مجلة جامعة سبها للعلوم البحتة والتطبيقية

Sebha University Journal of Pure & Applied Sciences

Journal homepage: www.sebhau.edu.ly/journal/index.php/jopas

Re-Injection of Formation Water and Sea Water to Increase Oil Recovery from Sandstone Rocks: A Laboratory Experiment Under Room Conditions

*Madi Abdullah Naser[a], Omar Ibrahim Azouza[b], Khairi Ahmed R Masaud[b]

[a] Department of Chemical and Petroleum Engineering, Academy for Postgraduate Studies, Tripoli, Libya.
[b] University Geomatika Malaysia, Kuala Lumpur, Malaysia.

Keywords:	A B S T R A C T
Formation Water Sea Water Oil Recovery Sandstone Reservoirs	Laboratory tests and field applications show that low-salinity water flooding could lead to significant reduction of residual oil saturation. There has been a growing interest with increasing number of low-salinity water flooding studies. However, there are few quantitative studies on the effect of using sea-water injections on oil recovery. As oil production continues, a drop-in reservoir pressure will occur due to the loss of reservoir fluids, and this drop-in pressure will lead to a decrease in oil production. The reservoir pressure is maintained by the water injection process. Where sea-water is injected into the aquifer area below the oil area to support the tank pressure. This study presents a laboratory investigation of the effect of salinity injection water on oil recovery, permeability, and relative permeability in the water flooding process. This study was conducted using several samples of sandstone saturated with oil by placing them in the reservoir conditions by placing them in a vacuum oven to ensure complete saturation of the samples with oil and then extracting the oil from them using liquid permeability where the samples are injected. With the formation water until reaching the recovery plateau and obtaining an average reading, the flow, permeability and pressure difference are measured, as well as the relative permeability and recovery factor, then the samples are injected again with sea water and the new results are recorded through seawater injection. The results of this study showed an increase in oil recovery with decrease in residual oil saturation and increase in the recovery factor.

إعادة حقن مياه التكوين ومياه البحر لزيادة استخلاص النفط من صخور الحجر الرملي: تجربة معملية تحت ظروف الغرفة

*مادى عبدالله نصر[1] و عمر إبراهيم اعزوزة[2] و خيرى احمد مسعود[2]

[1] قسم الهندسة الكميائية والنفطة، الاكاديمية الليبية للدراسات العليا، طرابلس، ليبيا

[2] جامعة جوماتيكا، كوالالمبو، ماليزيا

الكلمات المفتاحية:	الملخص
مياه التكوين مياه البحر استخراج النفط خزانات الحجر الرملي	تظهر الاختبارات المعملية والتطبيقات الحقلية، أن غمر المياه منخفضة الملوحة يمكن أن يؤدي إلى انخفاض كبير في تشبع الزيت المتبقي. كان هناك اهتمام كبير بعدد متزايد من الدراسات السابقة لفيضان المياه منخفضة الملوحة. ومع ذلك، هناك القليل من الدراسات حول تأثير استخدام حقن مياه البحر على استخلاص النفط. مع استمرار إنتاج النفط، سيحدث انخفاض في ضغط المكمن بسبب فقدان سوائل المكمن، وسيؤدي هذا الانخفاض في الضغط إلى انخفاض في إنتاج النفط. يتم الحفاظ على ضغط الخزان من خلال عملية حقن الماء. حيث يتم حقن مياه البحر في منطقة الخزان الجوفي تحت منطقة النفط لدعم ضغط الخزان. تقدم هذه الدراسة استقصاء معملي لتأثير حقن الماء الملحي على استخلاص الزيت، والنفاذية المطلقة، والنفاذية النسبية في عملية غمر المياه. أجريت هذه الدراسة باستخدام عدة عينات من الحجر الرملي المشبع بالزيت وضعها في ظروف المكمن عن طريق وضعها في فرن تفريغ لضمان التشبع الكامل للعينات بالزيت ثم استخلاص الزيت منها باستخدام نفاذية السائل حيث يتم حقن العينات. مع ماء التكوين حتى الوصول إلى هضبة الاسترداد والحصول على قراءة متوسطة، يتم قياس التدفق والنفاذية وفرق الضغط، وكذلك النفاذية النسبية وعامل الاسترداد، ثم

Corresponding author:
E-mail addresses: madinaser2004@gmail.com, (O. I. Azouza) omar.i.azouza@gmail.com, (K. A. R Masaud) Khairi@geomatika.edu.my

يتم حقن العينات مرة أخرى بماء البحر ويتم تسجيل النتائج الجديدة من خلال حقن مياه البحر. أظهرت نتائج
هذه الدراسة زيادة في استخلاص الزيت مع انخفاض في تشبع الزيت المتبقي وزيادة في معامل الاستخلاص.

Introduction

Extraction of oil and gas from underground reservoirs often is accompanied by water or brine, which is referred to as produced water. As reservoirs mature, especially if secondary or tertiary recovery methods are used, the quantity of water climbs and often exceeds the volume of the hydrocarbons before the reservoir is exhausted. The cost of producing, handling, and disposing of the produced water often defines the economic lifetime of a field and the actual hydrocarbon reserves; therefore, understanding and predicting the aspects, behavior, and problems induced by the produced-water flow is important (1). Diagnosing the source of the increased water production from a well is important in deciding whether to pursue water-shutoff options. First, if the field is water flooded, water must be produced to recover the oil in accordance with relative permeability; only water in excess of this should be a target for remedial treatments (2). Re-injected produced water into a sandstone reservoir at the initial stage is to maintain reservoir pressure, replace produced oil, and provide for the recovery of oil by water displacement. Time management also one of the most important factors which may influence the oil recovery. The right time to inject water is very important (3).

Naser et al 2018 concluded that the impact of seawater on oil recovery in sandstone core samples was higher than carbonate core samples. At higher temperature, the oil recovery was more than at lower temperature. Likewise, increasing the aging time for both sandstone and carbonate core samples, cumulative oil recovery was increased drastically (4).

Several core flooding experiments were conducted using sandstone by injecting seawater (high, low salinity and different pH). The results of this study have been shown that the oil recovery increases as the injected water salinity down to 6500 ppm and when the pH is around 7. This increase has been found to be supported by an increase in the permeability. We also noticed that the impact of pH on oil recovery is low when the pH is less than 7. (5). Gaborone Water Lake acidity (pH) has impact effect on oil recovery. The oil recovery is increased with decreased the salinity of Gaberoun Water Lake (6). The objective of this paper is to maximum oil recovery from a sandstone reservoir from formation water and sea water injection.

EXPERIMENTAL MATERIALS:

Core Samples: Sandstone was used to obtain fifteen samples with a diameter from 3.78 to 3.81 cm with different lengths. Figure 1 shows the samples after the process of cutting and leveling by cutting and leveling devices and cleaning the samples manually and then drying them from the oven.

Figure 1: Sandstone Samples

Oil Sample: Oil was used to saturate the sandstone samples with viscosity is 11.4 cp, density is 0.810 g/cc, and specific gravity is 0.8124.

Formation Water: Formation water with a density is 8.47, salinity is 25000, and density of 8.47 ppg, and pH is 7.567.

Sea Water: Sea water with the density is 1.025 g/ml and that the density and pH is 8.034.

EXPERIMENTAL EQUIPMENT:

Manual Saturator: The manual saturator enables the end user to obtain remarkable saturation of cleaned and dry core samples by the simple process as shown in the figure 2. The measurement of porosity (connected pore space) by the liquid saturation method involves the gravimetric determination of pore volume by obtaining: the weight of the core sample clean and dry, the weight of the sample saturated with a liquid of known density, and the weight of the saturated sample submerged in the same liquid. The samples are placed in the saturation cell and evacuated by applying high vacuum for a few hours. The de-aerated liquid used to saturate the core sample is then introduced in the saturator cylinder while maintaining the vacuum. The saturation pump is used to inject additional saturating liquid into the saturation cell containing the sample so as to increase the pressure to 2,000 psi for 4 hours to assure complete saturation of the core.
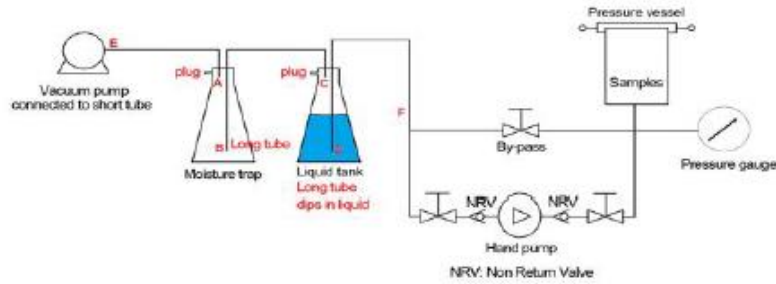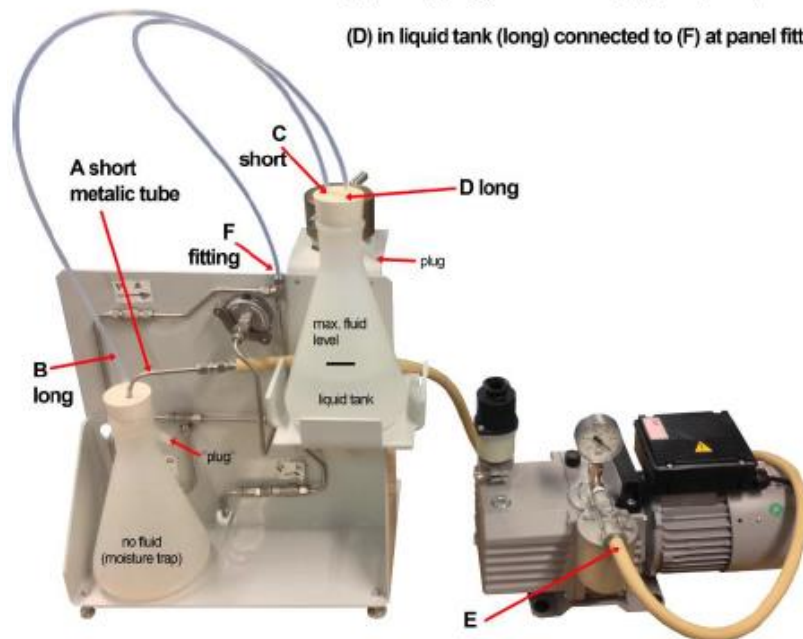
Figure 2: Installation and Diagram Manual Saturator

Liquid Permeameter: The Liquid Permeameter is an instrument dedicated to routine core analysis. The pressure control regulator is used to adjust gas pressure up to 100 psi in a vessel initially filled water (brine) as shown in the figure 3. The gas pressure transfers water into the sample at constant pressure. The flow rate exiting the core sample is determined by measuring the time to fill a graduated flask. After reporting the sample diameter and length, the flow measured and the upstream pressure in a template XLS file, the liquid permeability is calculated from Darcy's law. Confining pressures up to 400 psig can be applied to the cores, and displayed on the Gas permeability console.

2. **Core Trimming**
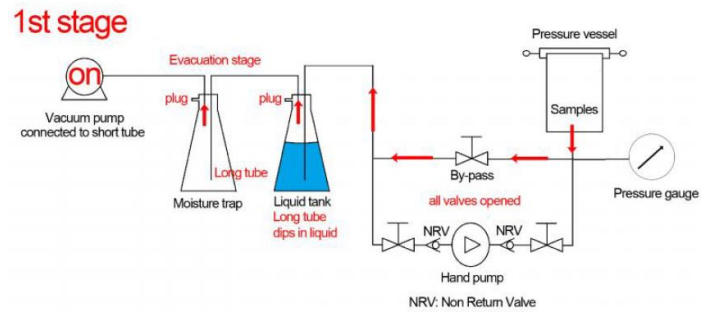3. **Core Saturation**

After obtaining the weight of each dry and clean sample. Load the basket with samples in cell saturation and follow these steps:

Step 1 SAMPLE LOADING: Obtain the weight of each dry, clean sample. Load the basket with the samples into the saturation cell. It is convenient to reduce the dead volume in the vessel by completing the volume with plastic plugs (provided). Close the saturation vessel lid as shown in the figure 5.

Figure 3: Liquid Permeameter

EXPERIMENT PROCEDURES:

Figure 4 shows the experimental procedures as follows:

1. **Core Cutting**

Figure 5: Step 1 Sample Loading

Step 2 VACUUM: Fill the jar with the test brine no more than half height to avoid damaging the vacuum pump. Switch the valves HV01, HV2 and HV3 open Start the vacuum pump. Start the vacuum pump. Wait for (at least) one hour, depending on the plug's permeability. For very low-permeability samples, the evacuation period should be as long as 12 to 18 hours (overnight). If saturate fluid does not show important ebullition from the 1st minute of evacuation, check that the corks of the moisture trap and liquid tank are correctly inserted as shown in the figure 6.

Figure 6: Step 2 Vacuum

Step 3 FILL: Valve status remains unchanged. Stop the vacuum pump. Disconnect the vacuum pump hose from the tank to break the vacuum. The desaturated liquid is drawn into the evacuated vessel containing the core samples. The cores are allowed to saturate. Wait until brine has been transferred to the cell (about 2 minutes) as shown in the figure 7.
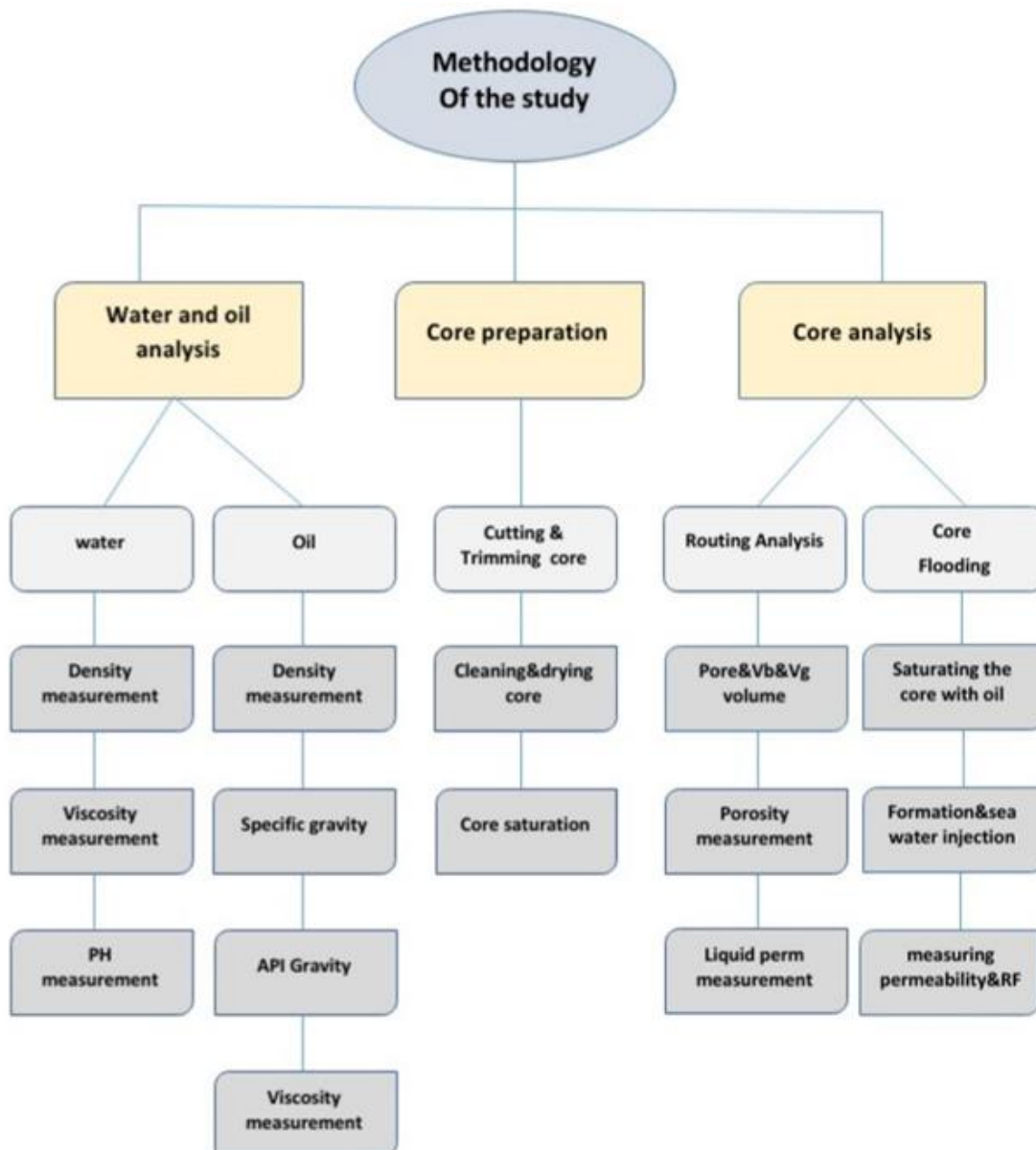
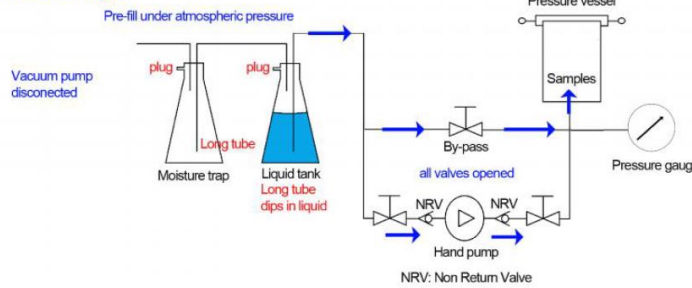

Figure 4: Experiment Procedures

Figure 7: Step 3 Fill

Step 4 PRESSURE: Switch the valve HV01 closed. Operate the hand pump to pressurize the liquid surrounding the sample to 2,000 psi. Pressure build-up requires that a few ml of saturating fluid is transferred. Thus, about 20 stokes are required to raise the pressure, assuming that action on the handle is slow enough (not faster than 20 strokes per minute). As soon as the gauge needle moves, a few more strokes will build the pressure up to 2,000 psi. If pressure does no build up, it may come from the insufficient evacuation of the saturated fluid or from leak (for instance the O-ring at the pressure vessel lid) as shown in the figure 8.
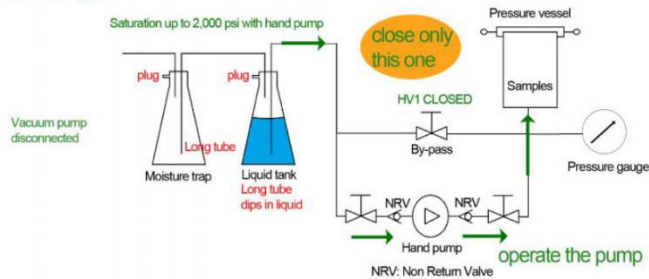

Figure 8: Step 4 Pressure

Step 5 VENT: Once the pressure has been applied during the required time (according to estimated permeability), the samples are saturated. Crack open valve HV01 to release the pressure from the tank and the samples. Extra water is suddenly expelled from pressure vessel to liquid tank.

Step 6 EMPTY: Once the pressure is back to atmospheric value, open by hand the vessel lid and remove the basket with cores.

Step 7 WEIGHTING SATURATED SAMPLES: Excess liquid is carefully removed (avoiding grain loss) from the sample and the saturated sample is weighed in air. When removing excess liquid from the sample surface, pre- cautions must be taken to ensure fluids are not removed from pores exposed at the surface. Weight the cores saturated to determine the pore volume and porosity.

Step 8 SHUT OFF: Open the drain valve of the tank to empty it. Rinse to remove any particle and also avoid future salt deposit when using brine as saturated fluid.

4.   **Liquid Permeability Measurement:**
The permeability of the sample is measured by using the Liquid permeability device by following the steps:

Step 1 MAIN SUPPLIES: Connect to main supply and power up the instrument at the main switch on the rear panel. The pressure transducers require a "warm up" period of about one hour before use. Switch the source valve ON / OFF to OFF position. Ensure that regulators are fully turned anticlockwise initially. Connect two regulated nitrogen supply to the appropriate ports on the rear of the instrument, i.e. Confining pressure supply at valve PRESSURE / VENT (1/8" OD) and core nitrogen supply at valve ON / OFF (1/8 " OD). Initialize the system by filling the dead volume with brine by proceeding without core in place at first step (confining pressure should NOT be applied).

Step 2 WATER INJECTION: The tank of the device is filled with water, closed and sealed with the insurance of the tank cover.

Step 3 SAMPLE LOADING: Ensure the integrity of the rubber sleeve carrying the sample. The sample is placed inside the device and closed.

Step 4 CONFINING SECTION: Regulate the confining pressure supply to the desired value without exceeding 400 psi. Regulate the core nitrogen supply without exceeding 100 psi. Turn confining valve PRESSURE / VENT to PRESSURE. Gas at desired pressure is now applied to the core holder sleeve. This pressure is now displayed on the confining pressure gauge.

Step 5 ENSURE SECTION: Ensure that regulators are fully turned anticlockwise initially. Install a beaker the outlet of the core holder.

Step 6 INJECTION SECTION: Switch source valve ON / OFF to ON. Slowly increase regulator to obtain desired liquid flow or test pressure. Let the flow stabilize, then place the graduated flask at the outlet of the core and start the stopwatch. Stop the watch as soon as the water level reaches the graduation as shown in the figure 9.
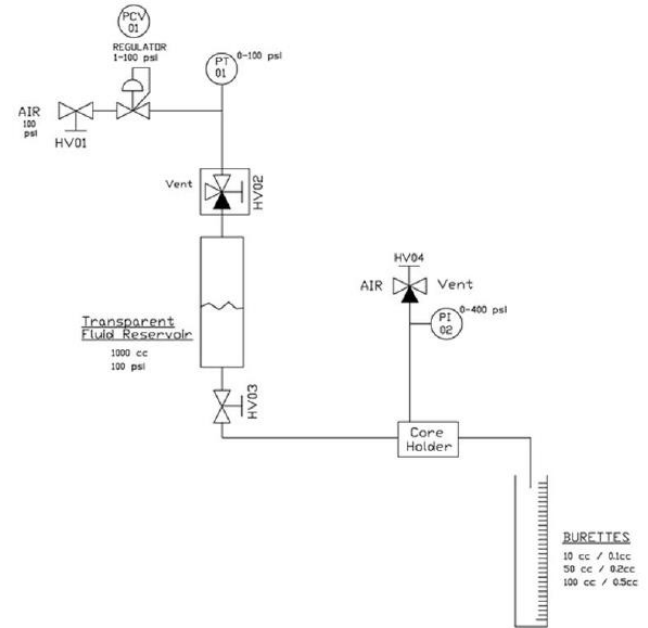

Figure 9: Flow Diagram

Formation Water Injection:
The steps of formation water injection experiment as shown in the following steps:

Step 1 OIL AGING: The core sample has been saturated with oil by using the vacuum pump and oven at 70 ºC for 2 months.

Step 2, Step 3, Step 4, and Step 5: These steps are the same in the liquid permeability measurement.

Step 6 OIL PRODUCING: Once the oil begins to produce, a graduated glass tube is placed to calculate the volume of oil obtained from the sample. The timer is turned on to calculate the time and rate of oil flow from the sample, until no more oil produced from the sample as shown in the figure 10.

Sea Water injection:
The steps of sea water injection experiment as shown in the liquid permeability measurement and formation water injection steps. The sea water injection experiment was done after formation water immediately for the same sample as shown in the figure 11.

Figure 10: Formation Water Injection

Figure 11: Sea Water Injection

EXPERIMENTAL RESULTS:

Bulk Volume: After measuring the lengths and diameter of the samples with Vernier callipers, the volume of the samples is measured using the bulk volume equation as shown in the Table 1.

Grain Volume: The grain volume is measured by knowing the bulk volume and the pore volume and substituting them in the grain volume equation as shown in the Table 1.

Pore Volume: After measuring the weights of each of the dry sample and the weight of the sample when it is saturated with water of density 1 g/cc, we use the equation to measure the pore volume as shown in the Table 1.

Porosity: After knowing the bulk volume and pore volume, we can measure the porosity as shown in the Table 1 and Figure 12.

Absolute Permeability: The absolute permeability of the sample was measured with one liquid saturation, and the following table shows the results of the permeability as shown in the table 2.

Recovery Factors Results: After measuring the volume of oil produced from the sample by injecting with water, we can now obtain the recovery factor, by dividing the volume of oil produced by the volume of the original oil inside the sample. The results of recovery factor of formation water injection as shown in Table 3 and Figure 13 and Figure 14.
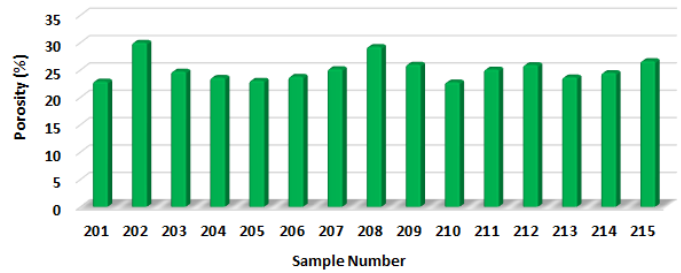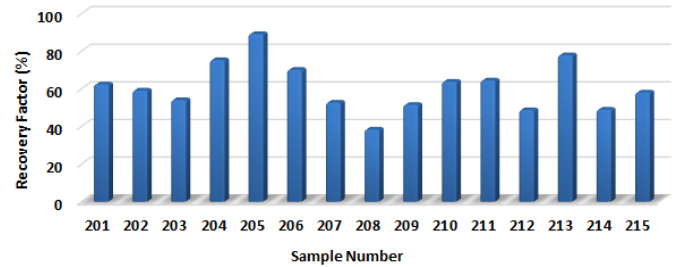

Figure 12: Porosity

Figure 13: Recovery Factors by Formation Water

After completing the injection of the sample with the formation water, we directly inject it with sea water, and calculate the amount of oil produced, to obtain the recovery factor as shown in Table 4.
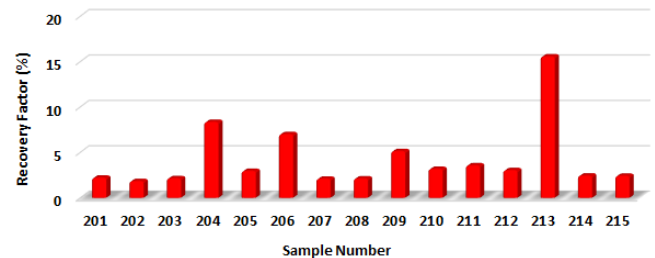

Figure 14: Recovery Factors by Sea Water

CONCLUSION:

From this study, the following points are concluded:

1. When injecting water at high pressure, the amount of recovered oil is less than when injecting at low pressures due to the lack of sufficient water distribution on the pores of the sample to displace the oil in it.

2. The largest amount of oil recovered is through rock samples that have the highest permeability.

3. Most of the oil is recovered from the sample upon initial injection with formation water before injection with sea water.

4. It is recommended not to remove the samples from the manual saturator until the pressure has been established for as long as it takes to ensure its final complete saturation to obtain a correct porosity reading.

5. When removing the oil-saturated samples from the vacuum oven, consider the removal of only the sample to be worked on and return the rest of the samples to the furnace and operate it to ensure its maximum saturation.

6. Make sure when cutting the samples that the edges are even and regularly so that the injection is done well and the liquid is evenly distributed over the entire sample.

7. When placing the sample in the liquid permeability, the integrity and tightness of the rubber sleeve in which the sample is placed must be ensured.

8. Adjust the confining pressure of the liquid permeability to a pressure of less than 400 psi to ensure the integrity of the sample and the rubber casing and to ensure that there is no leakage of compressed gas through the piping.

9. When conducting the experiment, we make the outlet tube of the liquid permeability as short as possible to avoid losing the liquid that sticks to the wall of the tube, which is difficult to count so that the result is more accurate

Table 1: Sample No, Diameter, Length, Bulk Volume, Pore Volume, Grain Volume, Dry Weight, Weight, and Porosity Results

Sample No	Diameter	Length	Bulk Volume	Pore Volume	Grain Volume	Dry Weight	Weight Saturated	Porosity
	cm	cm	ml	ml	ml	(g)	(g)	%
201	3.81	4.24	48.34	11.09	37.25	90.33	102.42	22.94
202	3.80	5.11	47.95	14.41	33.55	112.10	126.50	30.04
203	3.80	4.30	84.76	12.07	72.68	93.63	105.70	24.76
204	3.80	4.60	52.17	12.32	39.85	99.01	111.33	23.62
205	3.80	3.74	42.42	9.79	32.62	79.28	89.07	23.09
206	3.79	4.25	47.95	11.42	36.53	90.16	101.58	23.81
207	3.80	4.41	49.90	12.58	37.32	92.85	105.44	25.22
208	3.81	4.31	49.14	14.39	34.75	94.35	108.73	29.27
209	3.80	3.71	42.08	10.95	31.13	81.74	91.69	26.02
210	3.78	3.39	38.04	8.67	29.37	70.53	79.20	22.78
211	3.76	5.55	61.63	15.49	46.14	118.28	133.76	25.13
212	3.80	3.00	34.02	8.82	25.20	63.41	72.24	25.94
213	3.80	3.95	44.80	10.62	34.18	85.38	96.00	23.70
214	3.80	4.00	45.36	11.12	34.25	86.21	97.33	24.51
215	3.79	3.81	42.98	11.47	31.52	80.23	91.70	26.68

Table 2: Absolute Permeability

Sample No	Length	Area	Time	Pressure Different	Fluid Viscosity	Flow Rate	Permeability
	(cm)	(cm^2)	(S)	(atm)	(cp)	(cc/s)	K (Darcy)
201	4.24	11.40	37.83	1.82	1.00	2.67	1.45
202	5.11	11.30	16.20	1.91	1.00	6.17	2.57
203	4.30	11.30	24.30	1.88	1.00	4.13	1.81
204	4.60	11.30	11.00	1.88	1.00	9.10	3.83
205	3.74	11.30	24.20	1.84	1.00	4.13	1.86
206	4.25	11.30	10.87	1.89	1.00	9.20	4.21
207	4.41	11.30	12.53	1.86	1.00	8.00	3.06
208	4.31	11.40	65.35	1.90	1.00	2.15	0.91
209	3.71	11.30	11.87	1.82	1.00	8.43	3.37
210	3.39	11.20	7.83	1.83	1.00	12.77	2.11
211	5.55	11.10	8.20	1.83	1.00	12.23	2.36
212	3.00	11.30	28.90	1.87	1.00	3.47	0.92
213	3.95	11.30	8.73	1.85	1.00	11.47	1.64
214	4.00	11.30	8.23	1.88	1.00	12.20	2.26
215	3.81	11.30	24.97	1.87	1.00	4.00	0.73

Table 3: Recovery Factors by Formation Water

Sample No	PH	Salinity	Oil Volume	Pore Volume	Recovery Factors
		ppm	ml	ml	%
201	7.57	25000	7.00	11.09	62.37
202	7.57	25000	8.00	14.41	59.18
203	7.57	25000	6.25	12.07	54.10
204	7.57	25000	9.00	12.32	75.31
205	7.57	25000	7.00	9.79	89.18
206	7.57	25000	7.50	11.42	70.16
207	7.57	25000	6.25	12.58	52.72
208	7.57	25000	4.50	14.39	38.43
209	7.57	25000	5.00	10.95	51.53
210	7.57	25000	5.00	8.67	63.87
211	7.57	25000	9.00	15.49	64.50
212	7.57	25000	4.00	8.82	48.74
213	7.57	25000	7.50	10.62	77.88
214	7.57	25000	5.00	11.12	48.98
215	7.57	25000	6.00	11.47	58.11

Table 4: Recovery Factors by Sea Water

Sample No	PH	Salinity	Oil Volume	Pore Volume	Recovery Factors
		ppm	ml	ml	%
201	8.03	21250	0.25	11.09	2.23
202	8.03	21250	0.25	14.41	1.85
203	8.03	21250	0.25	12.07	2.16
204	8.03	21250	1.00	12.32	8.37
205	8.03	21250	0.25	9.79	2.97
206	8.03	21250	0.75	11.42	7.02
207	8.03	21250	0.25	12.58	2.11
208	8.03	21250	0.00	14.39	2.14
209	8.03	21250	0.50	10.95	5.15
210	8.03	21250	0.25	8.67	3.19
211	8.03	21250	0.50	15.49	3.58
212	8.03	21250	0.25	8.82	3.05
213	8.03	21250	1.50	10.62	15.58
214	8.03	21250	0.25	11.12	2.45
215	8.03	21250	0.25	11.47	2.43

REFERENCES:
[1]- https://petrowiki.spe.org/Produced_oilfield_water

[2]- Dalrymple, Dwyann. 2013. Produced Water Management - "Waste to Value". https://webevents.spe.org/products/produced-water-management-waste-to-value-spe-distinguished-lecturer

[3]- Madi Abduallah Naser., Improving Recovery from Oil Sandstone Reservoir by Re-inject of Produced Water by Using Eclipse_E300 Software. The First Scientific Conference on Engineering and Environment, held in Sebha University in Sebha City, Libya, 12–14 February 2018. https://doi.org/10.51984/jopas.v17i1.124

[4]- Madi Abdullah Naser, Mohamed Erhayem, Ali Hegaig, Hesham Jaber Abdullah, Muammer Younis Amer Abdalsalam Ali Mohamed., Comparative Study of Using Sea-Water for Enhanced Oil Recovery in Carbonate and Sandstone Reservoirs: Effects of Temperature and Aging Time on Oil Recovery. The Journal of Earth Energy Engineering, Universitas Islam Riau, Indonesia, 2018. https://doi.org/10.25299/jeee.2018.vol7(2).2126

[5]- Madi Abdullah Naser, Mohammed A Samba, Yiqiang Li., An Experimental Investigation the Optimum of Salinity and Ph of Sea-Water to Improve Oil Recovery from Sandstone Reservoir as A Secondary Recovery ProcesspHJournal of Petroleum and Geothermal Technology, Department of Petroleum Engineering Universitas Pembangunan Nasional "Veteran" Yogyakarta. Indonesia, 2020. https://doi.org/10.31315/jpgt.v1i2.3810

[6]- Naser, M; Erhayem, M; Hegaig, A; Abobakr, M; Abobakr, B; Masood, A., Discover of GWLI as chemical flooding using SIT: experiment and analysis on key influence factor for oil recovery improvement. The Earth and Environmental Science Conference and Exhibition held in Yogyakarta City, Indonesia, Thursday - Friday, 11 - 12 October 2018. https://iopscience.iop.org/article/10.1088/1755-1315/212/1/012072

[7]- Naser, Madi Abdullah; Azouza, Omar., LABORATORY INVESTIGATION OF A NEW LIBYAN CHEMICAL EOR: Impact of GWLI on Relative Permeability, Wettability, Oil Recovery, Breakthrough and Fractional Flow., Journal of Earth Energy Engineering., Universitas Islam Riau (UIR) Press., 2019. https://doi.org/10.25299/jeee.2019.vol8(2).2234