Effect of Sand Grain Size on Spontaneous Imbibition of Surfactant Solution

(Pengaruh Ukuran Butir Pasir Pada Imbibisi Spontan Larutan Surfaktan)

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Abstract
In spontaneous imbibition researches, surfactant has been employed to control interfacial tension (IFT) and wettability. In this paper, the evaluation of grain size effect on spontaneous imbibition of surfactant solution is presented. In this work, the synthetic porous media (sand packs) with uniform and non-uniform grain size from 30 mesh to 100 mesh were made. The porous media were initially saturated by oil. Then they were immersed in brine with salinity of 62 to 40,000 ppm for 24 hours. After that, the porous media were immersed in surfactant solution with concentration of 0.2% for another 24 hours. The total oil recovery during these treatments was measured. The experiment was separated into three parts in order to investigate the effect of uniform grains, non-uniform grains, and salinity in spontaneous imbibition. The results show that grain size and porosity were proportional to oil recovery. In the case of porous media with uniform grain size, the effect of grain size on recovery factor is stronger than that of porosity. Meanwhile the salinity has an the optimum condition for a maximum recovery factor. In this study, it happened at salinity of 20,000 ppm. Oil recovery factors observed in this study ranged from 66.7% to 91.1%.

Keywords: Spontaneous Imbibition; Grain Size; Surfactant; Salinity; Recovery Factor

Sari
Dalam penelitian ini, evaluasi efek ukuran butir pada imbibisi spontan larutan surfaktan disajikan. Pada penelitian ini dibuat media berpori sintetik (sand packs) dengan ukuran butir seragam dan tidak seragam dari 30 mesh sampai 100 mesh. Media berpori awalnya jenuh oleh minyak. Kemudian direndam dalam air garam dengan salinitas 62 sampai 40,000 ppm selama 24 jam. Setelah itu, media berpori direndam dalam larutan surfaktan dengan konsentrasi 0,2% selama 24 jam lagi. Perolehan minyak total selama perlakuan ini diukur. Percobaan dikelompokkan menjadi tiga bagian untuk menyelidiki pengaruh butiran seragam, butiran tidak seragam, dan salinitas dalam imbibisi spontan. Hasil penelitian menunjukkan bahwa ukuran butir dan porositas berbanding lurus dengan perolehan minyak. Dalam hal media berpori dengan ukuran butir seragam, pengaruh ukuran butir pada faktor perolehan lebih kuat daripada porositas. Sedangkan salinitas memiliki kondisi optimum untuk faktor perolehan yang maksimal. Pada penelitian ini terjadi pada salinitas 20,000 ppm. Faktor perolehan minyak yang diamati dalam kajian ini bervariasi dari 66.7% hingga 91.1%.

Kata-kata kunci: Imbibisi Spontan; Ukuran Butir; Surfactan; Salinitas; Faktor Perolehan

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I. INTRODUCTION
Spontaneous imbibition is a process where wetting phase flow into a porous medium to displace non-wetting phase. Imbibition mechanism is controlled by surface energy that results in capillary pressure [1,2]. The imbibition mechanism involves a complex interaction among capillary, gravity and viscous forces. Imbibition due to capillary forces is known as spontaneous capillary imbibition or natural imbibition [3, 4].

Several spontaneous imbibition of surfactant solution tests have been conducted by previous researchers to improve displacement efficiency. Surfactants have two functions to enhance oil recovery: alter wettability and reduce interfacial tension (IFT) [5, 6]. Spontaneous imbibition tests using surfactant have been conducted for conventional oil-wet fractured carbonate rock. [7-9]. Austad et al. (1998) have demonstrated that spontaneous imbibition of water into short, oil/neutral wet, and low-permeable chalk cores (2-3 mD) took place in the presence of a cationic surfactant [10]. While spontaneous imbibition phenomena of surfactant solution in shale were observed by Shuler et al. (2011) and Wang et al. (2011) [11, 12].

The objective of this paper is to analyze the performance of the spontaneous (capillary) imbibition into oil saturated sand pack. The results are evaluated in terms of ultimate oil recovery for
various different sand grain distribution, salinity, and surfactant concentrations.

II. METHOD

The materials used in this research are sand, paraffin oil, anionic surfactant, NaCl powder, and brine. While the equipment used is a sieve shaker, Amott apparatus, measuring cups, and balance.

In making sandpack samples, several materials such as silica sand are needed. Because the grain size of the sand varies, the grain size is separated by using a sieve shaker. The filter sizes used are 30, 40, 50, 60, 70, and 100 mesh. The sand pack container made from a pipe and two lids. Each cylindrical lid perforated with 4 holes. They were purposed for flow in and flow out. The diameter of each hole is 2 mm. A screen was placed on the lid prevent sand flowing out of the sandpack. The length of the sandpack is 9.61 cm and diameter is 2.70 cm.

The procedure of this research is as follows:
1. Measurement of the weight of the empty sandpack.
2. Preparation of unconsolidated silica sand. The sand grains can consist of one or several grain sizes. In this study, each size of sand grain in a mixture has the same fractional weight (% wt). The sand is stirred evenly to form a uniform grain arrangement. The sand mixture was then put into the container, compacted, and closed.
3. Measurement of the weight the sandpack filled with sand.
4. Determination of the weight of sand by comparing steps 3 and 1.
5. Calculation of oil density by measuring volume and mass.
6. Saturation of the sandpack by immersing the sandpack in oil for 24 hours.
7. Measurement of the weight the sandpack containing sand and oil.
8. Determination of the weight of oil by comparing steps 7 and 3.
9. Determination of the initial volume of oil in the sandpack by dividing the steps 8 by 5.
10. Soaking a sandpack containing sand and oil into an Amott cell filled with brine with a salinity of 62, 20,000, or 40,000 ppm for 24 hours.
11. Measuring the volume of oil that comes out of the sandpack.
12. Adding surfactants to brine with a concentration of 0.2%.
13. Soaking a sandpack containing sand and oil into an Amott cell filled with surfactant solution for another 24 hours.
14. Measurement of the volume of oil that comes out of the sandpack.
15. Determination of the total recovery factor after brine imbibition and surfactant solution imbibition.

In this study, pore volume (PV) and porosity calculated using the equations 1 and 2 as follows [13]:

\[
PV = \frac{m_{ss} - m_{ds}}{\rho_f} \quad (1)
\]

and

\[
\phi = \frac{PV}{BV} \quad (2)
\]

where PV is pore volume (ml); \(m_{ss}\) is mass of saturated sand sample (gr); \(m_{ds}\) is mass of dry sand sample (gr); \(\rho_f\) is fluid density (gr/ml); and BV is bulk volume (ml).

Correlation between the radius of pores \((r_c)\) and the effective diameter of grains \((d_g)\) can be estimated as follows [14]:

\[
r_c = \frac{d_g}{3} \sqrt{\frac{\phi^2}{(1 - \phi)^2}} \quad (3)
\]

where \(r_c\) is average diameter of pores (cm) and \(d_g\) is average grain diameter of grains (cm).

III. RESULTS AND DISCUSSION

The study is designed to assess the relationship between the size of unconsolidated sand grains and the oil recovery factor after spontaneous imbibition. The imbibition mechanism is carried out in two stages, namely water imbibition and followed by polymer solution imbibition. The observed recovery factor is based on the volume of oil that comes out of the sandpack after the two imbibition mechanisms.

A. Effect of Uniform Sand Grain Size

In this case the sandpack contains uniformly size of sand grains. The sand grains have only one size from 30-mesh to 100-mesh. The effect of grain size and porosity is shown in Figures 1 and 2, respectively. Figure 1 indicates the relationship between the grain size of the sand (mesh) and the recovery factor. The figure shows that the recovery factor tends to increase as grain size increases. The smaller the grain size tends to cause a larger surface area of the pore walls and a smaller diameter of the pore channel. These properties will affect the imbibition mechanism. The estimated radius of pore is given in Table 1. In this case it can be stated that the recovery factor is not only affected by the porosity, but also by the size of the sand grains. Table 1 shows a variation of grain size of 0.0446 cm and a variation of porosity of 6.3% resulting in a variation of the recovery factor of 24.4%. Figure 2 shows the relationship between porosity and recovery factor. The figure shows that the greater the
porosity does not always cause the recovery factor to increase. In this case, it can be stated that the effect of grain size on the recovery factor is stronger than that of porosity.

Figure 1. Effect of Uniform Grain Size on Recovery Factor

Figure 2. Effect of Porosity on Recovery Factor

Table 1. Experimental Results of Uniform Grain Size

<table>
<thead>
<tr>
<th>Group</th>
<th>Sand pack</th>
<th>Grain Size, Mesh</th>
<th>Porosity, %</th>
<th>Est. Radius of Pores, cm</th>
<th>RF, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>50</td>
<td>48.9</td>
<td>0.0136</td>
<td>91.1</td>
</tr>
<tr>
<td>2</td>
<td>40, 60</td>
<td>50</td>
<td>44.3</td>
<td>0.0075</td>
<td>85.2</td>
</tr>
<tr>
<td>3</td>
<td>40, 50, 60</td>
<td>42.8</td>
<td>0.0062</td>
<td>89.0</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>30, 50, 70</td>
<td>42.6</td>
<td>0.0051</td>
<td>81.2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>30, 40, 50, 60, 70</td>
<td>42.1</td>
<td>0.0047</td>
<td>80.0</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3 shows that the recovery factor tends to decrease as the deviation standard of the sand grain size increases (more heterogeneous sand grains). Figure 4 shows that the recovery factor tends to increase as the porosity increases. There is proportional relationship between heterogeneity of sand grain size and porosity. The more heterogeneous the porous medium, the smaller the porosity, since the smaller sand grains can occupy the pore space between the larger sand grains. In this case a porosity variation of 6.1% results in a variation of the recovery factor of 20.6%.

Table 2. Experimental Results of Uniform Grain Size

<table>
<thead>
<tr>
<th>Group</th>
<th>Sand pack</th>
<th>Grain Size, Mesh</th>
<th>Porosity, %</th>
<th>RF, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>46.0</td>
<td>89.0</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>40, 60</td>
<td>44.3</td>
<td>85.2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>40, 50, 60</td>
<td>42.8</td>
<td>80.7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>30, 50, 70</td>
<td>42.6</td>
<td>81.2</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>30, 40, 50, 60, 70</td>
<td>42.1</td>
<td>0.0047</td>
<td>80.0</td>
</tr>
</tbody>
</table>

B. Effect of Non-Uniform Sand Grain Size

Figures 3 and 4 show the relationship between the grain size of sand (mesh) and porosity on the recovery factor, respectively. In this case, each sample uses one or a combination of grain sizes from 30 mesh to 80 mesh as shown in Table 2. In each sandpack, the weight percentage of each grain size in a sand mixture is the same.

Table 3 shows the effect of salinity and porosity on the recover factor for an average grain size of 50 mesh. The table shows that salinity has an optimum value for the oil recovery factor. The optimum condition in this study is for a salinity of 20,000 ppm which causes an oil recovery factor of 86.1%. Salinity is a factor that can alter wettability [15, 16]. While changes in wettability from oil wet to water wetness.
wet will increase the oil recovery factor.

![Figure 4. Effect of Porosity on Recovery Factor](image)

Table 3. Effect of salinity and porosity on recovery factor

<table>
<thead>
<tr>
<th>Sandpack</th>
<th>Salinity, ppm</th>
<th>Average Porosity, %</th>
<th>RF, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>62</td>
<td>49.6</td>
<td>79.8</td>
</tr>
<tr>
<td>2</td>
<td>20,000</td>
<td>49.6</td>
<td>86.1</td>
</tr>
<tr>
<td>3</td>
<td>40,000</td>
<td>49.2</td>
<td>84.6</td>
</tr>
</tbody>
</table>

IV. CONCLUSIONS

Based on the results of research and analysis, it can be stated that grain size, porosity, and salinity have an effect on oil recovery factor in the spontaneous imbibition process of surfactant solution. In sandpacks with uniform grains, the effect of grain size on recovery factor is stronger than that of porosity. For the case of non-uniform grains, the oil recovery factor is not only affected by the porosity but also by the heterogeneity of the sand grains. A mixture of sand with a more varied grain size tends to result in a lower oil recovery factor. There is an optimum salinity that results in a maximum oil recovery factor. In this study, the maximum oil recovery factor of 86.1% occurs at salinity of 20,000 ppm.

REFERENCES

Distribution of Sands and Sandstones.
Developments in Sedimentology, 1, 71-75.
https://doi.org/10.1016/S0070-4571(08)70469-2


https://doi.org/10.1021/ef201435g