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ACCURATE DETERMINATION OF GEOPRESSURED
AQUIFER SALINITY FROM THE SP LOG

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ABSTRACT

The amount of gas dissolved in geopressured brine is water salinity dependent. When water samples are available, water salinity is determined by direct analysis. In the absence of water samples, which is often, water salinity is estimated using conventional well logging interpretation techniques. The water resistivity, R_w , is first calculated from the SP log. The salinity is then obtained using available correlations. It is not unusual to obtain poor correlations between the values obtained from water samples and those estimated from the SP especially in deep geopressured south Louisiana formations.

The basic SP equation $SP = -K \log(a_w/a_{mf})$ was examined. The parameter K was found to vary with the shale resistivity R_{sh} . A new interpretation chart relating SP to R_{sh} , R_{mf} and R_w was obtained.

The use of the new equation resulted in a significant improvement in the correlation between water salinity values obtained from water samples and those estimated from the SP log.

INTRODUCTION

The SP log has been extensively used to evaluate formation water salinity. The water resistivity, R_w , is first calculated from the log. The salinity is then obtained using available correlations relating salinity to formation water resistivity. It has been noted in several wells that have been tested in deep abnormally-pressured South Louisiana formations that logging calculations do not appear to give accurate representation of water salinity. The SP method tends to underestimate the salinity.

The amount of gas dissolved in geopressured brines depends on temperature, pressure and salinity. Figure 1 shows the solubility of methane in water as a function of total dissolved solids at 300°F and 15,000 psia. At these temperature and pressure conditions an underestimation of the salinity from 100,000 ppm to 50,000 ppm will result in the overestimation of the amount of gas in solution by almost 23%. The salinity is also used as screening parameter in the selection of dry holes for the "wells of opportunity" program.

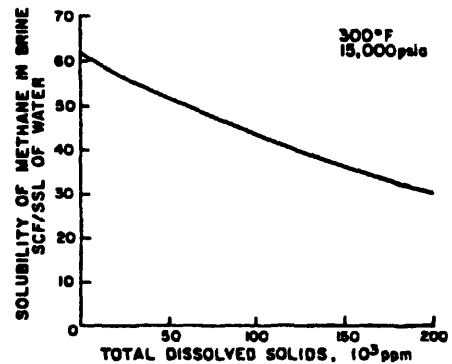


Fig. 1 Effect of water salinity on the amount of methane in solution at 300°F and 15,000 psia

The discrepancy between water salinity values obtained from water samples and those estimated from SP logs could be due to the quality of water samples. Water samples recovered may exhibit dilution and contamination characteristics due to mixing with condensation water or drilling fluids. However, such discrepancy continues to exist when reliable water samples are available.

The purpose of the study reported in this paper was to examine the method traditionally used to calculate R_w from the SP Log and to develop a new calculation approach yielding more reliable water salinity values.

TRADITIONAL APPROACH

The method traditionally used to calculate R_w from the SP log is based on the well known equation

$$SP = -K \log(a_w/a_{mf}) \quad (1)$$

where:

- SP = SP log deflection in millivolts; corrected for bed thickness and other measurement environment,
- a_w = Activity of the formation water in gr-ion/liter,
- a_{mf} = Activity of the mud filtrate in gr-ion/liter,
- K = Coefficient which depends on the formation temperature ($K = 61 + 0.133T$; T in °F).

For pure NaCl solutions that are not too concentrated, resistivities are inversely proportional to activities. However, the inverse proportionality does not hold exactly at high concentrations or for all types of waters. Therefore, Goudouin, Texier, and Simard² introduced the concept of equivalent resistivity. The equivalent resistivity, by definition, is inversely proportional to the activity. By this definition equation (1) becomes:

$$SP = -K \log(R_{mfe} / R_{we}) \quad (2)$$

where R_{mfe} and R_{we} are the mud filtrate equivalent resistivity and the formation water equivalent resistivity, respectively. Graphical relation between true and equivalent resistivities is available in the literature³. Equation (2) has been extensively used to estimate R_w from SP values.

Kharaka and co-workers⁴ reported detailed chemical analysis of several formation water samples from 7 oil and gas fields in the Lafayette, La., area. These chemical analyses were determined using a new, reliable technique.⁵ These waters are predominantly NaCl with an average concentration of Ca and Mg less than 5% by weight. The water resistivity values of these samples were calculated using the technique proposed by Ucock, Ershaghi and Olhoeft.⁶ The comparison of these values and those estimated from the corresponding SP log deflections using equation (2) resulted in Fig. 2. The discrepancy between SP-log-calculated values and chemical-analysis-calculated values is evident.

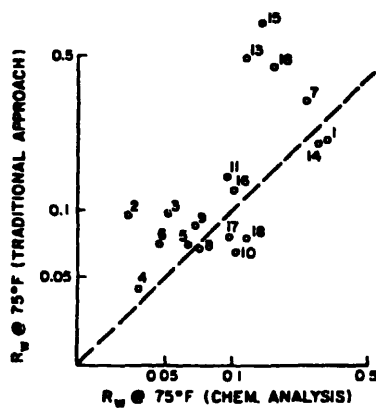


Fig. 2 Comparison between R_w from SP log and R_w from chemical analysis

This discrepancy could be the result of one or both of the two assumptions which are implicit in equation (2). These two assumptions are:

1. Both formation water and mud filtrate are pure NaCl solutions.
2. The shale is a perfect membrane, i.e., one through which only cations can pass.

The effect of salts other than NaCl was investigated.^{7,8} This effect was found to be relatively small for brines containing less than 5% by weight of salts other than NaCl and can not account for the above significant discrepancies.

NON-IDEAL MEMBRANE BEHAVIOR OF SHALES

Equations (2) and (3) assume that shale formations behave ideally as cationic permeable membranes. Laboratory measurements with shale membranes cut from cores commonly show a potential different from that calculated for an ideal membrane.^{2,9,10} For the purpose of practical interpretation, K should be related to an available shale electric property which would reflect shale membrane characteristics.

The only shale electric property readily available is the shale electric resistivity, R_{sh} , reported on a resistivity log. Several attempts were made to incorporate R_{sh} in the SP expression. A hypothetical value K_T of the coefficient K was calculated from equation (3) using R_w values from chemical analysis. K_T is the value of coefficient K , which if used in equation (3), will yield a perfect agreement between R_w values from the SP and R_w values from chemical analysis. In Fig. 3, the K_T values are plotted against the ratio R_{sh}/R_{mf} . This was done in an attempt to include, in one dimensionless term, two of the parameters which seem to be important. Although no precise relationship can be inferred, two interesting features can be noticed. For a constant R_{sh}/R_{mf} value, K_T tends to increase as the SP reading increases. This is indicated by dotted-line trends. A trend defined by a solid line is also indicated. This trend could be related, according to the high SP values, to clean formations.

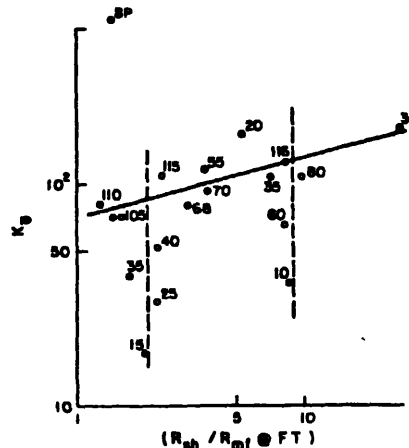


Fig. 3 K_T vs. R_{sh}/R_{mf} ratio

Fig. 3 shows that coefficient K is a function not only of the temperature, but also of the measurement environment as well. An expression for K would be hard to obtain because of the many unknowns involved. However, a parameter exists that reflects all the possible variables controlling the SP phenomenon. Such a parameter is, of course, the SP reading itself. In fact, when the ratio R_{mf}/R_w is plotted versus R_{sh}/R_{mf} , (Fig. 4) a well-defined relationship is obtained for each value of the SP. In order to present the correlation in a more convenient way, interpolated values of Fig. 4 are plotted on Fig. 5, where R_{mf}/R_w is plotted against the SP reading as a function of several R_{sh}/R_{mf} values.

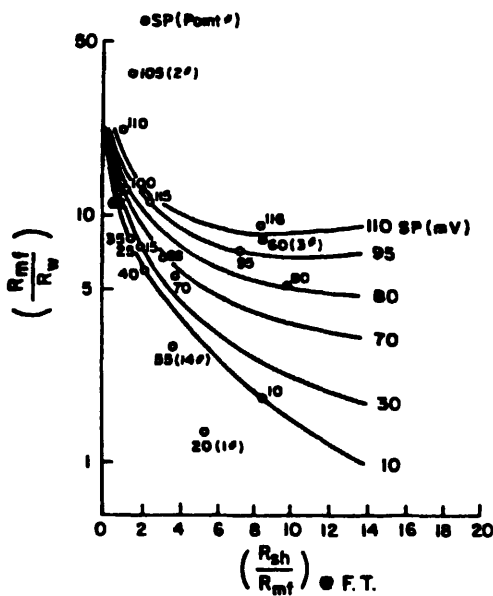


Fig. 4 Correlation Between R_{mf}/R_w and R_{sh}/R_{mf}

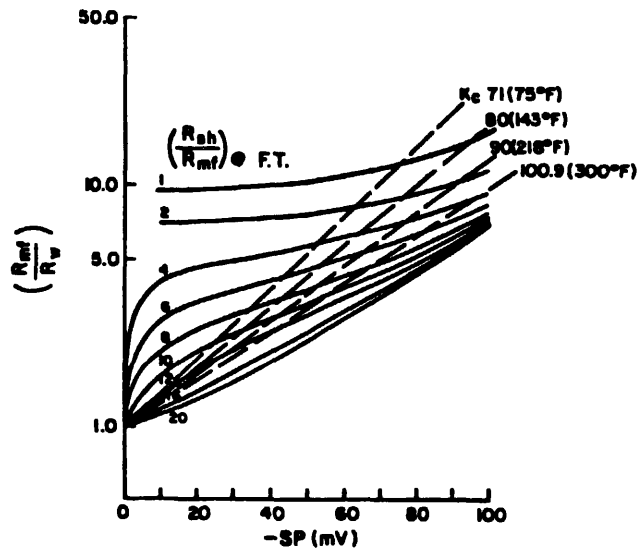


Fig. 6 Empirical comparison between old and new approach

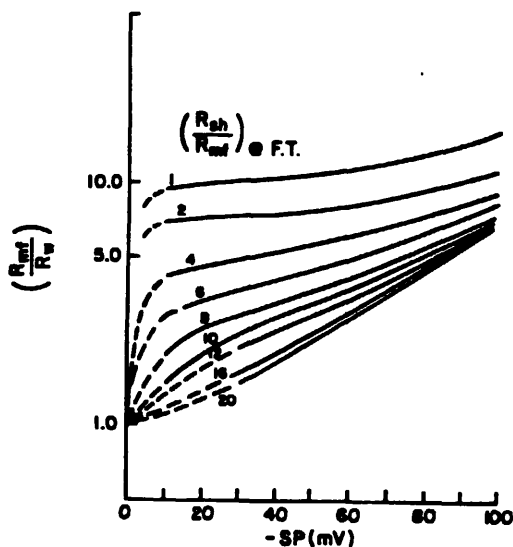


Fig. 5 Correlation Between R_{mf}/R_w and SP Value

For comparison purposes, the correlation of Fig. 5 was superimposed on the graphical presentation of equation (2) representing the old interpretation approach, Fig. 6. The old and new interpretation approaches are close at high SP values. A considerable deviation is noticed at low SP values.

Using the correlation of Fig. 5 the R_w values for the samples used in Fig. 1 were calculated and plotted in Fig. 7 versus the values calculated from the chemical analyses. An excellent agreement is clearly indicated, despite the fact that some of the data points were obtained in shaly formations.

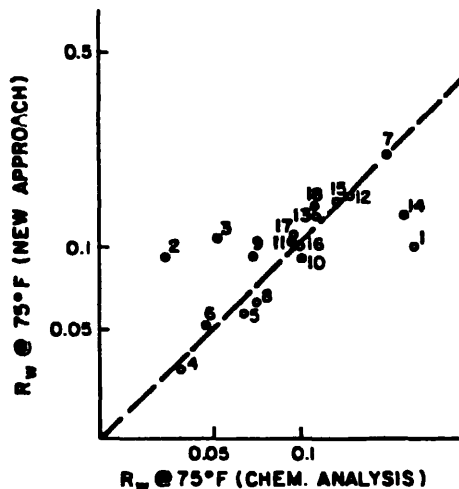


Fig. 7 Comparison of the R_w Values Calculated Using the New Correlation and Those Obtained from Chemical Analysis

APPLICATION OF THE NEW CORRELATION TO GEOPRESSURED WELLS

The new correlation was used to calculate salinity values in 6 geopressured formations encountered in wells of opportunity. For comparison purposes, salinities using the traditional approach were calculated as well. Table 1 shows the data and the results of the calculations. Figures 8 and 9 show the comparison between the calculated salinities and the values estimated from chemical analyses. The dotted lines in figs. 8 and 9 represent the calculated standard error.

Table 1

Well	SALINITY, TDS		
	Chemical Analysis	Old Techn.	New Techn.
1. Pleasant Bayou#2	120,872	101,680	123,380
2. Beulah Simon #2	96,140	66,590	112,570
3. Fairfax-Foster#2	169,193	136,220	144,840
4. E. Delcambre#1, a	122,564	44,580	92,560
5. E. Delcambre#1, b	105,439	36,750	87,260
6. Praire Canal#1	42,386	24,870	68,360

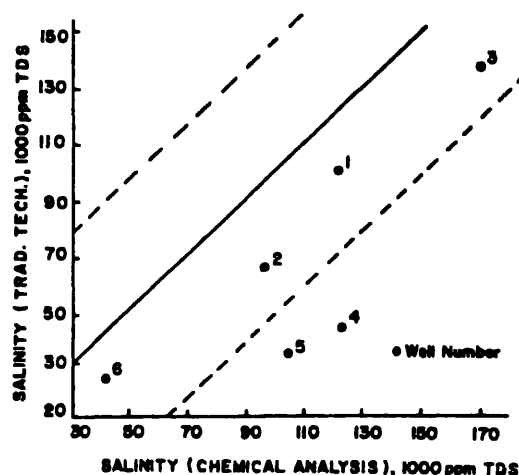


Fig. 8 Geopressed brines: salinity using traditional technique vs chemical analysis values

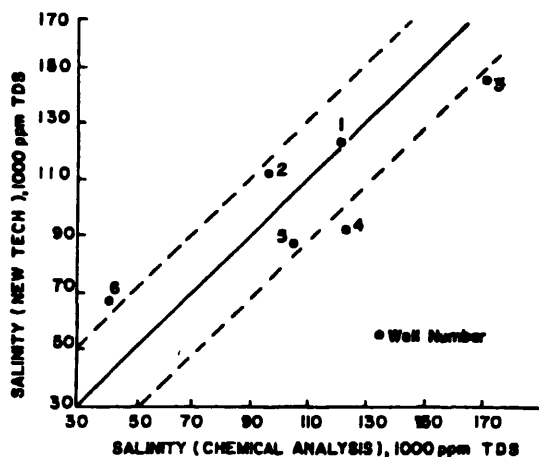


Fig. 9 Geopressed brines: salinity using new technique vs chemical analysis values

A qualitative analysis of these figures reveals the advantage of the new correlation to estimate the salinities for the formation under study. This fact is reinforced by mentioning that an average error of 4.06% and a standard error of $\pm 1,500$ ppm were obtained when the new correlation was employed. On the other hand, the traditional approach yielded an average error of -39.4% and a standard error of $\pm 47,300$ ppm. The statistical parameters have to be carefully considered because of the limited number of data points available.

CONCLUSIONS

The traditional SP equation $SP = -K \log(a_w/a_{mf})$ which assumes ideal membrane behavior of shales where K is only temperature dependent, yields inaccurate values of R_w . To account for the non-ideal membrane behavior of shales, K should be expressed in terms of R_{sh} , R_{mf} and R_w . A new relation giving SP as a function of R_{sh} , R_{mf} and R_w was established, Fig. 5. The use of this new correlation resulted in a significant improvement of the accuracy of R_w and water salinity values, as indicated by their excellent agreement with values obtained from chemical analyses.

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