SCIENTIFIC CONTRIBUTIONS OIL AND GAS
Vol. 38, Number 3, December 2015: 1 of 5

RESEARCH AND DEVELOPMENT CENTRE FOR OIL & GAS TECHNOLOGY LEMIGAS

Journal Homepage:http://www.journal.lemigas.esdm.go.id

A CASE STUDY OF FORMATION DAMAGE MITIGATION ON "X" FIELD, SUMATRA

STUDI LABORATORIUM MITIGASI KERUSAKAN FORMASI, KASUS LAPANGAN "X" SUMATRA

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First Registered on November 23rd 2015; Received after Correction on December 28th 2015
Publication Approval on: December 31st 2015

ABSTRAK

Kerusakan formasi dapat menyebabkan turunnya produksi minyak, oleh sebab itu upaya mitigasi/ pencegahan kerusahan formasi menjadi sangat penting untuk dilakukan. Kenyataannya, semua operasi di lapangan seperti: pemboran, penyelesaian sumur, kerja ulang perbaikan sumur, produksi dan stimulasi berpotensi untuk menimbulkan kerusakan formasi. Pada kasus ini operator minyak A mempunyai rencana untuk membuang produksi air dari sumur minyak kedalam formasi B, J, K, D, M. Sebelum dilakukan operasi di lapangan, studi laboratorium harus dilaksanakan untuk meneliti pengaruh dari injeksi air tersebut kedalam formasi.Hasil test laboratorium akan digunakan sebagai masukan untuk perencanaan pengolahan air, sehingga air tidak menyebabkan kerusakan formasi. Eksperimen di laboratorium dilaksanakan dengan melakukan pengukuran permeabilitas air sebagai fungsi volume air yang diinjeksikan. Analisa XRD juga dilakukan untuk menunjang hasil penelitian. Di dalam studi laboratorium ini sampel batuan dari formasi B, J, K, D, M diinjeksi atau diuji dengan terhadap: air tanpa salinitas, air bersalinitas, air produksi dari sumur minyak yang tidak maupun yang difilter (disaring). Hasil dari studi di laboratorium menunjukan semua formasi sangat sensitive (mudah mengalami kerusakan formasi) jika diinjeksikan dengan air dari sumur minyak lapangan X, demikian juga dengan air tak bersalinitas. Kerusakan formasi dapat dicegah dengan melakukan penyaringan dan menaikan salinitas air injeksi. Potensi kerusakan formasi pada umumnya disebabkan oleh lempung yang partikelnya mudah lepas dan termigrasi (Kaolinite), walaupun ada sebagaian kecil disebabkan oleh lempung yang mudah mengembang (Smectite).

Kata Kunci: *Kerusakan formasi, air injeksi, pembuangan air produksi, pengolahan air, kompatibilitas air-batuan, lempung yang berpartikel migrasi, lempung yang mengembang*

ABSTRACT

Formation damage might cause low oil well productivity, therefore it is very important to effectively handle this issue. In fact, every operation in the field-drilling, completion, workover, production and stimulation, is a potential source of formation damage. In this case study, the oil company "A" plan to dispose produced water into Formation B, J, K, D,M. Laboratory tests were performed to investigate the effect of the injection of water into the reservoir formation. The experiment was conducted by measuring water permeability as a function of fluid volume injection. In addition, XRD analysis was also performed on effluent filtrate to support the results. Prior to investigating the sensitivity of reservoir rock to the fluid injection, the samples were injected with fresh water, saline water, produced water collected from Central Injection Facility, and also Filtered CIF Water. The results indicated that all formations were sensitive to fresh water and produced water. Moreover, the use of a filter will improve the water quality. Therefore, the produced water should be treated by using a filter and increasing water salinity. The XRD analysis showed that the potential damage is mostly caused by fine migration clay, however, swelling clay is also present in the small part of formation. The test results will be used for water treatment design, so as to minimize formation damage.

Keywords: Formation damage, water injection, disposed produced water, water treatment, water-rock compatibility, fine migration clay, swelling clay

I. INTRODUCTION

Laboratory and field studies indicate that almost every operation in the field- drilling, completion, workover, production and stimulation, is a potential source of damage to well productivity. Formation damage has long been recognized as a source of serious productivity reductions in many oil and gas reservoirs.

Formation damage may result from a variety of conditions. A systematic approach is therefore necessary in the design and execution of engineering laboratory core flow tests in order to generate realistic data which might be scaled to appropriate field conditions to optimize solutions for formation damage.

Oil Company "A" operates "X" Field that is located in Central Sumatra has planned to dispose of produced water from Central Injection Facility (CIF) into reservoir formations. The X Field has five formations which are "K" formation, "B" formation, "J" formation, "D" formation, and "M" formation. The lithology of the reservoir is Argillaceous sand stone with average porosity and permeability value of 31.14% and 3741 mD, respectively. The issue of the potential formation damage problem is of concern when water is not compatible with the reservoir formation. Prior to this study on the implications of the water disposal on reservoir rocks, Oil Company "A" initiated a project study designed to assess the reduction of permeability caused by water that is not compatible with reservoir rocks.

The objectives of the study are focused on five main points, as follows:

- To determine the compatibility of reservoir rock and the fresh water.
- To observe whether or not the KCL level currently being used should be changed.
- To study the magnitude of the formation damage that could be expected from produced water that is collected from CIF (Central Injection Facility) Station.
- To analyze the potential of scaling tendency that might be occur caused by the incompatibility between produced and reservoir rock.
- To study the effectiveness of filtering the CIF produced water.

The formation damage experiment was conducted by measuring water permeability as a function of fluid volume fluid injection (fresh water, saline water, water collected from CIF (Central Injection Facility), and also Filtered CIF Water). The results of laboratory tests are used as data support for water treatment design before the water is injected into the reservoir formation.

During injection into reservoir rock, formation damage might occur caused by several sources such as: the accompanying invasion and migration of solids, clay swelling, and geochemical transformations. In fine solids migration, the damaging solids may come directly from the fluid system or from the formation itself. The intrusion and deposition of the mobile particles may block the reservoir rocks pore-throats which reduces the permeability.

II. METHODOLOGY

In this study, a formation damage experiment was conducted by measu225

ring water permeability as a function of fluid volume injection. In addition, XRD analysis was also performed on effluent filtrate to support the results. Prior to investigating the sensitivity of reservoir rock to the character of fluid injection, the samples were injected with fresh water, saline water, water collected from CIF (Central Injection Facility), and also Filtered CIF Water.

A. Laboratory Test Preparation

Before conducting the required formation damage tests, some preparations should be done such as : to prepare the sample and also the fluid that will be used in the laboratory test.

1. Sample Preparation

Prior to performing the required laboratory tests, a set of plug-size samples representing various depths, taken from 5X well conventional cores (depth intervals from 822.65 feet to 1270.50 feet) of K, B, J, D, M formation, were prepared. In general, the samples are characterized by unconsolidated sandstone.

Under such conditions the cores were drill-plugged using a one and half inch diameter bit, about 2 and 2.5 inches [5 to 6 cm] in length, while lead tubes of the same diameter were prepared for the plug’s sleeve. After drilling, the plugs were inserted carefully into the lead sleeves, where the two ends of the plugs were closed using a double metal screen of 120 mesh (inside) and 60 mesh (outside). The samples were finally squeezed with nitrogen under a pressure of 400 psig for about 5 minutes to prevent potential damage during fluid saturating in the coming various tests. The squeezing pressure of 400 psi was given under an assumption that the rock sample could be seated in the lead sleeve and the characteristic of the rocks is not influenced.

After plug retrieval, all samples were thoroughly extracted, leached of all salts, and dried in a controlled humidity oven at 60 deg. C, 45% RH. Porosity and air permeability were then measured in the Routine Core Analysis Laboratory. In detail, the values of porosity and air permeability are presented in Figure 1. A total number of 83 samples represented B, J, D, K, M formation were selected for formation damage test.

2. Fluid Preparation

In accordance with information provided by A Company, the formation water data collected from 6F well and 4H represented K, B, J, D, and M Formations was used for the test. The simulated formation brine was used as saturating and displacing fluid throughout the sample preparation and measurements. Table 1 shows the constituents of simulated brines.

B. The Experiment

In the laboratory experiment, there were five (5) kinds of sensitive tests performed, as follows:

- Sensitivity test on fresh water
- Sensitivity test on filtered water
- Scaling tendency analysis
- Sensitivity test on water salinity
- Sensitivity test on produced water salinity

The results of these tests are used as data support in water treatment design, so the injected water would not cause formation damage.

1. Sensitivity Test on Fresh Water

20 samples taken from 5G well represented by “K”, “B”, “J”, “D”, and “M” Formation were selected

Table 1
Simulated brine data

Well Name Formation Data	Unit	6F B	6F J	4H M	6F D	6F K
Na^{+}	(mg/l)*	367	352	457	352	367
K^{+}	(mg/l)	44.2	41.8	676	41.8	44.2
Mg^{2+}	(mg/l)	21.56	21.01	24.1	21.01	21.56
Ca^{2+}	(mg/l)	42.4	48.1	77.9	48.1	42.4
Sr^{2*}	(mg/l)	0.19	1.23	1.41	1.23	0.19
Ba^{2+}	(mg/l)	0.9	0.5	0.54	0.5	0.9
Fe^{2+}	(mg/l)	0.09	1.05	0.01	1.05	0.09
Zn^{2+}	(mg/l)					
Cl^{-}	(mg/l)	219	162	683.82	162	219
$SO42^{-}$	(mg/l)	0.7	6.4	42.1	6.4	0.7
F^{-}	(mg/l)					
Bicarbonate as HCO3	(mg/l)		924.03	1009.94	924.03	993.81
Carboxylic acids**	(mg/l)					
TDS (Measured)	(mg/l)	1711	1582	2110	1582	1711
Salinity					1100	1300

for the Fresh Water Sensitivity Test. In the process, the samples were initially vacuumed and pressure saturated using the simulated formation brine as described previously, and then flushed using the same brine until 100 Pore Volume. In this condition, water permeability was measured as a function of volume throughput (brine volume injected).

After that, distillate water was injected into the sample until 100 Pore Volume, then water permeability was measured as a function of volume throughput (distillate water volume injected). At terminal condition, the water permeability at flow reversed direction was also measured. The test was performed on ambient condition.

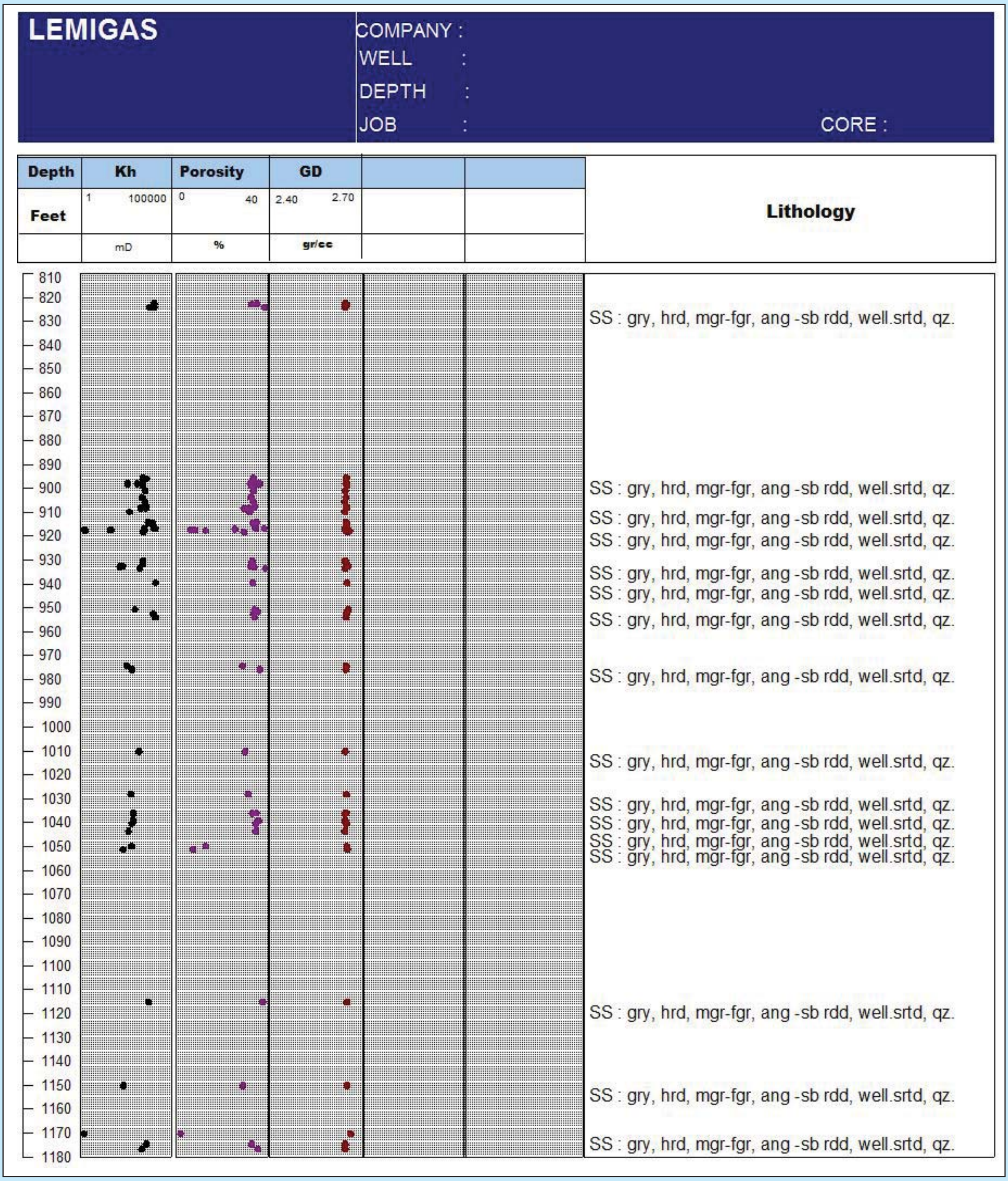

Figure 1
Porosity and permeability data of core sample from X1 well, X field.

2. Sensitivity Test on Filtered Water

The test was performed on 17 samples taken from 5G well of “K”, “B”, “J”, “D”, and “M” Formations. The injected water was produced water collected from CIF (Central Injected Facility) station of “A” Field. At first, all of the samples were saturated with 100% simulated formation brine, then flushed using the same brine until 100 Pore Volume.

Under these conditions, water permeability was measured as a function of volume throughput (brine volume injected). After that, filtered CIF water was injected into the samples until 100 Pore Volume CIF water, water permeability was also measured as a function of volume throughput. Then, the samples were flushed using the unfiltered CIF water until 100 Pore Volume, and at this condition water permeability was measured as a function of volume throughput. At terminal condition, the water permeability at flow reversed direction was also measured. The test was performed on ambient condition.

3. Scaling Tendency Analysis

The Scaling Tendency Test was performed on 17 samples taken from 5G well of “K”, “B”, “J”, “D”, and “M” Formations. Following the procedure, the samples were initially vacuumed and pressure saturated using the simulated formation brine as described previously, and then flushed using the same brine until 100 Pore Volume. In this condition, water permeability was measured as a function of volume throughput (brine volume injected). Subsequently, the CIF water was injected into the samples until 100 Pore Volume, and water permeability was measured as a function of volume throughput. The effluent water was collected with filter paper. At terminal condition , the water permeability at flow reversed direction was also measured. The test was performed on ambient condition. XRD analysis was conducted on effluent

Table 2
Results of the fresh water sensitivity test

				Formation Brine		Fresh Water		
Formation	No. Sampel	Depth (ft)	Ka, mD	K1, mD	K2, mD	K3, mD	K4, mD	K Reversed
K	45	822.65	11705	8085.29	4576.05	4681.73	1338.08	1311.76
	119	898.12	2812	288.71	207.29	96.83	59.66	99.52
	142	907.7	2008	127.02	83.16	75.32	21.89	65.26
	146	908.3	2188	196.75	142.20	101.69	75.86	80.61
	147	908.45	3863	139.92	104.74	121.61	86.45	137.23
	170	914.55	6951	1070.17	707.44	702.89	392.74	424.73
	209	933.5	1871	37.18	17.02	17.16	8.15	12.95
B	23	1018.3	566	14.16	8.60	7.27	3.57	4.44
	304	1010.3	175	130.31	79.04	65.43	37.77	67.80
	316	1019.7	1090	162.73	79.35	84.32	40.00	62.48
	324	1028.25	607	3.76	1.75	1.59	0.74	2.51
J	24	1112.05	9008	6473.74	4279.56	4030.89	2315.93	2631.42
	607	1116.9	3794	1190.36	456.38	382.49	154.39	194.34
	416	1102.25	638	3.86	2.71	2.57	1.43	2..80
	422	1108.15	1017	48.72	37.41	31.85	19.13	44.55
D	507	1187.6	1808	124.49	86.84	85.49	54.92	66.19
	522	1201.4	2110	19.79	14.92	17.52	12.13	13.28
	523	1202.5	1817	132.08	90.06	86.11	56.51	67.52
	525	1203.25	651	23.30	17.89	14.96	10.77	12.33
M	37	1265.45	2064	286.95	217.81	195.82	114.25	125.29

Note:
K1 : water permeability at initial brine injection
K2 : water permeability at 100 PV brine
K3 : water permeability at initial distillate water injection
K4 : water permeability at 100 PV distillate water injection

Table 3
Results of sensitivity test on filtered water

Formation	No. Sampel	Depth, ft	Ka,mD	Formation Brine		CIF (un filtered)		CIF (un filtered)		
				Kl,mD	K2,mD	K3,mD	K4,mD	K5,mD	K6,mD	K Reserved, mD
K	46	822.9	10701	4708.98	1269.91	3768.86	1744.00	3938.90	1819.58	791.48
	120	898.9	2656	65.48	37.98	39.94	15.44	24.29	8.97	16.32
	123	901.15	3790	1605.62	812.60	870.37	325.60	661.54	231.03	240.48
B	309	1014.7	2768	1629.26	501.81	662.39	260.46	441.35	169.90	172.83
	321	1026.9	334 836	3.41	1.35	1.81	1.04	1.02	0.36	0.72
	337	1035.95	811	3.21	2.12	1.52	0.41	0.97 0.70	0.25	0.27
	338	1036.25		2.01	0.84	1.03	0.29		0.18	0.19
J	25	1112.2	7790	4766.68	1655.28	2917.59	1908.75	2557.57	729.26	744.03
	28	1117.05	4626	3355.72	923.57	2943.33	1726.99	3020.23	1732.03	1862.11
	30	1117.95	4962	3272.35	1016.83	1700.87	898.18	1701.00	328.92	369.49
	466	1150.2	242	70.15	25.52	51.61	22.71	36.71	9.61	12.45
D	508	1188.25	1754	494.63	160.03	163.42	47.28	103.83	23.03	25.41
	524	1202.85	2372	1111.73	364.61	770.08	229.96	286.47	85.07 7.43	102.36
	526	1203.8	404	163.70	53.69	83.61	24.97	33.81	15.95	7.67
	527	1204.3	2372	386.15	133.55	84.91	25.36	62.03		16.17
M	36	1263.7	11619	9781.95	3972.69	6125.53	1696.15	6774.13	1325.30	1526.62
	584	1269.5	2688	974.03	176.45	772.85	214.00	339.33	96.81	123.13

filtrate.

4. Sensitivity Test on Water Salinity

A total of 21 samples taken from 5G well of "K", "B", "J", "D", and "M" Formations were assigned for Sensitivity on Brine Salinity. In the process, under room temperature conditions, the samples were initially vacuumed and pressure saturated using the simulated formation brine as described previously, and then flushed using the same brine until 100 pore volume. In this condition, water permeability was measured as a function of volume throughput (brine volume injected). Afterwards, the samples were injected with 3% KCl water until 100 pore volume, then water permeability was measured as a function of volume throughput (3% KCl water injected). Next, the samples were flushed with 5% KCL water until 100 pore volume, then water permeability was also measured as a function of volume throughput. The water permeability at reversed direction flow was also recorded.

5. Sensitivity Test on Produced Water Salinity

Sensitivity on produced salinity test was carried out on 22 samples taken from 5G well of "K", "B", "J", "D", and "M" Formation. At first, the samples were saturated using the simulated formation brine, then flushed using the same brine until 100 pore volume, and the water permeability was measured as a function of volume throughput (brine volume injected). Subsequently, CIF water was injected into the samples until 100 pore volume, at this condition water permeability was measured as a function of volume throughput (CIF water volume injected). The water permeability at reversed direction flow was also recorded.

III. RESULTS

A. Results of the Fresh Water Sensitivity Test

Results of the Fresh Water Sensitivity Tests are summarized in Table 2 as follows.

The experiment was performed at ambient condition. At first, the sample was injected with formation brine, the recorded water permeability at initial injection (K1) was ranged between values of 37.18 mD to 8085.29 mD, 3.76 mD to 162.73 mD, 3.86 mD to 6473.74 mD, 19.79 mD to 132.08 mD, for "K", "B", "J", "D" formations, respectively and value of 286.95 mD for "M" Formation. The injection was stopped at 100 Pore Volume, the recorded permeability (K2) under these conditions ranged between value of 17.02 mD to 4576.05 mD, 1.75 mD to 4279.56 mD, 14.92 mD to 90.06 mD, for "K", "B", "J", "D" formations, respectively and 217.81 mD for "M" formation.

Next, the fresh water was injected into the sample, the recorded water permeability at initial injection (K3) was ranged between 17.16 mD to 4681.73 mD, 1.59 mD to 84.32 mD, 2.57 mD to 4080.89 mD, 14.96 mD to 86.11 mD, for K", "B", "J", "D" formations, respectively and 195.82 mD for "M" formation. The injection was finished until 100 Pore Volume fresh, and at this condition the recorded water permeability (K4) ranged between values of 8.15 mD to 1338.08 mD, 0.74 mD to 40 mD, 1.43 mD to 2315.93 mD, 12.13 mD to 56.51 mD, for "K", "B", "J", "D" formations, respectively and 114.25 mD for "M" formation. At terminal condition, the water permeability at flow reversed direction was also measured. The recorded water permeability ranged between 12.95 mD to 1311.76 mD, 2.51 mD to 67.80 mD, 2.8 mD to 2631.42 mD, 12.33 mD to 67.52 mD for "K", "B", "J", "D" formations, respectively and 114.25 mD for "M" formation.

B. Results of Sensitivity Test on Filtered Water

Results of Sensivity Test on Filtered Water are displayed in Table 3.

The test was conducted at ambient condition. At first, the samples were injected with formation, at initial condition the recorded water permeability (K1) values ranged between 65.48 mD to 4708.98 mD, 2.01 mD to 1629.26 mD, 70.15 mD to 4766.68 mD, 163.70 mD to 1111.73 mD, 974.03 mD to 9781.95 mD for for "K", "B", "J", "D", "M" formation, respectively. The process was finished after injection with 100 Pore Volume formation brine, the recorded water permeability at this condition (K2) ranged between 37.98 mD to 1269.91 mD, 0.84 mD to 501.81 mD, 25.52 mD to 1655.28 mD, 53.69 mD to 160.03 mD, 176.45 mD to 3972.69 mD for for "K", "B", "J", "D" , "M" formation, respectively.

Later, the filtered CIF produced water was injected into the samples, at initial injection the recorded water permeability (K3) ranged between 39.94 mD to 3768.86 mD, 1.02 mD to 662.39 mD, 51.61 mD to 2943.33 mD, 83.61 mD to 770.08 mD, 772.85 mD to 6125.53 mD for for "K", "B", "J", "D", "M" formation, respectively. The injection ended when 100 Pore Volume was produced , and at this condition the water permeability was measured. The measured water permeability (K4) value ranged within 15.44 mD to 1744 mD, 0.29 mD to 260.46

Table 4
Results of scaling tendency analysis

Formation	No. Sampel	Depth, Feet	Ka, mD	Formation Brine		CIF		
				Kl,mD	K2,mD	K3,mD	K4,mD	K Reversed, mD
B	310	1015.25	3227.00	1593.25	808.01	541.16	330.77	236.01
	341	1038.5	287.00	4.07	2.02	2.32	1.32	1.14
	343	1039.4	831.00	16.61	6.47	6.46	2.21	-
	350	1043.7	441.00	4.43	1.75	2.66	0.54	-
D	513	1192.5	2072.00	799.55	362.06	333.92	115.08	112.79
	528	1204.7	1376.00	186.74	85.12	121.10	38.18	51.09
	529	1205.75	775.00	155.22	79.19	61.55	18.05	12.20
	571	1253.55	3643.00	1417.38	787.43	764.61	400.81	317.73
J	29	1117.6	5967.00	4724.94	3028.81	3030.18	810.41	875.49
	33	1157.75	5261.00	4927.44	1813.20	2885.95	632.16	516.25
	430	1115.25	5826.00	4079.50	2848.78	3892.80	1041.12	1848.01
K	51	824.25	12088.00	7013.21	2933.45	3110.20	2168.05	-
	127	903.8	2514.00	771.11	308.40	293.38	152.67	-
	187	918.5	497.00	1.28	0.46	0.34	0.06	-
	188	918.65	206.00	0.63	0.22	0.20	0.09	-
	135	905.65	3874.00	2534.30	1364.62	1943.37	701.90	-
M	39	1267.65	5261.00	3603.46	1403.27	1522.61	581.38	642.25

Note:
K1 : water permeability at initial brine injection
K2 : water permeability at 100 PV brine
K3 : water permeability at initial GIF water injection
K4 : water permeability at 100 PV GIF water injection

mD, 22.71 mD to 1908.75 mD, 24.97 mD to 229.96 mD, 214 mD to 1696.15 mD mD for “K”, “B”, “J”, “D”, “M” formations, respectively.

Next, the samples were flushed with the unfiltered CIF produced water, at an initial injection the recorded water permeability (K5) ranged between 24.29 mD to 3938.90 mD, 0.7 mD to 441.35 mD, 36.71 mD to 3020.23 mD, 33.81 mD to 286.47 mD, 96.81 mD to 1325.30 mD, for for “K”, “B”, “J”, “D”, “M” formation, respectively. The injection finished at 100 Pore Volume fluid, the water permeability (K6) values ranged between 8.97 mD to 1819.58 mD, 0.18 mD to 169.90 mD, 9.61 mD to 1732.03 mD, 7.43 mD to 85.07 mD, 96.81 mD to 1325.30 mD for “K”, “B”, “J”, “D”, “M” formations, respectively. Finally, the water permeability at flow reversed direction was also measured. The recorded water permeability ranged within 16.32 mD to 791.48 Md, 0.19 mD to 172.83 mD, 12.45 mD to 1862.11 mD, 7.67 mD to 102.36 mD, 123.13 mD to 1526.62 mD, for “K”, “B”, “J”, “D”, “M” formations, respectively.

C. Results of Scaling Tendency Analysis

Results of Sensivity Test on Filtered Water are shown in Table 4. The recorded water permeability value (K1) ranged within 4.07 mD to 1588.25 mD, 155.22 mD to 1417.38 mD. 4079.50 mD to 4927.44 mD, 0.63 mD to 7013.21 mD for “K”, “B”, “J”, “D” formations, respectively and 3603.46 mD for “M” formation, when the samples were flushed with formation at initial condition. The brine injection was performed until 100 pore volume fluid injection, then the water permeability (K2) was measured. The results indicated value ranged within 1.75 mD to 808.01 mD, 79.19 mD to 787.43 mD, 1813.20 mD to 3028.81 mD, 0.22 mD to 2933.45 mD for “K”, “B”, “J”, “D” formations, respectively and 1403.27 mD for “M” formation.

Afterwards, CIF produced water was injected into the samples, initially, recorded water permeability value (K3) ranged between 2.32 mD to 541.16 mD, 61.55 mD to 764.61 mD,2885.95 mD to 3892.30 mD, 0.2 mD to 3110.20 mD for “K”, “B”, “J”, “D” formations, respectively and 1521.61 mD for “M” formation. The injection was stopped at 100 Pore Volume fluid injection. At this condition, the recorded water permeability (K4) was within 0.54 mD to 330.71 mD, 18.05 mD to 400.81 mD, 632.16 mD to 1041.12 mD, 0.06 mD to 2168.05 mD for “K”, “B”, “J”, “D” formations, respectively and 581.38 mD for “M” formation. At terminal condition, the water permeability at flow reversed direction was also measured. The reversed water permeability indicated values ranged within 1.14 mD to 236.01 mD, 12.20 mD to 317.73 mD, 516.25 mD to 1848.01 mD, for “K”, “B”, “J”, “D” formations, respectively and 542.25 mD for “M” formation. The results of XRD analysis on effluent filtrate is displayed on table 5b. The results show that generally, the formations are dominated by Illite and Kaolinite.

In the scaling tendency test, some of samples produced only a small quantity of effluent filtrate

Table 5
Summary of XRD analysis on effluent filtrate result

No	No. Sample	Formasi	Clay Mineral (%)				Carb. Mineral (%)			Other Mineral (%)				Total (%)		
			Smec.	Illite	Kaol.	Chlor.	Calc.	Dolo.	Sider	Quartz	K-Feld	Plag.	Pyrite	Clay	Carb.	Other
1	51	K					100									
2	251	K		15	15		1		1	64	3		1	30	2	68
3	310	B		4	8			2		86				12	2	86
4	343	B		7	15					78				22		78
5	350	B		20	30		8			42				50	8	42
6	39	J			16				8	60	16			16	8	76
7	513	D		8	14					73	5			22		78
8	528	D								100						100
9	529	D		5	7					88				12		88

Note:
Smec. : Smectite
Kaol. : Kaolinite
Chlor. : Chlorite
Calc. : Calcite
Carb. : Carbonate
Dolo : Dolomite
Sider. : Side rite
K-Feld : K-Feldspar
Plag. : Plagioclase

Table 6
Results of sensitivity test on water salinity

				Formation Brine		KCL3%		KCL5%		
Formation	No. Sampel	Depth, ft	Ka,mD	Kl,mD	K2,mD	K3,mD	K4,mD	K5,mD	K6,mD	K Reversed, mD
K	116	895.95	4529	229.26	134.5	185.88	102.24	148.96	86.27	161.3
	136	905.8	2430	881.89	613.12	372.42	204.83	262.62	185	90.24
	139	906.4	3080	931.62	647.7	670.35	413.38	416.15	293.15	294.08
	148	908.6	1303	146.92	39.18	48.92	28.16	45.34	31.94	32.28
	171	914.7	9587	5176.2	1932.45	1403.35	1005.12	1252.9	765.41	607.93
	185	918.25	2975	94.3	35.2	54.43	38.99	12.37	7.72	10.86
	203	930.65	837	753.64	281.36	217.74	113.74	130.02	73.4	89.46
	240	950.75	1010	741.31	593.88	580.07	457.68	598.22	378.06	89.46
B	315	1019.15	1605	329.96	179.77	144.02	107.78	110.48	75.38	-
	362	1050.05	657	157.85	91.42	40.05	18.08	13.69	6.95	21.83
	364	1051.25	234	14.14	4.94	14.11	4.93	2.16	1.78	1.42
	367	1052	869	1.27	0.41	0.41	0.23	0.36	0.3	0.53
J	26	1116.6	2271	1631.71	1078.67	1195.38	799.82	1075.84	719.84	2631.42
	31	1157.5	5622	4847.83	3204.73	3586.15	2399.46	2227.76	1575.57	1642.11
	34	1157.9	7002	6248.96	4482.68	2848.62	1718.63	2890.52	2044.31	1642.11
	435	1119.7	2219	359.99	258.24	147.69	89.11	157.96	125.81	113.28
D	520	1199.45	2072	1066.36	746.45	707.06	436.25	813.09	535.76	66.19
	530	1206	966	206.03	148.28	189.82	146.72	169.38	122.5	128.02
	532	1208.2	483	10.29	3.5	5.4	1.84	2.38	1.45	2.74
	572	1254.35	5452	4027.67	2807.96	1225.19	417.72	3121.33	1880.73	1817.7
M	38	1265.6	4795	2389.69	1813.91	983.42	695.79	1036.24	731.46	915.52

Note:
K1 : water permeability at initial brine injection
K2 : water permeability at 100 PV brine injection
K3 : water permeability at initial 3% KCl water injection
K4 : water permeability at 100 PV 3% KCl water injection
K5 : water permeability at initial 5% KCl water injection
K6 : water permeability at 100 PV 5% KCl water injection

material, therefore it can't be analyzed by the XRD.

D. Results of Sensitivity Test on Water Salinity

The results of Sensitivity Test on Water Salinity can be seen in Table 6. At first, the samples were injected with formation brine. The recorded water permeability (K1) was within 94.30 mD to 5176.20 mD, 1.27 mD to 329.96 mD, 359.99 mD to 6248.96 mD, 10.29 mD to 4027.67 mD for "K", "B", "J", "D" formations, respectively and 2389.69 mD for "M" formation.

The brine injection was ended at 100 pore volume injection, whereas the recorded water permeability value (K2) ranged between 35.20 mD to 1932.45 mD, 0.41 mD to 144.02 mD, 258.24 mD to 4482.68 mD, 3.5 mD to 2807.96 mD, for "K", "B", "J", "D" formations, respectively and 1813.91 mD for "M" formation.

Next, the brine with 3% KCl concentration was injected into samples, at initial injection, the recorded water permeability (K3) was within 48.92 mD to 1403.35 mD, 0.41 mD to 144.02 mD, 147.69 mD to 3586.15 mD, 5.40 mD to 1225.19 mD for "K", "B", "J", "D" formations, respectively and 983.42 mD for "M" formation. The process was continued until it reached 100 Pore Volume fluid injection, at this condition the water permeability (K4) was measured, recorded value ranged between 28.16 mD to 1005.12 mD, 0.23 mD to 107.78 mD, 89.11 mD to 2399.46 mD, 1.84 mD to 436.25 mD for "K", "B", "J", "D" formations, respectively and 695.79 mD for "M" formation.

Later, brine with 5% KCl concentration was injected into the samples. At initial injection the recorded water permeability (K5) ranged between 12.37 mD to 1252.90 mD, 0.36 mD to 110.48 mD, 157.96 mD to 2890.52 mD, 2.38 mD to 3121.33 mD for "K", "B", "J", "D" formations, respectively and 1036.40 mD for "M" formation. The fluid injection was stopped at 100 pore volume fluid injection,

Table 7
Results of sensitivity test on produced water salinity

Formation	No. Sampel	Depth, ft	Ka,mD	Formation Brine		GIF water		
				Kl,mD	K2,mD	K3,mD	K4,mD	K Reversed mD
K	141	907.55	4291.00	3637.09	2554.29	1375.14	381.28	612.69
	144	908	2038.00	68.96	45.22	9.95	1.05	612.69
	169	914.4	5457.00	2396.78	1316.84	1297.00	408.35	577.88
	176	916.75	11854.00	6101.26	4406.47	1341.23	403.53	283.92
	202	930.5	4291.00	635.73	195.54	246.73	68.42	69.15
	204	931.25	1244.00	860.90	394.95	370.88	179.11	172.56
	206	931.5	2876.00	2561.68	1357.32	1027.11	470.47	339.90
	266	974.3	357.00	2.74	0.75	1.83	0.52	1.15
B	375	1057.65	360.00	1.08	0.29	0.45	0.13	0.31
J	20	1107.45	649.00	380.93	244.18	474.16	200.79	180.69
	21	1107.6	3567.00	1288.54	699.40	823.35	220.20	245.00
	22	1107.75	1265.00	429.79	285.37	208.46	97.03	102.51
	32	1157.65	6685.00	2955.35	1863.73	2926.14	770.58	750.85
	35	1158.05	6449.00	4213.47	1811.24	3858.95	1091.53	516.25
	491	1174.85	4066.00	1817.18	878.64	1184.25	316.72	126.38
	494	1176.75	2371.00	1112.94	487.17	351.89	94.11	155.40
D	521	1200.25	2090.00	1900.34	825.47	937.67	280.01	332.90
	533	1209.15	301.00	10.96	3.35	2.72	0.95	2.44
	576	1258.5	1632.00	1342.84	321.92	451.59	73.23	145.25
	577	1259.4	9893.00	4770.79	2650.44	1241.98	249.06	561.16
M	40	1268.65	1934.00	846.87	331.79	293.13	101.07	214.58
	585	1270.5	2668.00	1067.42	300.34	365.64	102.93	116.34

Note:
K1 : water permeability at initial brine injection
K2 : water permeability at 100 PV brine
K3 : water permeability at initial GIF water injection
K4 : water permeability at 100 PV GIF water injection

at this condition the water permeability (K6) was measured, resulted in interval value of 7.72 mD to 765.41 mD, 0.30 mD to 75.38 mD, 125.81 mD to 2044.31 mD, 1.45 mD to 1880.73 mD mD for "K", "B", "J", "D" formations, respectively and 731.46 mD for "M" formation. Moreover, the water permeability at flow reversed direction was also measured. The reversed water permeability indicated value ranged within 32.28 mD to 607.93 mD, 0.53 mD to 21.83 mD, 113.28 mD to 2631.42 mD, for "K", "B", "J", "D" formations, respectively and 915.52 mD for "M" formation.

E. Results of Sensitivity Test on Produced Water

Salinity

Results of sensitivity test on produced water salinity is displayed in Table 7.

First, the formation brine was injected into the samples, at initial injection the record water permeability (K1) value was within 2.74 mD to 6101.26 mD mD, 380.93 mD to 4213.47 mD, 10.96 mD to 4770.79 mD, 846.87 mD to 1067.42 mD for "K", "J", "D", "M" formations, respectively and 1.08 mD for "B" formation. The process was ended at 100 pore volume fluid injection, at this condition, the water permeability value (K2) ranged between 0.75 mD to 4406.47 mD, 244.18 mD to 1863.73 mD, 3.35 mD to 2650.44 mD, 300.34 mD to 331.79 mD mD for "K", "J", "D", "M" formations, respectively and 0.45 mD for "B" formation. At 100 pore volume fluid injection, the water permeability value (K4) ranged between 0.52 mD to 470.47 mD,

Next, the produced water from CIF station in Field "X" was injected into samples, at initial injection, water permeability value (K3) ranged within 1.83 mD to 1375.14 mD, 208.46 mD to 3858.95 mD, 2.72 mD to 1241.98 mD, 293.13 mD to 365.64 mD for "K", "J", "D", "M" formations, respectively and 0.45 mD for "B" formation. The injection continued until 100 pore volume fluid injection, at this condition, the water permeability (K4) value ranged within 0.52 mD to 470.47 mD, 94.11 mD to 1091.53 mD, 101.07 mD to 102.93 mD for "K", "J", "D", "M" formations, respectively and 0.13 mD for "B" formation. Furthermore, water permeability at reversed flow direction indicated value ranged within 1.15 mD to 612.69 mD, 102.51 mD to 750.85 mD, 2.44 mD to 561.16 mD, 116.34 mD to 214.58 mD for "K", "J", "D", "M" formations, respectively and 0.13 mD for "B" formation.

IV. DISCUSSION

A. Analysis on Results of Fresh Water Sensitivity Test

Analysis of the results of the fresh water sensitivity test can be seen in table 8. For K Formation, when the samples were injected with formation brine, there was a reduction in water permeability of approximately between 25.1% to 54.2% experienced by all samples (see Table 3 and Figure 2). The highest reduction was recorded by sample no. 209. A comparison of water permeability indicates low to moderate initial liquid-to-water permeability ratios for most samples tested (ratio = 0.02 - 0.691) which means the samples have character which is very sensitive with water.

As the samples was injected with fresh water, the ratio of liquid to water permeability drops further to a range of values of 0.009 to 0.4. Furthermore, most samples also experienced an increase in water permeability reduction value of 25.40 % to 71.42% (see Table 3). This means the samples are also sensitive with fresh water, with the exception of sample no. 45, all of the samples show increases in water permeability when the flow injection was eventually reversed which indicates the presence of fine migrations.

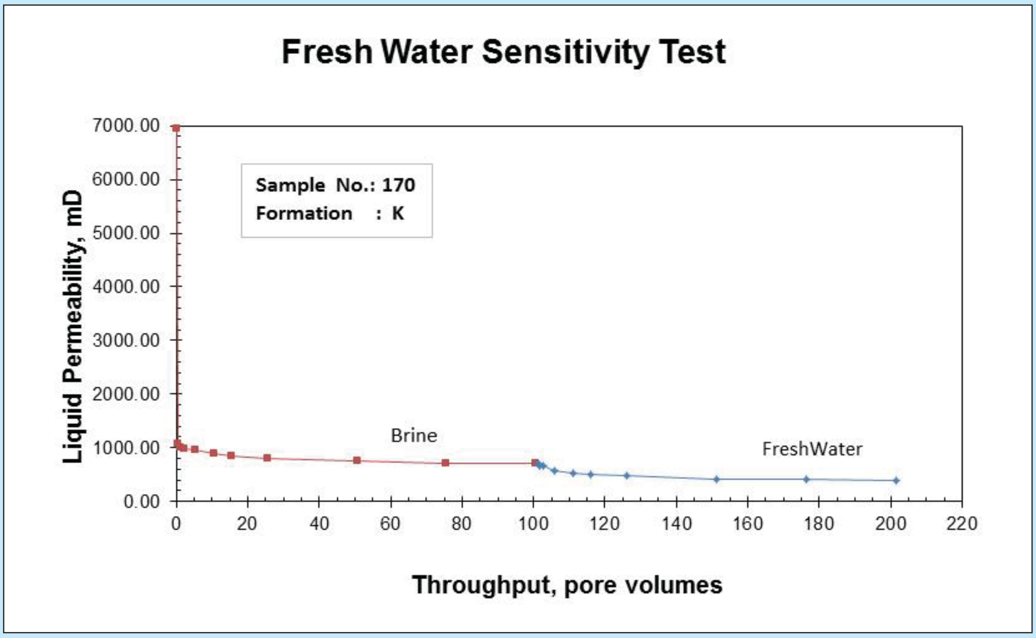

Figure 2
Performance of water permeability reduction of fresh water sensitivity test on sample no 170, "K" formation.

Samples of B formation indicate almost the same performance as K samples. Reduction in water permeability by approximately between 39.2% to 53.6% were experienced by the samples, when samples were flushed with formation brine. A comparison with water permeability indicates very low to moderate initial liquid-to-water permeability ratios for most samples tested (ratio = 0.006 - 0.75) which mean the samples are very sensitive with water.

However, during fresh water injection, reduction in water permeability of the samples went up to interval value of 42.28% to 53.84%. Moreover, the ratio of water permeability decreased to a range of values of 0.003 to 0.375. This performance shows that B formation is sensitive to fresh water. Figure 3 displays performance of permeability reduction during fresh water sensitivity test on "B" formation. The value of water permeability at the reversed flow injection was raised, which indicated the presence of fine migration.

For J Formation, the samples showed a reduction in permeability by an average value of 37.1%, when flushed with formation brine. The ratio of water permeability shows a low average value of 0.272, which mean the samples are sensitive with water. When the samples were injected with fresh water, the reduction of water permeability increased to an average value of 46.59%. Furthermore, the ratio of water permeability decreased to an average value of 0.146 which showed Jaga formation is sensitive to fresh water. Figure 4 shows the figure of permeability reduction for "J" formation. Apparently, the formation damage was mainly caused by fine migration as the value of water permeability at the reversed flow injection was raised for all samples. All of the samples show increases in water permeability when the flow injection was eventually reversed which indicates the presence of fine migrations.

Samples of D formation recorded average value of 27.4% in water permeability reduction when formation brine was injected into the samples. A comparison with water permeability indicates very low initial liquid-to-water permeability ratios for samples tested (average ratio = 0.047) which means the samples have character very sensitive to water. As the samples were injected with fresh water (distillate water), the water permeability reduction raised slightly to average value of 32.22%. However, the ratio of water permeability to initial water permeability decreased to an average value of 0.031. This performance shows that the samples are sensitive to fresh water. All of the samples show increases in water permeability when the flow injection was

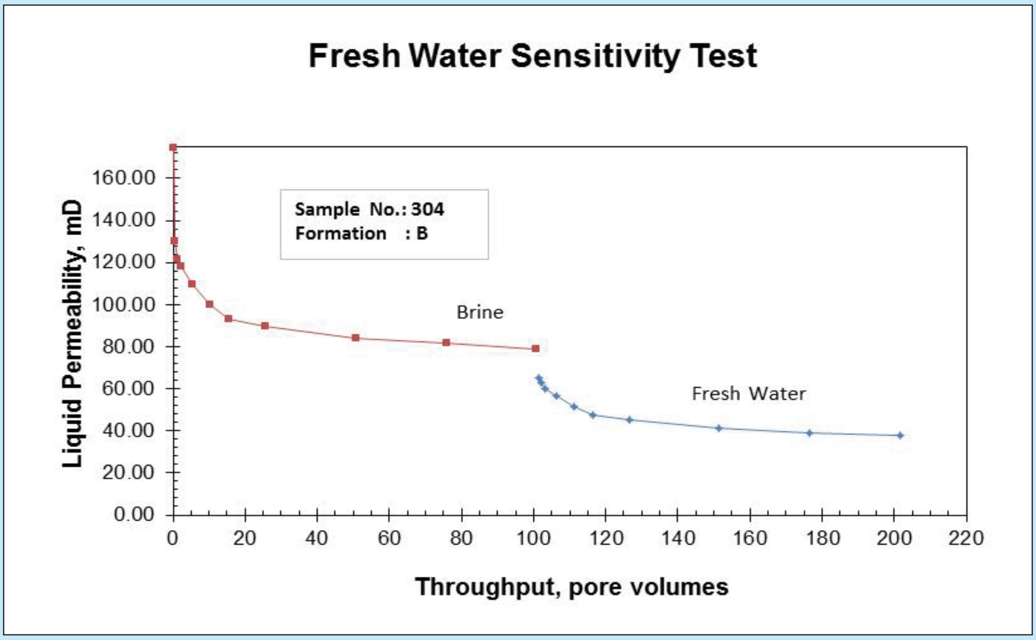

Figure 3
Performance of water permeability reduction of fresh water sensitivity test on sample no 304, "B" formation.

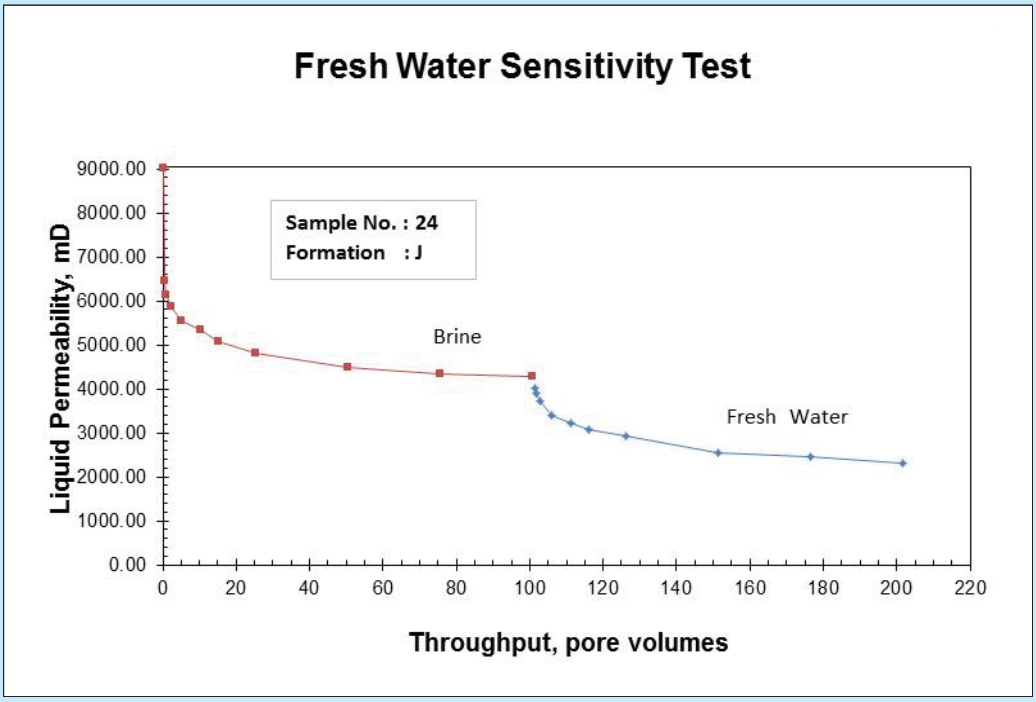

Figure 4
Performance of water permeability reduction of fresh water sensitivity test on sample no 24, "J" formation.

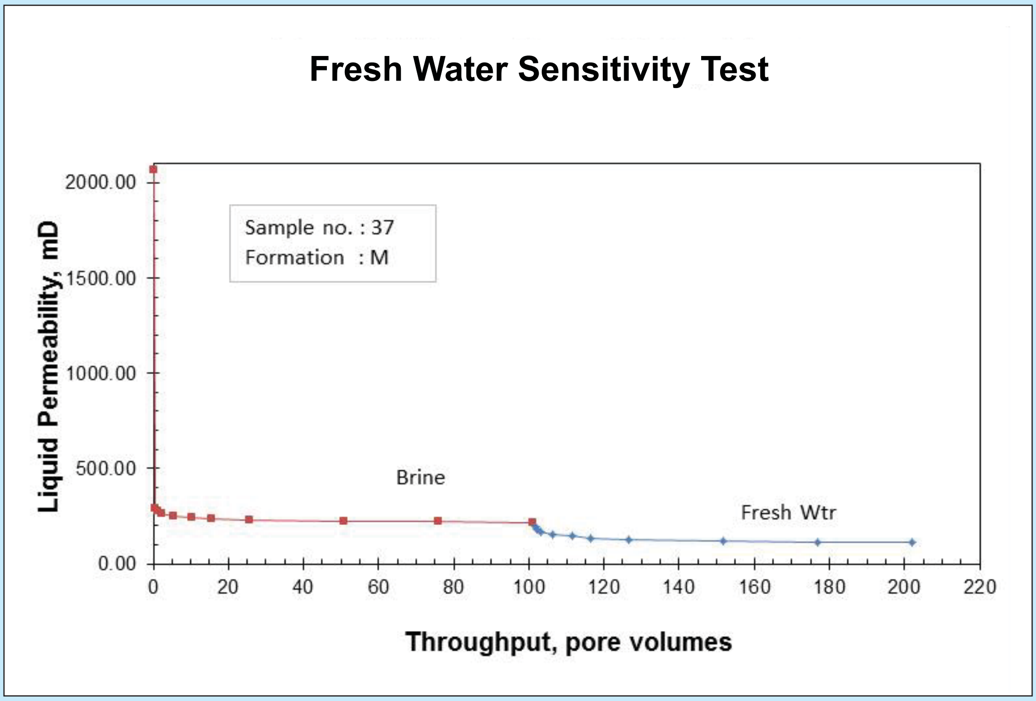

Figure 5
Performance of water permeability reduction of fresh water sensitivity test on sample no 37, "M" formation.

eventually reversed which indicates the presence of fine migrations.

Sample no. 37 represents M formation indicated a value of 24.09% in water permeability reduction when formation brine was flushed into the samples. The ratio of initial water permeability to water permeability recorded a low value of 0.139 and is characterized as sensitive to water. When the fresh water (distillate water) was injected to samples, the water permeability reduction increased to a value of 41.65%. Figure 5 displays figure of water permeability reduction. However, the ratio of air permeability to initial water permeability decreased to a value of 0.095 which means the samples are sensitive to fresh water.

It seems that all of the formations are sensitive to the fresh water as mostly the samples have experienced increasing water permeability reduction and a decreasing ratio of initial water permeability to water permeability. Permeability reduction during fluid flow, as acknowledged, could be caused by various factors but it is fairly acceptable that the plugging occurrence was likely to be caused by fine migration and swelling clay in the rock samples. The occurrence of fine migration was indicated by increases in water permeability when the flow injection was eventually reversed. A small quantity of swelling clay also existed in the upper part of Kedua formation, as the reversed water permeability showed a decrease.

B. Analysis on Results of Filtered Water Sensitivity Test

Table 9 displays analysis of the results of return permeability core test for samples no.46, no.120, no 123 of K formation. The results show that for formation brine injection, the ratio of initial water

Table 8
Analysis of fresh water sensitivity test result

Formation	No. Sampel	Depth (ft)	Ka, mD	Brine		Fresh Water		
				Kl/Ka	Reduction K1-K2 (%)	K3/Ka	Reduction K3-K4(%)	K Reversed mD
K	45	822.65	11705.00	0.691	43.403	0.400	71.419	1311.76
	119	898.12	2812.00	0.103	28.200	0.034	38.393	99.52
	142	907.7	2008.00	0.063	34.531	0.038	70.934	65.26
	146	908.3	2188.00	0.090	27.727	0.046	25.401	80.61
	147	908.45	3863.00	0.036	25.143	0.031	28.909	137.23
	170	914.55	6951.00	0.154	33.894	0.101	44.125	424.73
	209	933.5	1870.76	0.020	54.211	0.009	52.526	12.95
B	23	1018.3	566.00	0.025	39.265	0.013	50.966	4.44
	304	1010.3	174.70	0.746	39.346	0.375	42.279	67.80
	316	1019.7	1090.00	0.149	51.238	0.077	52.564	62.48
	324	1028.25	607.00	0.006	53.636	0.003	53.841	2.51
J	24	1112.05	9008.00	0.719	33.894	0.447	42.545	2631.42
	27	1116.9	3794.00	0.314	61.660	0.101	59.635	194.34
	416	1102.25	638.00	0.006	29.636	0.004	44.253	2.80
	422	1108.15	1017.00	0.048	23.220	0.031	39.933	44.55
D	507	1187.6	1808.00	0.069	30.244	0.047	35.762	66.19
	522	1201.4	2110.00	0.009	24.600	0.008	30.773	13.28
	523	1202.5	1817.00	0.073	31.818	0.047	34.372	67.52
	525	1203.25	651.00	0.036	23.235	0.023	27.976	12.33
M	37	1265.45	2064	0.139	24.094	0.095	41.653	125.29

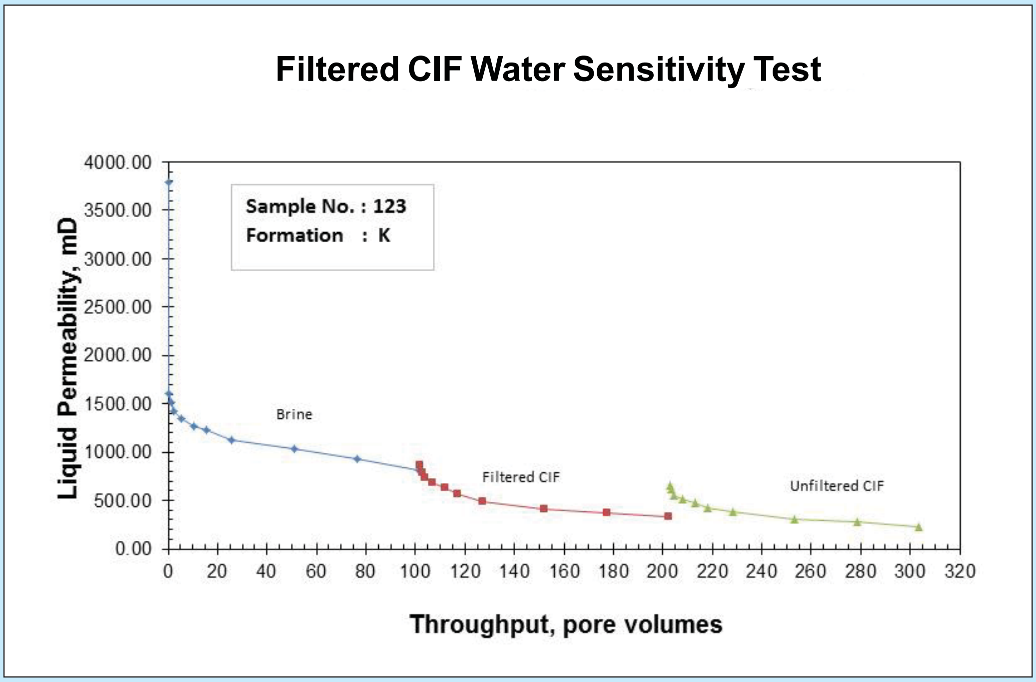

Figure 6
Performance of water permeability reduction of filtered water sensitivity test on sample no 123, "K" formation.

Table 9
Analysis of filtered water sensitivity test result

Formation	No. Sampel	Depth, ft	Ka,mD	Brine		GIF Filtered		OF Un Filtered		
				KI/Ka	K1-K2 Reduction%	K3/Ka	K3-K4 RpHurtinn%	K5/Ka	K5-K6 Reduction%	K Reversed, mD
K	46	822.9	10701.00	0.44	73.03	0.35	53.73	0.37	53.80	791.48
	120	898.9	2656.00	0.02	42.00	0.02	61.33	0.01	63.07	16.32
	123	901.15	3790.00	0.42	49.39	0.23	62.59	0.17	65.08	240.48
B	309	1014.7	2768.00	0.59	69.20	0.24	60.68	0.16	61.50	172.83
	321	1026.9	334.00	0.01	60.42	0.01	42.79	0.00	64.74	0.72
	337	1035.95	836.00	0.0	34.09	0.0	73.03	0.00	73.77	0.27
	338	1036.25	811.00	0.0	58.07	0.0	72.07	0.00	74.41	0.19
J	25	1112.2	7790.00	0.61	65.27	0.37	34.58	0.33	71.49	744.03
	28	1117.05	4626.00	0.73	72.48	0.64	41.33	0.65	42.65	1862.11
	30	1117.95	4962.00	0.66	68.93	0.34	47.19	0.34	80.66	369.49
	466	1150.2	242.00	0.29	63.62	0.21	55.99	0.15	73.81	12.45
D	508	1188.25	1754.00	0.28	67.65	0.09	71.07	0.06	77.82	25.41
	524	1202.85	2372.00	0.47	67.20	0.32	70.14	0.12	70.30	102.36
	526	1203.8	404.00	0.41	67.20	0.21	70.14	0.08	78.03	7.67
	527	1204.3	2372.00	0.16	65.41	0.04	70.14	0.03	74.29	16.17
M	36	1263.7	11619.00	0.84	59.39	0.53	72.31	0.58	80.44	1526.62
	584	1269.5	2688.00	0.36	81.88	0.29	72.31	0.13	71.47	123.13

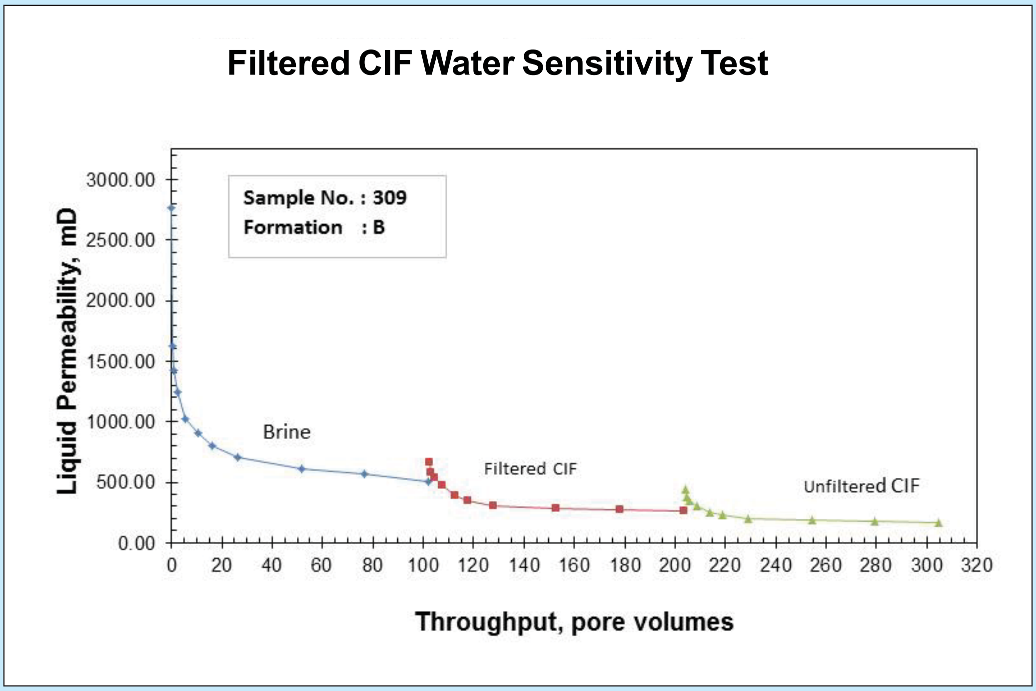

Figure 7
Performance of Water permeability reduction of filtered water sensitivity test on sample no 309, “B” formation.

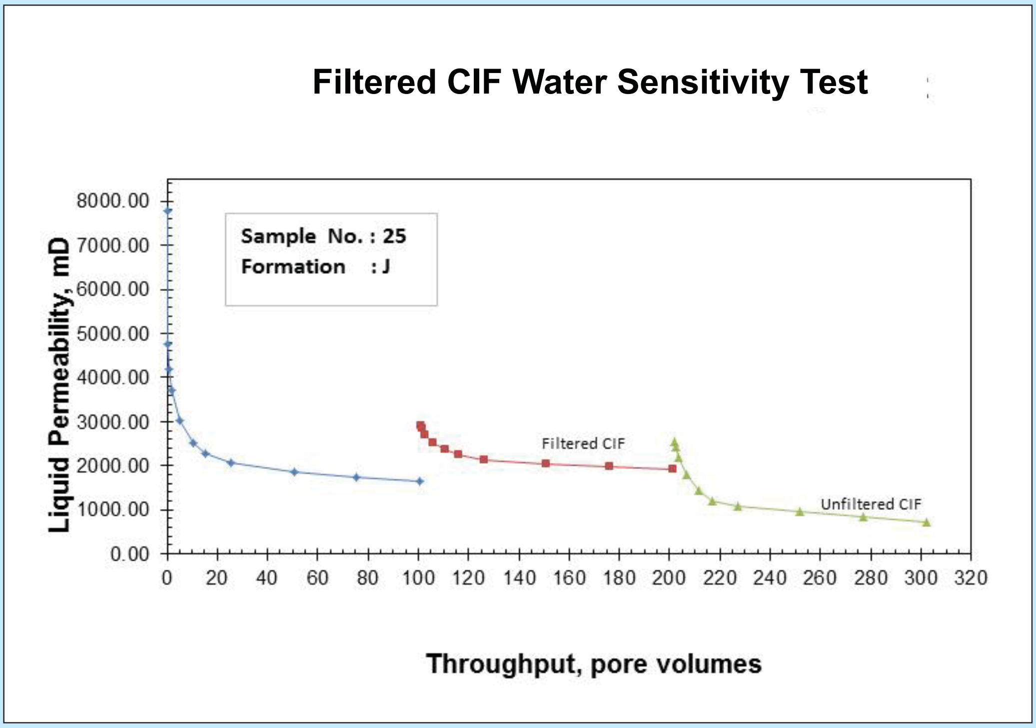

Figure 8
Performance of water permeability reduction of filtered water sensitivity test on sample no 25, “J” formation.

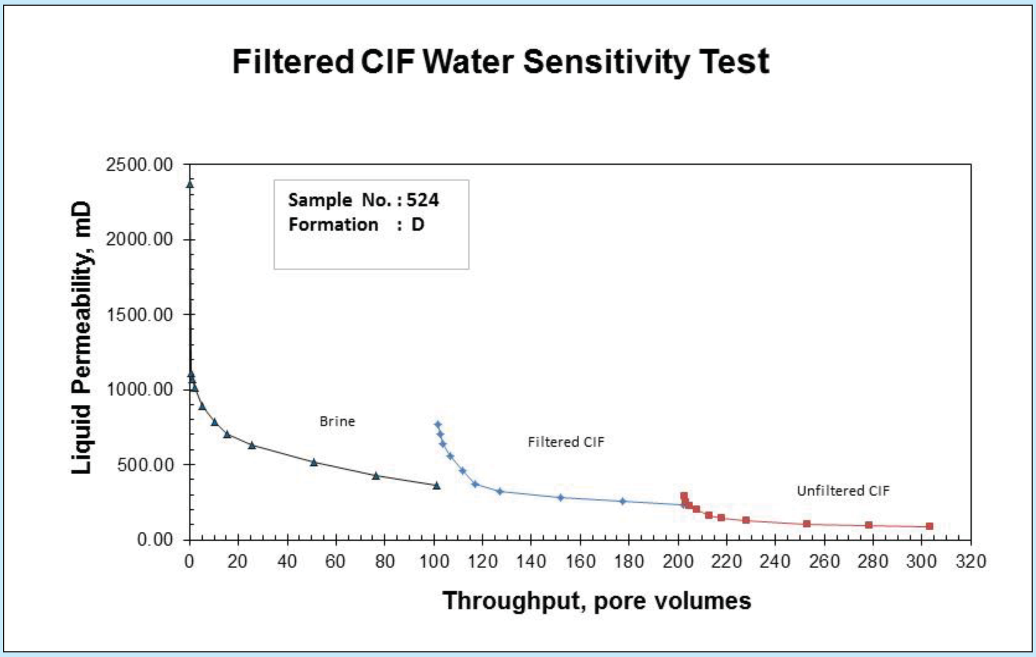

Figure 9
Performance of Water permeability reduction of filtered water sensitivity test on sample no 524, "D" formation.

permeability to water permeability indicates an average value of 0.3, whereas percentage water reduction from initial water permeability to water permeability at 100 PV brine injection records a value of 54.81%. When the samples were flushed with filtered CIF water, the ratio of initial water permeability to water permeability has an average value of 0.2. Moreover, all samples experienced reduction in water permeability with average value of 59.22%. As the samples were injected by unfiltered CIF water, the ratio of initial water permeability to water permeability dropped slightly to an average value of 0.18, whereas the reduction of initial water permeability to water permeability at 100 PV CIF resulted in an average value of 60.65. Mostly, samples show increases in water permeability when the flow injection was eventually reversed which indicates the presence of fine migrations. An exception was sample no.46, the water permeability at reversed flow showed a decrease which indicates the presence of swelling clay. The figure of water permeability reduction in this test for "K" formation can be seen in Figure 6.

The test was also performed on samples no. 309, no. 321, no.337 and no. 338 of B formation, and as the samples were injected with formation brine, the ratio of initiial water permeability to water permeability recorded an average value of 0.15 and the water permeability reduced by an average value of 55.45%. When the filtered CIF water is flushed into the sample, the ratio of initial water permeability to water permeability fell to an average value of 0.06. The initial water permeability, however, fell on average to 62.14 at the end of injection (100 PV filtered CIF). During CIF, the ratio of initial water permeability to water permeability dropped to an average value of 0.04, whereas the water reduction recorded average value of 68.61%. All of samples show increasing in water permeability when the flow injection was eventually reversed which indicates the presence of fine migrations. Figure 7 displays results of water permeability reduction.

For J Formation which was represented by samples no.25, no.28, no.30 and no. 466, when the samples were injected by formation brine, the ratio of initial water permeability to water permeability indicated average value of 0.57 and the water reduction recorded value of 67.57%. However, when the samples were injected with filtered CIF, the ratio of initial water permeability to water permeability decreased to an average value of 0.39, whereas the water permeability reduced in average value of 44.77%. As the CIF water was injected to the samples, the ratio of intial water permeability to water permeability dropped slightly to an average value of 0.37, but the water permeability reduction was raised significantly to an average value of 67.15%. All of the samples show increases in water permeability when the flow injection was eventually reversed which indicates the presence of fine migrations. Figure 8 displays figures for water permeability reduction.

The samples no. 508, no. 524, no.526 and no.527 of D formation show the following performance during the test. As the formation brine was initially injected into the samples, the ratio of initial water permeability to water permeability recorded a value of 0.33, and the water permeability decreased in average value of 66.87 %. Next, the filtered CIF water was injected into the samples, at this condition, the ratio of initial water permeability to water permeability indicated an average value of 0.17. During filtered CIF , the water permeability reduced on average of 70.37%. When the CIF water was injected into the samples, the ratio of initial water permeability to water permeability dropped to average value of 0.07, whereas the water permeability reduction increased to an average value of 0.07. All of samples demonstrate increases in water permeability when the flow injection was eventually reversed which indicates the presence of fine migrations. The figure of water permeability reduction in this test for “D” formation can be seen in Figure 9.

M formation was represented by samples no.36 and no.584. When samples were initially flushed with formation brine, a comparison of water permeability indicates moderate initial liquid-to-water permeability ratios valued of 0.6 on average. After that, the samples were injected by filtered CIF water, the ratio of water permeability and the water permeability reduction recorded average values of 0.41 and 72.31%, respectively. Next, the CIF water was injected into the samples, and a comparation initial water permeability to water permeability showed decreasing to low average value of 0.35, whereas water permeability reduction recorded average value of 75.95 %. All of the samples demonstrate increases in water permeability when the flow injection was eventually reversed which indicates the presence of fine migrations.

Table 10
Analysis on results of scalling tendency analysis test

Formation	No. Sampel	Depth, ft	Ka,mD	Brine		GIF		
				Kl/Ka	K1-K2 Rpdurtion%	K3/Ka	K3-K4 Rpdurtion%	K Reserved. mD
K	51	824.25	12088.00	0.58	58.17	0.26	55.57	
	127	903.8	2514.00	0.31	60.01	0.12	65.46	
	187	918.5	497.00	0.00	64.39	0.00	81.77	
	188	918.65	206.00	0.00	64.39	0.00	55.87	
	135	905.65	3874.00	0.65	46.15	0.50	63.88	
B	310	1015.25	3227.00	0.49	49.29	0.17	49.27	236.01
	341	1038.5	287.00	0.01	50.35	0.01	50.11	1.14
	343	1039.4	831.00	0.02	61.04	0.01	65.86	
	350	1043.7	441.00	0.01	60.44	0.01	79.57	
J	29	1117.6	5967.00	0.79	35.90	0.51	73.26	875.49
	33	1157.75	5261.00	0.94	63.20	0.55	78.1	516.25
	430	1115.25	5826.00	0.70	30.17	0.67	73.26	1848.01
D	513	1192.5	2072.00	0.39	54.72	0.16	65.54	112.79
	528	1204.7	1376.00	0.14	54.42	0.09	68.47	51.09
	529	1205.75	775.00	0.20	48.99	0.08	70.67	12.20
	571	1253.55	3643.00	0.39	44.44	0.21	47.58	317.73
M	39	1267.65	5261.00	0.68	61.06	0.29	61.82	642.25

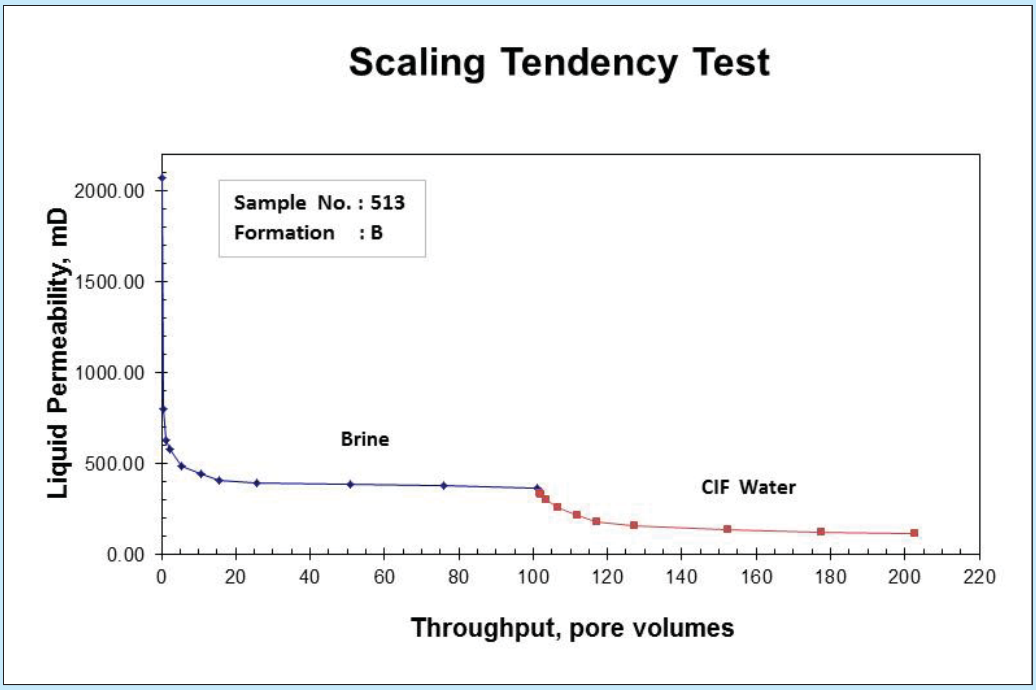

Figure 10
Performance of water permeability reduction of scaling tendency test on sample no 513, "B" formation.

The results of the return permeability core test demonstrates that all of the samples are sensitive to CIF water which is indicated by the lowest ratio of water permeability to water permeability and the highest water permeability reduction. Filtering CIF water made a slight improvement in water sensitivity as the water permeability reduction value was smaller than the unfiltered CIF water. An exception was Jaga Formation, filtering CIF water might be able to decrease significantly water permeability reduction. Formation damage was mainly caused by fine migrations, however, small quantity of swelling clay also existed in the upper part of Kedua formation.

C. Analysis on Results of Scaling Tendency Analysis Test

The results of Scaling Tendency Analysis test can be seen in Table 10. The samples no.51, no.127, no.187, no.188, and no.135 of K formation experienced a reduction in water permeability and the ratio of initial water permeability to water permeability average value of 58.61% and 0.31, respectively when it was injected with formation brine. After that, the CIF water was injected into the samples, and the water permeability reduced at an average value of 64.51% which corresponded to the ratio of initial water permeability to water permeability of an average value of 0.13. The XRD analysis on effluent filtrate results showed the presence of significant amounts of kaolinite and other fine particles such as illite. (see Table 5).

The test was conducted on samples no.310, no. 341, no.343 and no.350 of B formation. During the formation brine injection, the water permeability reduction recorded an average value of 55.28 which corresponded to the ratio of initial water permeability to water permeability average value of 0.13. After being injected with CIF water, the water permeability reduction soared up to an average value of 79.57%, whereas the ratio of initial water permeability to air permeability went down to an average value of 0.05. The performance of water permeability reduction is displayed in Figure 10. The XRD analysis on effluent filtrate results indicated the presence of kaolinite (10.33%) and illite (17.67%).

J formation was represented by samples no. 29, no. 33, and no.430. During formation brine injection, the water permeability reduction and the ratio of initial water permeability to air permeability recorded an average value of 43.09% and 0.81, respectively. Next, the samples were flushed with CIF water. In this condition, water permeability

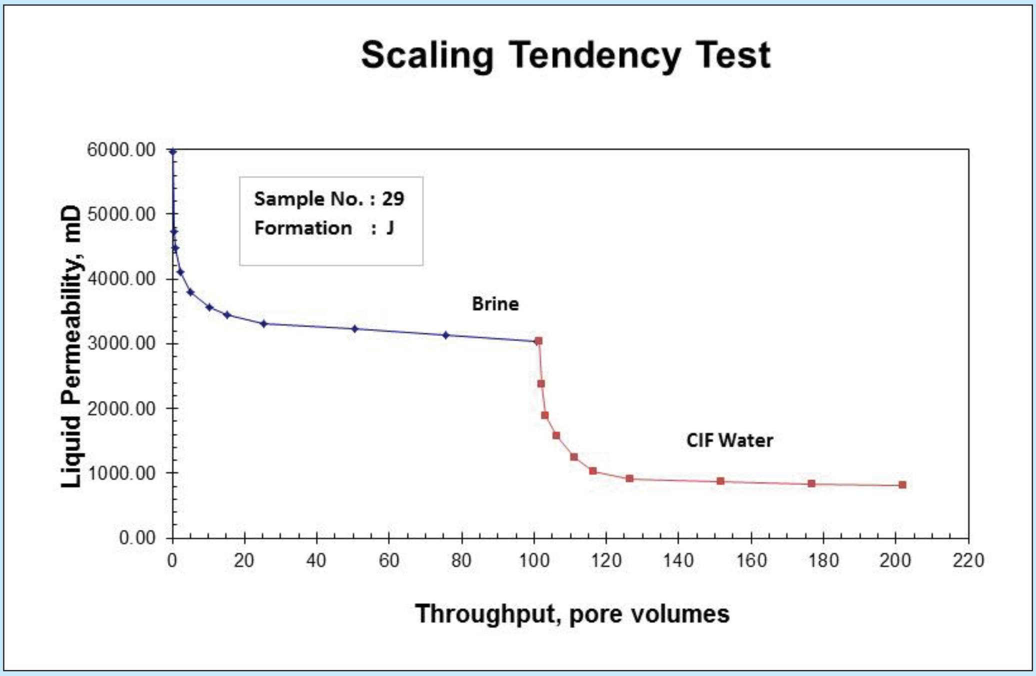

Figure 11
Performance of water permeability reduction of scaling tendency test on sample no 29, "J" formation.

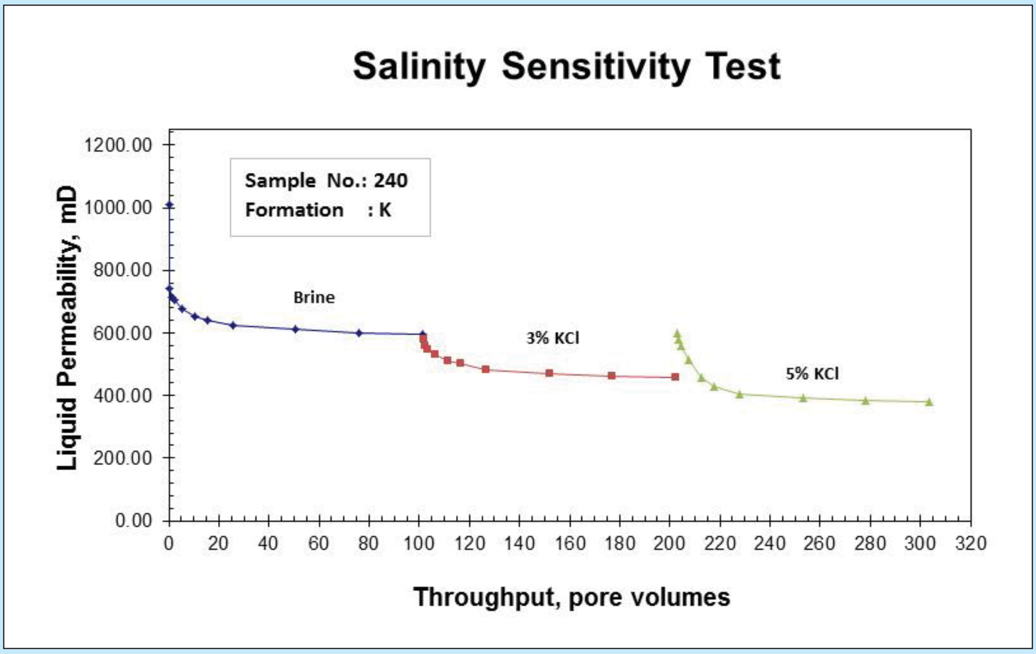

Figure 12
Performance of water permeability reduction of brine salinity sensitivity test on sample no 240, "K" formation.

reduction increased dramatically to an average value of 74.87%. In contrast, the ratio of initial water permeability to air permeability dropped to an average value of 0.55. Figure 11 shows the performance of water permeability reduction. The XRD analysis on effluent results showed no material substance.

The scaling tendency analysis test was performed on samples no. 513, no.528, no.529 and no. 571 of D formation. The samples initially were flushed with formation brine, during the test, the water permeability was reduced at an average value of 50.64%, whereas the ratio of initial water permeability to air permeability was 0.28 on average. After that, the samples were injected by CIF water, then the water permeability reduction increased to an average value of 63.06% which corresponded to ratio of initial water permeability to water permeability with an average value of 0.13. XRD analysis results on effluent filtrate showed that the samples contained Illite and Kaolinite with an average value of 6.5% and 10.5%, respectively.

M formation was represented by sample no.39. During the formation brine injection, the water reduction recorded a value of 61.06% which corresponded to the ratio of initial water permeability to water permeability with an average value of 0.68. When the samples were flushed with CIF water, the water permeability reduction increased slightly to a value of 61.82% whereas the ratio of initial water permeability to water permeability decreased to a value of 0.29. XRD analysis on effluent filtrate indicated the presence of kaolinite with a value of 16%.

The Scaling Tendency Analysis Test results demonstrate that mostly formations are sensitive to CIF water,indicated by increases in water permeability reduction and a decrease in the ratio of initial water permeability to water permeability. XRD analysis on effluent filtrate shows that fine migration may have taken place, indicated by the significant amounts of kaolinite and other fine particles such as illite. The clay particles in the pore space migrated to fill pore-throats causing permeability reduction. Moreover, Illite in fibrous form can be attributed as swelling clay. Swelling clay reduced formation permeability by peeling off the pore surface and plugging pore throat.

D. Analysis on Results of Sensitivity Brine Salinity

Table 11 presents the results of Sensitivity on Brine Salinity. The samples no 116, no.136, no.139, no.148, no.171, no.185, no.203 and no.240 of K formation were selected for the test. When the samples were flushed with formation brine, the water

Table 11
Analysis on results of sensitivity on brine salinity

Formation	No. Sampel	Depth, ft	Ka,mD	Brine		3% KCl		5% KCl		K
				Kl/Ka	K1-K2 Reduction%	K3/Ka	K3-K4 Reduction%	K5/Ka	K5-K6 Reduction%	Reversed,mD
K	116	895.95	4529.00	0.051	41.333	0.041	45.000	0.033	42.084	161.30
	136	905.8	2430.00	0.363	30.476	0.153	45.000	0.108	29.557	90.24
	139	906.4	3080.00	0.302	30.476	0.218	38.333	0.135	29.557	294.08
	148	908.6	1303.00	0.113	73.333	0.038	42.434	0.035	29.557	32.28
	171	914.7	9587.00	0.540	62.667	0.146	28.377	0.131	38.909	607.93
	185	918.25	2975.00	0.032	62.667	0.018	28.377	0.004	37.593	10.86
	203	930.65	837.00	0.900	62.667	0.260	47.764	0.155	43.544	89.46
	240	950.75	1010.00	0.734	19.888	0.574	21.100	0.592	36.802	89.46
B	315	1019.15	1605.00	0.206	45.517	0.090	25.165	0.069	31.774	-
	362	1050.05	657.00	0.240	42.083	0.061	54.861	0.021	49.221	21.83
	364	1051.25	234.00	0.060	65.026	0.060	65.026	0.009	17.697	1.42
	367	1052	869.00	0.001	67.449	0.000	45.000	0.000	17.808	0.53
J	26	1116.6	2271.00	0.718	33.894	0.526	33.091	0.474	33.091	2631.42
	31	1157.5	5622.00	0.862	33.894	0.638	33.091	0.396	29.275	1642.11
	34	1157.9	7002.00	0.892	28.265	0.407	39.668	0.413	29.275	1642.11
	435	1119.7	2219.00	0.162	28.265	0.067	39.668	0.071	20.356	113.28
D	520	1199.45	2072.00	0.515	30.000	0.341	38.301	0.392	34.109	66.19
	530	1206	966.00	0.213	28.030	0.197	22.705	0.175	27.681	128.02
	532	1208.2	483.00	0.021	65.972	0.011	65.906	0.005	39.286	2.74
	572	1254.35	5452.00	0.739	30.283	0.225	65.906	0.573	39.746	1817.70
M	38	1265.6	4795	0.498	24.094	0.205	29.247	0.216	29.412	915.52

permeability reduced at an average value of 47.94%, whereas the ratio of initial water permeability to water permeability recorded an average value of 0.379. After that the samples were injected with 3 % KCl brine, recorded water permeability reduction and the ratio of water permeability dropped to an

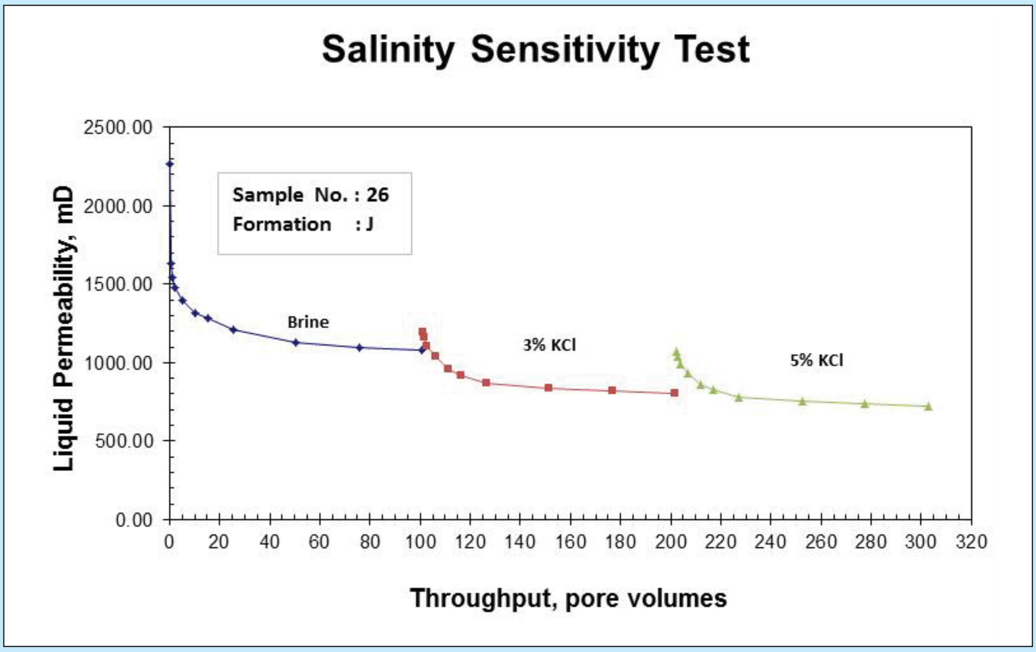

Figure 13
Performance of water permeability reduction of salinity sensitivity test on sample no 26, "J" formation.

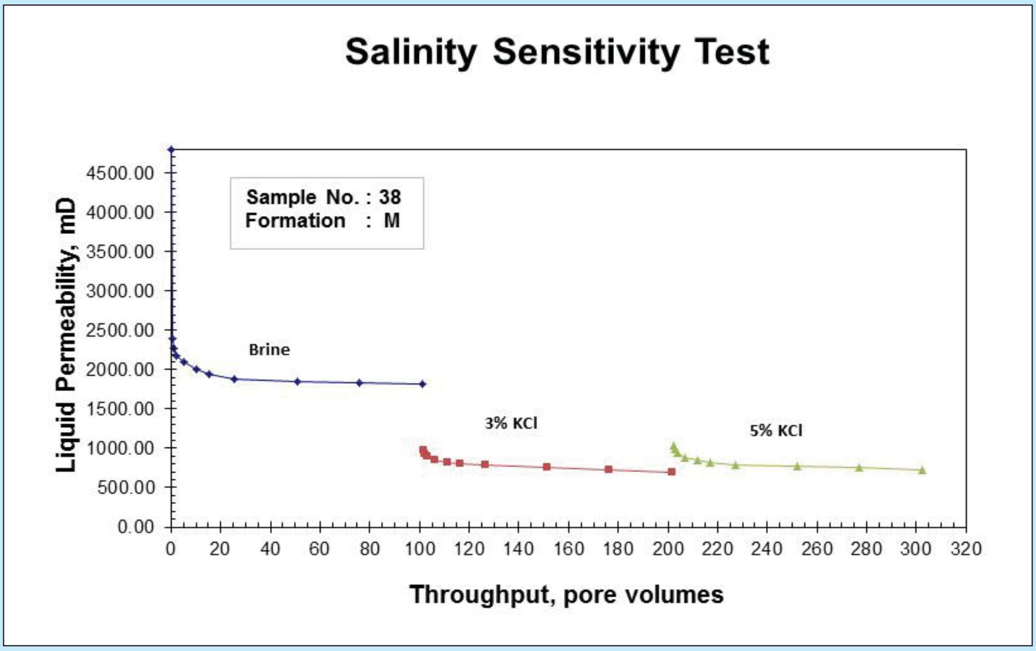

Figure 14
Performance of water permeability reduction of salinity sensitivity test on sample no 38, "M" formation.

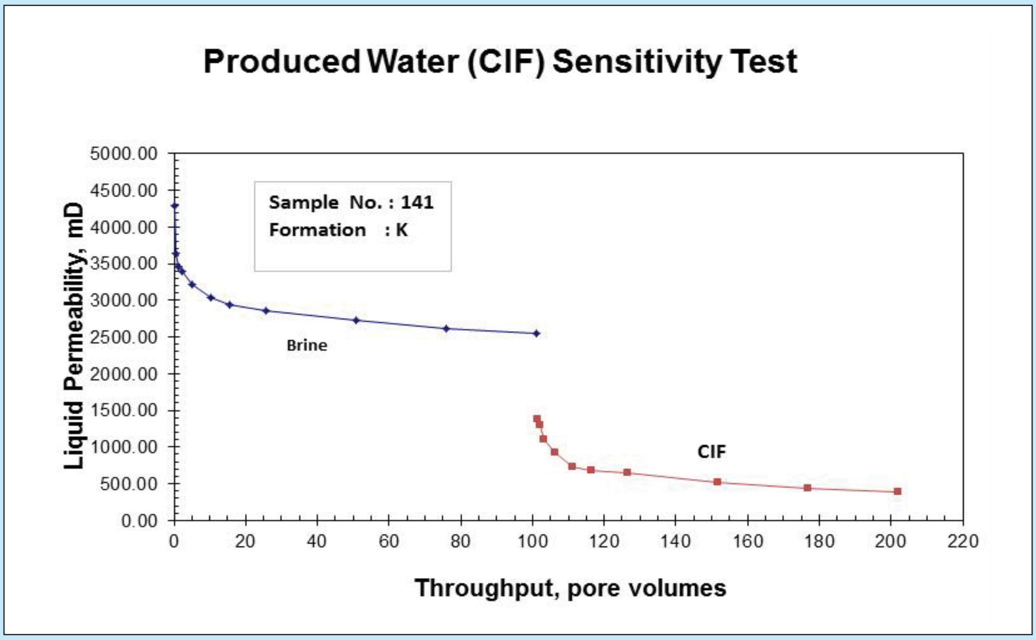

Figure 15
Performance of water permeability reduction of produced water sensitivity test on sample no 141, "K" formation.

average value of 37.05% and 0.18, respectively. Then, 5% KCL brine injection was applied to the samples, during injection, the water permeability reduction and the ratio of initial water permeability decreased to an average value of 35.95 % and 0.15. Figure 12 shows the performance of water permeability reduction.

The presence of fine migration clay such as kaolinite and Illite as indicated by XRD analysis in the scaling tendency test was confirmed as mostly samples demonstrated increases in water permeability at reversed flow injection. Samples no 136 and no.240, however, have experienced decreases in water permeability, the flow injection was eventually reversed which indicated swelling clay. Moreover, Illite in fibrous form can be attributed as swelling clay.

The test was also conducted on samples no 315, no. 362, no. 364, and no. 367 which represent B formation. The samples were initially flushed with formation brine, at this condition, water permeability reduction and the ratio initial water permeability to air permeability recorded average values of 55.02% and 0.13, respectively. Then, 3% KCL brine was injected into the samples and during the injection water permeability reduction and the ratio of initial water permeability to water permeability indicated an average value of 47.51% and 0.053, respectively.

When the samples were injected with 5% KCl brine, the water permeability reduction and also the ratio of initial water permeability to water permeability both dropped to an average value of 29.12% and 0.025, respectively. Mostly, samples show increases in water permeability when the flow injection was eventually reversed which indicates the presence of fine migrations. An exception was sample no.364, where the water permeability at reversed flow showed a decrease which indicates the presence of swelling clay.

J formation was represented by samples no.26, no.31, no.34 and no. 435. When the samples were injected with formation brine, the water permeability reduction and the ratio of initial water permeability to water permeability recorded average values of 31.08% and 0.66, respectively. Next, the samples were injected by 3% KCl brine, the water permeability reduction and the ratio of initial water permeability to water permeability indicated average values of 36.38% and 0.41, respectively. Then, the 5% KCl brine was injected into the samples, the water permeability reduction and the ratio of initial water permeability to water permeability decreased to average values of 28% and 0.34, respectively. Figure 13 shows this reduction in water permeability.

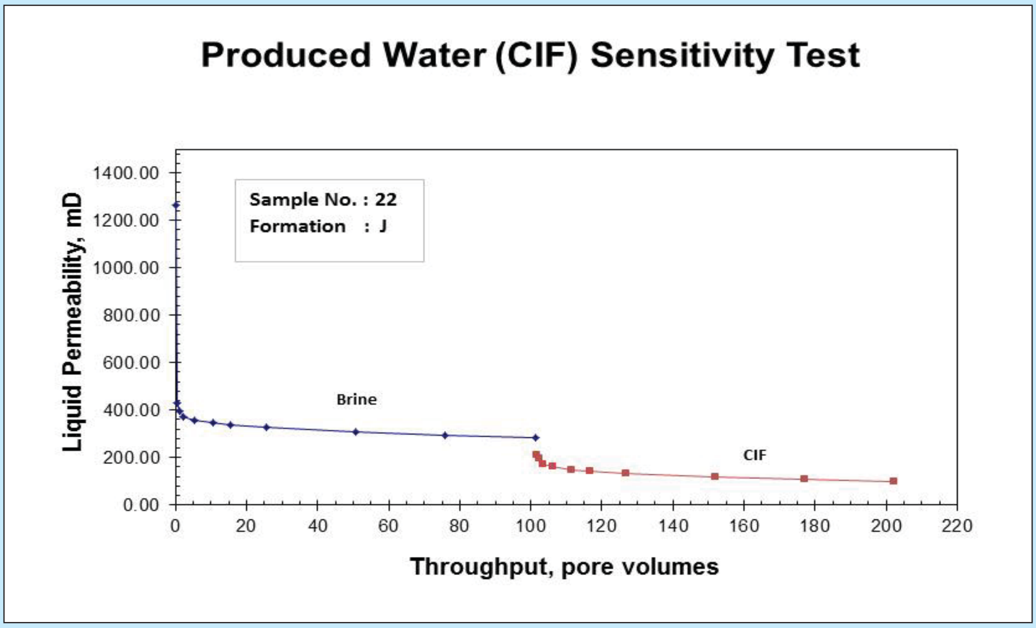

Figure 16
Performance of water permeability reduction of produced water sensitivity test on sample no 22, "J" formation.

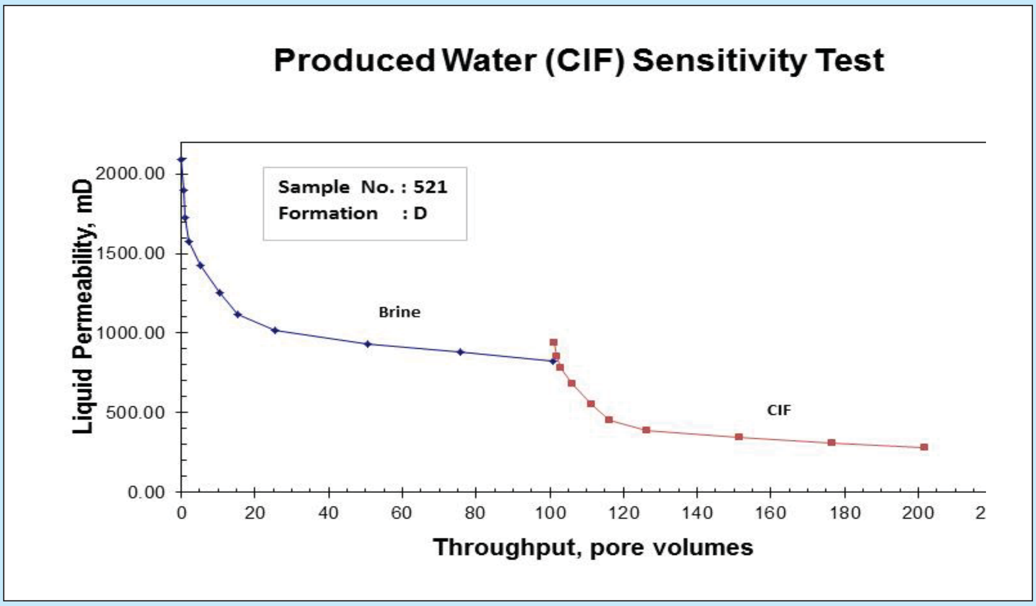

Figure 17
Performance of water permeability reduction of produced water sensitivity test on sample no521, "D" formation.

The test was also conducted on samples no 315, no. 362, no. 364, and no. 367 which represent D formation. During the formation brine injection, the water permeability reduction and the ratio of initial water permeability to water permeability recorded average values of 38.57% and 0.37, respectively. Afterwards, 3% KCl brine was injected into the samples, the water permeability reduction and the ratio of initial water permeability to water permeability resulted in average value of 48.20% and 0.38, respectively. When 5% KCl brine was injected into the samples, the water permeability reduction went down to an average value of 35.20%, whereas the ratio of initial water permeability to water permeability increased to an average value of 0.29.

Sample no 38 was selected to represent M formation. When this sample was flushed with formation brine, the water permeability reduction and the ratio of initial water permeability to water permeability indicated average values of 38.57% and 0.37, respectively. Next, the 3% KCl brine was injected into the samples, the water permeability reduction and the ratio of water permeability to water permeability recorded average values of 29.25% and 0.20, respectively. During the 5% KCl, the water permeability reduction and the ratio of initial water permeability to water permeability raised slightly to average values of 29.41% and 0.22, respectively. Figure 14 shows the reduction in water permeability. Furthermore, the presence of mobile fine is shown by the sample in the form of an increase in water permeability when flow direction was reversed at terminal condition.

Results of this test show that increasing the brine salinity might be able to maintain the water permeability, since all of samples demonstrate decreasing water permeability reduction when brine injection is changed from 3% KCl to 5% KCl.

E. Analysis on Results of Sensitivity on Produced Water Salinity Test

Analysis on Results of Sensitivity on Produced Salinity test are presented in Table 12. A total of 8 samples from K formation were selected for the test. During formation brine injection, water permeability reduced in average value of 47.52% that corresponded to the ratio of initial water

Table 12
Analysis on Results of Sensitivity on Produced water salinity test

Formation	No. Sampel	Depth, ft	Ka,mD	Brine		GIF		
				Kl/Ka	K1-K2 Reduction%	K3/Ka	K3-K4 Reduction%	K Reversed, mD
K	141	907.55	4291.00	0.85	29.77	0.32	72.27	612.69
	144	908	2038.00	0.03	34.42	0.00	89.45	-
	169	914.4	5457.00	0.44	45.06	0.24	68.52	577.88
	176	916.75	11854.00	0.51	27.78	0.11	69.91	283.92
	202	930.5	4291.00	0.15	69.24	0.06	72.27	69.15
	204	931.25	1244.00	0.69	54.12	0.3	51.71	172.56
	206	931.5	2876.00	0.89	47.01	0.36	54.19	339.90
	266	974.3	357.00	0.01	72.73	0.01	71.79	1.15
B	375	1057.65	360.00	0.003	72.84	0.001	71.29	0.31
J	20	1107.45	649.00	0.59	35.90	0.73	57.65	180.69
	21	1107.6	3567.00	0.36	45.72	0.23	73.26	245.00
	22	1107.75	1265.00	0.34	33.60	0.16	53.45	102.51
	32	1157.65	6685.00	0.44	36.94	0.44	73.67	750.85
	35	1158.05	6449.00	0.65	57.01	0.60	71.71	516.25
	491	1174.85	4066.00	0.45	51.65	0.29	73.26	126.38
	494	1176.75	2371.00	0.47	56.23	0.15	73.26	155.40
D	521	1200.25	2090.00	0.91	56.56	0.45	70.14	332.90
	533	1209.15	301.00	0.04	69.48	0.01	65.02	2.44
	576	1258.5	1632.00	0.82	76.03	0.28	83.78	145.25
	577	1259.4	9893.00	0.48	44.44	0.13	79.95	561.16
M	40	1268.65	1934.00	0.44	60.82	0.15	65.52	214.58
	585	1270.5	2668.00	0.40	71.86	0.14	71.85	116.34

permeability to water permeability valued of 0.45 in average. Then, CIF water was injected into the samples, resulting in increasing water permeability reduction and decreasing the ratio of initial water permeability to water permeability of 68.77% and 0.17 on average, respectively which proved that the K formation was sensitive with CIF water. The performance of water permeability during the test can be seen in Figure 15.

B Formation was represented by sample no.375. The result shows that for B formation the ratio of initial water permeability to water permeability for formation brine and CIF water indicates a very low value of 0.003, whereas water permeability reduction corresponds to a value of 72.84. For CIF, the ratio of initial water permeability dropped to 0.003, however, water permeability reduction stayed at 71%.

J formation was represented by samples no. 20, no. 21, no. 22, no. 32, no. 35 and no. 491. A comparison with water permeability indicates moderate initial water-to-water permeability ratios of 0.47 on average. Reductions in water permeability by approximately between 33.60% and 57.01% were experienced by all samples that corresponded to an average value of 45.29. However, when CIF water was injected, the ratio of initial water-to-water permeability went down to an average value of 0.37, whereas water permeability reduction increased to an average value of 68.04%. The performance of water permeability during the test is shown in Figure 16.

The test was performed on samples no.521, no. 533, no.576 and no.577 of D formation. Reduction in water permeability increased from an average value of 61.63 to 74.72, however, the ratio of initial water- to- water permeability decreased from an average value of 0.56 to 0.21, when brine injection was changed to CIF. The performance of water permeability during the test is shown in Figure 17.

Samples no.40 and no.585 of M formation have undergone the test. The ratio of initial water-to-water permeability and water permeability reduction was 0.42 and 66.34%, respectively. When the samples were injected with CIF water, the ratio of initial water-to-water permeability dropped to an average value of 0.14, whereas the water permeability reduction increased slightly to an average value of 68.68 %. Figure 18 displays the performance of water permeability reduction during the test.

Throughout the test series, the occurrence of fine migration and swelling clay were observed. The occurrence of fine migration was indicated by increases in water permeability when the flow injection was eventually reversed. However, the presence of swelling was proved by a decrease in water permeability at reversed flow injection. This

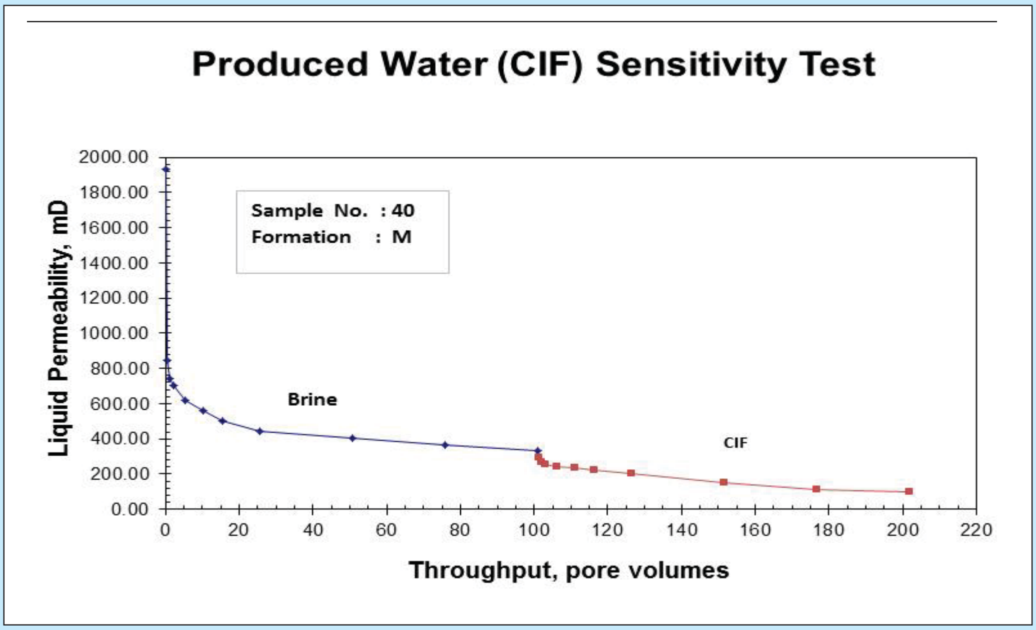

Figure 18
Performance of water permeability reduction of produced water sensitivity test on sample no 40, “M” formation.

suggestion is supported by XRD analysis on effluent filtrate, which shows that fine migration may have taken place indicated by the presence of significant amounts of kaolinite and other fine particles such as illite. Furthermore, Illite can act as swelling clay in the fibrous form.

Sensitivity on Produced Salinity Test results also show that CIF might cause water permeability to be reduced further since the sample contains significant amounts of Kaolinite and illite. Because of that, CIF should be arranged carefully as it has potential to lead to formation damage.

V CONCLUSION

From the study a set of conclusions have been drawn, as follows:

All formations are sensitive to fresh water.

All of the samples are sensitive to CIF water indicated by a low ratio of water permeability to water permeability and a high reduction in water permeability.

Filtering CIF water made a slight improvement in water sensitivity as the water permeability reduction value was smaller than the unfiltered CIF water. However, for Jaga Formation, filtering CIF water might be able to decrease significantly the reduction in water permeability.

The presence of Kaolinite and Illite within the samples has the potential to cause permeability reduction through fine migration and also swelling of clay, respectively.

Increasing the brine salinity might be able to maintain the water permeability, since all of the samples demonstrated decreasing water permeability reduction when brine injection changed from 3 % KCl to 5 % KCl.

Recommendation

The study proved that all of the formations are sensitive to fresh water. Using saline water is recommended as a tool to prevent clay swelling.

Filtering CIF water is recommended in order to decrease formation permeability reduction.

There is potential formation damage caused by fine migration and swelling clay.

ACKNOWLEDGEMENT

The Author would like to thank our colleagues in Evaluation Formation and Sediment group of PPPTMGB "LEMIGAS" for their help and support: Mr. Andy Setyo, Mr. Nandang Triaji, Mr. Eddy Yuliastono for the sensitivity tests data and Ms.Yunita Musu, Mr. Ijang Samosir for XRD Analysis. This work was part of Formation Damage Project funded by PT CPI.

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