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CALCULATION OF GEOTHERMAL WATER SALINITY FROM WELL LOGS - A STATISTICAL APPROACH

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ABSTRACT

This paper presents a simple, statistical technique of estimating average geothermal water salinity from any section of a well. The method is based on crossplotting resistivity data from shallow and induction well logs, the slope of the crossplot being proportional to the formation water salinity. Examples are given from several sections of the well RRGE 91 at the Raft River geothermal field. The salinities estimated for these zones agree well with the salinity measured from the produced water.

INTRODUCTION

The salinity of a geothermal water is an important parameter, for it influences the acceptability of the water from the point of view of environmental impact, usage, and operational problems (such as scaling and solid waste disposal). The salinity is usually measured from the produced geothermal water. However it can be estimated from well logs. The advantage of estimating water salinity from well logs is the ability of this approach to do so at any and all depths logged in a well. Thus a complete salinity profile for the well can be generated. Such a profile is preferable to a single value measured from the produced water, which itself is a mixture of waters from all depths communicating with the open part of the well. Salinity profile also is a characteristic useful to the reservoir engineers in deciphering the reservoir geometry and mechanics, to the geologist in correlation and developing conceptual models, and to the environmental scientist in monitoring changes in subsurface water quality.

There are several ways of estimating salinity profiles from well logs, all of which require careful processing of digitized well logs on a computer. Otherwise the estimated profile can be grossly in error. However, time and budget may not always justify elaborate computer processing. This paper presents a fast and simple approach to obtaining a discretized salinity profile, where the average salinity for a number of discrete zones is estimated. This approach is adequate and often more reliable than others if all one merely wants is the average salinity over a few discrete zones in the well.

PROCEDURE

It is well known in the logging literature1 that

\[ F = \frac{R_o}{R_w} = \frac{\omega}{R_{mf}} \]  

where \( F \) is formation resistivity factor, 
\( R_o \) = true resistivity of the uninvaded zone, 
\( R_w \) = formation water resistivity, and 
\( R_{mf} \) = resistivity of the mud filtrate.

By applying required corrections to the resistivity from a deep-investigation induction log \( R_{ID} \) one can estimate \( R_o \). Similarly, by correcting the resistivity value from a shallow-investigation electrical log \( R_{IS} \) one can obtain \( R_w \). The value of the mud filtrate resistivity at the wellhead condition is usually provided with the log. By correcting this value for the reservoir temperature one can estimate \( R_{mf} \). Thus \( R \) can be calculated from (1). A complete salinity profile can be generated by repeating these calculations for each depth.

When the average salinity value for a section of a well is all that is required, the calculation effort can be sharply reduced. This paper presents such an approach by introducing approximations \( R_{ID} = R_w \) and \( R_{IS} = R_{mf} \), which usually introduce less error in a statistical approach such as the one proposed here than in the single-point calculation approach. Under this assumption (1) becomes

\[ R_{ID} = \frac{R_w}{R_{mf}} R_{IS} \]  

If we replace \( R_w \) and \( R_{mf} \) in (2) by average values over a given well section, then

\[ R_{ID} = \frac{\bar{R}_w}{R_{mf}} R_{IS} \]  

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where $\bar{R}_w$ is the average $R_w$ and $\bar{R}_{mf}$ is the average $R_{mf}$.

Equation (3) indicates that a plot of $R_w$ vs. $R_{IS}$ should have a linear trend with a slope of $(R_w - R_{mf})$. Thus by plotting $R_w$ and $R_{IS}$ directly from a log or data tape one can obtain a linear trend. By fitting a straight line to this trend one can estimate $(R_w - R_{mf})$. $R_{mf}$ can be estimated by correcting the mud filtrate resistivity at surface conditions to the average temperature ($T$) of the well section under study:

$$\bar{R}_{mf} = \bar{R}_{mf} \text{ at Surface Conditions} \left( \frac{T + 6.77}{T} \right)$$

where $T$ is the surface temperature then $\bar{R}_w$ can be calculated from:

$$\bar{R}_w = \bar{R}_{mf} \cdot (\text{slope of } R_{ID} \text{ vs. } R_{IS} \text{ Plot})$$

If the plot does not show a linear trend, the resistivity data may need correction or the water salinity or temperature or both may be too variable over the section to make it useful to calculate an average $R_w$. In such cases either data correction or division of the section in subsections may resolve the problem. This approach is independent of lithology as long as there is no conductive component in the rock matrix, such as high concentration of pyrite or shale. Once $\bar{R}_w$ at $T$ is known, the salinity in NaCl equivalent can be easily estimated from standard charts.

**RESULTS**

Figures 1 through 7 show plots of deep induction resistivity ($R_w$) vs. Laterolog $\delta$ (a Schlumberger Trademark) resistivity ($R_{IS}$) from seven different sections of the well RRGE #1 in Raft River geothermal field. Table 1 shows the calculation procedures to obtain water salinity from the plot of each zone. In spite of scatter all plots exhibit linear trend. Figure 3 shows two possible linear trends perhaps indicating two different salinity or temperature (or both) levels within that section. The two trends can be separated by appropriately dividing the section into two subsections and reploting.

The produced water from the RRGE #1 well is reported to have a salinity of about 1700 parts per million (ppm). The openhole section of the well is 3,624 to 4,989 ft, of which all depths do not contribute equally to the total well flow. Thus it is natural that the observed salinity of 1700 ppm lies between the values of 1600 and 2100 ppm of zone 6 (3340-4300) and zone 7 (4300-4590), respectively. The range of calculated salinities in Table 1, namely 1600 to 2400 ppm, agrees well with the production experience in the part of the Raft River field where RRGE #1 is located.

**ACKNOWLEDGEMENT**

This work was a part of the engineer's degree thesis of Mr. J. M. Jusbasche at Stanford University. Financial help for this work was provided by the Stanford Geothermal Program and Southern California Edison Company.

**REFERENCES**


**TABLE 4: SALINITY CALCULATION FOR WELL RRGE #1, RAFT RIVER FIELD, CASSIA COUNTY, IDAHO**

<table>
<thead>
<tr>
<th>DEPTH SECTION INTERVAL</th>
<th>FORMATION</th>
<th>SLOPE</th>
<th>AVERAGE</th>
<th>$R_{mf}$</th>
<th>$R_{mf}$</th>
<th>$R_w$</th>
<th>SALINITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>(feet)</td>
<td>ILS vs LL8 TEMPERATURE @ meas. Temp @ zone Temp</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 100 - 850 Conglomerate 0.889 88</td>
<td>3.4 @ 65</td>
<td>2.5</td>
<td>2.22</td>
<td>2100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 900 - 1220 Sandstone 0.530 115</td>
<td>6.2 @ 54</td>
<td>3.0</td>
<td>1.59</td>
<td>2250</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 1220 - 2350 Tuff and Sandstone 0.480 129</td>
<td>6.2 @ 54</td>
<td>2.7</td>
<td>1.30</td>
<td>2400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 2350 - 2800 Tuff and Sandstone 0.640 140</td>
<td>6.2 @ 54</td>
<td>2.3</td>
<td>1.47</td>
<td>1800</td>
<td></td>
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<tr>
<td>5 2800 - 3340 Sandstone &amp; Siltstone 0.600 158</td>
<td>6.2 @ 54</td>
<td>2.12</td>
<td>1.27</td>
<td>2000</td>
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<tr>
<td>6 3340 - 4300 Tuffaceous Siltstone 0.540 186</td>
<td>6.2 @ 54</td>
<td>1.82</td>
<td>0.98</td>
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<td>7 4300 - 4590 Tuffaceous Siltstone 0.720 238</td>
<td>6.2 @ 54</td>
<td>1.42</td>
<td>1.02</td>
<td>1600</td>
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</table>
FIGURE 1: PLOT FOR ZONE 1

FIGURE 2: PLOT FOR ZONE 2

FIGURE 3: PLOT FOR ZONE 3

FIGURE 4: PLOT FOR ZONE 4
FIGURE 5: PLOT FOR ZONE 5

FIGURE 6: PLOT FOR ZONE 6

FIGURE 7: PLOT FOR ZONE 7