OIL PRODUCTION ENHANCEMENT USING BOTTOM-HOLE WATER SINK: A GUIDELINE FOR OPTIMUM DESIGN APPLICATION

Taufan Marhaendrajana; Institut Teknologi Bandung, and Isop Alliyah; Institut Teknologi Bandung

ABSTRACT
Bottom hole water sink has been reported to be a successful tool to increase oil production by minimizing water coning problem. The idea of this method is to create a pressure-sink in the water-zone to provide a counter force balance opposing the one caused by production through the well perforation in the oil zone. This is done by same well producing the water zone simultaneously with the oil zone. Then, with appropriate design, it is expected the oil-water contact stay stable and the water coning is prevented. Although some applications have been successful, others reported failures when implementing this method. The opposing results may be explained by our conclusion of literature study that there is a missing link between the concept and the application in the field. This work fills the missing link by developing a general guideline for optimum design of bottom-hole water sink. The guideline considers interval perforation and reservoir anisotropy. The important results are (i) optimum oil-water zone production ratio, (ii) generalized inflow performance window (IPW) that provide envelop for water coning, reverse coning and segregated flow, and (iii) critical rate for water coning.

INTRODUCTION
Water coning is a major factor that reduces oil productivity and oil recovery. Some researches conducted study on the critical rates\(^1\) and water breakthrough time\(^6\) as parameter considerations to control water coning. In some cases, producing oil well below the critical rate is not considered economical.

Downhole (or bottom-hole) water sink (DWS) was introduced to control water coning without limiting the oil production rate below its critical rate (Fig. 1). The first attempt to use DWS concept is suggested by Driscoll\(^9\) with perforating the water zone to control water coning in addition to the perforation intervals in the oil zone. This is a modification of the earlier patented method by Widmyer\(^10\) who proposed a well completion principle with separated production of oil and water by perforating both the top and bottom completion in the oil zone.

Theoretical work on DWS was conducted by Wojtanowics et al.\(^11\)-\(^12\) These works studied the mechanism and performance of DWS.

![Figure 1. Schematic of downhole water sink.](image)

To differentiate from the past researches, this paper is intended to provide a unified graphical approach. It can be used by practical engineers as a simple guideline for DWS design. This method incorporates parameters affecting water coning such as permeability anisotropy, and perforation interval.

MODEL DESCRIPTION
Results are generated using numerical reservoir simulator. As this is a single well problem, radial coordinate is best to represent flow direction from reservoir into the well. Smaller grid block size is used near the well since fluid velocity increases near the well. Vertically, the model is divided into small thickness of layer to appropriately capture the water coning.
The indicator used to evaluate the performance of DWS is oil recovery factor at ten years of well life. Although one may have different argument on the time span selection, it is more reasonable than using ultimate recovery factor.

The preliminary analysis indicates that the maximum oil recovery using DWS is achieved if perforated zone water is closed to the water-oil contact and the oil zone is perforated at the top. This is clearly explained as follows; (i) perforating oil zone at the top will delay coning breakthrough, (ii) draining water closer to WOC requires less drawdown to balance water coning induced by the oil zone production.

In the evaluation of DWS performance, we use base case data presented by Inikori (2002) as in Tables 1 and 2. Some well/reservoir and DWS design parameters are varied and the optimum condition is determined for every set of parameter combination. Data range of the parameters mentioned above is listed in Table 3.

Table 1. Rock Properties

<table>
<thead>
<tr>
<th>Rock Characteristics</th>
<th>Oil Zone</th>
<th>Water Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity, %</td>
<td>30</td>
<td>37</td>
</tr>
<tr>
<td>Vertical permeability, md</td>
<td>500</td>
<td>500</td>
</tr>
<tr>
<td>Horizontal permeability, md</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>Compressibility, psi-1</td>
<td>4x10^-6</td>
<td>4x10^-6</td>
</tr>
</tbody>
</table>

Table 2. Fluid Properties

<table>
<thead>
<tr>
<th>Oil</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubble point pressure, psia</td>
<td>1000</td>
</tr>
<tr>
<td>Compressibility, psi-1</td>
<td>1.5x10^-5</td>
</tr>
<tr>
<td>Density, lbm/cuft</td>
<td>53.9</td>
</tr>
<tr>
<td>FVF, rb/stb</td>
<td>1.26</td>
</tr>
<tr>
<td>Viscosity, cp</td>
<td>1.25</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Formation Water</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressibility, psi-1</td>
<td>3x10^-5</td>
</tr>
<tr>
<td>Density, lbm/cuft</td>
<td>62.47</td>
</tr>
<tr>
<td>FVF, rb/stb</td>
<td>1.02</td>
</tr>
<tr>
<td>Viscosity, cp</td>
<td>0.46</td>
</tr>
</tbody>
</table>

Table 3. Data Range Used in Simulation Model

<table>
<thead>
<tr>
<th>Variables</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical anisotropy (k_v/k_h), md</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Liquid production in the oil zone, stb/d</td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td>Liquid production in the water zone, stb/d</td>
<td>0</td>
<td>10000</td>
</tr>
<tr>
<td>Standoff (from top)</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>Perforation interval (h_o/h_w)</td>
<td>0.2</td>
<td>0.75</td>
</tr>
</tbody>
</table>

This paper does not vary water-oil mobility ratio, although this variable affect water coning. It is our first attempt to find whether the graphical approach is possible for DWS design (however, as continuation of this study, we are currently investigating the effect of water-oil mobility).

RESULTS AND DISCUSSION

The performance of DWS compared to conventional well is depicted by Fig. 2. Addition DWS (if designed appropriately) in water zone increases oil recovery up to about 50% (equivalent to incremental recovery of 43%). For this case, the oil zone production is 100 stb/d and the water zone production is 22000 stb/d.

Producing liquid of 22000 stb/d may be impossible from a single well. If we use practical range, the reasonable value is up to 5000 stb/d production from water zone. This constraint still gives us oil recovery factor of 30% (incremental recovery of 23%).

It is noted from Fig. 2 that for a particular oil zone production rate, there is an optimum liquid production from water zone for a DWS completion. Oil recovery factor generally increases as the water zone production increases. This is because DWS prevent water coning, and at some point oil coning occurs in the water zone perforation. The recovery factor shown in Fig. 2 is total oil recovery from both top (oil zone) and bottom (water zone) completions.

The total recovery decreases as the water zone production increases, after it has reached a maximum recovery. During this region, the oil coning extremely dominates as the reversal of water coning.

For a given reservoir and fluid characteristics, the optimum DWS condition is determined from simulation. In case of penetration ratio (interval perforation) of 0.2, it is plotted in Fig. 3 for various vertical anisotropy k_v/k_h. Linear relationship between ratio of oil-water zone production and oil zone production is observed for k_v/k_h from 0.1 to 1.
Fig. 3 shows different linear relationship for different value of $k_v/k_h$. Different $h_p/h_o$ also gives other linear trends. It can be generalized using correlation in Eq. 1 to 3. This correlation is validated by the simulation output, and it is reasonably accurate (Fig. 4).

\[
R_	ext{opt} = A q_{\text{top}} + B \tag{1}
\]

Where

\[
A = 2.2511 \times 10^{-3} \left( \frac{k_v}{k_h} \right)^{-0.0568} \left( \frac{h_p}{h_o} \right)^{-0.0319} \tag{2}
\]

\[
B = 0.0048 \left( \frac{k_v}{k_h} \right)^{-0.1409} \left( \frac{h_p}{h_o} \right)^{0.3014} \tag{3}
\]

Optimum condition such as presented by Eq. 1 to 3 does not differentiate between stable (segregated) or reverse coning flow. In some cases, the production from bottom completion is re-injected into the reservoir. For this scenario, one prevents producing oil from bottom completion. In other words, segregated flow should prevail and reverse coning flow is avoided.

Inikori et al.\textsuperscript{13,14} uses Inflow Performance Window (IPW) plot to identify flow regime during DWS operation (Fig. 5). IPW correlate water zone production ($q_{\text{bottom}}$) and oil zone production ($q_{\text{top}}$) in term of Water Breakthrough Line (WBL) and Oil Breakthrough Line (OBL). Region below WBL indicates water coning and above OBL indicates reverse coning. Between the two lines, lower portion is a region where segregated flow prevails; the upper portion is unstable contact—water coning and reverse coning may occur alternately.

The IPW show in Fig. 6 is obtained from various values of vertical permeability anisotropy, penetration ratio, perforation standoff, and liquid rate of top and bottom completions. With this figure one can easily uses those data information to get desired DWS production mode (i.e., reverse coning...
or segregated flow). The definition of $Q_{top}^*$ and $Q_{bottom}^*$ used in this plot is as follows.

$$Q_{top}^* = Q_{top} + (10^{a_1}) \left( \frac{k_v}{k_h} \right)^{a_2} \left( \frac{h_p}{h_o} \right)^{a_3}$$  \hspace{1cm} (4)$$

$$Q_{bottom}^* = Q_{bottom} + (10^{b_1}) \left( \frac{k_v}{k_h} \right)^{b_2} \left( \frac{h_p}{h_o} \right)^{b_3}$$  \hspace{1cm} (5)$$

Where: $a_1=2.401433$, $a_2=0.518346$, $a_3=1.283428$; and $b_1=3.227316$, $b_2=0.842945$, $b_3=1.567493$).

Further, combination of optimum DWS condition (Eq. 1) and IPW plot yields a DWS Guideline Plot (DGP) which is shown in Fig. 7. This plot uses semilog axes. The optimum line is generated for $kv/kh = 0.5$ and $hp/ho = 0.2$. Maximum recovery for DWS is achieved generally in reverse coning mode. This chart can be interpreted as above optimum line DWS is over-designed and below water-breakthrough line DWS is under-designed. The white-color region is the envelope for desired DWS condition (DWS Envelope).

**CONCLUSIONS**

From this study we observe that:

1. The maximum total oil recovery for DWS well is generally obtained under reverse coning mode.
2. Correlation relating the reservoir/well properties with optimum DWS design is proposed. The optimum condition is based on total oil recovery (top and bottom completions).
3. DWS Guideline Plot (DGP) is proposed as a tool to evaluate and design DWS completion.
4. For generalizing the applicability of DGP, inclusion of water-oil mobility ratio should be studied further.

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**REFERENCES**

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