Effect of Mixing Efficiency in Dilution Water Consumption in a Crude Oil Desalting Plant

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Abstract. Oil produced in most of wells contains water and dissolved salts; mainly NaCl, CaCl\textsubscript{2} and MgCl\textsubscript{2}, which can cause several problems in the refining process. At first, dilution water mixes with the formation water. Then, water removes from crude oil. The dilution water injection rate is usually between 3 to 7 percent of the inlet oil flow rate. The pressure drop across mixing valve provides the energy to shear the dilution water droplets. In this research, a two stages desalting plant modelled by using a code and Hysys software. This paper investigates the effect of increasing mixing efficiency of first and second stage, desalting efficiency and dehydration efficiency in a crude oil desalting plant in south west of Iran- Ahwaz. Maximum allowable water content in the outlet crude oil for satisfying purchase conditions has been limited to 0.1% volume and salt content to 10 pounds in thousand barrels. Results showed, by increasing mixing efficiency of first stage by 5% (from 80% to 100%), dilution water decreased 10.5 barrel per day. whereas, increasing mixing efficiency of second stage in a similar way decreased dilution water consumption 88 barrels per day.

Keywords: crude oil desalting, two stage desalting, mixing efficiency, static mixer.

1. Introduction

Oil produced in most of wells contains water and dissolved salts; mainly NaCl, CaCl\textsubscript{2} and MgCl\textsubscript{2}, which can cause several problems in the refining processes. In a desalting process, dilution water mixes with the formation water. Then, water removes from crude oil. Settling, chemical, heat, mechanical, electrical coalescences used for crude oil desalting\cite{1, 2}. In chemical coalescence demulsifier agent added to the crude oil \cite{3}. The dilution water must be injected with the same droplet size as the formation water \cite{4}. The dilution water injection rate is usually between 3 to 7 % of the inlet oil flow rate \cite{5}. Maximum allowable water content to satisfy purchase conditions has been limited to 0.1% volume and salt content to 10 pound per thousand barrels. The most common method of mixing is to inject the dilution water into the crude oil and then flow the oil stream through a mixing valve. The pressure drop across the valve supplies the energy to shear the dilution water droplets \cite{4}. Disposal water flow rate, water content in outlet oil, salinity of inlet oil, and dilution water, mixing efficiency and maximum allowable salt content in the outlet oil are major parameters in a crude oil desalting. 

Forero\textit{et al.} investigated implementation of static mixers, which make reduction in maintenance costs \cite{6}. They measured pressure drop, desalting, and dehydration efficiency of Cartagena and Barrancabermeja refinery in Ecopetrol and showed that water content in the outlet crude oil reduced \cite{7}. Static mixers have better particle size distribution rather than other mixing devices \cite{8}. Mahdi \textit{et al.} assessed the effects of mixing time, settling time, dilution water ratio, temperature and demulsifier on dehydration and desalting process \cite{9}. Saudi Aramcoused static mixer in a crude oil desalting plant and had 40 % reduction in amount of dilution water \cite{10}. In this research, a two stage desalting plant was modelled and effect of increasing mixing efficiency of first and second stage were investigated by using a code and Hysys software.

2. Theory

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As solving the material balance for a two stage system with recycle is so difficult, the best method for determining the dilution water rate is trial and error [4]. Fig. 1 revealed a schematic of a two-stage desalting system with a recycle. The code (Fortran language) helps to calculate the required dilution water flow rate to meet the specified outlet salt content of the oil. According to the assumptions of this research, oil flow rate, inlet water cut, specific gravity of the inlet water, salinity of the inlet water, and dilution water, allowable salt content in the outlet crude oil, water cut at each desalting stage, mixing efficiency at each desalting stage should be known. The inlet and outlet water flow rate could be obtained from equation (1 & 2).

\[
A = \frac{Q_0X_a}{1 - X_a} \\
C = \frac{Q_0X_c}{1 - X_c}
\]

(1)

From the specified outlet oil salt content, outlet salinity could be obtained as below:

\[
K_c = \frac{Z(1 - X_c)}{1000X_c}
\]

(3)

In equation (4), the water cut at outlet of first stage, determines the water flow rates at outlet of first stage.

\[
B = \frac{Q_0X_b}{1 - X_b}
\]

(4)

Assuming a salinity for \(K_b\) and \(K_c\), the required dilution water rate could be obtained from equation (5). Mixing efficiency \((E_2)\) defines as the fraction of the dilution water that mixed with crude oil.

\[
Y = \frac{B(K_y - K_b)}{E_2(K_y - K_s)}
\]

(5)

The water material balances around second stage desalter and second stage mixer gives recycle flow rate:

\[
V_2 = B + Y - C
\]

(6)

The salt material balances around second stage desalter and second stage mixer gives recycle water salinity:

\[
V_2K_2 = BK_b + YK_y - CK_c
\]

(7)

\[
R = A + E_1V_2
\]

(8)

\[
S = B + E_2Y
\]

(9)

Salt material balance around first stage mixer gives \(K_b\). Salt material balance around second stage gives \(K_c\). Substituting \(K_b\) and \(K_c\) in equation (7) gives:

\[
V_2K_2 = \frac{BAK_a(S - C) + RYK_y(S - E_2C)}{SR + BE_1(S - C)}
\]

(10)

By rearranging equation (7), \(K_b\) obtained. If the calculated \(K_b\) from Equation (7) does not equal the assumed \(K_b\), the next \(K_b\) should be determined, and should be returned to equation (5). Desalting/dehydration efficiencies can be calculated from equation (11) and (12) by using desalting plant data [10].

\[
\eta_{SRE} = 1 - \frac{Z_{OUT}}{Z_{IN}}
\]

(11)

\[
\eta_{WRE} = 1 - \frac{X_{OUT}}{X_{IN}}
\]

(12)

**3. Results and discussion**

Table 1 shows operating condition for a crude oil desalting plant in south west of Iran. At first, code validated by design value of the plant. Table 2 shows desalting efficiency and dehydration efficiency. In table 3, code results compared with Hysys software and design value. Hysys enables to model mixing
efficiency, which usually assumes 80%. By increasing mixing efficiency of first stage by 5% (80% to 100%), dilution water decreased 10.5 BPD (fig. 2). Inlet water flow to second stage (74.108 BPD) and first stage (74.107 BPD) increased (fig. 2 & 3). Salinity of first stage desalter reduces 0.327 lb/bbl (fig. 4), whereas salinity of recycle water remains constant (fig. 5). By increasing mixing efficiency of second stage in a similar way, dilution water (88 BPD) and inlet water to first and stage (70.78 BPD) decreased (fig. 6, 7). Salinity of both first stage desalter (0.349 lb/bbl) and recycle water (0.106 lb/bbl) increased (fig. 8 & 9). Dilution water rate has slope -2.217 for mixing efficiency of first stage, while the slope of mixing efficiency of second stage is reported -17.6. Finally, it can be inferred that increasing mixing efficiency of first and second stage did not have efficient alteration on salinity of first stage desalter and recycle water.

### Table 1: Operating condition for a crude oil desalting plant

<table>
<thead>
<tr>
<th>Inlet value</th>
<th>Dilution water</th>
<th>outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>quantity</td>
<td>symbol</td>
<td>value</td>
</tr>
<tr>
<td>Pressure</td>
<td>-</td>
<td>150</td>
</tr>
<tr>
<td>Winter</td>
<td>-</td>
<td>60</td>
</tr>
<tr>
<td>Crude oil flow rate</td>
<td>Q</td>
<td>55000</td>
</tr>
<tr>
<td>Inlet water flow rate to second</td>
<td>X</td>
<td>10</td>
</tr>
<tr>
<td>stage</td>
<td>Salinity of first stage outlet</td>
<td>K₁</td>
</tr>
<tr>
<td>API degree</td>
<td>-</td>
<td>33.04</td>
</tr>
<tr>
<td>Specific</td>
<td>SWG</td>
<td>0.86</td>
</tr>
</tbody>
</table>

### Table 2: Desalting efficiency and dehydration efficiency

<table>
<thead>
<tr>
<th>XIN</th>
<th>XOUT</th>
<th>ηRE</th>
<th>ZIN</th>
<th>ZOUT</th>
<th>ηRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>0.1%</td>
<td>99%</td>
<td>8683 ppm</td>
<td>21 ppm</td>
<td>99.75%</td>
</tr>
</tbody>
</table>

### Table 3: Crude oil desalting plant result

<table>
<thead>
<tr>
<th>symbol</th>
<th>Hysys result</th>
<th>Design value</th>
<th>Model result</th>
<th>Error.%</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>inlet water flow rate in oil</td>
<td>A</td>
<td>6000</td>
<td>6111</td>
<td>6111.111</td>
<td>0.001 BPD</td>
</tr>
<tr>
<td>first stage water-outlet flow rate in oil</td>
<td>B</td>
<td>55</td>
<td>55</td>
<td>55.055</td>
<td>0.1 BPD</td>
</tr>
<tr>
<td>flow rate of residual water in the outlet oil</td>
<td>C</td>
<td>55</td>
<td>55</td>
<td>55.055</td>
<td>0.1 BPD</td>
</tr>
<tr>
<td>inlet water flow rate to first stage desalter</td>
<td>R</td>
<td>7742</td>
<td>7761</td>
<td>7699</td>
<td>0.79 BPD</td>
</tr>
<tr>
<td>inlet water flow rate to second stage</td>
<td>S</td>
<td>1700</td>
<td>1705</td>
<td>1643</td>
<td>3.63 BPD</td>
</tr>
<tr>
<td>dilution water flow rate</td>
<td>Y</td>
<td>1645</td>
<td>1650</td>
<td>1643</td>
<td>0.4 BPD</td>
</tr>
<tr>
<td>flow rate of water disposal water</td>
<td>V₁</td>
<td>1645</td>
<td>1650</td>
<td>1643</td>
<td>0.4 BPD</td>
</tr>
<tr>
<td>salinity of first stage outlet water in oil</td>
<td>K₁</td>
<td>-</td>
<td>71.11</td>
<td>67.42</td>
<td>5.18 ppm</td>
</tr>
<tr>
<td>salinity of second stage recycled water</td>
<td>K₂</td>
<td>-</td>
<td>2.56</td>
<td>2.53</td>
<td>1.17 ppm</td>
</tr>
</tbody>
</table>

Fig. 1: Two stage desalting system
4. Conclusion

At this study a two stage desalting plant modelled. Comparison between increasing mixing efficiency of first stage and second stage showed increasing mixing efficiency of second stage has more effect on reducing dilution water consumption. It can be concluded that increasing mixing efficiency of first stage causes rising in amount of water that enter first and second stage desalter, while increasing mixing efficiency of second stage has a reverse effect. On the other hand, there is trivial differences between salinity of first stage outlet water in the oil and salinity of second stage recycled water stream. As increasing mixing efficiency of second stage is more effective, it is recommended to install static mixer before second stage desalter.

5. Acknowledgements

The authors thank National Iranian oil company (NIOC) and National Iranian South oil company (NISOC) for providing invaluable advice and assistance on fulfilling the work and their financial supports.

6. Nomenclature
7. References