INFLUENCE OF ACTIVATED CARBON ON TOTAL SUSPENDED SOLIDS AND RELATIVE PLUGGING INDEX OF INJECTION WATER FROM X-OILFIELD

PENGARUH KARBON AKTIF TERHADAP TOTAL PARTIKEL PADATAN YANG TIDAK TERLARUT DAN INDEKS PENYUMBATAN RELATIF PADA AIR INJEKSI DARI LAPANGAN MINYAK X

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ABSTRAK

Air yang terproduksi akan digunakan sebagai air injeksi untuk keperluan injeksi air (water flooding), tetapi, berdasarkan hasil uji kualitas air memperlihatkan bahwa kualitas air injeksi rendah yang disebabkan oleh banyaknya partikel padatan dengan konsentrasi TSS yang tinggi dan indeks penyumbatan relative (RPI) tinggi di dalam air injeksi tersebut. Apabila, kondisi air injeksi tanpa treatment diinjeksikan ke dalam formasi, akan menyebabkan penyumbatan yang serius. Pada studi ini, dua metode yang digunakan untuk meminimalkan masalah TSS dan RPI yang tinggi yaitu: treatment dengan chemical (scale inhibitor) dan filtrasi dengan karbon aktif. Penggunaan scale inhibitor dengan konsentrasi optimum pada air injeksi dapat menurunkan TSS dan RPI, tetapi scale inhibitor tidak bekerja efektif, sehingga kualitas air injeksi setelah penambahan scale inhibitor masih rendah dan dapat menyebabkan penyumbatan didalam formasi. Metode lain yang digunakan adalah filtrasi dengan karbon aktif yang mempunyai karakteristik adsorpsi dan area spesifik yang luas untuk menyerap marerial yang tidak terlarut di dalam air injeksi. Setelah filtrasi, filtrate air injeksi menghasilkan air dengan kondisi yang jernih. Berdasarkan hasil uji laboratorium menunjukkan bahwa filtrate injeksi air mengandung sedikit sekali partikel padatan dengan ukuran partikel yang kecil dan indeks penyumbatan relative rendah. Apabila, filtrate air injeksi di injeksi kedalam formasi, kemungkinan terjadi plugging dapat diminimalkan, meskipun, ada kenaikan nilai pH, tetapi secara umum, filtrate air injeksi dapat dikategorikan kualitas air yang bagus.

Kata kunci: Karbon aktif, total partikel padatan yang tidak terlarut (TSS), indeks penyumbatan relative (RPI)

ABSTRACT

Produced water will be used as injection water for water flooding need, but, based on the results of water quality tests show poor injection water quality caused by a lot of solids particles with high total suspended solids (TSS) concentration and high relative plugging index (RPI) obtained in the injection water. When, the condition of injection water without treatment is injected into formation will cause serious plugging. In this study, two methods used to minimize the high TSS and RPI problems are treatment with chemical and filtration (activated carbon). The use of optimal concentration of scale inhibitor in the injection water can reduce TSS and RPI in the injection water, but it does not work effectively, so that its water quality is still poor water quality and can cause plugging in the formation. Another method is filtration with activated carbon filter media which has characteristics of adsorption and large specific area to filter insoluble materials in the injection water. After filtration, the filtrate of the injection water results in clear water condition. Based on the results of laboratory tests indicate that the filtrate of the injection water contains the least solids particles with small particle size, low total suspended solids concentration and low relative plugging index value. When, it is injected into formation, the possibility of plugging occurrence can be *minimized, although, there is increase of pH value, but, in general, the filtrate of the injection water can be categorized good water quality.*

Keywords: *Activated carbon, total suspended solids, relative plugging index.*

I. INTRODUCTION

Produced water is the aqueous liquid phase that is co-produced from a producing well along with the oil and/or gas phases during normal production operations. Usually, the fluids that are removed from the reservoir by the producing well and are brought to the surface and separated into oil, gas and water streams. It should be noted that, over the life of the well or field, the volume of water produced will exceed the volume of oil produced by a factor of 3-6 times. Unfortunately, at the present time, the produced water is not a saleable product of the operation. Hence, an operator is faced with a serious challenge of how to handle relatively large amounts of produced water at the lowest possible cost. In general, suspended solids in produced water may originate from formation fines, scale deposits, corrosion products or bacterial activity. Depending on such factors as size, shape and concentration, particulate matter in the injection water may have a tendency to cause plugging in the formation (Jones, 1988). Therefore, the objective of the produced water treating system is to remove or reduce suspended solids and to decrease relative plugging index to a level that makes the produced water suitable for use. Next, system should be designed to result in the lowest possible capital and operating life-cycle costs. The produced water will be used as injection water for enhanced oil recovery purposes by water flood. Related to this, it is required to do perform laboratory tests, injection water quality tests before and after treatment with scale inhibitor and filtration with activated carbon filter media.

II. WATER QUALITY

The produced water used as injection water and formation water have the constituent and properties of water of greatest importance in water injection system. Determination of water quality tests in the laboratory are very important in order to know whether the injection water fulfills or not as displacement fluid in water flooding process.

One of the main laboratory priority tests is water compatibility test to know whether the injection water is compatible or not with formation water at certain mixing ratio (Jones, 1988)

Any insoluble materials exist in produced water is called by suspended solids that it contributes to reduce its water quality, such as calcium carbonate scale ($CaCO_3$). The quantity of solids which can be filtered from a given volume of water using a membrane filter is one basis for estimating the plugging tendency of water (Patton, 1986).

Water analysis is carried out in order to determinate cation and anion in the water samples and also physical properties with using API - RP45 standard operational procedure. Produced water/injection water and formation water contain calcium ion as a major constituent of oilfield readily combine with bicarbonate, carbonate or sulfate ions and precipitate to adherent scales or suspended solids. Magnesium ions are usually present in much lower concentration than calcium. Sodium is major constituent in oilfield water, but does not normally cause any problem. The natural iron content of both waters normally is quite low and its presence is usually indicative of corrosion. Barium is of importance primarily because of its ability to combine with the sulfate ion to form barium sulfate. The major source of chloride ion in the produced water is sodium chloride (Patton, 1986).

The results of water analysis are used to calculate calcium carbonate scaling index tendency with using Stiff and Davis method.

The equation is as follows:

$$SI = pH - K - pCa - pAlk$$

SI = scaling index

pH = actual pH of the water

K = a constant which is a function of salinity, composition and water temperature.

The solubility of calcium carbonate scale is highly dependent on pH value (Patton, 1986). The results of the calculation may be summarized as follows:

1. If SI is negative, the water is under- saturated with $CaCO_3$ and scale formation is unlikely.
2. If SI is positive, the water is super-saturated with $CaCO_3$ and scale formation is indicated.

3. If SI is zero, the water is at the saturation point.

The injection water system, water quality is a measure of the relative degree of plugging which occurs when a given volume of water is passed through a membrane filter of a given pore size. Figure 2.1 below shows water quality plot, namely cumulative volume (ml) vs flow rate (ml/second).

The cumulative volume through the filter is recorded as a function of time, and the flow rate for each time increment is calculated from data. The flow rate is plotted versus cumulative volume. The slope of the line indicates the quality or degree plugging which occurred with that particular water sample. The meaning of curves in Figure 2.1 are as follows:

Curve 1 Excellent. No plugging

Curve 2 Poorer than curve 1, indicating plugging of the filter.

Curve 3 Poorest of the three curves. The flow rate dropped much more rapidly, indicating faster plugging.

Then, general quality rating of relative plugging index (RPI) with using Cerini method (Patton, 1986) can be seen in following table.

RPI stands for relative plugging index, TSS for total suspended solids and MSTN for millipore slope test number. When the RPI value of injection water indicates less than 3, means excellent water quality, in a range of 3 - 10 for good water quality and questionable in a range of 10 - 15. The RPI value is more than 15 categorized as poor water quality (Patton, 1986).

If, the injection water indicates poor water quality with high total suspended solids is injected into formation, there will be plugging occurrence in the formation shown in Figure 2.2 (Johnson *et al.,* 1999).

A lot of solids particles in the injection water can be minimized by filtration through activated carbon filter media or called activated charcoal or activated coal. It is a form of carbon that has been processed to make it extremely porous and thus to have a very large surface area available for adsorption or chemical reactions. The characteristics of the activated carbon are as follows: high adsorption, large specific surface area, developed pore structure and widely used in water purification (Richaed and Bertrand 2005).

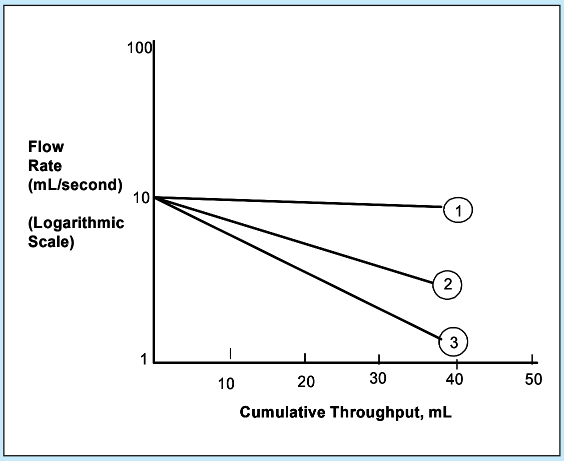


Figure 2.1
Water quality plot (Patton, 1986)

Table 2.1
Relative plugging index quality rating

RPI	General Quality Rating
< 3	Excellent
3 - 10	Good to Fair
10 - 15	Questionable
>15	Poor

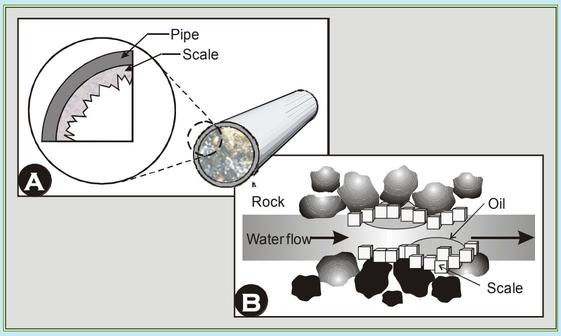


Figure 2.2
The Occurrence of Scale in the Formation
(Johnson *et al.,* 1999)

III. RESULTS AND DISCUSSIONS

In this study, all laboratory tests results show a sequence of related each other and are discussed in this section. The laboratory tests are focused on water compatibility test, total suspended solids, water analysis, scaling index calculation ($CaCO_3$), turbidity value and relative plugging index, particle size and morphology of TSS by scanning electron microscope. The section can be divided into two main parts:

A. The Injection Water Quality Tests Results

Before using the injection water as displacement fluid in water flooding process, firstly, it is very important to know whether the injection water is compatible or not with formation water. Refer to Jones (1988), tests of water compatibility is carried out at certain mixing ratio (%), IW : FW = 0 : 100, 25 : 75, 50 : 50, 75 : 25 and 100 : 00. Based on laboratory test, the injection water is compatible with formation water at reservoir temperature (65°C) condition. Trend of curve in Figure 3.1 decreases from 90.03 mg/L, 74.19 mg/L, 69.15 mg/00L, 57.85 mg/L and 48.75 mg/L. Although, the TSS concentration of injection water is still high (48.75 mg/L), but it is compatible with formation water.

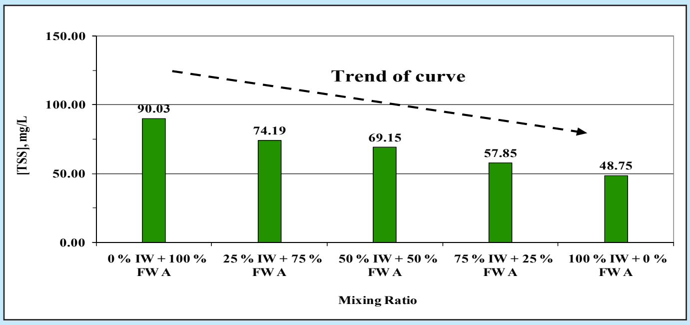


Figure 3.1
The Results of Water Compatibility Tests Between Injection Water with Formation Water at Reservoir Temperature Condition (65°C)

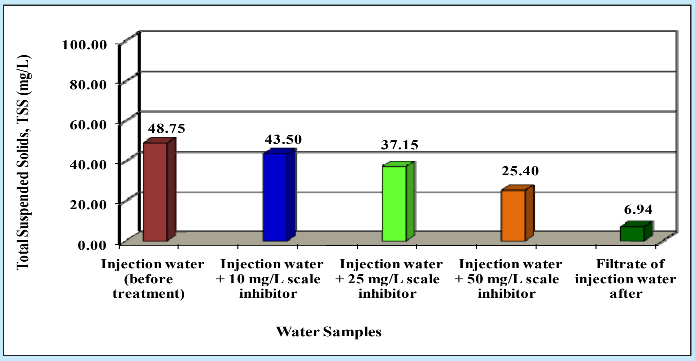


Figure 3.2
The Results of Total Suspended Solids Concentration Determination Before and After Treatment with Scale Inhibitor and Filtration with Activated Carbon

Calcium carbonate scale is one of suspended solids content which is not dissolved in the injection water. Addition of scale inhibitor into the injection water is expected to be able minimize calcium carbonate scale problem with reducing total suspended solids concentration. Relation to this, addition of 0.00 mg/L, 10 mg/L, 25 mg/L and 50 mg/L scale inhibitor concentration into the injection water sample respectively result in decrease of TSS concentration (shown in Figure 3.2) from 48.75 mg/L (0.00 mg/L scale inhibitor) to 43.50 mg/l (10 mg/L scale inhibitor), 37.15 mg/L (25 mg/L scale inhibitor) and 25.40 mg/L (50 mg/L scale inhibitor). After addition of 50 mg/L scale inhibitor (optimal concentration and also for economic factor) into the injection water results in high TSS concentration (25.40 mg/L), which it is not unable to reduce TSS concentration sharply (TSS < 8 mg/L). This case is caused by its function of scale inhibitor which is designed only to reduce scaling problem, such as calcium carbonate scale.

Table 3.1 presents the results of three water samples analysis, namely: injection water (before treatment), injection water (containing 50 mg/L scale inhibitor) and filtrate of injection water (after filtration with the activated carbon). The three water samples have pH value in a range of 8.50 – 9.05, the existence of calcium ions are in arrange of 5.68 mg/L - 26.79 mg/L, bicarbonate ion in arrange of 1920.40 – 2243.82 mg/L and carbonate ion in a range of 102.13 mg/L - 116.16 mg/L and salinity concentrations in a range of 10629.18 mg/l – 10729.91 mg/L. The results of three water samples analysis mentioned above show high potential to form calcium carbonate scale. Refer to Patton (1986), when the injection water contain calcium, bicarbonate and carbonate ions at high pH value (>8.00), there will be occurrence of reaction between calcium ion with bicarbonate and carbonate ions form calcium carbonate scale. The form of calcium carbonate scale is not only caused by incompatible ions (calcium with bicarbonate and carbonate ions) and pH value factors, but, also, salinity factor with concentration in a range of 10629.18 mg/L - 10732.09 mg/l (> 400 mg/L).

Calcium carbonate scaling index is calculated based on the water analysis results with using Stiff and Davis method. Based on the results of scaling index (SI) calculation, the SI value of the injection water is 2.01 that is higher than 0.00, it means calcium carbonate scale formed. The scaling index of injection water (containing 50 mg/L scale inhibitor) shows the lower scaling index value (SI = 1.65) compared with the injection water before treatment (SI = 2.01), but the calcium carbonate scale is still formed, because SI value is more than 0.00 with the reaction as follows:

$$Ca^{+2} + HCO_3^- \longrightarrow CaCO_3 \downarrow \text{ solid}$$

$$Ca^{+2} + CO_3^= \longrightarrow CaCO_3 \downarrow \text{ solid}$$

$$CaCO_{3\ solid} + L \longrightarrow CaL_{\ solution}$$

The chain of calcium carbonate scale is separated and bound by scale inhibitor (L) to be calcium-ligand (CaL) in solution. The effectiveness of scale inhibitor works to prevent the calcium carbonate scale, it depends on type and concentration of scale inhibitor. The scale inhibitor used in this study show the effectiveness to minimize calcium carbonate scale around 65.64%.

Relative plugging index test is very important carried out in order to know plugging index of the analyzed water samples. Based on the laboratory tests results (presented in Figure 3.3), amount of solids particles exist in the injection water (containing 50 mg/L scale inhibitor) is less than solids particles in the injection water, therefore the TSS concentration of the injection water (containing 50 mg/L scale inhibitor) is 25.40 mg/L and lower than TSS concentration of the injection water (TSS = 48.75 mg/L). Therefore, the injection water before treatment indicate higher relative plugging index (RPI=66.34) compared with the injection water (containing 50 mg/L scale inhibitor) with 30.72 relative plugging index. Both water samples present high value of relative plugging index (RPI > 10), so that these can be categorized as poor water quality with trend of curves no. 3 for the injection water and no. 2 for the injection water

Table 3.1
The Results of Injection Water Analysis
Before and After Treatment with Scale Inhibitor and Filtration with Activated Carbon

No	Laboratory Tests	Unit	Injection Water Before treatment	Injection Water After Treatment (50 mg/L scale inhibitor)	Filtrate of Injection Water After Filtration with Activated Carbon
1	Sodium, Na^+ (calc)	mg/L	4448.11	4326.60	4380.10
2	Calcium, Ca^{++}	mg/L	26.79	9.19	5.68
3	Magnesium, Mg^{++}	mg/L	14.12	9.79	6.53
4	Iron, Fe^{++} (total)	mg/L	0.18	0.15	0.10
5	Barium, Ba^{++}	mg/L	0.10	0.10	0.10
6	Chloride, Cl^-	mg/L	5486.90	5292.70	5040.70
7	Bicarbonate, HCO_3^-	mg/L	2243.82	2233.85	1920.40
8	Sulfate, $SO_4^=$	mg/L	1.40	2.40	0.00
9	Carbonate, $CO_3^=$	mg/L	116.16	112.70	102.13
10	Hydroxide	mg/L	0.00	0.00	0.00
11	Specific Gravity, 60/60 ^oF		1.0072	1.0003	1.0001
12	pH @ 77 ^oF		8.50	8.60	9.05
13	Salinity	mg/l	10732.09	10629.18	10729.91
14	Hydrogen Sulphide	mg/l	-	-	-
15	Hardness	mg/l	99.87	73.47	70.09
16	TDS (Total Dissolved Solids)	mg/L	13570.00	12562.49	13041.18
17	Resistivity at 125 ^oF	(ohm - meter)	0.3479	0.3411	0.3461

Table 3.2
The Results of Scaling Index Tendency Calculations of Injection Water Before and After Treatment with Scale Inhibitor and Filtration with Activated Carbon

No.	Laboratory Tests	Units	Injection Water Before Treatment	Injection Water After Treatment with Scale Inhibitor	Filtrate of Injection Water After Filtration with Activated Carbon
1	Calcium, Ca^{+2}	ppm	26.79	9.19	5.68
2	Bicarbonate, HCO_3^-	ppm	2,243.82	2,233.85	1,920.40
3	Carbonate, $CO_3^=$	ppm	116.16	112.70	0.00
4	Sulfate	ppm	1.40	2.40	1.20
5	pH		8.50	8.60	9.05
6	$CaCO_3$ scaling Index (SI)				
	Scaling Index at 77 °F		1.11	0.75	0.92
	Scaling Index at 140 °F		2.01	1.65	1.82
	Remarks				
	$CaCO_3$ scale at 77 °F		SI > 0, Formed	SI > 0, Formed	SI > 0, Formed
	$CaCO_3$ scale at 140 °F		SI > 0, Formed	SI > 0, Formed	SI > 0, Formed
7	Actual $CaSO_4$ conc.	meq/l	0.0292	0.0500	0.00210
	Solubility at 77 °F	meq/l	44.96	45.40	45.47
	Solubility at 140 °F	meq/l	44.96	45.40	45.47
	Remarks		Solubility > than Actual $CaSO_4$ conc.	Solubility > than Actual CaSO4 conc.	Solubility > than Actual $CaSO_4$ conc.
	$CaSO_4$ scale		Unformed	Unformed	Unformed

(containing 50 mg/L scale inhibitor). When, the injection water with high TSS concentration and high relative plugging index is injected into formation, particulate matter in the injection water may have a tendency to cause plugging in the formation (Jones, 1988).

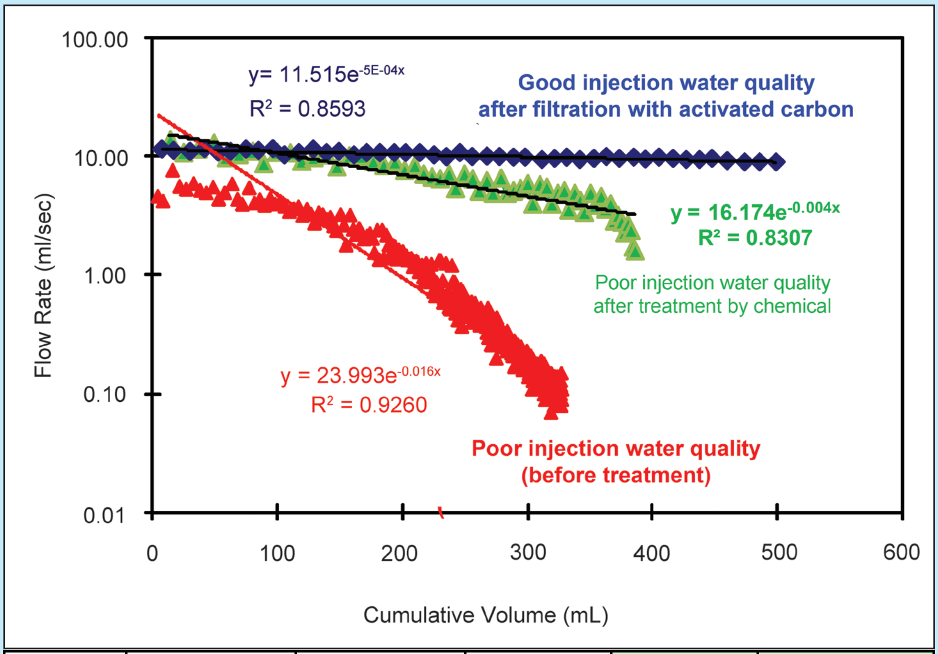
From the results of the injection water (before treatment) quality tests mentioned above is poor water quality, it is required another method (non chemical), such as filtration with activated carbon to improve water quality to be good water quality.

B. Filtrate of The Injection Water Quality Tests Results

Another approach to solve oilfield water problem is the use of the activated carbon, which is expected, firstly, it is able to replace the use of chemical (scale inhibitor). Secondly, to solve high TSS concentration and high relative plugging index value in the injection water. Refer to Richaed and Bertrand (2005), the activated carbon filter media has high adsorption and large specific surface area characteristics. The injection water which has 48.75 mg/L TSS concentration, 66.34 relative plugging index and 55.05 NTU is filtered through the activated carbon filter media. Based on the laboratory tests, the TSS concentrations in the injection water decrease from 48.75 mg/L (before treatment) to 6.94 mg/L for filtrate of the injection water (shown in Figure 3.2). It is lower than the TSS concentration limit (< 8 mg/L) for water flooding need.

The result of the filtrate of injection water analysis in Table 3.1 indicates that it contains 5.68 mg/L calcium ion, 0.00 mg/L sulfate ion and 1920.40 mg/L bicarbonate ion, 102.13 mg/L carbonate ion and 9.05 pH value. When, the results of filtrate of injection water analysis is compared with the results of the injection water analysis, the concentrations of calcium, bicarbonate and carbonate ion decrease, however, there is an increase of pH value from 8.50 to 9.05. Laboratory studies (Richaed and Bertrand, 2005) have identified the cause of the pH rise, which occurs during water treatment with activated carbon, as an interaction between the naturally occurring anions and protons in the water and the carbon surface. The interaction can be described as an ion exchange type of phenomenon, in which the carbon surface adsorbs the anions and corresponding hydronium ions from the water. By increasing pH value from 8.50 to 9.05, it means the filtrate of injection water still has potential to form calcium carbonate scale with 1.82 scaling index value (SI > 0).

The injection water quality can be improved from poor to good water quality after filtration with active carbon filter media. This case is caused by two main points; firstly, decrease of total suspended solids (TSS) concentration from 48.75 mg/L to 6.94 mg/L. Secondly, decrease of relative plugging index (RPI) from 66.34 to 7.48. By decreasing TSS and RPI result in lower amounts of solids particle in filtrate of the injection water compared with amounts of solids particles in the injection water. The difference of the

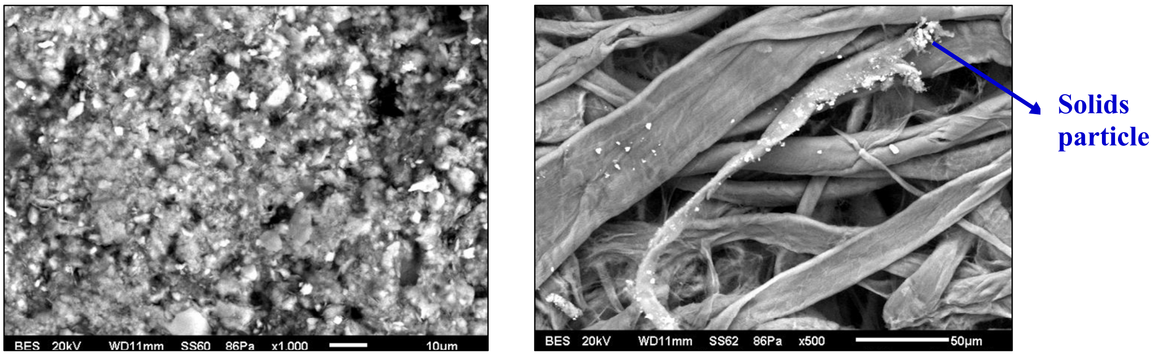


X	Y	MTSN	TSS (mg/L)	RPI	REMARK
7.16 498.23	11.47385 8.97583	-0.542868102	6.94	7.48	Good Water Quality

X	Y	MTSN	TSS (mg/L)	RPI	REMARK
13.61 385.62	15.27538966 3.20209306	-4.56009206	25.40	30.72	Poor Water Quality

X	Y	MTSN	TSS (mg/L)	RPI	REMARK
4.61 327.24	22.26642907 0.119608156	-17.58892652	48.75	66.34	Poor Water Quality

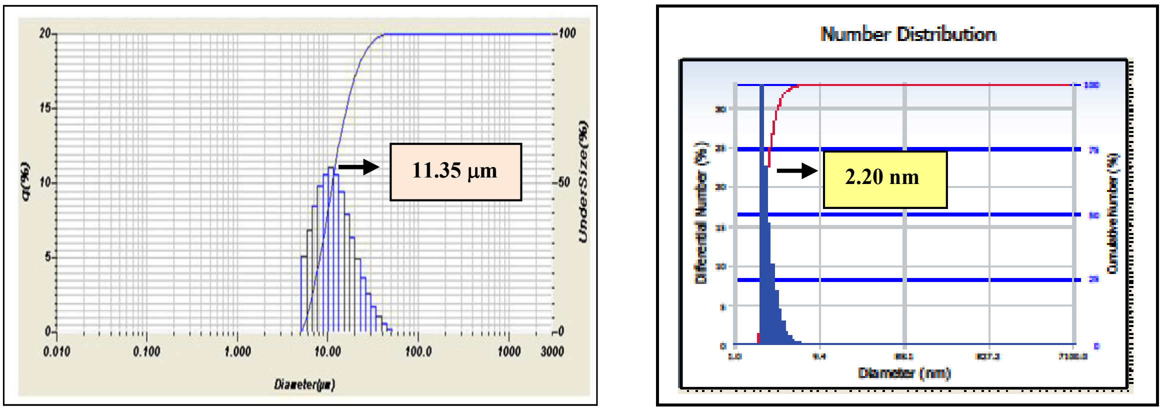
Figure 3.3
Comparison of Injection Water Relative Plugging Index Determination Results Before and After Treatment with Scale Inhibitor and Filtration With Using Activated carbon



Injection water
Before filtration,
High TSS = 48.75 mg/L
High RPI = 66.34
Particle size = 11.35 μm

Filtrate of Injection water
After filtration with activated carbon
High TSS = 6.94 mg/L
High RPI = 7.48
Particle size = 2.20 nm

Figure 3.4
Comparison of Total Suspended Solids Morphology of Injection Water Before Treatment and After Filtration with Activated Carbon by Scanning Electron Microscope (SEM)



Injection water
Before filtration,
High TSS = 48.75 mg/L
High RPI = 66.34
Particle size = 11.35 μm

Filtrate of Injection water
After filtration with activated carbon
High TSS = 6.94 mg/L
High RPI = 7.48
Particle size = 2.20 nm

Figure 3.5
The Result of Particle Size Analysis of Injection Water Before treatment and After Filtrate with Activated Carbon Filter Media

solids particles form is detected by scanning electron microscope (shown in Figure 3.4). The filtrate of the injection water indicates clear water condition with low turbidity value (8.45 NTU) and small particle size (2.20 nm) shown in Figure 3.5.

In brief summary, the active carbon filter media works effectively to reduce high TSS and high RPI of the injection water. Although, there is increase of pH value, but the filtrate of the of injection water indicate good water quality for water flooding need.

IV. CONCLUSION

Based on the results of this study can be concluded as follows:

1. Injection water (before treatment) is compatible with formation water, although it contains high total suspended solids.
2. The use of scale inhibitor (50 mg/L optimal concentration) is unable to reduce high total suspended solids concentration and high relative plugging index problems in the injection water effectively and totally.
3. The use of the activated carbon filter media (no chemical) can improve the injection water quality from poor to good with decreasing high total suspended solids from 48.75 mg/L to 6.94 mg/L (TSS limit < 8 mg/L), high relative plugging index from 66.34 to 7.48 (RPI limit < 10), turbidity value from 55.05 NTU to 8.45 NTU and particle size from 11.35 µm to 2.20 nm.

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