

Application of Anthracite and Activated Carbon Filter Media to Enhance Injection Water Quality for Water Flooding Operations in “DE” Field

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ABSTRACT - Produced water is used as injection water for water-flooding. When untreated injection water of poor quality is introduced into the formation, it can lead to severe plugging. This is primarily due to the poor quality of the water, which is characterized by high levels of solid particles, elevated turbidity, a high scaling index, significant oil content, high total suspended solids (TSS) concentration, and a high RPI. The application of anthracite and activated carbon filter media has been shown to effectively reduce the scaling index, oil content, turbidity, particle size, TSS, and RPI in the injection water. These filter media enable the removal of insoluble materials from the injection water. By evaluating the effectiveness of different filter media on injection water quality, it is possible to select a filtrate with improved water quality, characterized by a clear appearance and minimal solid particles. The resulting filtrate demonstrated very low total suspended solids (TSS) concentrations and a significantly reduced RPI value. Overall, the filtrate can be classified as high-quality injection water suitable for water flooding applications. The morphology of the TSS before and after filtration through anthracite and activated carbon filter media was determined using SEM.

Keywords: Various filter media (anthracite, active carbon, silica sand, gravel, scaling index, oil content, turbidity, TSS, RPI, morphology of TSS by SEM)

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INTRODUCTION

Water flooding is one of the most widely applied secondary recovery methods for maintaining reservoir pressure and enhancing oil displacement efficiency (Wilhite 1986). The success of a water flooding program is highly dependent on the quality of the injection water. In most fields, produced water, which is co-produced with oil and/or gas and separated at the surface, represents a major component of reservoir fluids. Over the lifetime of a well, the volume of produced water typically reaches three to six times the volume of oil produced; therefore, it has no market value and becomes a liability that must be managed and disposed of at the lowest possible cost (Boari et al., 1997; Cowan 1997). Produced water generally contains insoluble materials or suspended solids that reduce its quality. These suspended solids may originate from fine formation, scale, oil residues, dissolved oxygen, corrosion products, or bacterial growth (Case 1970; Patton 1977). Depending on their size, shape, and concentration, particulate matter in the injection water can plug reservoir formations (Jones 1988). Therefore, the primary objective of a produced water treatment system is to remove or reduce suspended solids and lower the plugging index to a level that makes the water suitable for injection into the reservoir.

Because produced water must be reused as injection water for enhanced oil recovery (EOR) by water flooding, the treatment system should be designed to achieve these goals while minimizing both capital and operating life-cycle costs (Havard, 2006; Ostroff, 1965). To ensure its suitability, laboratory testing and injection water quality analysis must be performed before and after treatment or filtration using different filter media, such as anthracite and activated carbon, to evaluate the effectiveness of the treatment process.

METHODOLOGY

The main sequence of laboratory tests in this study are as follows : a). Determination of injection water quality before treatment; b). Determination of injection water quality after filtration through activated carbon and anthracite filter media. This study used injection water before filtration (IW) from the gathering station and formation water (FW) from the wellhead, anthracite, and activated carbon filter media, as well as filtrate S13-FIW after filtration through anthracite and filtrate S14-FIW after filtration through activated carbon filter media. The standard operational procedures for laboratory tests are presented in Table 1.

Table 1. Standard operational procedure of laboratory tests

No.	Laboratory Test	Unit	Methods
1	Water Compatibility	Compatibility or not Trend of curve	Corrosion and water technology textbook
2	Water Analysis	mg/L	API-RP45
3	Scaling Index (SI)	-	Stiff and Davis
4	Total Suspended Solid (TSS)	mg/L	API-RP45
5	Relative Plugging Index (RPI)	-	Cerini
6	Turbidity	NTU	Turbidity Standard (manual book)
7	Oil Content	Infrared – Hach spectrometer	
8	Particle Size in Water	mm	ASTM D 4822-88 SOP particle size analyzer
9	Total Suspended Solids Morphology	-	Scanning Electron Microscope (SEM)

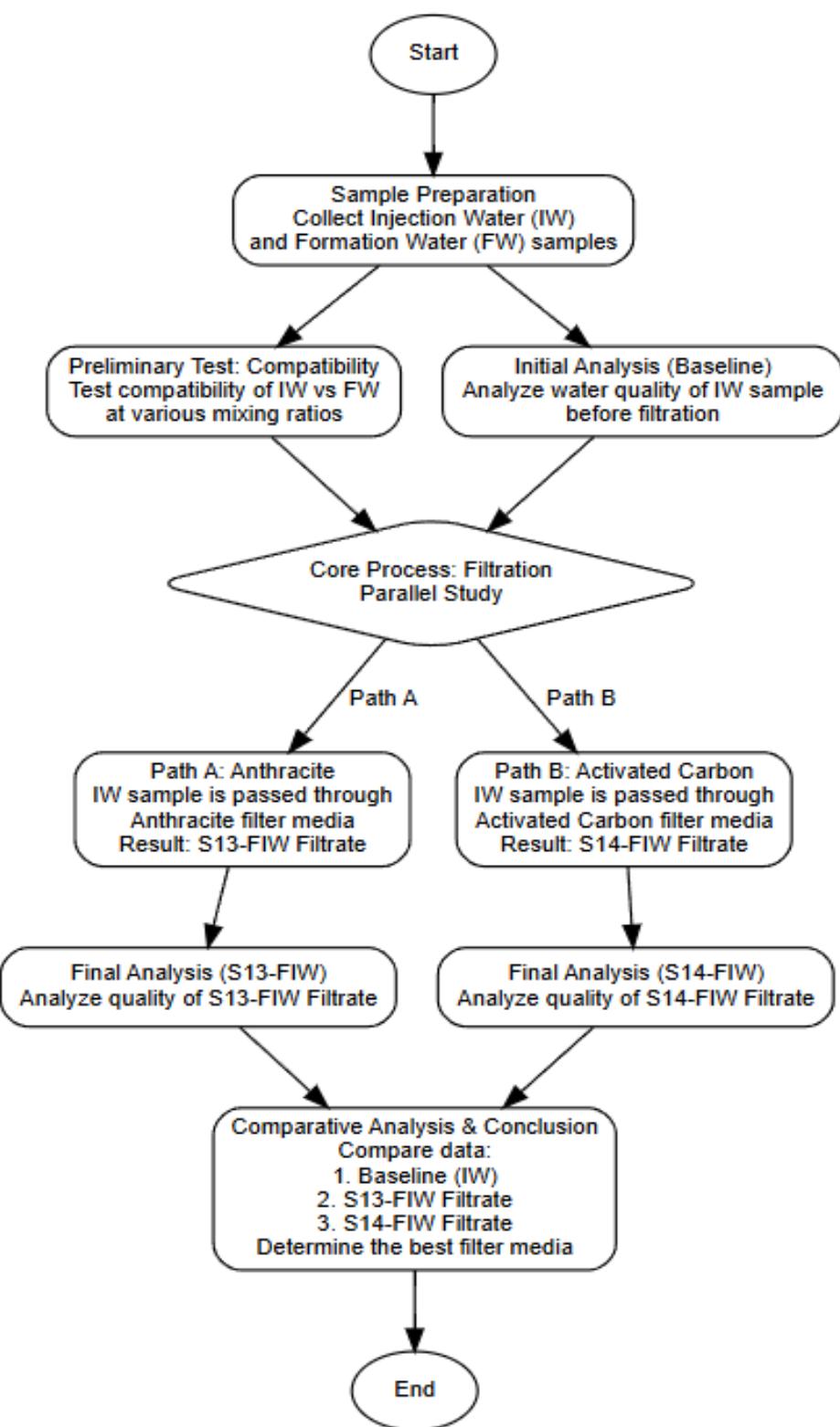


Figure 1. Research flow diagram

RESULT AND DISCUSSION

Injection and formation waters contain many solids and dissolved solids, and the quality and quantity of these solids are critical to the performance of water injection operations. Laboratory water analysis is essential for evaluating the quality of injection water used to displace oil from the reservoir (Patton 1986; SPE 20689; Paul 1986; Shyrock & Knox 1965) because it provides valuable information on the composition of the water.

Suspended solids in injection water are undesirable because they are responsible for problems such as emulsion blockage and calcium carbonate scale (Caplan 1975). The amount of suspended solids was measured by the amount of solids retained on a filter (Patton 1986), which is crucial for determining the overall quality of injection water.

Water analysis includes the determination of the concentrations of some of the salts, and some of the other parameters include the physical properties of the water, which are carried out according to the standards in the API RP-45 manual. Produced, injection, and formation waters usually contain a significant amount of Ca, which reacts with other components present in water and forms scales or suspended solids.

Magnesium is present in formation and produced water but at much lower concentrations than calcium; therefore, it is not as significant a contributor to scale formation as calcium. Sodium is another major ion in oilfield water; however, it is not a major contributor to scale formation; thus, monitoring it is not critical. There is usually a very low concentration of naturally occurring iron in produced and formation water, but if it is present in high concentrations, it is an indication of corrosion, which can have serious consequences for the entire operation. Barium is rarely present; however, if it is, it can react with sulfate to form a barium sulfate scale, which is undesirable and can cause significant problems. Chloride is mainly present in produced water as sodium chloride (Patton 1986; Cowan J.C.

1976), and this is an important factor to consider when evaluating the quality of the water.

Once the water analysis results are obtained, they are used to calculate the probability of scale formation, as this information is essential for determining the best course of treatment. One of the most common approaches is the Stiff and Davis method, which provides significant insight into how to treat water and whether the injection water is acceptable for producing oil from the reservoir. The equation:

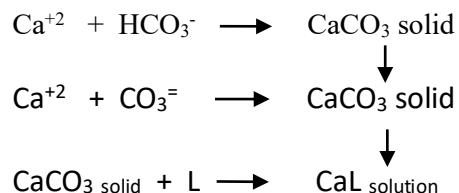
$$SI = pH - K - pCa - pAlk$$

SI = scaling index

pH = actual pH of the water

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

The solubility of the calcium carbonate scale is highly influenced by the pH of water (Patton 1986). The results of the scaling index (SI) calculation are summarized as follows. 1). If the SI is negative, the water is undersaturated with calcium carbonate ($CaCO_3$), and scale formation is unlikely; 2). If the SI is positive, the water is supersaturated with $CaCO_3$, indicating a high scaling potential; 3). If the SI is zero, the water is at equilibrium, that is, it is at the saturation point for $CaCO_3$. Reaction scale inhibitor with calcium carbonate scale:



The formation of calcium carbonate scales can be mitigated by using a scale inhibitor. These inhibitors (denoted as L) bind to calcium ions to form calcium-ligand complexes (CaL) in solution, thereby effectively preventing the precipitation of calcium carbonate. The efficiency of a scale inhibitor in preventing scale formation depends on its type and concentration.

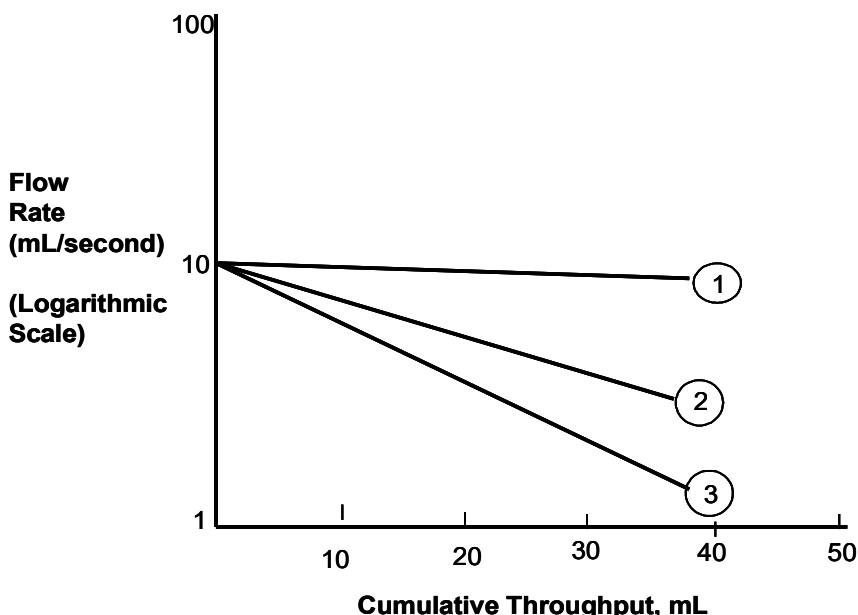


Figure 2. Water quality plot (Patton 1986)

The cumulative volume of water passing through the filter was recorded as a function of time, and the flow rate for each time increment was calculated. The flow rate was plotted against the cumulative volume of the solution. The slope of the resulting curve indicates the water quality and degree of plugging caused by the water sample. The curves in Figure 2 are interpreted as follows: a).Curve 1: Excellent water quality with no plugging; b).Curve 2: Water quality was poorer than that of Curve 1, indicating some plugging of the filter; c).Curve 3: The poorest water quality of the three curves, with a rapid decrease in the flow rate, indicating significant and rapid plugging. The general quality rating of the relative plugging index (RPI) using the Cerini method (Patton 1986) is presented in following table.

Table 2. Relative plugging index quality rating

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

The general quality rating of the relative plugging index (RPI) was determined using the Cerini method (Patton 1986) as follows: The RPI, along with total suspended solids (TSS) and the milli-pore slope test number (MSTN), was used to classify water quality. The RPI values were categorized as follows: 1). RPI < 3 : Excellent water quality; 2). RPI between 3 and 10: Good water quality; 3). RPI between 10 and 15: questionable water quality; 4). RPI > 15 indicates poor water quality.

If injection water with poor quality (RPI > 15) and high total suspended solids is injected into the formation, it will result in plugging of the reservoir formation, as illustrated in Figure 3 (Johnson et al., 1999). This highlights the importance of ensuring that the injection water meets the required quality standards to minimize formation damage and maintain the efficiency of the water-flooding process.

Oil content before and after treatment

The oil content in water reduces the injectivity of water, and emulsion blocks are one of the causes of this reduction. This was stated by C.C. in Applied Water Technology. Patton stated that oil in water will reduce the injectivity by two-thirds; therefore, the maximum oil content in injection water (Peraturan Menteri Lingkungan Hidup No.19 tahun 2010 for exploration and oil and gas

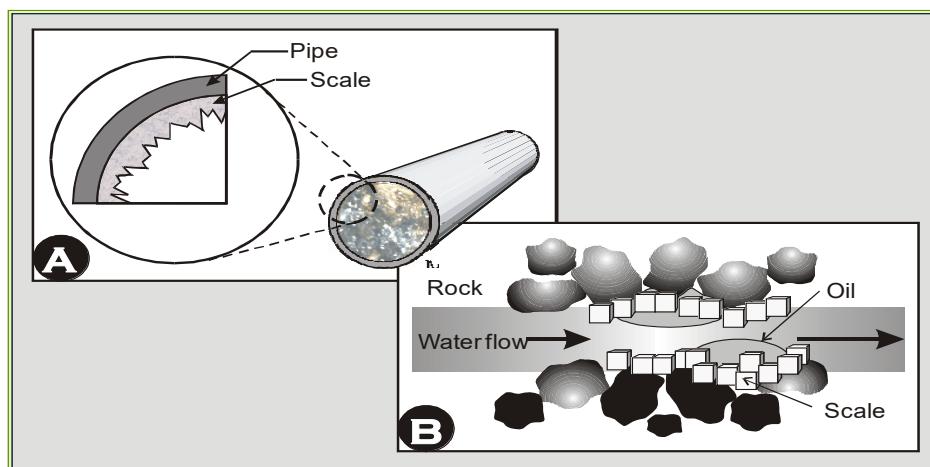


Figure 3. The occurrence of scale in the formation (Cowan & Weinritt 1877)

production) when used as a displacement fluid in water flooding is 15 ppm. Therefore, it is important to measure the oil content in the injection water before any water flooding is carried out in the oilfield, as this will help avoid emulsion blockage and maintain the injectivity of the water in the reservoir.

The oil content should be reduced as much as possible, ideally to zero, because this is crucial for the success of water-flooding operations. This is done using reverse demulsifiers, which help reduce the oil content and, hence, the chance of emulsion blocks occurring, as shown in Figure 4, thus reducing the risk of emulsion blockage and maintaining the injectivity of the water in the reservoir.

Turbidity before and after treatment

Turbidity is the cloudiness of a water sample due to substances not dissolved in the water, which may be due to solids, oil, or gas bubbles. Turbidity measures the amount of cloudiness in water and is a key indicator of water quality. High turbidity can lead to formation plugging, where solids in the water reduce the porosity of the reservoir rock, inhibiting the flow of fluid; therefore, turbidity is also used to measure the effectiveness of the filters. Therefore, turbidity is a critical parameter, and the sample must be sufficiently clean for injection (Patton 1986; Hach 2004; Case 1970).

Total suspended solids (TSS)

In the context of water injection, total suspended solids (TSS) encompass all undissolved materials, including scale precipitates, oil droplets, and bacterial populations (Patton, 1986). The concentration of TSS serves as a primary indicator of injection water quality, where an increase in TSS corresponds to a degradation in quality. Consequently, the potential for formation plugging is directly influenced by TSS levels. As noted by (Patton 1986), this plugging tendency is often assessed by quantifying the mass of solids that can be filtered from a known water volume using membranes.

Particle size distribution analysis before treatment and after treatment

The particle size distribution is useful for determining the necessity of filtration and is also used to select an appropriate filter. It is also used to monitor and control the filter performance, because this information is crucial for optimal filter operation. Figure 5 shows the method used to determine the particle size distribution, providing a standardized approach for particle size analysis. The method described is in accordance with the ASTM D 4822-88 SOP, ensuring a reliable and consistent measurement process. It uses a particle size distribution analyzer; therefore, the results obtained were accurate and reproducible.

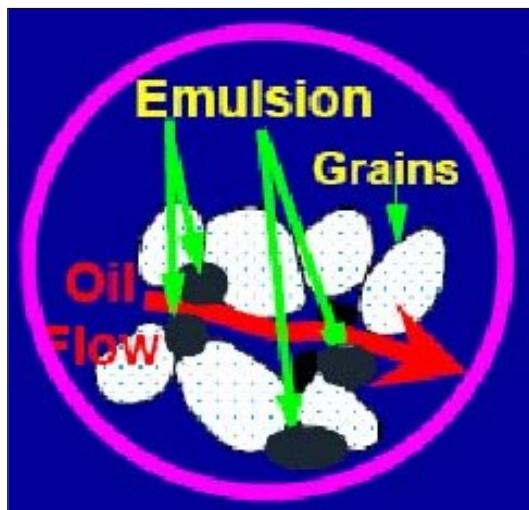


Figure 4. The occurrence of emulsion block in the formation (Case 1970)



Figure 5. HORIBA laser scattering particle size distribution analyzer LA-950 (manual book)

Anthracite filter media

Anthracite for filtration was selected from premium-grade anthracite with the highest carbon content and washed with water to remove the vast majority of minerals and ash. It is also sized and washed to be used as a filtration medium because this process is performed to fulfil the strict requirements for water filtration (Aashish & Amattyia 2024). The anthracite filter media has various sizes in the range of 0.60 mm to 41.28 mm, standard Europea EN12904 & American AWWA B100, and characteristics such as stable chemical property, high mechanical strength, super adsorption, large surface area, raw material (high quality coal), granular shape, low specific gravity, high percentage of carbon (90 %), and long use cycle (Aashish & Amattyia 2024).

Activated carbon filter media

The concentration of solid particulates in the injection water can be significantly reduced by using activated carbon as a filter medium. The effectiveness of this material, also known as active charcoal, stems from its unique physical properties. It is engineered to be extremely porous, resulting in a large specific surface area and a well-developed pore structure. These characteristics confer a high adsorption capacity, making it a superior material for purification processes, including the treatment of injection water (CPL Carbon Link 2008).

Scope of works

In this study, all laboratory test results show a sequence of related each other and are discussed in this section, which consists of three main parts.

- Injection water (IW) quality laboratory tests before treatment included water compatibility between injection water and formation water, water analysis, scaling index calculation (CaCO_3), turbidity, oil content, total suspended solids (TSS), relative plugging index (RPI), and particle size and morphology of TSS using scanning electron microscopy (SEM).
- The filtrate of injection water quality laboratory tests after filtration through anthracite filter media (S13-FIW), including water analysis, scaling index calculation (CaCO_3), turbidity, oil content, total suspended solids, relative plugging index, particle size, and morphology of TSS by scanning electron microscopy.
- Filtrate of injection water quality laboratory tests after filtration through activated carbon filter media (called S14-FIW), including water analysis, scaling index calculation (CaCO_3), turbidity, oil content, total suspended solids, relative plugging index, particle size, and morphology of TSS by scanning electron microscopy.

Process of filtration through filter media

Anthracite and activated carbon filter media are

used for: a). To increase the injection water quality from poor to good; b). To solve the injection water problem without using chemicals; c). To obtain an optimal particle size in the injection water, the pore throat size distribution (greater than 1 mm).

Filtration tests using the filter media were performed as follows: 1). The filtration equipment must be kept clean; 2). A filter/screen is located at the bottom of the equipment. 3). The filter medium must be clean; 4). The filtration equipment must be clean; 5). A filter/screen is located at the bottom of the equipment; 6). The filter media must be clean; 7). The filter media were flushed with distilled water until they were clean; 8). After the condition of filter media is clean, check turbidity of water; 9). The injection water flows into the filtration equipment through the filter media (a continuous process); 10). The injection water that flows out of the equipment is referred to as the filtrate; 11). Filtrate of quality laboratory tests, namely S13-FIW and S14-FIW.

The scope of works mentioned in this section has been carried out, and all the results of the laboratory tests are discussed in this section, which consists of three main parts:

- **Results of Water Compatibility Tests Between Injection Water with Formation Water.** Before using the injection water as a displacement fluid in the water-flooding process, it is important to determine whether the injection water is compatible with the formation water. Refer to Jones (L.W 1988, Makmur T 2004), Lemigas Report, 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 tests, the injection water (IW) was compatible with the formation water (FW) at room temperature (25 °C). Trend of curve in Figure 6 decreases from 52.00 mg/L, 50.63 mg/L, 49.25 mg/L, 47.88 mg/L and 46.50 mg/L. Although the TSS concentration of the injection water is still high (46.50 mg/L), the injection water IW was compatible with the FW formation water.
- **Comparison of Water Quality Laboratory Tests.** This Section presents a comparison of the water quality laboratory test results for three water

samples: injection water before treatment, filtrate of injection water (S13-FIW) after filtration through anthracite, and filtrate of injection water after filtration through activated carbon filter media.

Water analysis was performed to determine the chemical composition, concentration of each constituent, and water properties (API RP-45; Patton 1986; Cowan 1976). The information includes the following: a). cationic (sodium, calcium, magnesium, iron, and barium); b). anionic (chloride, bicarbonate, sulphate, carbonate); c). properties (specific gravity, pH, resistivity).

The results of the injection water analysis before treatment are listed in Table 3. The concentration of calcium (Ca^{+2}) ion was 63.50 mg/L, 2745.09 the bicarbonate ion concentration was 0.00 mg/L sulfate and carbonate ion concentrations were 0.00 mg/L, the hydroxide ion concentration, and the pH value was 8.51.

Second, the result of the filtration of injection water through anthracite filter media is called filtrate S13 – FIW. Based on the laboratory test results, the filtrate of the S13-FIW analysis indicated the lowest pH value of 7.90 in Table 4 with 11.65 mg/L calcium ion, 2289.62 mg/L bicarbonate ion, and 0.00 mg/L carbonate and sulfate ion concentrations, respectively.

Third, Table 3 shows the result of filtration of injection water through activated carbon filter media, called filtrate S14 – FIW, which presents a higher pH value of 8.80 with 13.97 mg/L calcium ion, 2338.86 mg/L bicarbonate ion, and 0.00 mg/L carbonate and sulfate ion concentrations.

The results of the water analysis above (presented in Table 4) were used to calculate the calcium carbonate scaling index and calcium sulfate scale solubility (Patton 1986; Cowan 1976). The term 'scale' is broadly applied to any hard deposit formed on equipment in the presence of water. The mineral scales most frequently encountered in oil and gas production operations are calcium carbonate (CaCO_3) and calcium sulfate (CaSO_4). The results of the injection water scaling index calculations are presented in Table 4. Temperature is a key factor that influences the scaling probability in oilfield systems. The calcium

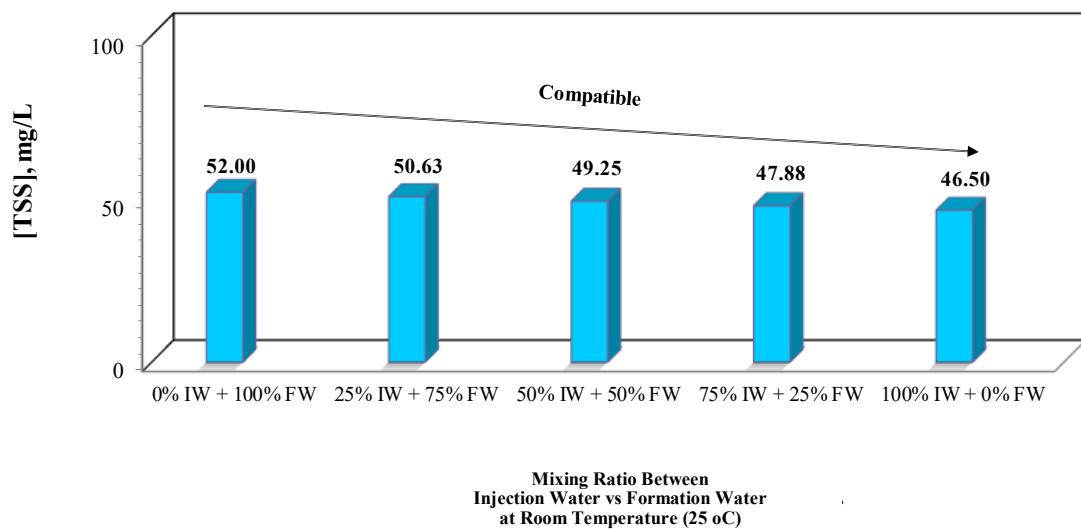


Figure 6. Results of water compatibility tests at room temperature condition between injection water vs formation water, "DE" field

Table 3. The results of water analysis injection water before treatment (IW) and filtrate S13-FIW after filtration through anthracite and filtrate S14-FIW after filtration through activated carbon filter media, DE – FIELD

No	Laboratory tests	Unit	Before treatment IW	After filtration through filter media	
				Anthracite	Activated carbon
				S13 - FIW	S14 - FIW
1	Sodium, Na ⁺ (calc)	mg/L	7500.79	6196.06	6440.67
2	Calcium, Ca ⁺⁺	mg/L	63.50	11.65	13.97
3	Magnesium, Mg ⁺⁺	mg/L	13.40	1.73	3.35
4	Iron, Fe ⁻ (total)	mg/L	0.26	0.03	0.07
5	Barium, Ba ⁺⁺	mg/L	7.36	0.95	1.84
6	Chloride, CT	mg/L	10124.52	8245.05	8606.64
7	Bicarbonate, HCO ₃ ⁻	mg/L	2745.09	2289.62	2338.86
8	Sulfate, SO ₄ ⁻	mg/L	0.00	0.00	0.00
9	Carbonate, CO ₃ ⁻	mg/L	0.00	0.00	0.00
10	Hydroxide	mg/L	0.00	0.00	0.00
11	pH @ 77 °F		8.51	7.90	8.80
12	Salinity	mg/L	18453.61	15071.81	15698.78
13	Hydrogen Sulphide	mg/L	0.002	-	-
14	Hardness	mg/L	213.69	30.91	48.66
15	TDS (Total Dissolved solids)	mg/L	20455.26	16742.93	17405.33
16	Resistivity at 125 °F	(ohm - meter)	0.2127	0.2556	0.2463

Table 4. Summary of scaling index tendency calculation results injection water before treatment (IW), filtrate S13-FIW after filtration through anthracite and filtrate S14-FIW after filtration through activated carbon filter media, DE - FIELD

No.	Laboratory Tests	Units	Injection Water Before Treatment	Filtrate of IW (S13-FIW)	Filtrate of IW (S14-FIW)
1	Calcium, Ca+2	(mg/l)	63.5	11.65	13.97
2	Bicarbonate, HCO3-	(mg/l)	2,754.09	2289.62	2,338.86
3	Carbonate, CO3=	(mg/l)	0	0	0
4	Sulfate	(mg/l)	0	0	0
5	pH		8.51	7.9	8.8
6	CaCO ₃ scaling Index (SI) at 77 °F		1.3	0.02	0.95
	Remarks: CaCO ₃ scale at 77 °F			SI > 0, Formed	SI > 0, Formed
7	Actual CaSO ₄ conc. Solubility at 77 °F	meq/l	0	0	0
	Remarks: CaSO ₄ scale	meq/l	44.48	46.61	46.56
			Solubility > Actual / Unformed	Solubility > Actual / Unformed	Solubility > Actual / Unformed

carbonate and calcium sulfate scaling tendencies for injection water samples were calculated at room temperature (77 °F) using the Stiff and Davis method (Patton, 1986; Cowan, 1976). First, the results of the calculation indicated a 1.30 scaling index of injection water. This indicates that calcium carbonate scale (CaCO₃) is likely to form (SI > 0). However, the calcium sulfate scale (CaSO₄) was not formed because the solubility of calcium sulfate (44.48 meq/L) was higher than the actual calcium sulfate concentration (0.00 meq/L), as shown in Table 4.

Second, the results of the calcium carbonate scaling index tendency calculation of the filtrate of injection water after filtration through anthracite filter media (S13-FIW) presented a value of 0.02. This indicates the formation of calcium carbonate scale (CaCO₃) (SI > 0). However, calcium sulfate scale (CaSO₄) was not formed because the solubility of calcium sulfate (46.61 meq/L) was higher than the actual calcium sulfate concentration (0.00 meq/L), as shown in Table 4.

Third, the results of the calcium carbonate scaling index tendency calculation of the filtrate of injection water after filtration through activated carbon filter media (S14-FIW) showed a value of 0.95. This indicates the formation of a calcium

carbonate scale (CaCO₃) (SI > 0). However, calcium sulfate scale (CaSO₄) was not formed because the solubility of calcium sulfate (46.56 meq/L) was higher than the actual calcium sulfate concentration (0.00 meq/L) in Table 4.

Total suspended solids (TSS) contain undissolved solids in the injection water (Patton 1986), such as scaling and emulsion blocks, which are common problems in the oil industry. When the concentration of TSS in the injection water is high, more undissolved solids are formed, resulting in a lower water quality.

However, when the concentration of TSS in the injection water is low, the amount of undissolved solids is low, and the water quality is high. One of the methods to reduce the high total suspended solids concentration in the injection water is to use anthracite (Aashish Poudel, I.M Amatty, 2024) and activated carbon (Y. K. Siong, J. Idris, M. Mazar Atabaki, 2013) filter media. The anthracite filter media was the most effective in reducing high turbidity, TSS concentration, and RPI values. It can change water quality from poor to good (Makmur T & Nuraini 2004). In this study, the anthracite filter media reduced the pH value (< 8.00). With a decrease in pH, the level of calcium carbonate scaling index also decreased from 1.30 at 77°F

(before filtration) to 0.02 at 77°F (after filtration through anthracite). Activated carbon can increase the pH value from 8.51 (pH IW before treatment) to 8.80 for the filtrate of injection water after filtration through activated carbon filter media. One of the important factors in determining the injection water quality for water flooding is the oil content of the injection water. Injection Water containing a high oil content can cause emulsion blocks in the reservoir formation (C.C. Patton, 1986).

Therefore, it is necessary to reduce the oil content using chemicals for high oil content and filter media. The maximum oil content in injection water (Peraturan Menteri Lingkungan Hidup No.19 tahun 2010) for exploration and oil and gas production), when used as a displacement fluid in water flooding, is 15 ppm. Based on the laboratory test results, the injection water before treatment contained a low oil content (2 mg/L), which decreased to 0.11 mg/L after filtration through anthracite (S13-FIW) and to 0.22 mg/L after filtration through activated carbon filter media (S14-FIW). These data were lower than the standards. Figure 7 shows a comparison of the relative plugging index test results for the three samples.

First, the injection water before treatment contained more solid particles with a darker (black) color with a high total suspended solids

(TSS) concentration of 46.50 mg/L, high turbidity value (60.43 NTU), high relative plugging index value (RPI =64.09), and 8.8503 μ m median particle size distribution, as presented in Figure 8. When Figure 7 is compared with Table 2, it can be classified as *poor water quality* because the RPI value is greater than 15 (CC. Patton 1986).

Second, the total suspended solids concentration, high turbidity value, and high relative plugging index can be reduced using anthracite and anthracite filter media. The filtrate of injection water after filtration through anthracite filter media (S13-FIW) had a turbidity value of 7.07 NTU, TSS concentration, 4.63 relative plugging index value of 0.5651 μ m with a median particle size distribution, as shown in Figure 9. When Figure 7 is compared with Table 2, it can be classified as good water quality because the RPI value is less than 10 (Patton 1986).

Third, the filtrate of the injection water after filtration through activated carbon had a turbidity value of 8.23 NTU, a TSS concentration of 6.94 mg/L, and a relative plugging index value of 7.59 with a median particle size distribution of 0.5802 μ m, as shown in Figure 20. When Figure 7 is compared with Table 2, it can be classified as good water quality because the RPI value is less than 10 (Patton CC 1986).

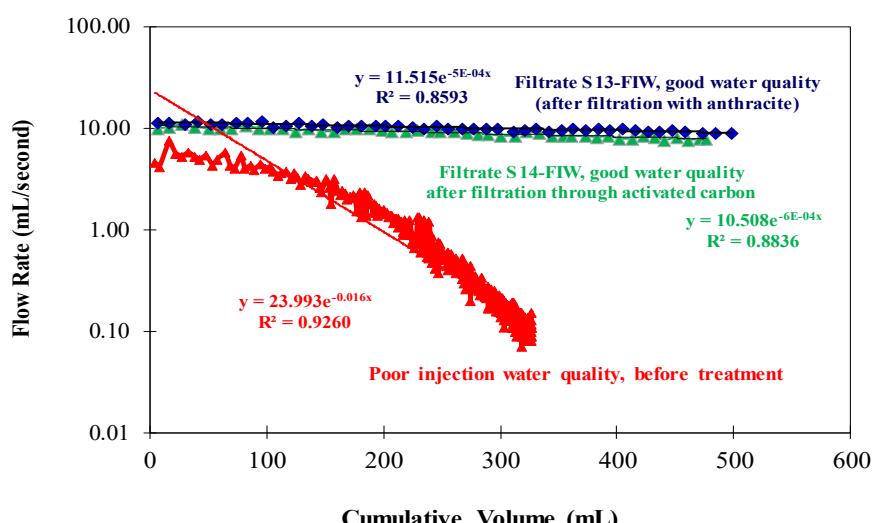


Figure 7 (a)

X	Y	MTSN	TSS (mg/L)	RPI	REMARK
7.16 498.23	11.47385 8.97583	-0.542868102	4.09	4.63	Good Water Quality
X	Y	MTSN	TSS (mg/L)	RPI	REMARK
6.61 476.90	10.4664078 7.893162448	-0.651441723	6.94	7.59	Good Water Quality
X	Y	MTSN	TSS (mg/L)	RPI	REMARK
4.61 327.24	22.26642907 0.119608156	-17.58892652	46.50	64.09	Poor Water Quality

Figure 7 (b)

Figure 7. Comparison of relative plugging index determination results injection water before treatment (IW), filtrate S13-FIW after filtration through anthracite and filtrate S14-FIW after filtration through activated carbon filter media, DE – field

The morphology of the total suspended solids (TSS) was detected using a scanning electron microscope (SEM). As explained above, the poor injection water quality before treatment was caused by the existence of a high total suspended solids (TSS=46.50mg/L) concentration.

This case is shown in Figure 11, which shows the morphology of the TSS of the injection water before treatment (IW) with many solid particles (median particle size = 8.8503 mm). Filtrates S13-FIW and S14-FIW were classified as having good water quality because both filtrate samples contained low total suspended solids concentrations (TSS = 4.09 mg/L for S13-FIW and TSS = 6.94 mg/L for S14-FIW).

Therefore, the amounts of solid particles in the S13-FIW and S14-FIW samples were lower, with small particle sizes (< 1 μ m), than those in the injection water before treatment. This case can be seen in Figure 12 morphology of TSS for S13-FIW and Figure 13 morphology of TSS for S14-FIW. Therefore, the use of anthracite and activated carbon filter media can change the injection water quality from poor to good quality.

CONCLUSION

The injection water before the treatment was compatible with the formation water, although it contained a high concentration of total suspended solids. For filtrate S13-FIW after filtration through anthracite filter media, anthracite reduced the pH value (<8.00) and improved the injection water quality from poor to good with a decrease in high TSS from 46.50 mg/L to 4.09 mg/L (TSS limit < 8 mg/L), high RPI from 64.09 to 4.63 (RPI limit < 10), turbidity value from 60.43 NTU to 7.07 NTU, and particle size from 8.85 μ m to 0.5651 μ m.

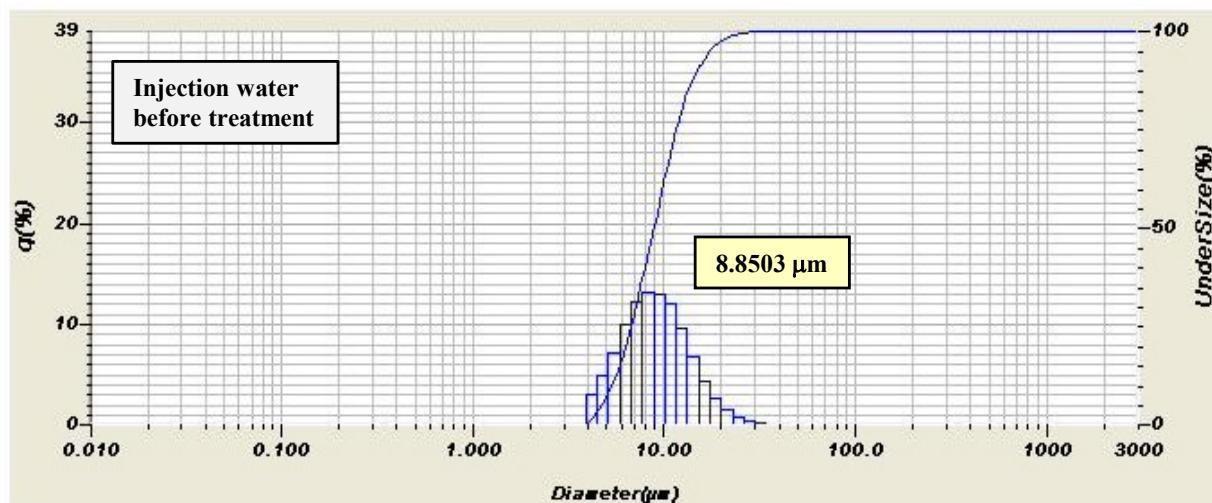
For filtrate S14-FIW after filtration through activated carbon filter media, the injection water quality improved with a decrease in the TSS from 46.50 mg/L to 6.94 mg/L (TSS limit < 8 mg/L), RPI from 64.09 to 7.59 (RPI limit < 10), turbidity from 60.43 NTU to 8.23 NTU, and particle size from 8.85 μ m to 0.5802 μ m.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of Curtin University of Tanri Abeng and other parties that have given to the research and the scientific writing fully done.

HORIBA

Laser Scattering Particle Size Distribution Analyzer LA-950



No.	Diameter (μm)	q(%)	UnderSize(%)
1	0.011	0.000	0.000
2	0.013	0.000	0.000
3	0.015	0.000	0.000
4	0.017	0.000	0.000
5	0.020	0.000	0.000
6	0.022	0.000	0.000
7	0.026	0.000	0.000
8	0.029	0.000	0.000
9	0.034	0.000	0.000
10	0.039	0.000	0.000
11	0.044	0.000	0.000
12	0.051	0.000	0.000
13	0.058	0.000	0.000
14	0.067	0.000	0.000
15	0.076	0.000	0.000
16	0.087	0.000	0.000
17	0.100	0.000	0.000
18	0.115	0.000	0.000
19	0.131	0.000	0.000
20	0.150	0.000	0.000
21	0.172	0.000	0.000
22	0.197	0.000	0.000
23	0.226	0.000	0.000
24	0.259	0.000	0.000

No.	Diameter (μm)	q(%)	UnderSize(%)
25	0.296	0.000	0.000
26	0.339	0.000	0.000
27	0.389	0.000	0.000
28	0.445	0.000	0.000
29	0.510	0.000	0.000
30	0.584	0.000	0.000
31	0.669	0.000	0.000
32	0.766	0.000	0.000
33	0.877	0.000	0.000
34	1.005	0.000	0.000
35	1.151	0.000	0.000
36	1.318	0.000	0.000
37	1.510	0.000	0.000
38	1.729	0.000	0.000
39	1.961	0.000	0.000
40	2.269	0.000	0.000
41	2.599	0.000	0.000
42	2.976	0.000	0.000
43	3.409	0.000	0.000
44	3.905	0.000	0.000
45	4.472	2.890	2.890
46	5.122	4.705	7.595
47	5.867	7.117	14.712
48	6.720	9.788	24.499

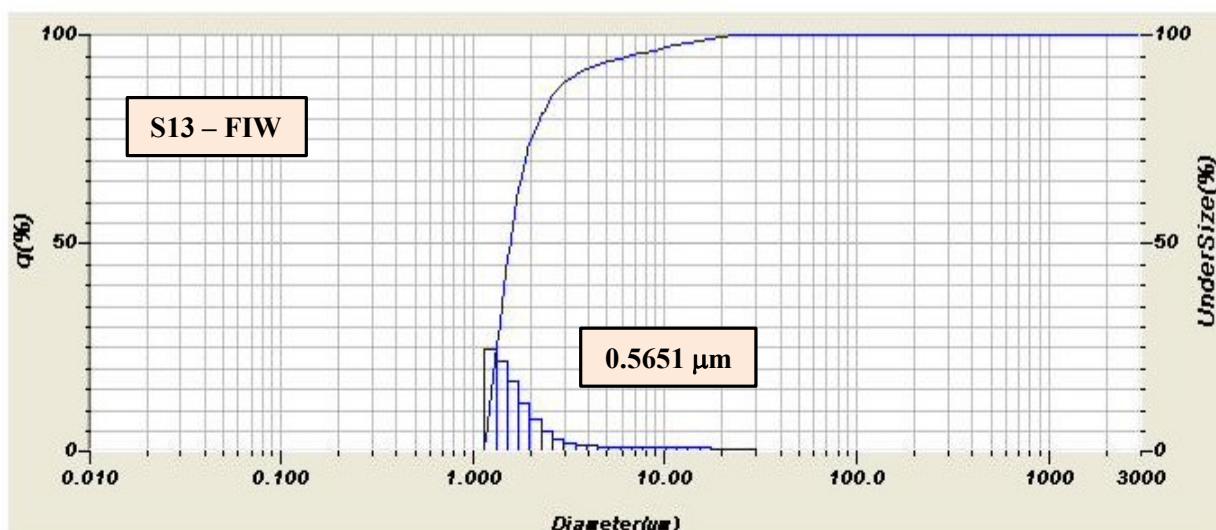
No.	Diameter (μm)	q(%)	UnderSize(%)
49	7.697	12.033	36.532
50	8.816	13.094	49.626
51	10.097	12.910	62.536
52	11.565	11.914	74.450
53	13.246	9.544	83.963
54	15.172	6.712	90.705
55	17.377	4.234	94.939
56	19.904	2.457	97.396
57	22.797	1.347	98.743
58	26.111	0.711	99.455
59	29.907	0.365	99.819
60	34.255	0.181	100.000
61	39.234	0.000	100.000
62	44.938	0.000	100.000
63	51.471	0.000	100.000
64	58.953	0.000	100.000
65	67.523	0.000	100.000
66	77.339	0.000	100.000
67	88.583	0.000	100.000
68	101.460	0.000	100.000
69	116.210	0.000	100.000
70	133.103	0.000	100.000
71	152.453	0.000	100.000
72	174.616	0.000	100.000

No.	Diameter (μm)	q(%)	UnderSize(%)
73	200.000	0.000	100.000
74	229.075	0.000	100.000
75	262.375	0.000	100.000
76	300.518	0.000	100.000
77	344.206	0.000	100.000
78	384.244	0.000	100.000
79	451.556	0.000	100.000
80	517.200	0.000	100.000
81	592.387	0.000	100.000
82	678.504	0.000	100.000
83	777.141	0.000	100.000
84	890.116	0.000	100.000
85	1019.515	0.000	100.000
86	1167.725	0.000	100.000
87	1337.481	0.000	100.000
88	1531.914	0.000	100.000
89	1754.613	0.000	100.000
90	2009.687	0.000	100.000
91	2301.841	0.000	100.000
92	2636.467	0.000	100.000
93	3000.000	0.000	100.000

Figure 8. Results of particle size distribution analysis injection water before treatment (IW), DE – field

HORIBA

Laser Scattering Particle Size Distribution Analyzer LA-950



No.	Diameter(μm)	q(%)	UnderSize(%)
1	0.011	0.000	0.000
2	0.013	0.000	0.000
3	0.015	0.000	0.000
4	0.017	0.000	0.000
5	0.020	0.000	0.000
6	0.022	0.000	0.000
7	0.026	0.000	0.000
8	0.029	0.000	0.000
9	0.034	0.000	0.000
10	0.039	0.000	0.000
11	0.044	0.000	0.000
12	0.051	0.000	0.000
13	0.058	0.000	0.000
14	0.067	0.000	0.000
15	0.076	0.000	0.000
16	0.087	0.000	0.000
17	0.100	0.000	0.000
18	0.115	0.000	0.000
19	0.131	0.000	0.000
20	0.150	0.000	0.000
21	0.172	0.000	0.000
22	0.197	0.000	0.000
23	0.226	0.000	0.000
24	0.259	0.000	0.000

No.	Diameter(μm)	q(%)	UnderSize(%)
25	0.296	0.000	0.000
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27	0.389	0.000	0.000
28	0.445	0.000	0.000
29	0.510	0.000	0.000
30	0.584	0.000	0.000
31	0.669	0.000	0.000
32	0.766	0.000	0.000
33	0.877	0.000	0.000
34	1.005	0.000	0.000
35	1.151	0.000	0.000
36	1.318	24.388	24.388
37	1.510	21.275	45.664
38	1.729	16.373	62.037
39	1.981	11.340	73.377
40	2.269	7.308	80.686
41	2.599	4.996	85.251
42	2.976	2.882	88.133
43	3.409	1.905	90.038
44	3.905	1.349	91.387
45	4.472	1.034	92.421
46	5.122	0.857	93.278
47	5.867	0.759	94.036
48	6.720	0.706	94.743

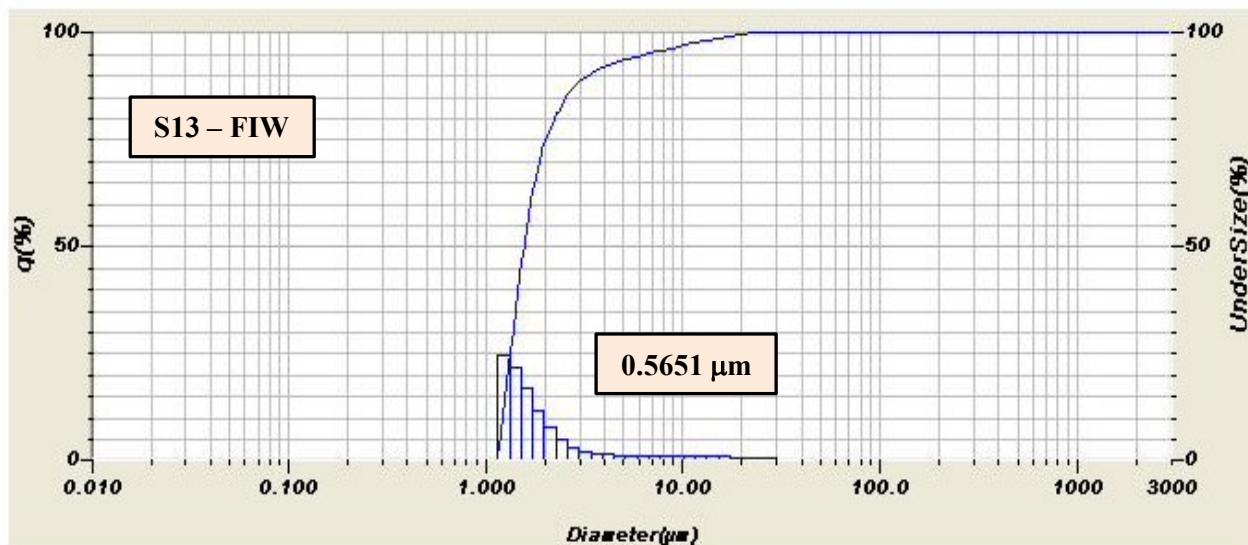
No.	Diameter(μm)	q(%)	UnderSize(%)
49	7.697	0.679	95.422
50	8.816	0.662	96.084
51	10.097	0.644	96.727
52	11.565	0.624	97.351
53	13.246	0.596	97.947
54	15.172	0.551	98.498
55	17.377	0.483	98.981
56	19.904	0.396	99.377
57	22.797	0.297	99.674
58	26.111	0.202	99.876
59	29.907	0.124	100.000
60	34.255	0.000	100.000
61	39.234	0.000	100.000
62	44.938	0.000	100.000
63	51.471	0.000	100.000
64	58.963	0.000	100.000
65	67.523	0.000	100.000
66	77.339	0.000	100.000
67	88.583	0.000	100.000
68	101.460	0.000	100.000
69	116.210	0.000	100.000
70	133.103	0.000	100.000
71	152.453	0.000	100.000
72	174.616	0.000	100.000

No.	Diameter(μm)	q(%)	UnderSize(%)
73	200.000	0.000	100.000
74	229.075	0.000	100.000
75	262.376	0.000	100.000
76	300.518	0.000	100.000
77	344.206	0.000	100.000
78	394.244	0.000	100.000
79	451.595	0.000	100.000
80	517.200	0.000	100.000
81	592.387	0.000	100.000
82	678.504	0.000	100.000
83	777.141	0.000	100.000
84	890.116	0.000	100.000
85	1019.515	0.000	100.000
86	1167.725	0.000	100.000
87	1337.481	0.000	100.000
88	1531.914	0.000	100.000
89	1754.613	0.000	100.000
90	2009.687	0.000	100.000
91	2301.841	0.000	100.000
92	2636.467	0.000	100.000
93	3000.000	0.000	100.000

Figure 9. Results of particle size distribution analysis filtrate S13-FIW after filtration through anthracite filter media, DE – field

HORIBA

Laser Scattering Particle Size Distribution Analyzer LA-950



No.	Diameter(μm)	q(%)	UnderSize(%)
1	0.011	0.000	0.000
2	0.013	0.000	0.000
3	0.015	0.000	0.000
4	0.017	0.000	0.000
5	0.020	0.000	0.000
6	0.022	0.000	0.000
7	0.026	0.000	0.000
8	0.029	0.000	0.000
9	0.034	0.000	0.000
10	0.039	0.000	0.000
11	0.044	0.000	0.000
12	0.051	0.000	0.000
13	0.058	0.000	0.000
14	0.067	0.000	0.000
15	0.076	0.000	0.000
16	0.087	0.000	0.000
17	0.100	0.000	0.000
18	0.115	0.000	0.000
19	0.131	0.000	0.000
20	0.150	0.000	0.000
21	0.172	0.000	0.000
22	0.197	0.000	0.000
23	0.226	0.000	0.000
24	0.259	0.000	0.000

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26	0.339	0.000	0.000
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30	0.584	0.000	0.000
31	0.669	0.000	0.000
32	0.766	0.000	0.000
33	0.877	0.000	0.000
34	1.005	0.000	0.000
35	1.151	0.000	0.000
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54	15.172	0.551	98.498
55	17.377	0.483	98.981
56	19.904	0.396	99.377
57	22.797	0.297	99.674
58	26.111	0.202	99.876
59	29.907	0.124	100.000
60	34.255	0.000	100.000
61	39.234	0.000	100.000
62	44.938	0.000	100.000
63	51.471	0.000	100.000
64	58.953	0.000	100.000
65	67.523	0.000	100.000
66	77.339	0.000	100.000
67	88.583	0.000	100.000
68	101.460	0.000	100.000
69	116.210	0.000	100.000
70	133.103	0.000	100.000
71	152.453	0.000	100.000
72	174.616	0.000	100.000

No.	Diameter(μm)	q(%)	UnderSize(%)
73	200.000	0.000	100.000
74	229.075	0.000	100.000
75	262.376	0.000	100.000
76	300.518	0.000	100.000
77	344.206	0.000	100.000
78	394.244	0.000	100.000
79	451.595	0.000	100.000
80	517.200	0.000	100.000
81	592.387	0.000	100.000
82	678.504	0.000	100.000
83	777.141	0.000	100.000
84	890.116	0.000	100.000
85	1019.515	0.000	100.000
86	1167.725	0.000	100.000
87	1337.481	0.000	100.000
88	1531.914	0.000	100.000
89	1754.613	0.000	100.000
90	2009.687	0.000	100.000
91	2301.841	0.000	100.000
92	2636.467	0.000	100.000
93	3000.000	0.000	100.000

Figure 10. Results of Particle Size Distribution Analysis Filtrate S14-FIW After Filtration through Activated Carbon Filter Media, DE – Field

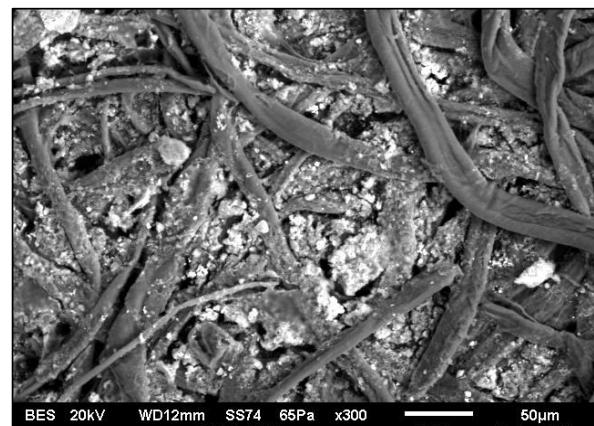
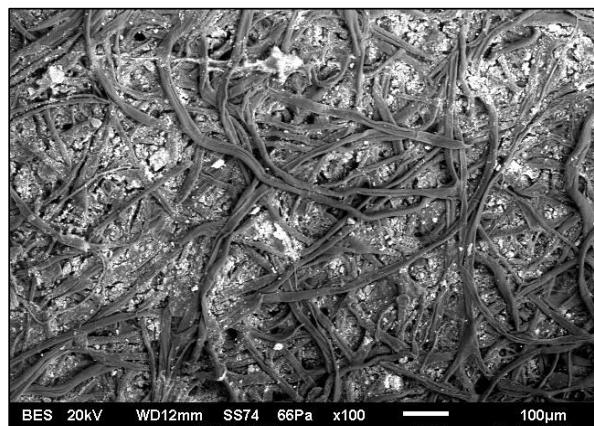


Figure 11. Morphology of total suspended solids of injection water before treatment (IW) by scanning electron microscope, multiply 100 x and 300x, DE – field

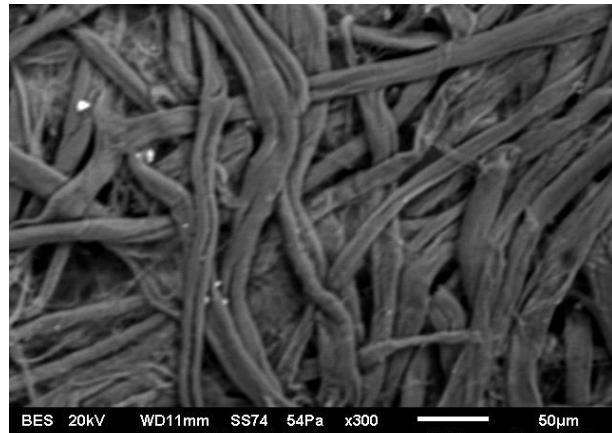
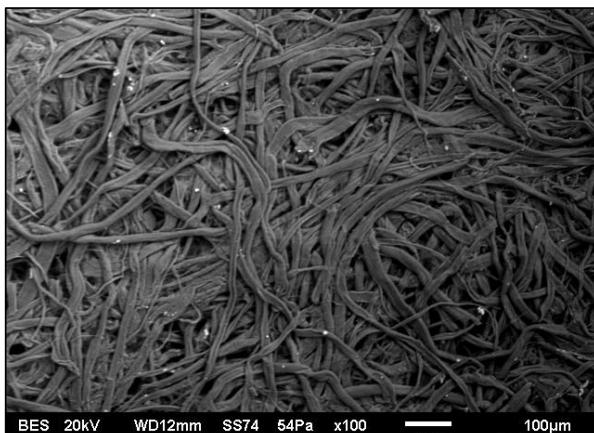


Figure 12. Morphology of total suspended solids of filtrate S13-FIW after filtration through anthracite filter media by scanning electron microscope (SEM) multiply 100x and 300x, DE field

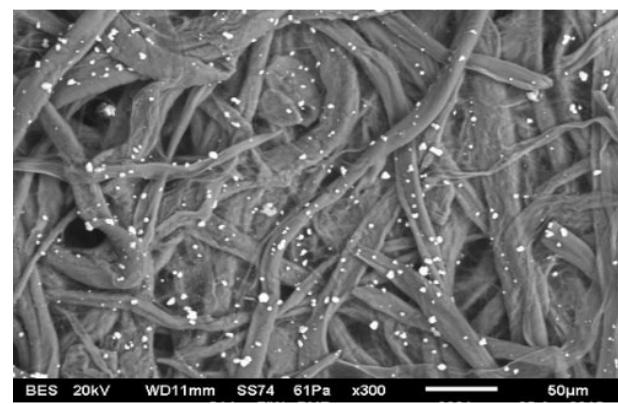
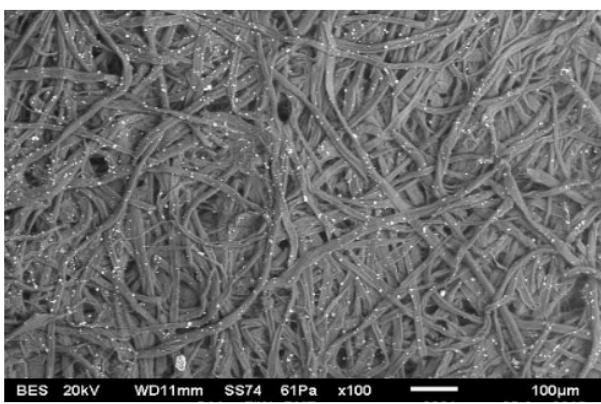


Figure 13. Morphology of total suspended solids of filtrate S14-FIW after filtration by active carbon filter media by scanning electron microscope (SEM) multiply 100x and 300x, DE field

GLOSSARY OF TERMS

Symbol	Definition	Unit
AC	An engineered filter medium characterized by extreme porosity and a large specific surface area, providing high adsorption capacity for purifying injection water	-
EB	A formation blockage caused by high oil content	
F	The term used for injection water that has flowed out of the Water naturally present in the reservoir, collected from the wellhead for compatibility testing with injection water	
FW	Formation water: Water naturally present in the reservoir, collected from the wellhead for compatibility testing with injection water	
IW	Injection water: Water introduced into a formation to maintain pressure and displace oil; often composed of treated produced water	
MSTN	Milli-pore Slope Test Number (MSTN): A parameter used alongside TSS and RPI to classify water quality according to the Cerini method.	
RPI	Relative Plugging Index (RPI): A metric derived from the Cerini method used to classify the quality of water and its tendency to plug formation pores. An RPI < 3 indicates excellent quality, while RPI > 15 indicates poor quality.	RPI
SI	Scaling Index (SI): A calculated value (using the Stiff and Davis method) used to predict the probability of scale formation. A positive SI indicates supersaturation (scaling likely), while a negative SI indicates undersaturation.	
SEM	Scanning Electron Microscope (SEM): An imaging tool used to detect and analyze the morphology of Total Suspended Solids (TSS) before and after filtration	
TSS	Total Suspended Solids (TSS): A measure of undissolved materials in water, including scale precipitates, oil droplets, and bacteria. High TSS	
WF	Water Flooding: A secondary recovery method applied to maintain reservoir pressure and enhance oil displacement efficiency.	

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