Systematic Software Supported Approach to Diagnose Oilfield Excessive Water Production Problems

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Abstract: Water is an inevitable by-product of oil production. Produced water has become one of the major environmental concerns in the oil industry. The first step in solving this problem is to correctly diagnose the source of the water before applying a successful treatment. Because of the lack of proper diagnostic approaches, the water treatment techniques have witnessed many failures in their application. This paper introduces a new systematic software program for decision making when diagnosing the water production problems and their sources through a logical algorithm. The software program was named MYA program after the initials of the three engineers who constructed the methodology, Motaz, Yassin and Ali. Case studies were taken from a Sudanese oil field and were diagnosed using this software. It was concluded that applying the algorithm improve the understanding and determining of the water production mechanisms. The program succeeded in giving a proper diagnosis to each type of water production mechanisms in short time without using of any Production logging data. Adoption of this software would result in obtaining a proper diagnosis and consequently an appropriate treatment would be applied leading to a significant increase in hydrocarbon recovery and reducing the risk and cost of environmental hazards of produced water.

Keywords: petroleum engineering; water production; environmental issues; improved oil recovery

1. INTRODUCTION

Water is an inevitable by-product of oil production. Water is one of the natural sources of reservoir energy driving the hydrocarbon to flow into the wellbore. In a water drive reservoir, the water in an adjacent aquifer moves into the reservoir, and sweeps the oil towards the wellbore. When the water drive is not strong, additional water is injected into the reservoir to maintain reservoir pressure and aid the movement of oil. As the oilfield matures, this sweep water is produced into the wellbore comiled with oil. Production of this water cannot be stopped without affecting the oil rate. Providing that the water production rate is below the Water Oil Ratio (WOR) economic level, no water shutoff treatment is needed. Problems arise when water breaks into the wellbore prematurely or when water production rate exceeds the WOR economic level, producing no or little oil with it. This type of water is usually referred to as ‘bad’ water or produced water [1]. Producing high amounts of such bad water will be firstly sensed with costs of handling this produced water. The cost of handling and disposing this unwanted water could have a negative impact on the economic life of the oil well. It is estimated that in 2011 oil companies spent costs of US$ 50 billion worldwide on handling produced water. In addition to the direct cost of handling the produced water, it also has negative impacts on the overall productivity rates. Excessive water production reduces the net oil production rate, increases corrosion rates in the production system and may eventually lead to early abandonment of the affected wells. The environmental issues in connection with water production are major concern for oil companies. They have to comply with strict environmental regulations and standards regarding water treatment and disposal facilities, which consequently increase production and handling costs. In order to be able to employ an effective water shutoff treatment, it is imperative to identify the source of excess water production first.

Water is one of the drive mechanisms inside a reservoir that will displace the oil towards the wellbore. Because of many reasons this water may be produced with oil and in many cases the water production rates exceed economical limit. This produced water causes many problems such as high handling and disposing costs in addition to expected
1.1 Mechanisms of Associated Water Production

In the reservoir water displaces oil. The ideal displacement is when water acts in a piston-like displacement to move the oil. If properties of oil will not favour this displacement then water will most likely bypass the oil and polluted water is produced as associated water. The problems that need water control can be categorized into two major categories: near well bore problems and in depth reservoir related problems. Those are depicted in waterconing, water channelling with and without crossflow, tubing and packer leaks, channels behind casing, fractures connecting to an aquifer or injector, poor areal and poor vertical sweep efficiencies. Knowing the source of the problem is very essential for any treatment. Each problem type requires a different approach to control and treat the problem effectively. In reality, an oil well can experience a combination of different problem types. However, reservoir related problems of coning and channelling through high permeability layers are more challenging to diagnose and treat [2].

Some of the conventional ways for identifying the water sources are Recovery Plot which is a semi log plot of WOR against cumulative oil production that helps to decide if the Water Shut Off techniques are needed or not. Another popular diagnosis method is Water Oil Ratio diagnostic plot which is log-log plot of water oil ratio versus time; it is an important method that was developed by [3] to diagnose four different water production mechanisms. Other methods are available to diagnose the different water production mechanisms that cause the water to be produced to the surface.

The importance of a diagnostic approach has been highlighted by many researchers[2] in many technical papers. However, there has not been much work done on this area of research. [4] discussed the basics of creating an algorithm to diagnose water production problems. His work included a simplified flowchart of how the diagnosis shall be carried, but was too generalized to be reliant on. [5] presented an approach to diagnosis and treatment, their work was very clear and helpful especially in the area of identifying the water source in the case being studied. Nevertheless, their work was too dependent on tests that should be carried out in order to determine the water source inside a well or reservoir. These tests, such as Production logging tool (PLT) are very costly to the operator company. In our work we overcome the problem of generalization and also the problem of needing empirical tests to be carried out.

2. METHODOLOGY

The objective of the paper is to reduce the water shutdown treatment failures by providing a methodology for proper diagnosis and building an algorithm and a software program that objectively determine the water production problem. The methodology is summarized in Figure 1.

In order to accomplish these objectives, first, we construct a systematic approach based on some selected diagnosis methods and link them in a logical order. First of all, we selected the most effective, both technically and economically, diagnosis methods. Which when put in a logical order will be enough to diagnose each of the water production mechanisms (WPMs). The diagnosis methods were selected based on the following criteria: theoretical methods rather than empirical tests with wide range of application and validity. And when put together in a logical order will be enough to diagnose each of the different WPMs.

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![Methodology Flowchart](chart.png)

Fig. 1: Methodology of the work
The Algorithm

Flow chart below shows the algorithm that was utilized in this study (Figure 2).

![Algorithm Flowchart](image)

**Fig. 2: Water Problems Diagnostic Algorithm**

The steps followed are prescribed below:

1. The first step of the algorithm is plotting the recovery plot [1] which is a semi log plot of water oil ratio (WOR) versus cumulative oil production (Np). If the recovery plots a normal depletion through the years such as expected, then no water shut off technique is required. If it shows the opposite then we proceed to the next step. Normal depletion means that the expected value of cumulative oil production at the economical water cut is equal to the value of that estimated from other prediction methods such as; reservoir simulation and decline curve analysis.

2. Second step is detecting the fractures presence using darcy equation [6] If the equation indicates linear flow around the wellbore then a fracture is present we then proceed to Step 3. If not we then jump to Step 4.

3. After confirming the presence of a fracture it is important to determine whether this fracture is conducting to an aquifer or an injection well. This will require an examination of the water flooding projects around performance data. If areal sweep efficiency (area of reservoir swept by the injected water to the total area) or vertical sweep efficiency (vertical portion of the reservoir swept by injected water to the total vertical interval) are inadequate then this shows a problem with water flood performance then this probably means that the detected fracture is conducting to an injection well. If not, then this suggests that the fracture is conducting to an aquifer.

4. If Step 2 shows there are no fractures present, then we directly examine the water flood performance...
data. If the value of areal sweep efficiency is less than 70%, that means the water bypassed oil in reservoir which is known as poor areal sweep efficiency. Likewise, if the vertical sweep efficiency is less than 70%, that means there are some layers that has not been swept. This WPM is called gravity segregated layer. If the water flood data shows no problem with water flood performance then proceed to the next step.

5. This step includes the use of water oil ratio (WOR) diagnostic Plots [3] to identify the WPMs. It is log-log plot of water oil ratio (barrels of water produced to barrels of oil produced) versus time. The WPM identified by these plots can be Water Coning, Water Channeling, Mechanical Failures and Water Coning with later Channeling. In the case of Water Channeling a further attention should be given to identify the presence of crossflow between layers, this can be achieved by using one of production logging tool (PLT) tools. In the case of mechanical failures mechanical integrity test (MIT) should be used to differentiate between Leakage in a packer, tubing or casing and Channels behind the casing.

6. The final step of the algorithm is an adequate treatment design for each of the WPMs.

7. The algorithm is logically ordered to diagnose each of the WPMs with simply using a few number of diagnosis methods.

8. Based on the above discussion the next step is to build a software program to help implement this algorithm easily and effectively. The software program was built using Visual Studio and SQL server implementing the programming Language C sharp, these two applications are mature and easy to use for the programmer or developer and helped to translate the algorithm into a program easily. The program consists of different fields that should be filled with well data including Reservoir data, Well Completion data, PVT data, water flooding data and Production Data. The program then performs the calculations and comparisons to determine the source of the water production. And the results will be shown along with the result indicators and the proposed treatment mechanism. Figure 2 show parts of the built program.

Table 1 presents the selected diagnosis methods used for the purpose of this work along with the water production mechanisms that they diagnose.

### Table 1: Selected diagnoses methods and the water production mechanisms they diagnose.

<table>
<thead>
<tr>
<th>No.</th>
<th>Diagnosis Method</th>
<th>Water Production Mechanisms</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Recovery plot</td>
<td>• Historical and future production trends for problem or no problem with water production.</td>
</tr>
<tr>
<td>2</td>
<td>Wor diagnostic plots</td>
<td>• Water coning. • Water channeling. • Mechanical failures. • Water coning with later channeling.</td>
</tr>
<tr>
<td>3</td>
<td>Darcy matrix equations</td>
<td>• Fracture from an aquifer. • Fracture from an injector.</td>
</tr>
<tr>
<td>4</td>
<td>Water flooding data</td>
<td>• Poor areal sweep efficiency • Gravity segregated layers</td>
</tr>
<tr>
<td>5</td>
<td>Mechanical integrity test</td>
<td>• Leakage in a packer, tubing or casing. • Channels behind the casing.</td>
</tr>
<tr>
<td>6</td>
<td>Critical coning rate</td>
<td>• Water coning</td>
</tr>
</tbody>
</table>
3. RESULTS

The data of five wells from a Sudanese oilfield, which are suffering from excessive water production, were obtained. The wells are denoted X1, X2, X3, X4, and X5. In the following section the technical and the economical results of studying those cases will be presented using the built program.

The software program was used to diagnose the excessive water production mechanisms for the five wells. The production data, PVT data, reservoir data, completion data and water flooding data of the five wells were entered in the program. After data entry appears recovery plot as the first step of the algorithm, the five wells showed insufficient amount of oil recovery when the production was extrapolated to the economical water production limit, which as expected indicated to excessive water production problems in the five wells. After that the program performed the calculations for the rest of data and by following the steps of the proposed algorithm, the results of the program for the source of water in the five wells were obtained.

The results of the program are presented in Table 2, showing the WPM along with the accuracy of the result and the indicators of the WPM, which are the factors and symptoms associated with each problem.

The water handling costs of the five wells every day are averaged as 15392.75 US$. These handling costs comprise the following processes costs: lifting costs, separation costs, de-oiling costs, filtering costs, pumping costs and injection costs. Table 3 shows the details of these calculations.

Thus the total water handling costs (Table 3) for the five wells is 15392.75 US$, which is quite high for being a daily cost. Annually this cost aggregates to be 5,618,080 US$. Not only that but this only represents a small portion, only five wells of the large oilfield Y which is known for excessive water production problems.

<table>
<thead>
<tr>
<th>WELL NAME</th>
<th>Detected WPM</th>
<th>Result Indicators</th>
</tr>
</thead>
</table>
| X1        | Fractured out aquifer | • Fracture presence near wellbore.  
• WOR tends increases rapidly with time. |
| X2        | Water Coning  | • Bottom water drive  
• WOR tends increases gradually with time.  
• Oil Production rate has exceeded critical coning rate. |
| X3        | Water Coning  | • Bottom water drive  
• WOR tends increases gradually with time.  
• Oil Production rate has exceeded critical coning rate. |

Table 2: Water diagnosis results for five wells experiment obtained from the software.
X4 Water Channeling  
- WOR tends increases rapidly with time.  
- High permeability Contrast between layers.  

X5 Water Coning  
- Bottom water drive  
- WOR tends increases gradually with time.  
- Oil Production rate has exceeded critical coning rate.

Table 3: The estimated water-handling costs for the present case studies.

<table>
<thead>
<tr>
<th>Process</th>
<th>AVERAGE COST PER BARREL</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capital Cost($)</td>
<td>Utilities($)</td>
<td>Chemical($)</td>
<td>Total Cost($)</td>
</tr>
<tr>
<td>LIFTING</td>
<td>1177.88</td>
<td>1445.58</td>
<td>N/A</td>
<td>2623.46</td>
</tr>
<tr>
<td>SEPARATION</td>
<td>1311.73</td>
<td>80.31</td>
<td>803.1</td>
<td>2195.14</td>
</tr>
<tr>
<td>DE-OILING</td>
<td>2168.37</td>
<td>N/A</td>
<td>1097.57</td>
<td>3265.94</td>
</tr>
<tr>
<td>FILTERING</td>
<td>1954.21</td>
<td>294.47</td>
<td>N/A</td>
<td>2248.68</td>
</tr>
<tr>
<td>PUMPING</td>
<td>3346.25</td>
<td>910.18</td>
<td>N/A</td>
<td>4256.43</td>
</tr>
<tr>
<td>INJECTING</td>
<td>803.1</td>
<td>N/A</td>
<td>N/A</td>
<td>803.1</td>
</tr>
<tr>
<td>AVERAGE</td>
<td>10761.54</td>
<td>2730.54</td>
<td>1900.67</td>
<td>$15392.75</td>
</tr>
</tbody>
</table>

REFERENCES


4. CONCLUSIONS

1. The results of applying the algorithm improve the understanding and determining of the different Water Production Mechanisms.  
2. Software program succeeded to give a diagnosis to each type of WPMs in short time without using of any Production logging tool.  
3. Economical evaluation of the wells is provided in the paper.