PETROPHYSICS, VOL. 56, NO. 4 (AUGUST 2015); PAGE 379–381; 3 FIGURES

TECHNICAL NOTE

The Bateman-Konen Resistivity-Salinity Transform II

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INTRODUCTION

According to Bateman and Konen (1977), if C is NaCl (i.e., sodium chloride) concentration in parts per million and $R_{75°F}$ is the brine resistivity at 75°F, then

$$R_{75°F} = 0.0123 + \frac{3647.5}{C^{0.955}} \quad . \tag{1}$$

This formula was originally derived by manually digitizing points at 75°F found in the resistivity-temperature-concentration chart from the 1975 Schlumberger Chart Book (Chart Gen-6) (Professor Richard Bateman, personal communication). In Fig. 1a, resistivity estimates (green line) from the Bateman-Konen formula are compared to resistivity values (yellow dots) hand-digitized from a later edition of the chart book are shown below.

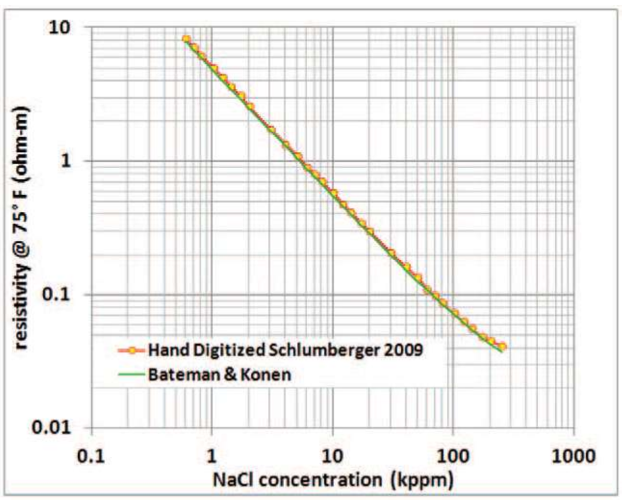

Fig. 1a—The Bateman-Konen function was developed by digitizing Chart Gen-6 in the 1975 Schlumberger chartbook and fitting a power law to the data. The goodness of fit is indicated here.

Resistivities are extended to other temperatures by means of Arps (1953) approximating formula

$$R_{T°F} = R_{75°F}\,\frac{75+6.77}{T+6.77} \quad . \tag{2}$$

The Bateman-Konen formula appears to be a good approximation in the log-log domain where it was originally digitized (Fig. 1a); however, when the same data are plotted in linear conductivity space (Fig. 1b) it can be seen that estimates of conductivity are systematically in error at concentrations above about 170,000 ppm NaCl. The maximum conductivity that a saturated NaCl brine would attain is approximately 24 S/m. Using this conductivity value in the Bateman-Konen approximation results in a concentration estimate of approximately 210,000 ppm NaCl, and error of approximately 16%.

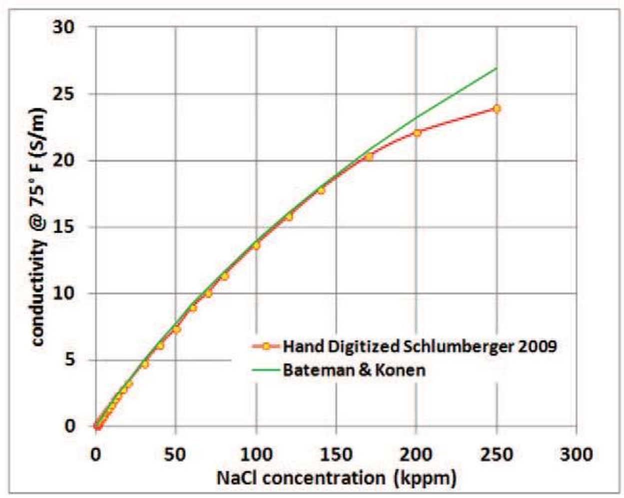

Fig. 1b—When the Bateman-Konen data are plotted as conductivity versus NaCl concentration on a linear grid, it becomes apparent that the predictions of the formula and the observed data diverge above salinities of about 170,000 ppm.

IMPROVED APPROXIMATION

Given the poor performance of this approximation at high salinity it is appropriate to ask whether a better approximation can be devised. Note that the Bateman-Konen formula was devised using resistivity in logarithmically scaled space, where their modified power law is an appropriate approximation for a nearly straight line. However, in conductivity space, plotted on linear scales, the conductivity appears to approximate a quadratic

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function of brine salinity. This curve is a quasiparabola with apex offset from the origin by shifts in both concentration and conductivity

$$\sigma = \sigma_0 + a_1(C - C_0) + a_2(C - C_0)^2, \tag{3}$$

where the conductivity offset is σ_0 and the concentration offset is C_0. A conductivity offset of about 24.3 and concentration offset of about 29.5 for the vertex of the parabola is suggested by inspection of the function in the figure 2, and validated by the numerical fitting. The requirement that the function be accurate over more than three orders of magnitude in both its domain and range requires that the constants be specified very accurately.

The resulting formula with its coefficients and offsets is

$$\begin{aligned} \sigma|_{75^\circ F} = 24.30853 - 0.0364(C - 29.46518957) \\ - 0.02922(C - 29.46518957)^2 \end{aligned} \tag{4}$$

where C is salinity (or NaCl concentration) expressed as a weight percent.[2] This function is plotted in Fig. 2. The manually digitized resistivity values (converted to conductivity) are plotted as blue diamonds. The conductivity function, Eq. 4, is represented by the centers of the red circles. The attempt was to choose constants that would center each red circle on the corresponding blue diamond. The Bateman-Konen approximation is shown as the red dashed line.

Figure 3a shows the same approximation in log-log space, and illustrates that for very low salinity, mostly out of the range of oilfield brines, the quasiparabola approximation loses accuracy. However, at the high concentration the right side of the concentration domain, shown expanded in Fig. 3b, the approximation is seen to be very good; the Bateman-Konen approximation is represented here by the red dashed line.

The approximation in Eq. 4 sacrifices the compactness and easily memorized Bateman-Konen approximation but it does permit better approximation of the conductivity-concentration relationship at high salinity. From a practical point of view, the Bateman-Konen formula should be used at low NaCl concentrations where it is most accurate, and the improved approximation should be used at high NaCl concentrations, where it is most accurate.

In extending this approximation to temperatures other than 75°F, one weakness remains: the Arps approximation. The data (Washburn et al., 1929) that Arps (1953) based his approximation on shows subtle curvature, which his approximation does not honor. Improving the Arps approximation is the subject of work now in progress.

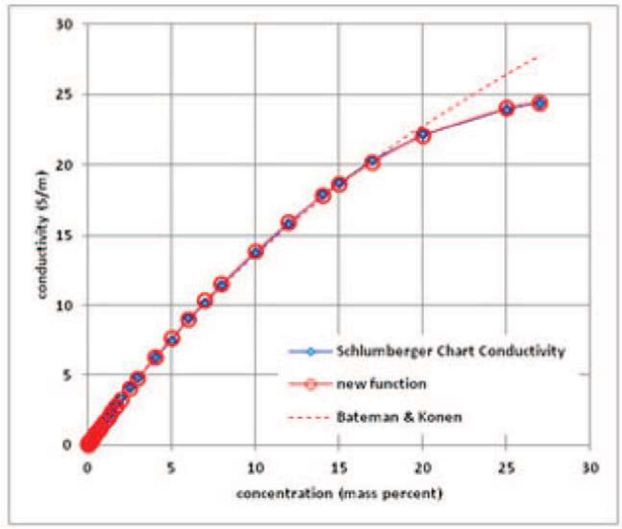

Fig. 2—This figure shows the Bateman-Konen approximation (red dotted line), together with the observed relationship (as digitized from Schlumberger Chart Gen-6; blue diamonds), and the predictions made by the approximating function proposed in this article (red circles). The data were fitted using coefficients that put a red circle around each blue diamond.

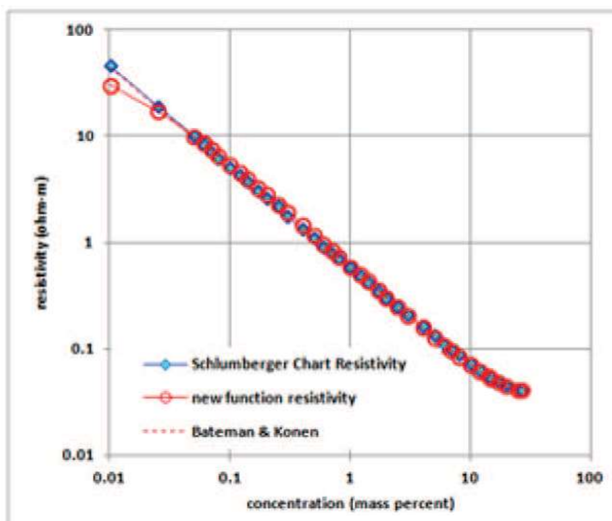

Fig. 3a—The same data shown in Fig. 2 are presented on a log-log plot. Using the log-log scale the data and both sets of predictions apparently agree for high salinity. The approximation presented in this article diverges from observations for very low salinity (< 0.05 wt%, or 500 ppm), not usually of interest in the realm of oilfield brines.

[2] Concentration is customarily quoted in parts per million (ppm) NaCl by weight. However, curve fitting is facilitated if the magnitude of the y value and x value are similar in magnitude. Expressing concentration in terms of weight percent achieves this objective. You will notice the number of significant digits specified in the offsets seems overly precise given the empirical nature of the data underlying the function. However, this seeming overprecison is necessary to maintain the accuracy of the approximation at high salinity where the value of C is very close to the value of the offset constant C_0, the same region where the Bateman-Konen approximation is inaccurate.

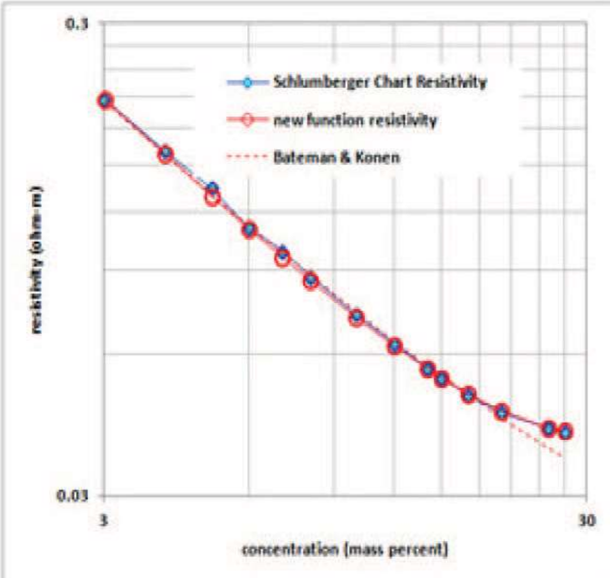

Fig. 3b—The same data shown in Fig. 2 are shown with the horizontal log axis expanded to zoom in on the interval 3 to 30 wt% NaCl. At this scale, the departure of the Bateman-Konen approximation from observation is readily visible. The approximation developed in this article continues to predict the data at high salinity.

NOMENCLATURE

a_1, a_2 = adjustable coefficients for best-fitting observations to the parabola
C = sodium chloride (NaCl) concentration, parts per million
C_0 = a concentration offset, parts per million
T = temperature, degrees Fahrenheit
$R_{75°F}$ = brine resistivity at 75°F
$R_{T°F}$ = brine resistivity at T, °F
σ = conductivity, S/m
σ_0 = conductivity offset, S/m

REFERENCES

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Bateman, R., and Konen, C., 1977, The Log Analyst and the Programmable Pocket Calculator, *The Log Analyst*, **18**(5), 3–11. See Eq. 5 et seq.

Schlumberger Limited, *Log Interpretation Charts*, 1972 Edition, chart Gen-9, 9.

Washburn, E.W., West, C.J., and Hull, C., Editors, 1929, *International Critical Tables of Numerical Data, Physics, Chemistry, and Technology*, McGraw-Hill Book Co., New York and London. The original is available at http://chla.library.cornell.edu/c/chla/browse/title/2944761.html . Relevant tables are also reproduced (with some corrections) in Arps (1953).