysical properties of rocks such as porosity and permeability were tested by many devices such as Gas Prosimeter, Liquid, and Gas Permeameter, Scanning Electron Microscopy, GeoSpec2 apparatus, and OFITE Spectral Gamma Ray Logger apparatus. Gas and liquid permeability were detected by the Gas Permeameter, liquid Permeameter, and GeoSpec2 instrument. Tests for porosity and permeability were performed before the flooding by gas, liquid, and GeoSpec2 devices, where the results of gas devices showed higher values than the results of liquid and GeoSpec2 devices due to the possibility of gas slipping, and therefore the gas results were corrected to ignore the effect of gas slipping using the Klink Enberg correction. The injection water was supplied from Dammam Formation by the South Oil Company. It was analyzed by Nahran Omar Laboratory / Basra. As the results show that it has very high salinity. A flooding system was devised to study the permeability damage resulting from the water injection. Various pore volumes were injected through the plugs at three interstitial velocities to show the influence of pore injected and choosing the best velocity for flooding. The best velocity inside the sample that causes less damage was the high velocity which is 627ft/day. The percentage of damage ratio was determined for each core sample at three velocities. It was low at a high velocity. By comparing all the results of permeability before and after the water flooding process, it was clear a significant reduction in the permeability values. Injecting a large amount of water over a long period of time is an effective method enhanced oil recovery methods for reservoirs for Al-Zubair in West Qurna field.

KEYWORDS

enhanced oil recovery, Waterflooding, petrophysical properties, Zubair reservoir, permeability.

INTRODUCTION

In the early life of oil reservoir production processes, production rates of hydrocarbons begun high where natural reservoir energy such as water drive or gas cap drive leads to pushing the oil toward the inlet and out of the well. Over the lifetime of oil, production rates start to drop off and both gas cap & water drive become depleted. Various techniques can be employed for increasing recovery of hydrocarbons, known as (EOR) Enhanced Oil Recovery such as CO2, saline water, steam flooding, or other fluids and materials. Water flooding has been utilized across the world as a method to maintain the pressure and increase the hydrocarbon recovery factor, furthermore to remove the undesirable water which is produced in the oil and gas wells [1]. The primary, secondary, and tertiary oil recovery are conventionally used to characterize hydrocarbons recovered according to the production method. The first method (primary oil recovery) describes the hydrocarbons production under the natural mechanisms presented without the additional help of injecting fluids like water or gas. The second (secondary oil recovery) presents the extra recovery that results from the traditional methods of immiscible gas injection and water injection.

Water flooding is the most mutual method of secondary oil recovery. Petrophysical properties are used to obtain the required information for reservoir rocks, in order to help the petroleum designer engineers in the calculation for planning well completion and hydrocarbon reserves during the reservoir operation life. The most important petrophysical properties are; porosity and permeability [2]. The reduction in petrophysical properties in the reservoir represents damage in that formation. During the period between the initial drilling and completion of wellbore production, the formation damage can occur at any time through this period. The Consequence of formation damage causes a reduction of reservoir productivity which is a non-economic operation. Water flooding is a common technology applied in heavy oil reservoirs after primary production, but the actual recovery mechanisms are still poorly understood [3]. After the development of water flooding, many changes may occur in the permeability and porosity of sandstone reservoirs at the time of development. The porosity and permeability changes are mainly affected by reservoir properties, well density, and water injection time [4].

Mungan made a test to research the function of changes in PH and salinity in damaging the core sample wherever formation damaged (reduction in permeability) [5]. He imputed the damage due to expand or disperse the clay mineral when connecting with less saline water than formation water, and then he referred to the primary cause of damage by blocking the pore path by dispersed particles. In any case of the type of clay core, permeability damage occurred as a result of salinity changes where the flow of acidic or alkaline solutions released the damaged clays. He used cores from the reservoir at the temperature of the reservoir and room. The Flow rate of fluids pumped across the cores was constant in all tests of permeability. Some researchers studied the passing behavior of particles that block the porous media [6]. Tests comprised of pumping clay suspension into sand pack under various conditions, measure the distribution of pore size, and observation of permeability and streaming particles concentration. Another researchers studied the formation damage and its impact on the production rate in the limestone reservoir [7].

He concluded that a high PH enhanced the formation damage due to the deposition of particles into porous and thus blocking the pore throats. Both of permeability and injectivity of wells reduction were used as quantitative measure to the formation damage during water flooding in oil reservoirs. Some researchers in their research included the study of factors that influenced on the productivity of well in two papers [8]. In the first one, they studied the invasion of drilling fluid particles in the porous media and their effects on permeability oil. Experiments had been carried out in which particular sized particles were added to the base mud. They concluded that the particle with less than one micron through the core near-wall surface caused considerable permeability damage and the particle with size 1-6 micron caused an increase in recovery. Noticed a difference in the infectivity level through the core samples in the laboratory and reservoir [9]. They proposed that the difference was caused because of the presence of a microfracture in the face of the wellbore which caused increasing in injectivity. Empirical results of offered water quality by permeability profiles gained with a multiport pressure core holder that explained the particle size and rock properties were a function to permeability impairment [10].

Muecke concentrated on both single and multi-phase fluid flow in the porous media and their influence on the movement of a fine particle [11]. Most of their studies of fines were in consolidated sandstone, but here the unconsolidated sandstone was chosen because of the capability of fine particles to separate facilely from larger sands. Gabriel and Inamdar performed an overall test for the chemical and mechanical (motivation, immigration, and plugging) interactions [12]. From the results of the test, flooding of the chemical compatible fluid at a velocity overtook the critical value in the core samples caused in acute permeability damage; however, the total damage in the permeability resulted when chemical incompatible fluid was flooded even before excessing the critical value of velocity. McCune used a device to filter the injection brine to 0.45 micron and remove the suspended solids for purpose of detecting water quality for used it in water flooding [13]. He imputed that the losses of permeability for the chemical interaction as PH and salinity changes, solid's deposition, the sensitivity of rock at the filtration level (0.45 micron). Eleri and Ursin made an empirical survey for 17 core samples and 25 runs [14].

The objective of their research was to seek the various mechanical and physical aspects which caused the formation damage as a result of motivation and deposition of suspended. Pore size, particle sizes, initial flow rate, and linear velocities through porous media were a function of particle movement within porous media. Vetter et al. conducted from their literature survey by using maximum permeability 200 md, that the usually agreeable philosophy, sub-micrometer particles may come in the reservoir rock to cause acute damage to the tight sandstone [15]. The present work aims to develop the formation by decrease the permeability in samples of West Qurna sandstone affected by water flooding that recovered from al Dammam Formation, which is injected directly without treatment and then, studies the causes of the alteration imposed on porosity and permeability, evaluate the advantage and disadvantage of water flooding, and determine the optimum velocity of water flooding to increase the permeability and minimize the alteration.

THEORY

The rock porosity is a function of storage capacity that can be holding fluids. Also, it can be defined as a ratio of the pore volume to the total volume. Porosity is classified into two distinct types: absolute porosity and effective porosity. This property is determined through the following generalized equation:

$$\emptyset = \frac{\textbf{Pore Volume}}{\textbf{Bulk Volume}}$$

Permeability is another important parameter that is a property of the porous media that measures the ability and capacity of the formation to transmit fluids. The permeability of the rock, k, is an important property because it monitors the flow rate and directional activity of reservoir fluids in the formation. The equation that defines permeability in terms of measurable quantities is called Darcy's Law, the permeability is measured by crossing a fluid of dynamic viscosity of (μ) through a core of measured length (L) and area (A) as follows:

$$\boldsymbol{K = \frac{q\,\mu\,L}{A\,\Delta p}}$$

Bulk volume irreducible (BVI), free fluid index (FFI), and effective porosity define as follow:

$$\mathbf{BVI = (Swi\text{-}\ Swb) \times \phi T \times BVW}$$

$$\mathbf{FFI = (1\text{-}Swi) \times \phi T}$$

$$\mathbf{\phi = (1\text{-}Swb) \times \phi T}$$

$$\mathbf{\phi T = \phi E \times BVW}$$

Where:

Swi = irreducible fluid saturation
Swb = Clay bound water saturation
BVW = Bulk volume water

The permeability is estimated from GeoSpec2 by using the following equation:

$$\mathrm{K} = \left[\left[\frac{\emptyset E}{C}\right]^2\left[\frac{FFI}{BBV}\right]\right]^2$$

Where; C = coated permeability coefficient

EXPERIMENTAL PART

The materials used in the experimental work were core samples, brine solution, and injection water.

Core Samples (Plugs)

Five samples of sandstone core were regained from wells number (2) of Zubair formation at depths (3219-3246) meters and were provided by South Oil Company. It was tested in the Reservoir laboratory and Research Unit in the Petroleum Technology Department. Table 1 shows the depths that the samples.

Table 1. Depth of plugs

Core No.	Depth (m)
1	3219
2	3223
3	3227
4	3240
5	3246

Brine Solution

Brine solution was prepared for saturating core samples in order to make the chemical compatible between formation water and injection water.

Injection Water

The injection water was provided from El-Dammam Formation. Its salinity equal to the concentration of (180,728) PPM. Table 2 shows the composition analysis of injection water conducted by Nahran Omer laboratory compared with the seawater.

Table 2. Al Dammam Water Analysis.

Physical and Chemical Parameters	Sea Water Analysis	Al-Dammam Water Analysis
pH @ 24.0 ± 0.1°C (pH units)	8.08	6.85
Density @ 20.07 ± 0.01°C (kg/L)	1.0038	1.1395
TSS (mg/kg)	36	1030
Measured TDS (mg/kg)	6512	180728
Calculated TDS (mg/kg)	6633	181203
Chloride	2002	111890
Sulphate	2327	682
Bromide	3.4	758
Total Carbonate (as Bicarbonate)	174	64
Hydroxide	0	0
Butyrate	< 2	< 5
Cl:Br	589	148
Lithium	< 0.1	3.5
Barium	< 0.4	< 2
Strontium	7	333
Calcium	315	12391
Magnesium	357	3736
Sodium	1417	50089
Potassium	17	1199
Iron	< 0.2	< 1
Copper	< 0.2	< 1
Zinc	< 0.1	2
Manganese	< 0.1	< 0.5
Aluminum	< 0.6	< 3
Sulphur	784	219
Total Barium	< 0.4	43
Total Cl^- equivalent (mg/kg)	3824	112770
Total Na^+ equivalent (mg/kg)	2469	72264
Total NaCl equivalent (mg/kg)	6293	185034
Cation/Anion Balance	99.55%	98.82%
Cation/Anion Bias	-0.45%	-1.18%

Cutting the Plugs

Using the Grinder apparatus and Rock well, the plugs were cutted in the horizontal direction and be parallel to the bedding plane with a length about 3.8 cm and diameter about 2.54 cm. the pure water was used to clean and cool cutting edge.

Cleaning and Drying the Plugs

The samples of fluids were taken away using Soxhelt extractor. Toluene (C7H8), Benzene (C6H6), and Methanol (CH3OH) were used at the same volumes (30 ml for each one) as an extracting solvent to remove salts and residual fluids as water (by Methanol) and residual oil (by Benzene and Toluene). Drying the samples at temperature (230 ^{o}C) is done by the oven.

Preparation the Brine Solution

Brine solution was prepared by dissolving a quantity of sodium chloride (NaCl) by 85% and other minerals and salts as (Magnesium, Potassium, Strontium, Calcium, Barium, and Zinc) by 15%. Water's salinity of the Zubair formation about 180,000 ppm) therefore, (180 gm) of sodium chloride and (1 gm) of every mineral and salt were used for each litter of distilled water then the samples saturated by the brine water for 24 hours using the vacuum pump.

Porosity Measurement

Each of the OFITE BLP-530 Gas Porosimeter and GeoSpec2 equipment (Figures 1 and 2, respectively) were used to determine effective porosity for samples. The working principle of Porosimeter is based on Boyle's law (P1V1 = P2V2). First, all samples were cutter, cleaned, and then evacuated from air by the vacuum equipment. Length, diameter, bulk volume, grain volume and inlet, and outlet pressure and volume of gas inside of plugs were measured and finally, the effective porosity was calculated as follow**:**

$$VB = \frac{\pi D^2 L}{4} \quad , \quad V3 = \frac{P1\,V1}{P2}$$

$$VG = V2 - V3 \quad , \quad \emptyset eff. = \frac{(VB - VG)100}{VB}$$

Where:

Øeff. = Effective porosity of core, % , VB = Bulk Volume, cc
D = Diameter, cm , L = Length, cm , VG = Core Grain Volume, cc ,
V1, V2 = Constants of Porosimeter which are dependent on geometry of the unit.
V3 = volume of gas inside the core holder, cc . , P1 = Upstream Pressure, atm,
P2 = Downstream Pressure, atm.

The second equipment that was used to measure the effective porosity (ØE) and (ØT) is GeoSpec2.

Finally, the effective porosity was measured by the liquid saturation method. Weighting of the dry sample before the saturation by water must be determined, after that the effective porosity was calculated by following:

$$V_P = \frac{Ws - Wd}{\rho s} \quad , \quad \emptyset eff. = \frac{PV}{BV} \times 100$$

Where:

VP = Pore volume, cc
Wd &Ws = Weight of dry & saturated sample, gm
ρL = density of freshwater, gm/cc

Figure 1. OFITE BLP-530 Gas Porosimeter apparatus.

Figure 2. GeoSpec2 apparatus

Permeability Measurement

Figure 3 shows the core lab PERG-200TM Gas Permeability apparatus which is used to measure the absolute permeability. Then the samples saturated in order to calculate the liquid permeability by liquid Permeameter and GeoSpec2 apparatuses. Air r permeability results were corrected for gas slippage employing Klinkenberg correlation. Permeability of gas and liquid can be calculated by Darcy's law:

$$k = \frac{C\,Q\,\mu\,L}{A\,(P1^2 - P2^2)}$$

Where:

K = Gas Permeability of samples, md, C = Conversion factor equal to 2000.
Q = rate of flow, cc/sec. , μ = gas viscosity = 0.0176 cp at the laboratory conditions.
L = Length of the sample, cm. , A = Cross-section area of the core sample, cm^2
P1 = Upstream Pressure, atm , P2 = Downstream Pressure, atm

Equipment that was used in this study, core lab PERG-200TM consisted of Permeameter and Fancher core holder, Permeameter consisted of a digital pressure conducer, flow-meter, and thermometer for measuring the temperature of the gas, figure 4. By giving several values of upstream pressures, the gas flow rate was recorded. A maximum compressed gas supply was 25 psig. The liquid Permeameter equipment figure 5 was similar to PERG 200TM gas Prosimeter however inlet pressure was constant (25 psig) and the passage time of 10 cc of freshwater through samples was recorded to calculate the flow rate, figure 6.

Figure 3. PERG-200^{TM} Gas Permeameter.

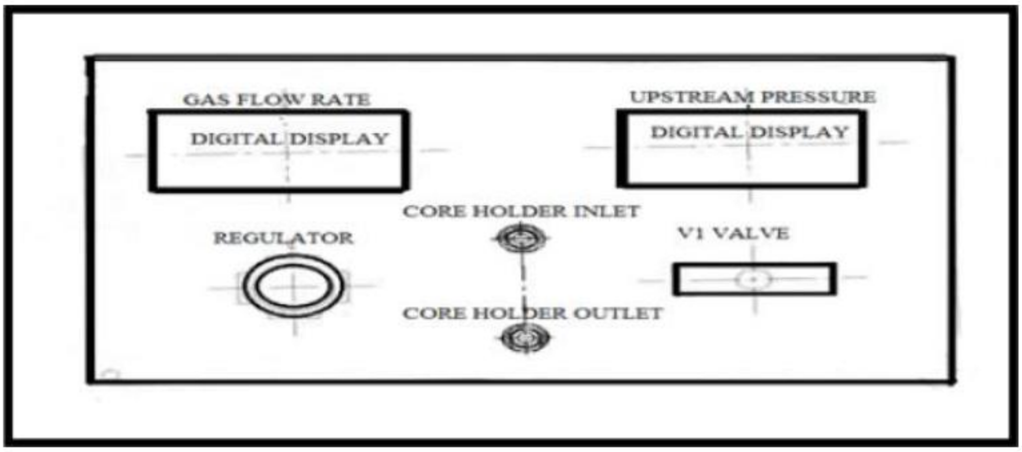

Figure 4. Front Panel of PERG-200^{TM} Gas Permeameter.

Figure 5. PERL-200^{TM} Liquid Permeameter.

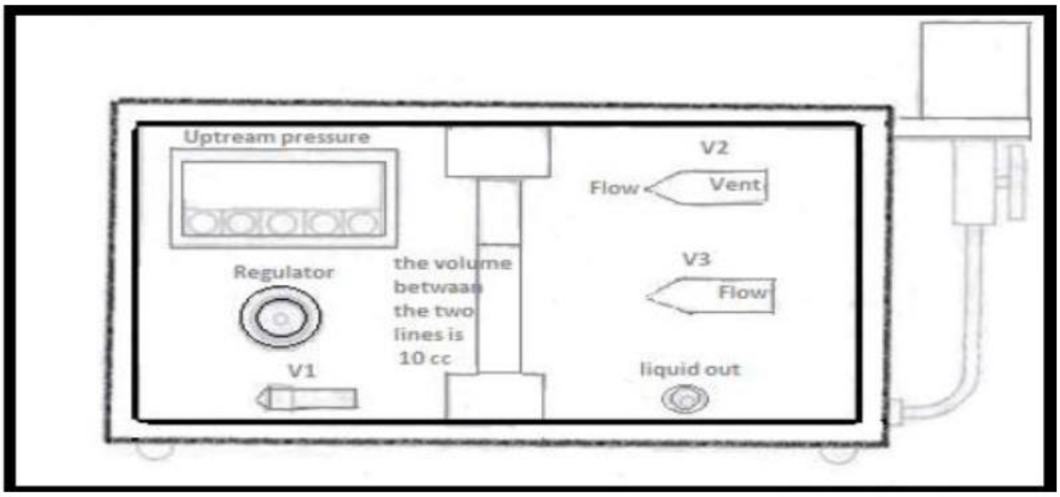

Figure 6. Front Panel of PERL-200^{TM} Liquid Permeameter.

Mineralogical Analysis

Figure 7 shows the OFITE Spectral Gamma Ray Logger and Scanning Electron Microscopy which is used to specify the contents of minerals in the samples, this equipment was in the Department of Geology/ University of Baghdad [16]. The scan type which that was used in Gamma-Ray Logger was Spectral Gamma.

Figure 7. OFITE Spectral Gamma Ray Logger

Tests Carried after Flooding

The formation damage "permeability alteration" was studied using a flooding system. A general vision of the experimental equipment is shown in figure (8 a) and schematically shown in figure (8 b). It consisted of three large devices with accessories connected each to others as follow:

1. Ruska Proportioning Pump.
2. Volumetric Pump.
3. Displacement Pump.
4. Dynamic Filtration Cell; consist of:-
a) Stainless Steel Cell.
b) Core Holder.
5. U- Tube Manometer.

Figure 8a. Flooding System.

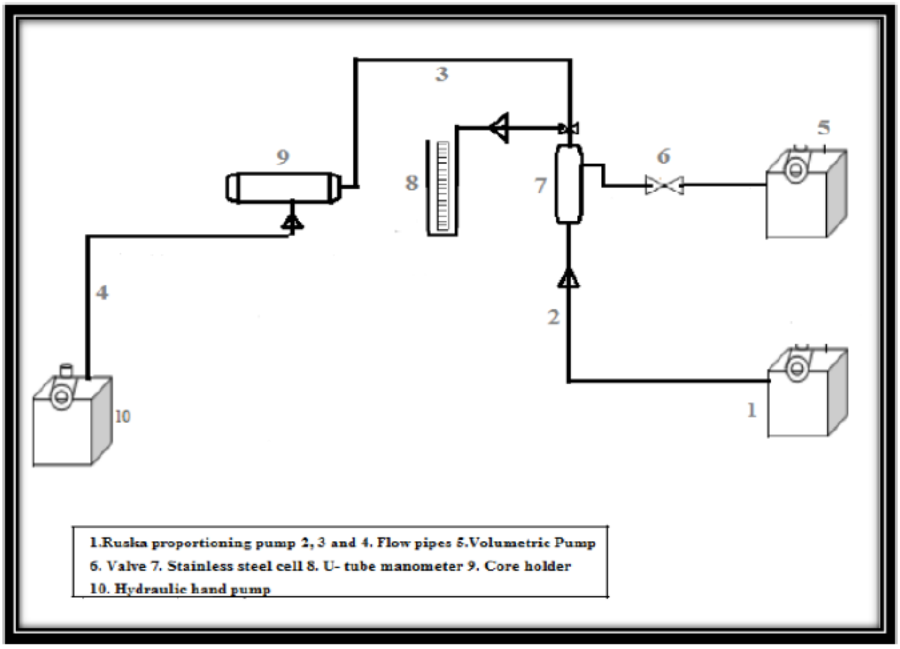

Figure 8b. Schematic diagram of flow system.

Flooding Experimental Procedure

The important work in any experiment is the calibration of all pressure gauge, instruments, and pumps. For a period of time about 24 hours, the plugs were discharged and then saturated with a brine solution of NaCl, after that the flooding process was implemented as follows:

1- The plugs were prepared for the water flooding process and then were placed into the core holder, the confining pressure that was applied for preventing bypass any fluid.

2- The water injection (from al-Dammam Formation) was circulated through the cores from the cell to the core holder for many periods of time and flow rates.

3- The values of pressures were recorded and the core sample was withdrawn from the core holder and then its permeability was calculated by Darcy's law.

4- Steps 1 through 4 repeated for every core sample at three interstitial velocities.

5- Percentage of permeability damage (Damage Ratio, DR) was calculated by comparison the original and damaged permeability [17] as follow:

$$DR = \left[\frac{\text{Rock permeability after damage,Kd}}{\text{original rock permeability,K}}\right] * 100$$

RESULTS AND DISCUSSION

Results of adverse mean pressure were plotted versus permeability as shown in figure 9 through 13 and then corrected to eliminate the gas slippage effect by using Klinkenberg correction.

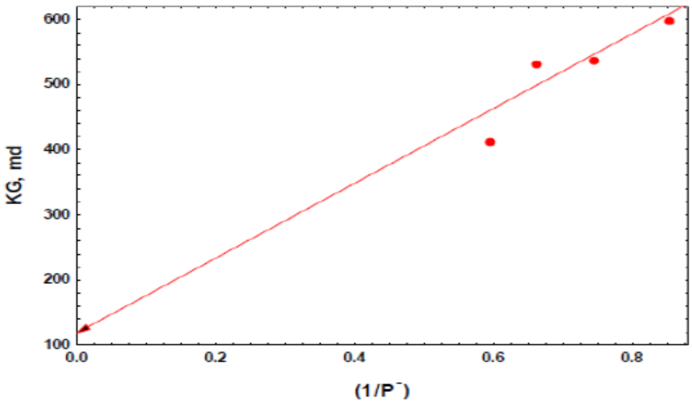

Figure 9. Permeability vs. (1/P-) for core no.(1)

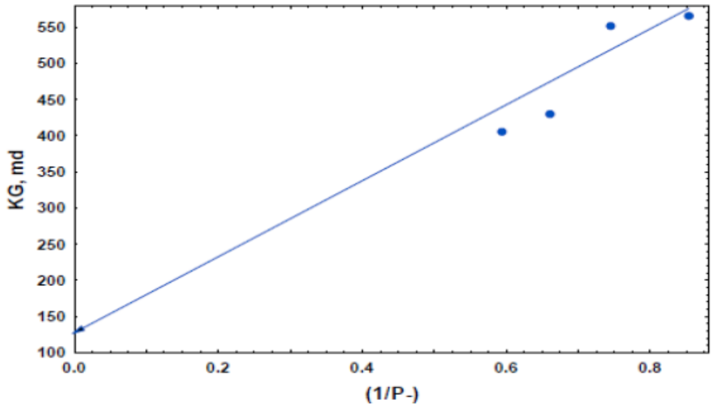

Figure 10. Permeability vs. (1/P-) for core no.(2)

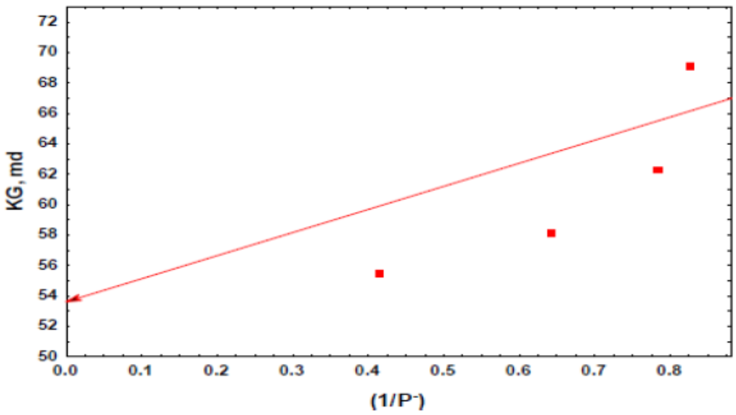

Figure 11. Permeability vs. (1/p-) for core no.(3)

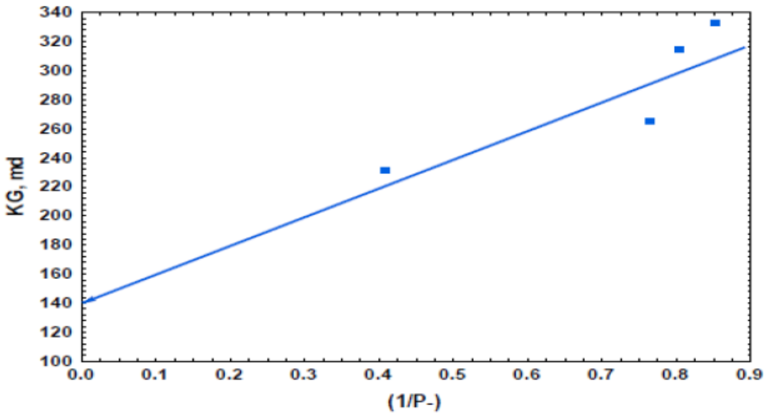

Figure 12. Permeability vs. (1/p-) for core no.(4)

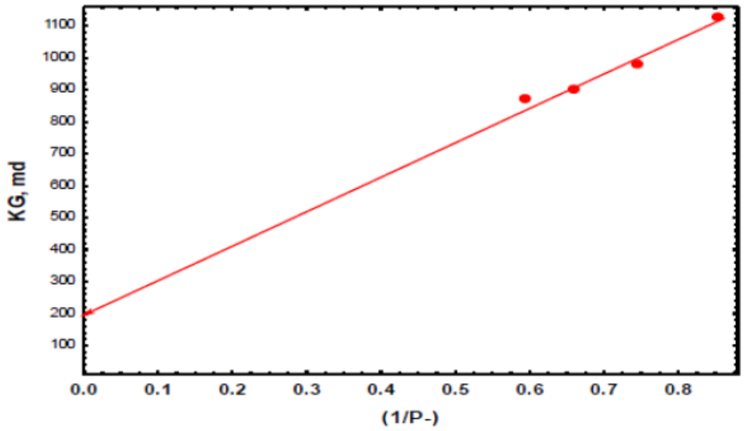

Figure 13. Permeability vs. (1/P-) for core no.(5)

Table 3 presents the results obtained by liquid Permeameter when 10 cubic centimeters of freshwater was passed through samples. All results of liquid and gas permeability measured by the liquid and gas permeameter, gas porosimeter, saturation method in addition to the GeoSpec2 device are listed in the table (4) [18, 19]. The average porosity by gas was about 30 %, 15.2 % by liquid, and 11.7% by GeoSpec2; the same applied to the permeability that equals 129 md by gas and 77 md by liquid and 230 md by using GeoSpec2.

Table 3. Calculations of liquid Permeability before flooding.

Core no.	Time, sec	Pressure, atm.	Differential pressure ,atm	Flow rate, cc/sec	Liquid permeability, md
1	74.4	2.46	1.462	0.13	75.1
2	118	2.49	1.49	0.08	47.3
3	100	2.54	1.54	0.1	53.2
4	40	2.47	1.47	0.25	139.6
5	80	2.49	1.49	0.125	69.8

Table 4. Final Results of Porosity and Permeability.

Core No.	Gas porosity, %	Liquid Porosity, %	GeoSpec2 porosity, %	Corrected Gas Perm. md	Liquid Perm., md	GeoSpec Perm., md
1	25.1	15.5	11.4	120	75.1	341
2	33.4	12.9	12.4	130	47.3	192
3	27.5	9.8	13.5	54	53.2	36
4	28.4	22.34	9	140	139.6	492
5	35.9	15.5	12	200	69.8	90

The reason for using three interstitial velocities (39.18, 89.6, and 627 ft/day) through the waterflooding process to determine the best velocity for flooding that gives less damage inside plugs. In this study through the operation of flooding, the best interfacial velocity was detected. It is the high interstitial velocity that equals (627 ft/day). Table 5 demonstrates the values of the average interstitial velocity that was used for each sample through the flooding process. As shown in figure 14 through (17) the permeability reduction due to damage was not increased significantly with a flow rate 560 cc/hr compared with the other flow rates, this indicates that the core samples were bearded significant scale damage resulting in permeability losses.

Table 5. Interstitial velocity of all core samples through the flooding process.

Core No.	V1(cm/sec), Q = 35(cc/hr)	V2(cm/sec), Q = 80(cc/hr)	V3(cm/sec), Q = 560 (cc/hr)
1	0.012	0.028	0.19
2	0.014	0.033	0.23
3	0.019	0.044	0.31
4	0.008	0.019	0.13
5	0.012	0.028	0.197

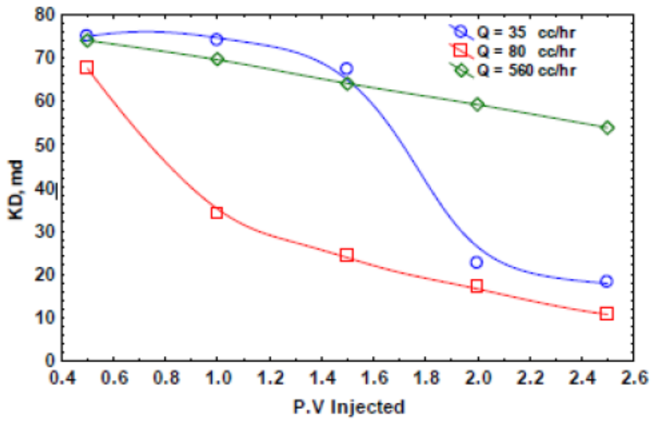

Figure 14. Permeability alteration with the injected pore volume for core no. (1).

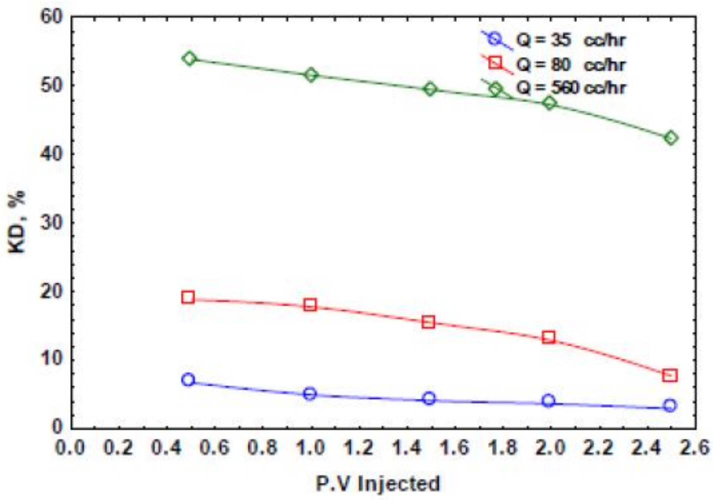

Figure 15. Permeability alteration with the injected pore volume for core no. (2).

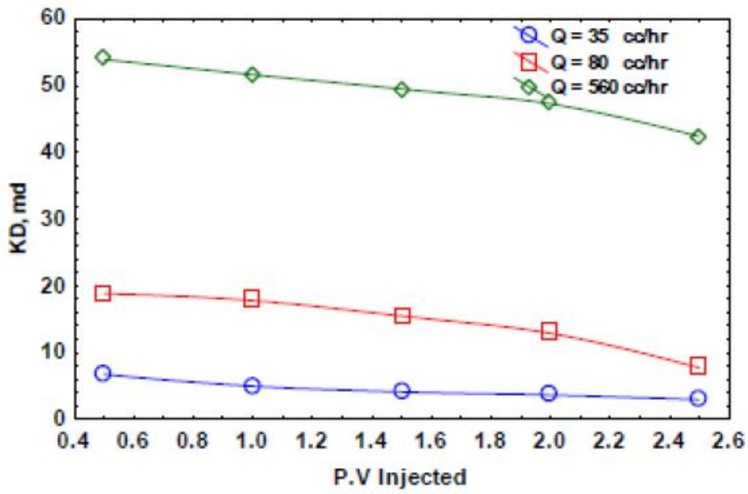

Figure 16. Permeability alteration with the injected pore volume for core no. (3).

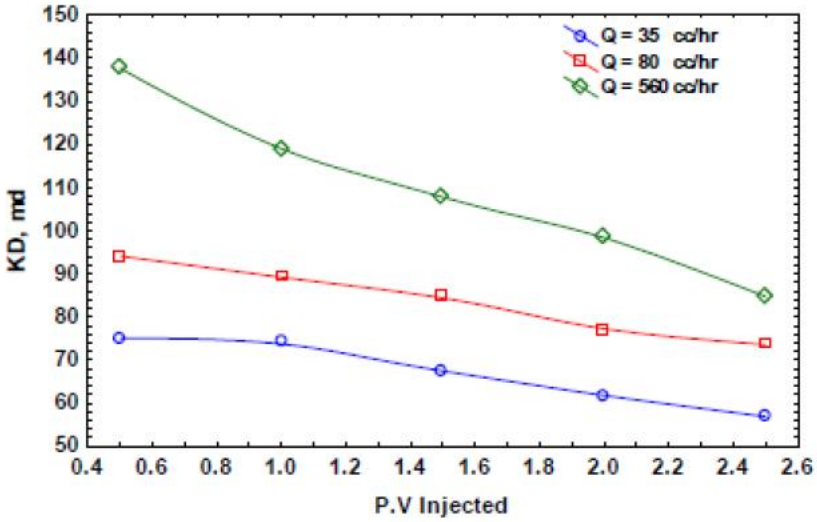

Figure 17. Permeability alteration with the injected pore volume for core no. (4).

The damage ratio is tabulated in the table 6 for all samples and then plotted versus injected pore volume as explained in figure 18 through (22). Damage ratios are approximately (66.9, 52.9, and 18.2%) at the three flow rates (35, 80, 560 cc/hr) respectively, this indicates to pore throats blocking. As shown in the tables and figures, the damage ratios are small at a high velocity than the low. It is an indication that the precipitation of scale formation was significant by using the low velocities causing a high damage ratio.

Table 6. Damage ratio for all core samples.

Core No.	DR% at 35 cc/sec	DR% at 80 cc/sec	DR% at 560 cc/sec
1	51.54	59.16	14.49
2	91.41	64.44	25.05
3	91.96	73.95	12.45
4	62.74	40.081	21.61
5	36.7	26.67	17.29

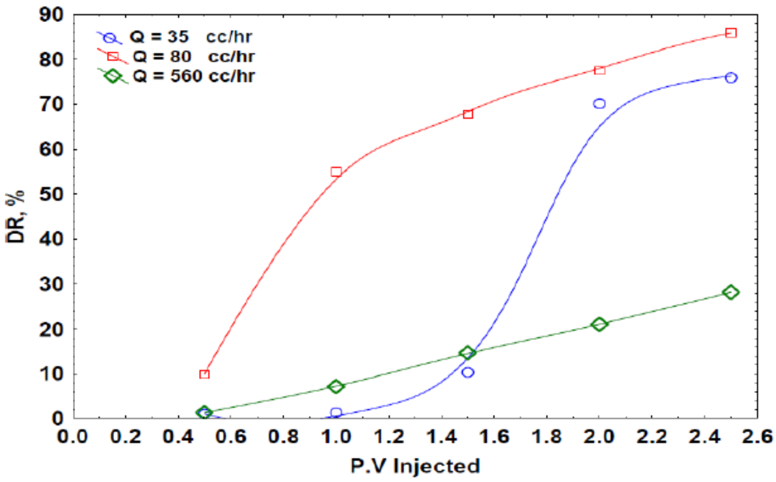

Figure 18. Damage ratio for core no. (1) at three flow rates.

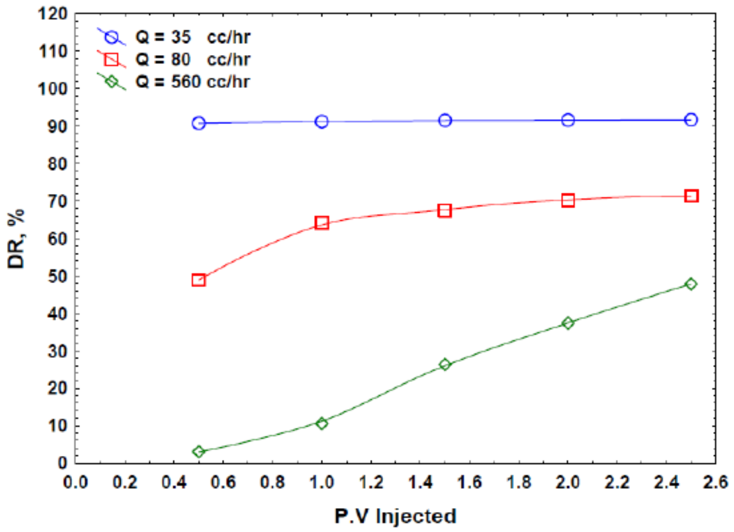

Figure 19. Damage ratio for core no. (2) at three flow rates.

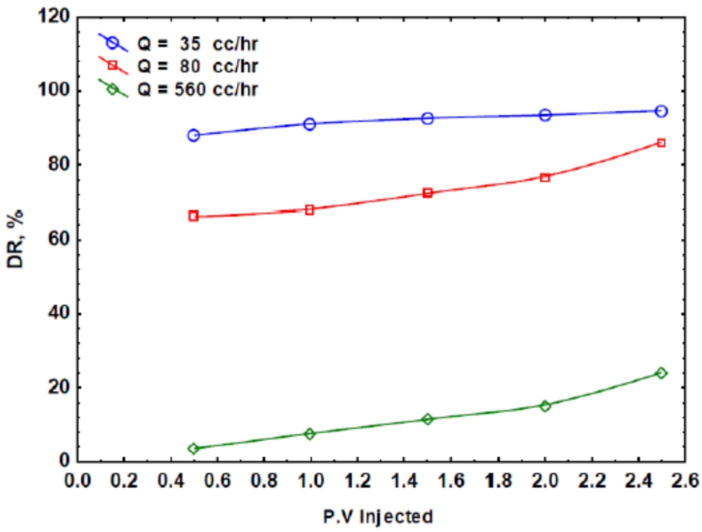

Figure 20. Damage ratio for core no. (3) at three flow rates.

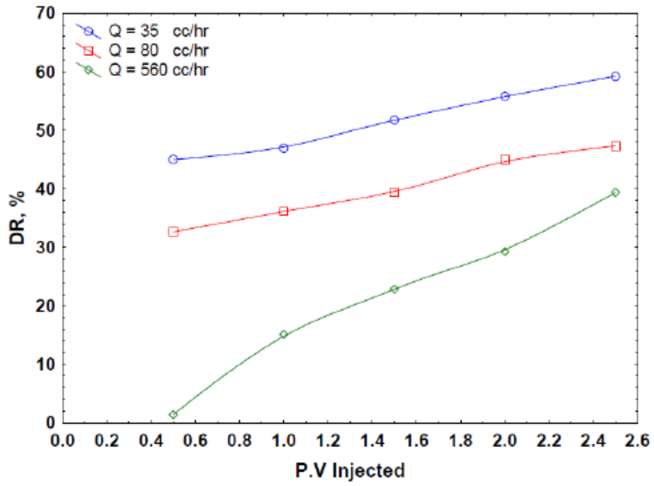

Figure 21. Damage ratio for core no. (4) at three flow rates.

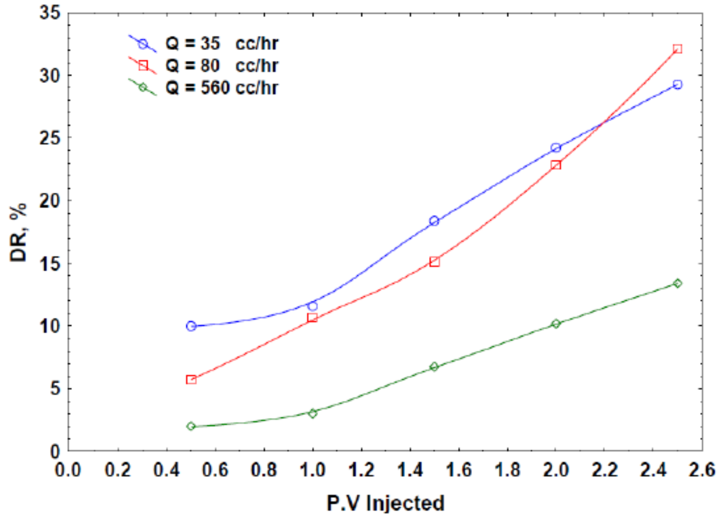

Figure 22. Damage ratio for core no. (5) at three flow rates.

CONCLUSIONS

1. Tests by Polarized Microscopy that were conducted in order for explanation of the results of porosity and permeability show the properties of samples as grain size (0.0625 to 2 µm), roundness (sub-angular), and sorting degree(Moderately to very well sorted). This indicates for high homogeneity in the formation thence good production and good flooding if the water has been treated before the re-injection process.

2. According to the experiences of core flood with the injection water by using a series of parameters as three injection flow rates (560, 80, 35 cc/hr) and five injected pore volume (0.5, 1, 1.5, 2, and 2.5 P.V), the results showed that the best result of permeability with less damage was at the high velocity (627 ft/day). However actually, in the field, the medium velocity represents the best than other velocities due to forming less fingering.

3. Laboratory experiments of water flooding have explained that precipitation of calcium carbonate, barium, and strontium sulfates took place when synthetic and formation waters were combined and that leads to the creation replacement of matrixes among particles and reduces permeability.

4. The permeability of plugs was examined at different pressures. It is decreased at a pressure increased.

5. Tests show that the damage ratio (DR) of plugs was large at low velocities and the worst permeability damage occurred in most samples due to the high rate of iron and other minerals.

6. Long term water floating increase oil displacement efficiency.

to sum up from the view of oilfield development, not only is waterflooding by means of maintaining reservoir pressure (energy) , but long term water flooding is also an efficient method of enhancing oil recovery of reserves.

REFERENCES

[1] D. Bennion, F. Thomas, D. Imer, and T. Ma, “Water quality considerations resulting in the impaired injectivity of water injection and disposal wells”, in Canadian International Petroleum Conference: Petroleum Society of Canada, 2000.

[2] T. Ahmed, “Reservoir engineering handbook”, Gulf professional publishing, 2018.

[3] D. Adams, “Experiences with waterflooding lloydminster heavy-oil reservoirs”, Journal of Petroleum Technology, Vol. 34, No. 1, Pp. 643-650, 1982.

[4] Z. Hongxing, L. Qingnian, L. Fengqin, and L. Yingping, “Variations of petrophysical parameters after sandstone reservoirs watered out in daqing oil field”, SPE Advanced Technology Series, Vol. 5, Pp. 128-139, 1997.

[5] N. Mungan, “Permeability reduction through changes in ph and salinity’, Journal of Petroleum Technology, Vol. 17, No. 1, Pp. 449-453, 1965.

[6] S.Y. Baghdikian, M.M. Sharma, and L.L. Handy, “Flow of clay suspensions through porous media, in SPE International Symposium on Oilfield Chemistry”, Society of Petroleum Engineers, 1987.

[7] S. Bagci, M. Kok, and U. Turksoy, “Determination of formation damage in limestone reservoirs and its effect on production”, Journal of Petroleum Science and Engineering, Vol. 28, Pp. 1-12, 2000.

[8] E. Glenn, and M. Slusser, “Factors affecting well productivity-ii. Drilling fluid particle invasion into porous media”, Transactions of the AIME, Vol. 210, Pp. 132-139, 1957.

[9] A.C. Todd, M. Noorkami, J. Tweedie, “Review of permeability damage studies and related north sea water injection”, in SPE Oilfield and Geothermal Chemistry Symposium: Society of Petroleum Engineers, 1979.

[10] A.C. Todd, J. Somerville, and G. Scott, “The application of depth of formation damage measurements in predicting water injectivity decline”, in SPE Formation Damage Control Symposium: Society of Petroleum Engineers, 1984.

[11] T.W. Muecke, “Formation fines and factors controlling their movement in porous media”, Journal of petroleum technology, Vol. 31, Pp. 144-150, 1979.

[12] G. Gabriel, and G. Inamdar. “An experimental investigation of fines migration in porous media”, in SPE Annual Technical Conference and Exhibition: Society of Petroleum Engineers, 1983.

[13] C. McCune, “On-site testing to define injection-water quality requirements”, Journal of Petroleum Technology, Vol. 29, Pp. 17-24, 1977.

[14] O. Eleri, and J. Ursin, “Physical aspects of formation damage in linear flooding experiments”, in SPE Formation Damage Control Symposium: Society of Petroleum Engineers, 1992.

[15] O. Vetter, V. Kandarpa, M. Stratton, and E. Veith, “Particle invasion into porous medium and related injectivity problems”, in SPE international symposium on oilfield chemistry: Society of Petroleum Engineers, 1987.

[16] A.M. Awadeesian, S.M. Awadh, M.A. Al-Dabbas, M.M. Al-Maliki, S.N. Al-Jawad, A.K.S. Hussein, “A modified water injection technique to improve oil recovery: Mishrif carbonate reservoirs in southern iraq oil fields, case study”, The Iraqi Geological Journal, Pp. 125-146, 2019.