



Reducing the Salinity of the Produced Water from Oil Field Using Activated Carbon Extracted from Waste Date Kernel

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ABSTRACT

Oil production operations are commonly divided into three periods: "Primary, Secondary and Enhanced Oil Recovery EOR". Primary recovery is considered as the initial production stage, resulting from the displacement of natural drive mechanisms that exist in a reservoir. Secondly, the secondary recovery period which is the water flooding, or gas injection. The final stage period is EOR period, which involves the injection of external material into a reservoir. Where the injected slug interacts with the reservoir rock or oil system to create favorable conditions in order to enhance the oil recovery.

The produced water can be used as the water flooding during the secondary recovery, but the high salinity of the formations yields a low recovery factor. Thus, some materials have been used to reduce the water salinity during the production in order to reinject it into the reservoir and cause a high recovery factor. The challenge to obtain an economic material which is able to reduce the salinity in the oil fields is still at stake. Thus, many materials need to be applied in order to test its ability to reduce the water salinity. The activated carbon extracted from waste date kernel have not used yet in this area. In the present paper, the activated carbon was prepared at lab by following specific procedures. Where, a different size of activated carbon extracted from date kernel used to treat the saline water, which later will be used for a spontaneous imbibition test for sandstone core samples after saturated with crude oil. A spontaneous imbibition test consisting of three scenarios of activated carbon at various temperatures and later compared with untreated reservoir water. In this study, the spontaneous imbibition test was performed at room temperature and oven temperature including (45, 55, and 70 °C). The results showed that activated carbon is a useful material to reduce the water salinity. Where, the best oil recovery was at a treated water with activated carbon volume (0.125), which was (70.41%), that was at the maximum used temperature.

دراسة حديثة لتقليل ملوحة المياه باستخدام الكربون المنشط المستخرج من نواة التمر

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الكلمات المفتاحية:

نواة التمر
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ماء التكوين

الملخص

بصورة تقليدية تم تقسيم عمليات استخلاص النفط الى ثلاث مراحل: أولية وثانوية وثلاثية (تحسين استخلاص النفط). تعتمد مرحلة الإنتاج الأولية على الطاقة الموجودة بصورة طبيعية في المكمن. وتعتمد عملية الإنتاج الثانوية على الغمر بالمياه، والمحافظة على الضغط، والحقن بالغاز. وتتضمن عمليات استخلاص النفط الثلاثية

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عملية العلاج
اختبار التشرب العفوي.

على حقن سائل من نوع معين في الخزان، حيث ان هذه السوائل تكمل الطاقة الطبيعية الموجودة في الخزان وبالتالي تؤدي الى تحسين انتاج النفط، وبصورة أخرى تتفاعل السوائل التي تم حقنها في الخزان مع صخور وزيتوت الممكن وتعمل على استعادة النفط. ويعزى حدوث هذه التفاعلات الى الخواص الفيزيائية والكيميائية التي تؤدي الى انتاج طاقة حرارية. أحد التفاعلات المهمة في المرحلة الثانوية وهي عياره عن ضخ المياه المنتجة الى الممكن. ولكن عادة المياه المنتجة تحتوي على ملوحة عالية مما يسبب في انتاج قليل. لذلك العمل على تقليل ملوحة المياه المنتجة شغلت العديد من البحوث. في هذه الدراسة البحثية تم استخدام احجام مختلفة من الكربون المنشط، والذي تم استخلاصه من نواة التمر، وذلك لاختبار التشرب التلقائي لعينات من الحجر الرملي يعد تشبعها بالنفط الخام. اختبار التشرب التلقائي يتكون من ثلاث سيناريوهات للكربون المنشط عند درجات حرارة مختلفة ومقارنتها لاحقاً بسيناريو واحد لمياه الخزان الغير معالجة. في هذه الدراسة، تم اجراء اختبار التشرب التلقائي عند درجة الحرارة العادية وكذلك عند درجات الحرارة 45 و55 و70 درجة مئوية. من خلال النتائج المتحصل عليها تبين أن أفضل استخلاص للنفط كان في المياه المعالجة بالكربون المنشط والذي بحجم 0.125 والذي كانت نسبته 70.41% وكان ذلك عند أقصى درجة حرارة مستخدمة

1. Introduction

After more than a century of petroleum production, different of petroleum fields are approaching the ends of their residual oil saturation. The residual of an oil usually undergoes three periods where different techniques are used to increase the crude oil production at maximum levels which are primary, secondary and EOR (Zhang, Gao, and Xue 2020; Elsharafi 2018; Samba and SYIHAB, n.d.; Green and Willhite 1998). These techniques are mainly aimed to serve a common purpose which is reducing the residual oil saturation which results in improvement of the displacement efficiency and improvement of the ultimate oil recovery. One of those techniques is low salinity water injection, many challenges about the low water salinity in the order to reduce the salinity with low cost. The challenges started at 1967 by Bernard, the study has presented about improvement in the recovery of oil by low or reduced salinity water (Bernard 1967). In 2000, Tchistiakov has presented about the interaction between the cation and clay which it is related to the low water salinity. In this study, only some cations are attached to the clay surface as an adsorbed layer, while others are free, forming a diffuse ionic layer, some distance away from the clay surface. The balance between thermal motion of the cations and electrostatic attraction can control the distribution and concentration of the free cation (Tchistiakov 2000). The low salinity challenges continuously until 2004. Where, Webb was presented about the low water salinity and has proved that the low water salinity can reduce the residual oil saturation. Thus, the oil recovery has increased (Webb, Black, and Al-Ajeel 2004). Consequently in 2008, Lager and others have shown that the oil molecules are attract on surface due to the clay negative charge by divalent cations. Where, the positive charges (ions) in calcium (Ca^{2+}) or magnesium (Mg^{2+}) helps to hold the oil molecules on the clay particles. During the low saline water injection, the monovalent ions, exchange with the divalent cations attract the oil droplet. Thus, the oil droplet will be free to move forward (Lee et al. 2010). Additional study in 2010 by Lee and others. Where, they have presented about the electric double layer, they noticed that the electric double layer has an outer diffuse layer (negative ions) and an inner adsorbed layer (positive ions). During the low salinity water containing less ions, the double layer is less compact, and the oil release from the clay surface is inhibited (Lee et al. 2010). Also in 2010, Austad and others has noticed that the negative charge on the clay due to role of clay minerals often characterized as cation exchange material (Austad, RezaeiDoust, and Puntervold 2010).

Based on the literature, many challenges are at stake for low salinity projects. In this paper, we have moved step more and check how to find a way to reduce the salinity of formation water with economic method. Thus, the activated carbon extracted from date kernel has been decided to be used in this study. Generally, the date kernel has been used as treatment for the oil fields in 2021 by Udeagbara and others (Udeagbara et al. 2021). However, the date kernel used as a

fiber material not as activated carbon. This study consider as the first study that used the activated carbon extracted from waste date kernel, in order to reduce the salinity of the formation water in the oil fields. The overall project plan of the present work is shown in figure 1

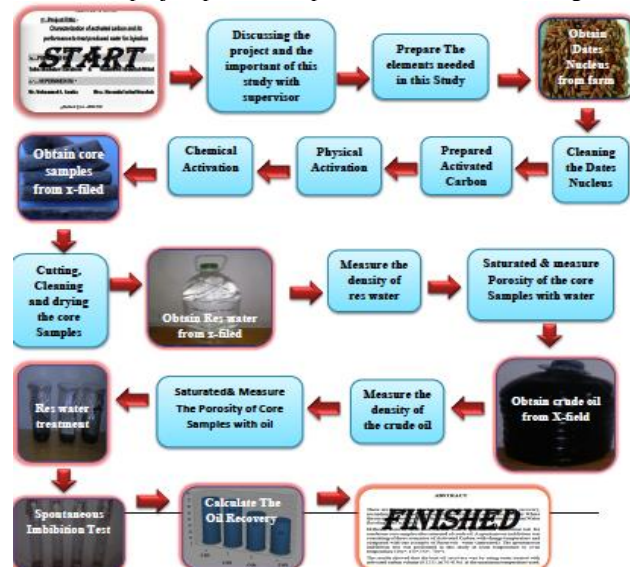


Figure 1. The Overall Project Plan

2. Experiments Procedure

2.1 Activated Carbon Preparation

2.1.1. First Stage of Activated Carbon Preparation

- Date kernels were washed several times using distilled water until the color of the water becomes clear as shown in figure 2.a.
- Dates kernels were placed in burning oven at $400^{\circ}C$ for a period of 24 hours. The kernels were completely burned and their color were changed to dark black as shown in figure 2.b.
- After that, the Dates kernels were grounded into fine powered parts as shown in figure 2.c.
- The grounded kernels were washed several times using distilled water as shown in figure 2.d.
- The grounded particles were put in drying oven at $105^{\circ}C$ for a period of 24h as shown in figure 2.e.
- After that, the grounded powders were classified into three different size (0.250, 0.125, 0.063) mm, the resulted samples as shown in figure 2.f were a non- activated carbon.

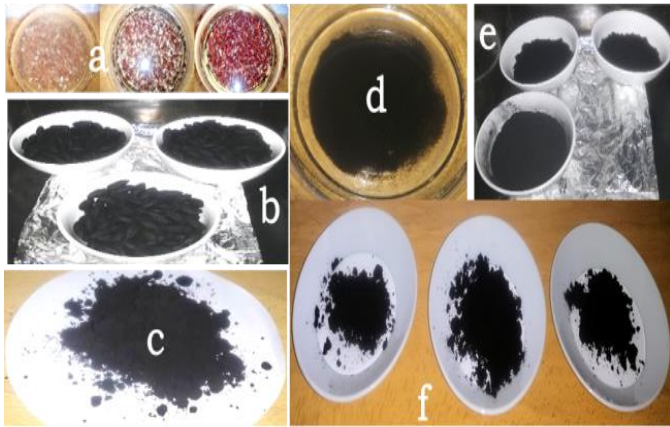


Figure 2. Carbon Activation First Stage

2.1.2 Second Stage of Activated Carbon Preparation

The non-activated carbon is activated by using a chemical such as zinc chloride (ZnCl₂), sulfuric acid (H₂SO₄), and sodium hydroxide (Na OH). The second stage of activated carbon preparation was carried out as the following:

- (i) A (10 g) of non-activated charcoal sample was add to a mixture of (H₂SO₄ (3N) and the ZnCl₂ (3N) in 50 ml of distilled water).
- (ii) A non-activated carbon mixture was exposed to boiling temperature (100C°) for a period time of 3 hours. Thus, the activated carbon was formed.
- (iii) The formed activated carbon was filtered
- (iv) The collected sample of activated carbon was washed using a distilled water for a several times and after each washing process, a pH was measured using a pH measurement device. The required pH value was 7.
- (v) In order to dry, the activated carbon, the samples were inserted in drying oven at temperature of (105 °C) for a period time of 24 hours. The activated carbon samples were ready for a reservoir water treatment.

2.2 Core Samples Preparation

The Core Samples Preparation has been done typically to the following procedures:

1. Clean all the samples.
2. Drying the samples and weight each sample.
3. Saturate the cores with distilled water and weight each sample.
4. Measure the bulk size of each sample.
5. Measure the pore size.
6. Measure porosity.
7. Drying the core sample and weight each sample again.
8. Saturated cores with oil and weight each core.
9. Measure the OOIP for each core.

3. Results and Discussion

3.1 Core Analysis Results

3.1.1 Pore Volume of Sandston Core Samples Results

The volume of fluids type, which inter to pore volume of sandstone reservoir core samples were calculated. Table 1 showing the results of pore volume with reservoir water. Table 2 showing the results of pore volume with reservoir oil.

3.1.2 Bulk Volume of Sandstone Core Sample Results

The bulk volume of sandstone reservoir core samples at different volumes were calculated using the cylinder volume base. Table 3 shows the bulk volume of sandstone core samples.

Table 1. Pore Volume of Sandstone Core with Reservoir Water.

Sample	W dry(g)	W sat (g)	Pw (g/cc)	Pv (cc)
C-101	62.8	70.4		7.49
C-102	59.9	69.3		9.27
C-103	53.6	64.3		10.55
C-104	63.2	71.7	1.0134	8.38
C-105	63.7	71.7		7.89
C-106	63.6	71.8		8.09

Table 2. Pore Volume of Sandstone Core with Reservoir Oil.

Sample	W dry (g)	W sat (g)	Po (g/cc)	Pv (cc)
C-101	62.8	69.3		8.155
C-102	59.9	67.7		9.786
C-103	53.6	62.6	0.797	11.29
C-104	63.2	70.6		9.284
C-105	63.7	70.6		8.657
C-106	63.6	70.8		9.033

Table 3. Bulk Volume of Sandstone Core Samples.

Sample	L (cm)	D (cm)	Vb (cc)
C-101	4.919	2.906	55.22
C-102	4.921	2.05	55.25
C-103	4.916	2.835	53.81
C-104	4.915	2.915	55.3
C-105	4.91	2.905	55
C-106	4.915	2.915	55.3

3.1.3 Porosity of Sandstone Core Sample Results

The porosity was obtained by dividing the pore volume by the bulk volume. Table 4 show the porosity of sandstone core samples. According to the obtained results, the maximum porosity of core sample in reservoir was 19.6% at sample C-103.

Table 4. Porosity of Sandstone Core Samples of reservoir.

sample	Vb (cc)	Vp (cc)	Porosity	
			%	fra
C-101	55.22	7.49	13.5	0.135
C-102	55.25	9.27	19.7	0.167
C-103	53.81	10.55	19.6	0.196
C-104	55.3	8.38	15.1	0.151
C-105	55	7.89	14.3	0.143
C-106	55	8.09	14.6	0.146

3.1.4 Original Oil in Place (OOIP) in Sandstone Core Results

Table 5 shows original oil in place (OOIP) of sandstone core samples, the cores samples were saturated with oil with density of 0.797 g/cc. Based on the obtained results, the maximum OOIP of sandstone core sample was 11.29 cc at sample C-103.

Table 5. (OOIP) in Sandstone Core Results.

Sample	W dry(g)	W sat (g)	OOIP (cc)
C-101	62.8	69.3	8.155
C-102	59.9	67.7	9.786
C-103	53.6	62.6	11.29
C-104	63.2	70.6	9.284
C-105	63.7	70.6	8.657
C-106	63.6	70.8	9.033

3.2 Reservoir Water Analysis

3.2.1 Reservoir Water Analysis Before the Treatment Process

Table 6. Shows the results of reservoir water analysis before the treatment process. The formation salinity was at 2400 ppm.

Table 6. Reservoir Water Analysis before the Treatment Process.

S.No	Test Type	Results
1	Ec ppt	2584
2	salinity ppt	2400
3	PH	6.77
4	TDs mg/l	22830
5	NH4 mg/l	0.15
6	NO3 ppm	2.820
7	Fe ppm	< 0.001
8	K ppm	600
9	Ca ppm	6535
10	Mg ppm	4130
11	SO4 ppm	2720
12	Cl ppm	138.2
13	Na ppm	11920

3.2.2 Reservoir Water Analysis after the Treatment Process

Table 7 shows the results of reservoir water analysis after the treatment process. The activated carbon proved it is ability to reduce the salinity until 2000 ppm. The particles size 0.125 mm was given the lowest salinity. The synthesis activated carbon has ability to adsorb the dissolved salts. The percentage of activated carbon also play an important factor to adsorb ability. The effect of activated carbon on adsorption of dissolved salts depends on size of activated carbon. However, the activated carbon has negative charge and based on Coulomb law, the static electric forces for charges that has different charges are attract with each other while the static electric forces that has same charges repel each other. Thus, two negative charges repel one another, while a positive charge attracts a negative charge. The attraction or repulsion acts along the line between the two charges. Thus, the negative charges will adsorb the positive charges in the water solution.

Table 7. Reservoir Water Analysis after the Treatment Process.

S.No	test type	results		
		0.250 mm	0.125 mm	0.063 mm
1	PH	6.9	6.96	6.88
2	Eo ms /cm	50.90	48.76	59.24
3	Salinity ppt	2200	2000	2200
4	TDs ppt	20007	19483	19870
5	NH ₄ ppm	0.11	0.16	0.13
6	NO ₃ ppm	0.98	0.02	0.14
7	Fe ppm	< 0.001	< 0.001	< 0.001
8	K ppm	10	8.40	9.5
9	Ca ppm	7	9	6
10	Mg ppm	57	10	10
11	SO ₄ ppm	197	158	171
12	Cl ppm	12	24	27
13	Na ppm	13	41	62

3.3 Spontaneous Imbibition Test

3.3.1 Effect of Formation Water, Time, and Temperature on the Oil Recovery of Core Samples

The spontaneous imbibition test was done by the formation water (untreated water), and the used sample was (C-101). At the beginning the temperature was about (27°C) for a period time of 24 hours, the oil extraction rate (OER) was (0.24%). By increasing the temperature

to (45°C) for a period of 72 hours, (OER) was increased to (10 %). The test was carried out for another 72 hours at 55 °C, the recovery factor was at (22.31 %). Finally, the temperature was raised to (70 °C) for 72 hours and (OER) was (46.8 %). Figure 3 shows the effects of reservoir water (untreated) on the oil recovery for sandstone core samples as function of time and temperature.

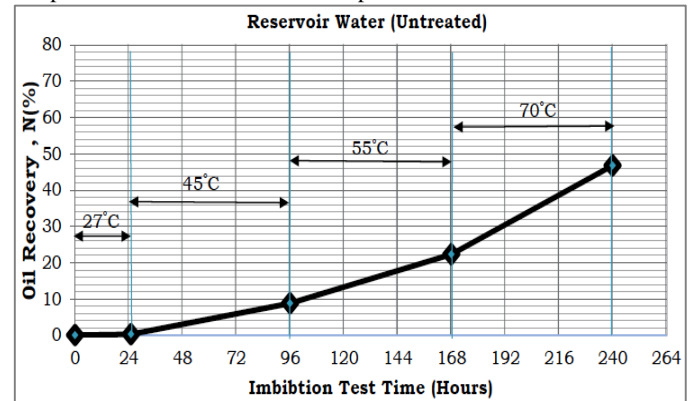


Figure 3. Effects of Reservoir Water (Untreated) on Oil Recovery of Sandstone Core Samples Related with Time and Temperature

3.4.2 Effect of Treated Formation Water, Time, and Temperature on the Oil Recovery of Core Samples

(i) First Scenario; Reservoir Water was Treated by Activated Carbon with size 0.250 mm.

The spontaneous imbibition test was done by the reservoir water treated by activated carbon with size of 0.250 mm, and the used sample was (C-102). At the beginning, the temperature was about (27 °C) for a period time of 24 hours and the oil extraction was about 0.14 %. Continuously, the oil extraction rate (OER) was 16 % by increasing the temperature to (45 °C) for a period of 72 hours. Then the test was carried out for addition 72 hours at the 55 °C, the OER was (34.13 %). Finally, the temperature was raised to (70 °C) for 72 hours and (OER) was (68.87%). Figure 4 shows the effects of reservoir water treated by activated carbon (0.250 mm) on the oil recovery for sandstone core samples in relation to time and temperature.

(ii) Second Scenario; Reservoir Water was Treated by Activated Carbon (0.125 mm)

The spontaneous imbibition test was done by the reservoir water treated by activated carbon with size of 0.125 mm, and the used sample was (C-103). At the beginning, the temperature was about (27 °C) for a period time of 24 hours. Thus, the oil extraction rate (OER) was (0.40 %). By increasing the temperature to (45°C) for a period of 72 hours, the OER was increased to (20%). Then the test was carried out for more addition 72 hours at 55o C, in this case the OER was (38.13 %). Finally, the temperature was raised to (70 °C) for 72 hours and the OER was 70.4 %. Figure 5 shows the effects of reservoir water (treated) on the oil recovery for sandstone core samples as function to time and temperature.

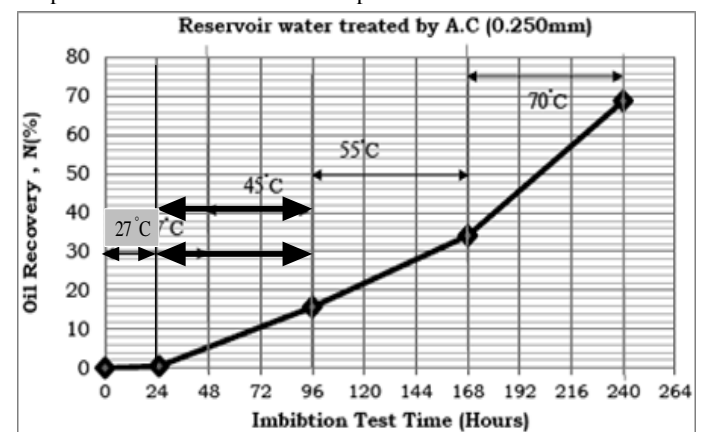


Figure 4. Effects of Reservoir Water Treated with Activated Carbon (0.250 mm) on Oil Recovery of Sandstone Core Samples Related with Time and Temperature.

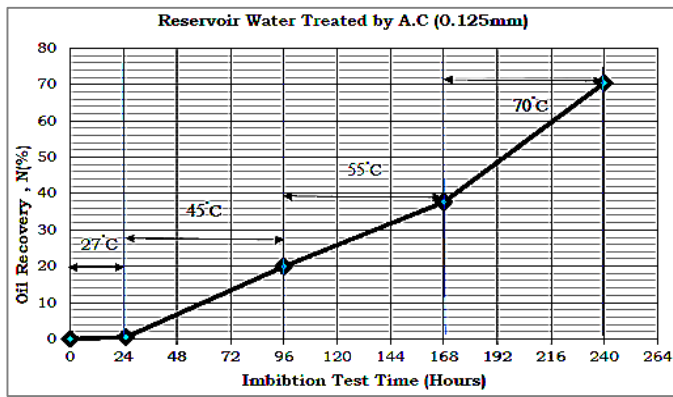


Figure 5. Effects of Reservoir Water Treated with Activated Carbon (0.125 mm) on Oil Recovery of Sandstone Core Samples Related with Time and Temperature.

(iii) Third Scenario; Reservoir Water was Treated by Activated Carbon (0.063 mm)

The spontaneous imbibition test was carried out by the reservoir water treated by activated carbon with size of 0.063 mm, and the used sample was (C-104), starting temperature was at (27 °C) for a period time of 24 hours, the OER was (0.32 %). Increasing the temperature to (45 °C) for a period of 72 hours, the OER was 10.01 %, then the test was carried out for addition 72 hours at the same temperature, in this case the OER was 24.01 %. Finally, the temperature was raised to 70°C for 72 hours and the OER was 53.10 %. Figure 6 shows the effect of reservoir water (treated) on the oil recovery for sandstone core samples in relation to time and temperature.

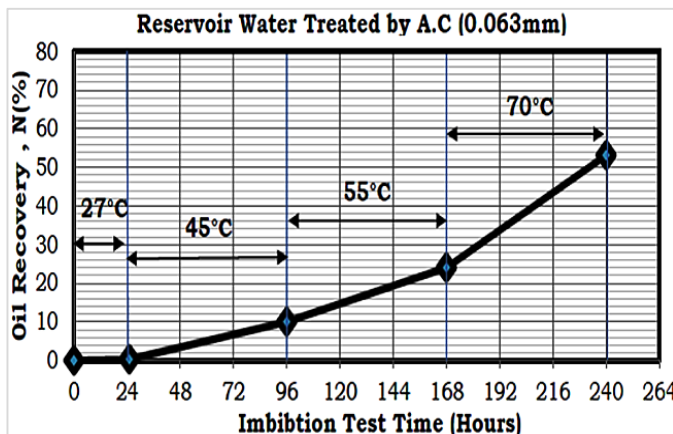


Figure 6. Effects of Reservoir Water Treated with Activated Carbon (0.063 mm) on Oil Recovery of Sandstone Core Samples Related with Time and Temperature

3.4.3 Comparison between the Effects of Oil Recoveries (Sandstone Rocks)

The spontaneous imbibition test of sandstone samples was performed by untreated reservoir water and treated reservoir water at different volumes of activated carbon, using different temperatures and different interval times. Figure 7 shows the comparison in terms of oil extraction. The extraction of oil in spontaneous imbibition test using the sample (C-101) which was carried out using a natural reservoir water (untreated reservoir water) with low rates despite the slight, the recovery was increased gradually when a different temperature was applied. The maximum oil extraction reached (46.8 %) at temperature (70 °C). Using the smaller size of 0.063 mm of activated carbon on the sample (C-104) gave the low recovery than other activated carbon sizes. However, the Activated Carbon (0.125 mm) has given the highest recovery factor compared with other scenarios. In addition, all the treated water setarious have given better recovery factor compared with untreated formation water.

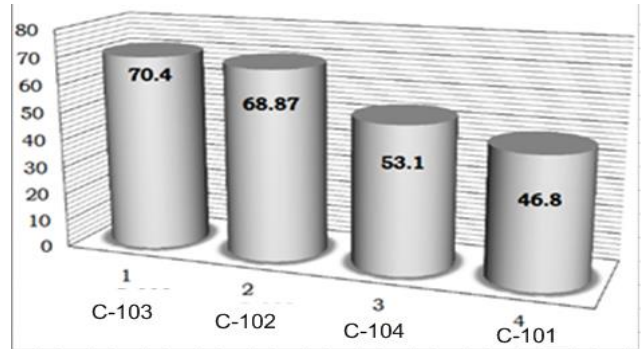


Figure 7. Comparison between Oil Recoveries for Sandstone Cores.

4. Conclusions and Future Recommendation

4.1 Conclusions

- (i) The oil recovery rates are highly related to the applied temperature, meaning that the oil recovery rates are directly proportional to the temperature.
- (ii) Activated carbon with a volume of (0.125 mm) has the highest efficiency as it gave the highest rate of oil recovery compared to volume (0.250 mm). While volume of (0.063 mm) had the lowest oil recovery rate;
- (iii) The overall conclusion is that the reservoir treated water with activated carbon is slightly better compared to the natural reservoir water (untreated reservoir water) in terms of oil recovery.

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