On the Application of Simandoux and Indonesian Shaly Sand Resistivity Interpretation Models in Low and High R_w Regimes

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Summary

Present paper is a re-look at the oil industry practices in making use of the Simandoux and Indonesian shaly sand resistivity interpretation models for formation evaluation. Considering the genesis of Indonesian equation to meet the requirements of fresh water formations of Indonesia, application of Indonesian equation in low connate water resistivity regime is examined in contrast to the water saturation ($S_w$) output of the Simandoux model. It has been shown that the use of the tortuosity prefactor $a$ less than unity is unwarranted if the Simandoux model is used in evaluating low $R_w$ formations. Indonesian equation at low $R_w$ regime demands truncation for the overshooting results of the model ($S_w>1$) at $S_w=1$ and yields relatively high values of $S_w$ where $S_w<1$. Given the critical role of effective porosity, the significance of non-linear $V_{sh}$ relations which may go neglected when an inappropriate model is used for log evaluation has been pointed out. Discussion has highlighted the need for appropriate core studies to estimate the real quantum shaliness from volume fraction of shale derived from different shale indicators. It is pointed out that the Simandoux model provides ample scope for customization using non-linear $V_{sh}$ relations, $R_{sh}$ and $a$, $m$, $n$ values and this may be a better option than using the Indonesian equation which has no physical basis.

Further, it is proposed that the average shale resistivity $R_{sh}$ may be replaced by the $R_{shw}$ defined as the shale resistivity of wet zones where effective porosity is zero. Discussion has been made also of the scenario where effective porosity ($\phi_{eff}$) is less than the cut-off porosity ($\phi_{c}$) demanded by the respective model and the risk involved in calibrating or fudging the model for customized $a$, $m$, $n$ values in such zones. Need for truncation in most cases arise out of incompatibility of $\phi_{eff}$ with average $R_{sh}$ and $\phi_{c}$ implicit in the model anatomy. Truncation of $S_w$ in shaly segments where $\phi_{eff} \approx 0$ and calibration of the model in wrong place can be avoided if average $R_{sh}$ can be replaced by $R_{shw}$, i.e. $R_{shw}$ at $S_w=1$ and $\phi_{eff} \approx 0$. It is shown that by acknowledging the impact of $R_{shw}$ and $\phi_{c}$ in making the $S_w$ values overshoot at $S_w=1$ the need for truncation can be avoided.

In the application of workflows for computing water saturation using assumed mineralogy, existing practice to avoid cosmetic truncation is to change the mineralogical composition without substantiating reasons. Application of this mineralogy alteration technique without explicit mention and explanation of the same may lead to unscientific application of arbitrary models such as Indonesian equation to a wide variety of formations to yield arbitrary values of saturation. Discussion as above if understood and applied may help to achieve a more objective application of Saturation models in formation evaluation.

Introduction

The state of the art well log interpretation software seeks to verify the choice and use of particular petrophysical models and assumptions with the re-computing of original curves subject to minimization of the error function. For this purpose, the different tool response equations as functions of fluid, clay and mineralogy are solved under the assumption of specific mineral model to achieve a volumetric picture of the complex lithology. Field observations and laboratory data can be incorporated for zone-wise interactive evaluations using error functions of reconstructed curves. Accuracy of the fluid and mineral interpretation thus appears to be ensured subject to the accuracy of the petrophysical model used in the inversion process. Apart from the limitations such as possibility of errors in the identification of `earth' model, uncertainties of log errors arising from bad hole, depth-matching and non-linear aspects of tool response equations, method is prone to errors possible from the wrong application of the
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petrophysical models such as Simandoux and the Indonesian equations. Present paper is an attempt to look at the application of above models vis-à-vis choice of parameters such as \( a, m, n, V_{sh} \) and \( R_{sh} \) in formation evaluation.

II. Implications of the Model Anatomy in Formation Evaluation

Simandoux model gave the algorithm for water saturation as:

\[
\left( \frac{\phi}{a R_w} \right) S_w^2 + \left( \frac{V_{sh}}{R_{sh}} \right) S_w - \frac{1}{a} = 0 \quad \Rightarrow (1)
\]

\[
S_w = \frac{-V_{sh} \pm \sqrt{V_{sh}^2 + 4 \frac{a}{\phi R_w}}} {2 \frac{V_{sh}}{R_{sh}}}
\quad \Rightarrow (1a)
\]

This expression later got modified by the insertion of \((1-V_{sh})\) to give better accommodation for shaliness of the formation and came to be known as the Modified Simandoux equation.

\[
\left( \frac{\phi}{(1-V_{sh}) a R_w} \right) S_w^2 + \left( \frac{V_{sh}}{R_{sh}} \right) S_w - \frac{1}{a} = 0 \quad \Rightarrow (1b)
\]

i.e.

\[
S_w = \frac{-V_{sh} \pm \sqrt{V_{sh}^2 + 4 \frac{a}{\phi R_w}}} {2 \frac{V_{sh}}{(1-V_{sh}) R_w}}
\quad \Rightarrow (1c)
\]

Equation 1(b) can be further generalized to account for dispersed clays by adding an exponent \( r \) to the linear \( V_{sh} \) term and introducing the variable saturation exponent \( n \) instead of \( 2 \) as:

\[
\left( \frac{\phi}{(1-V_{sh}) a R_w} \right) S_w^n + \left( \frac{V_{sh}}{R_{sh}} \right) S_w - \frac{1}{a} = 0 \quad \Rightarrow (1d)
\]

Indonesian equation introduced by Poupon and Leuvex was a modification effected on the Simandoux equation to strike a better evaluation of the fresh water formations:

\[
S_w = \frac{\sqrt{\frac{1}{R_w}}}{\sqrt{\frac{(1-\frac{2}{\phi V_{sh}})}{R_{sh}}} + \sqrt{\frac{\phi^m}{(a R_w)}}}
\quad (2)
\]

In the application of these models to specific formations, industry follows no axiomatic approach in terms of critical factors such as –

1. Formation water resistivity \( R_w \) regime for Simandoux and Indonesian models
2. Choice of respective shale function \( V_{sh} \) from Gamma Ray, Spontaneous Potential or Sonic \( A_1 \) index
3. Value of shale resistivity \( R_{sh} \)
4. Choice of \( a, m \) and \( n \) parameters

Use of the latest computing techniques involving inverse modeling offers no immunity to the mistakes possible in respect of the above. As for example, if we consider the formation water resistivity regimes of the aforesaid models, it can be easily understood that expressions 1(a) and 2(a) works fine at low \( R_w \) values as both numerator and denominator has the factor \( \phi^r R_w \). Values of \( a \) less than unity does not impinge on the output of the Simandoux equation drastically because of the balance achieved in between the numerator and denominator. But this model was found to be deficient for relatively higher values of \( R_w \) as encountered in Indonesia and hence the Indonesian equation was given shape.

On the other hand, in the Indonesian model, denominator to \( R_w \) function has the critical component of formation characteristics viz., \( \sqrt{\phi^m/a R_w} \) and therefore low values of \( R_w \) and values of \( a \) less than unity tend to reduce the \( S_w \) values significantly. Use of Indonesian equation to evaluate a low \( R_w \) regime may necessitate an \( a \) value less than unity such as 0.62 simply as a fudging parameter having no physical relevance. When the low \( R_w \) formations yield satisfactory \( S_w \) values with a =1, m = 2 and n =2 for the Simandoux equation, application of Indonesian equation to such situations with a = 0.62 may look quit odd and result
will be a fudged evaluation whose merits shall be open to discussion.

It is worth mentioning here that the Simandoux equation alone has a theoretical basis as compared to the ‘Indonesia’, ‘Nigeria’ or the ‘Venezuela’ equations originally fudged for specific areas appearing in their names. Results of either of these models can be obtained using the variants of Simandoux equations with the adoption of appropriate shale functions and customization variables such as \( a, m \) and \( n \), known respectively as the tortuosity prefactor, cementation exponent and saturation exponent.

**Decisive Influence of the Shale Function**

Limiting ourselves to a study in contrast of the Simandoux and Indonesian equations the respective shale modules of these expressions are:

\[
\frac{V_{wh}^x}{R_{wh}} \times \frac{n}{S_w^n} \Rightarrow \text{Simandoux} \quad (1c)
\]

and

\[
\left( \frac{V_{sh}(1-V_{sh})}{\sqrt{R_{sh}}} \right) \Rightarrow \text{Indonesian} \quad (2a)
\]

-where \( V_{sh} \) is the linear shale volume as computed from Gamma Ray or Spontaneous Potential etc.

Linear estimation of clay index from GR, SP, N-D cross plot, Density-Sonic cross plot etc in general over estimate \( V_{sh} \) if they are not calibrated using laboratory data. Most of the shale indicators \( V_{sh} \) render \( V_{sh} = 1 \) in shaly zones which is rarely the case as noted by Hawkins’ quoting the study of Hower et al. XRD study of shale cuttings from Gulf Coast formations had shown that average weight percent clay ranged only 55-68% in shale samples taken between 1850-5500 metres. A recent study on the use of ECS and NMR logs in combination to XRD and IR Spectroscopy studies on cores to evaluate the shaly sands has also stressed the need for derivation of ‘shaliness’ from the volume fraction of shale \( V_{sh} \). Therefore, non-linear relationships which have given better accommodation to shale effects as known in literature may also be used to arrive at results matching with field experience.

\[
f(V_{sh}) = 0.33\{2^{2+GRI} - 1]\]

\( = V \Rightarrow \text{for older/consolidated formations} \quad (3)\)

\[
f(V_{sh}) = 0.083\{2^{3.7+GRI} - 1]\]

\( = V \Rightarrow \text{for younger/unconsolidated formations} \quad (3a)\)

Optimum shale values have to be derived from the above non-linear \( f(V_{sh}) \) value of shale volume or modifications thereof through Clavier, Steiber or any other corrections that may be found necessary for a sound evaluation.

Clavier et al in 1971 had introduced the formula:

\[
V_{sh(\text{optimum})} = 1.7 - \sqrt{3.38 - (V + 0.7)^2} \Rightarrow \quad (3b)
\]

and Steiber (1973) had introduced:

\[
V_{sh(\text{optimum})} = \frac{0.5 \times V}{1.5 - V} \Rightarrow \quad (3c)
\]

Errors associated with the shale indicators tend to increase the apparent shale volume and therefore the minimum value is desirable for use in log evaluation. Customization of the models to different regions of specific characteristics may demand the use of linear shale functions as such without going into the non-linear modifications and optimizations.

**Critical Role of Shale Resistivity \( R_{sh} \)**

The denominator in the shale terms is resistivity \( R_{sh} \) of the shale decided by the log analyst relying on shoulder beds vis-a-vis field experience. Despite the advent of volumetric analysis and inversion modeling to minimize the errors possible, the industry practice is still to assume a common value of \( R_{sh} \) for a location or for formations encountered in a well. Practice introduces an element of uncertainty in view of the effective shale content vis-a-vis shale effect and coupled with the uncertainty possible of the formation water resistivity \( R_w \) bring in a complexity that can become a source of error in formation evaluation. A glance over the model algorithms under discussion clearly suggests that –

1. It is the balance of the shale term and porosity term that decide the \( S_w \) values.
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2. The use of effective porosity values tends to minimize the porosity contribution.
3. Use of linear $V_\text{sh}$ volume and assumed $R_{sh}$ of a laminated formation model may introduce an unrealistic shale term into the evaluation process.
4. Factor (2) and (3) above may lead to wrong customization of the model at intervals where effective porosity is nearly zero.

It becomes therefore apparent that even the use of modern computing processes like Expert Log Analysis or Interactive Petrophysics does not offer blanket immunity from mistakes possible in the application of models and the choice of relevant parameters.

III. Axiomatic Approach to Select and Apply the Model

1. Application of Simandoux and Indonesian models only to their respective $R_w$ regimes

Errors in customization and fudging over wet zones with departure from standard conditions of $a = 1, m = 2$ and $n = 2$ can be avoided if we stick to the application of models to their respective $R_w$ regimes. Little justification can be adduced in support of the application of Indonesian model to low $R_w$ regimes, given the theoretical foundations of Simandoux model and its variants possible to satisfactorily account for shaliness.

2. Derivation of shale resistivity $R_{sh}$ for the models under the limit $S_w = 1$ shall be of great utility in overriding discrete values possible from the use of same average $R_{sh}$ value across a zone.

Considering the Simandoux model, a cut off value of $R_{sh} = R_{shw}$ for the wet zones can be derived as:

$$R_{shw} = \left( \frac{1}{R_t} - \frac{V_\text{sh}}{\alpha R_w} \left( 1 - \frac{1}{V_\text{sh}} \right) \right)^{-1} \Rightarrow (4)$$

Higher values of $R_{sh}$ in wet shaly zones shall lead to $S_w$ values higher than unity. Any effort to lower those $S_w$ values by using lower $R_{sh}$ values in the model shall lead to erroneous $S_w$ values at $S_w < 1$.

In the case of the Indonesian equation, $R_{shw}$ can be approximated by putting $\phi_{\text{eff}} = 0$ and $S_w = 1$ and we obtain –

$$R_{shw} = \left( V_\text{sh} \left( 1 - \frac{1}{V_\text{sh}} \right) \right)^2 R_t \Rightarrow (5)$$

3. Truncation of the $S_w$ output for cosmetic purpose must be restricted to points where $\phi_{\text{eff}}$ is less than or equal to the cut off porosity ($\phi_{\text{co}}$) of the model.

In the case of Simandoux model, considering the wet zones, we can rewrite the expressions and solve for porosity $\phi_{\text{co}}$ as:

$$\phi_{\text{co}} = \left[ \left( \frac{1}{R_t} - \frac{V_\text{sh}}{R_{shw}} \right) \right]^{\frac{1}{m}} \Rightarrow (6)$$

Now at this maximum of the function, $S_w = 1$, porosity $\phi$ cannot be less than zero. It becomes therefore obvious that $1/R_t > V_\text{sh}/R_{shw}$ if the model is to give a genuine $S_w = 1$ output (not truncated) over the wet zones. Further, it can be easily understood that for any formation, the equation (6) defines a porosity cut off ($\phi_{\text{co}}$) for the minimum value of $R_t$ encountered. Depending upon the value of $R_{shw}$, magnitude of $\phi_{\text{co}}$ may increase or decrease. Application of the model to the high $R_w$ regime may lead to a higher $\phi_{\text{co}}$ that may exceed the effective porosity over the shaly wet zones. Then the computed $S_w$ will overshoot 1 and fudging of the same to $S_w = 1$ by altering $m$ and $n$ leads to unrealistic values for hydrocarbon bearing zones.

In fact the Simandoux model gives a non-zero $S_w$ output even when $\phi_{\text{eff}} = 0$ as:

$$S_w = \frac{R_{shw}}{V_\text{sh} R_t} \Rightarrow (7)$$

Model can be therefore calibrated for choosing the value of $R_{shw}$ at points where effective porosity is zero as $R_{sh} = V_\text{sh} \times R_t$. Effect of a high $R_{shw}$ value chosen at $\phi_{\text{eff}} = 0$ will be to make the $S_w$ value overshoot in shales. Therefore when effective porosity is close to zero, the output of the Simandoux model is controlled by $R_{shw}$ and not by $a, m$ and...
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n. Care needs to be taken to see that the model is not calibrated or over-compensated in terms of low \( R_{sh} \) in shaly intervals where \( S_w \) may be more than unity when an average or common \( R_{sh} \) value is used. \( S_w \) output of the Simandoux model shall be representative of \( a, m \) and \( n \) only over intervals where \( \phi_{cut} > 0 \). For the Indonesian model \( \phi_{co} \) may be derived as:

\[
\phi_{co} = \left[ \frac{1}{\sqrt{R_t}} \left( \frac{V_{sh}(1-S_w)}{V_{sh}} \right) \right] \frac{1}{n} = \left( \frac{V_{sh}(1-S_w)}{V_{sh}} \right) \frac{1}{n} \Rightarrow (8)
\]

\( V_{sh}(1-V_{sh}/2) \) will be greater than \( V_{sh} \) always and when contrasted with the Simandoux equation, \( 1/R_t > V_{sh}/R_{sh} \) for \( \phi \geq 0 \) at \( S_w = 1 \). \( S_w \) being close to \( V_{sh} \) when \( V_{sh} \) is high with shaly formations, the situation is controlled by higher \( R_w \) values of the fresh water formations. When the Indonesian equation is applied to low \( R_t \) regime, the effective porosity corresponding to minimum \( R_t \) value encountered at which \( S_w = 1 \) will be low and in hydrocarbon zones the wrongly fudged models shall lead to under estimation of \( S_w \) and hydrocarbon reserves shall be inflated.

Discussion as above suggests that the models must be fudged over wet zones having effective porosity equal to or greater than the \( \phi_{cut} \) demanded by the model and not at zones where effective porosity is equal to zero. When contrasted with the Simandoux equation, Indonesian equation facilitates easier fudging by choosing \( a < 1 \) even in shaly zones where \( \phi_{co} = 0 \). Fudging Indonesian model over wet zones of \( \phi_{co} = 0 \) or \( \phi_{co} < \phi_{co} \) by taking values of \( a < 1 \), or \( m \) and \( n \) lower than \( 2 \) shall lead to a wrong estimation of hydrocarbon reserves.

III. Examples

1. Sandstone PX1: Interval CAGG-CAHE

(a) Indonesian Model

Calcareous sandstone with average matrix density of 2.69 gm/cc processed using the complex lithology model and Indonesian equation presents the following details:

Zone parameters: \( a = 0.62 \), \( m = 2 \), \( n = 2.15 \), \( R_{sh} = 2.4 \Omega \cdot M \), \( R_w = 0.11 \Omega \cdot M \).

In Table-1 below \( S_w \) represents the output of a modern conventional processing software using complex lithology model while \( S_w,J \) are the raw values from Indonesian equation. \( S_w,J,\phi_{co} \) is a hypothetical \( S_w \) computed for \( \phi_{co} \) of the model for respective \( R_t \) and \( \phi \). It is apparent from the \( \phi_{co} \) data that the model used here is not applicable at effective porosities less than \( \phi_{co} \) and the zone parameters fixed over wet zones of effective porosity less than the \( \phi_{co} \) is not really representative of the formation. \( S_w \) computed as 100% or more are in fact less by more than 10% as this error can be understood to be arising from \( a = 0.62 \) adopted in the computation by applying the model to zero effective porosity.
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<th>(S_w)</th>
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Table-1

On the contrary when we take \( a = 1 \), the change from \( a = 0.62 \) to \( a = 1 \) has no effect at \( S_w \) of effective porosities less than \( \phi_w \) but leads to increased \( S_w \) at effective porosities higher than \( \phi_w \). It may be noted that for the same \( S_w \) of water zones, at \( Sw = 50\% \), the increase had been nearly 20\% i.e. the model calibrated at \( \phi_{eff} < \phi_w \) leads to significant over estimation of reserves.

Plot-1 below presents the evaluation along with \( R_s \) and \( \phi \) on secondary axis for the complete zone. It is well evident that the \( S_w \) profile that make use of \( a = 0.62 \) is the result of judging the model at porosities below the \( \phi_w \) defined by equation (8).
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(b) Simandoux Model

Simandoux model is better suited in low $R_w$ ($=0.11$) regime as above. Plot-2 depicts the original data of conventional complex lithology processing software with zone parameters $a = 0.62$, $m = 2.15$, $n = 2$, $R_{sh} = 2.4 \Omega \cdot m$, $R_w = 0.11 \ \Omega \cdot m$ applied in Indonesian equation in contrast to the output of Simandoux model ($S_{w\_Sim}$) with parameters $a = 1$, $m = 2$, $n = 2$. $R_{sh}$ has been taken to be 2.75 in the upper part and 2.0 $\Omega \cdot m$ in the lower part below 1085.36m so that the cosmetic requirement of avoiding $S_w$ overshoot in $\phi_{eff} = 0$ points can be met with the untruncated output. Choice of average $R_{sh}$ value say 2.5 or 2.75 affects only the maximum of the $S_w$ function at $\phi_{eff} = 0$.

Plot-2: Indonesian $S_w$ ($a = 0.62$, $m = 2.15$, $n = 2$) versus Simandoux $S_w$ ($a = 1$, $m = 2$, $n = 2$).
Application of Saturation Models – Indonesian vs Simandoux

Discussion

When we inadvertently apply the different models to scenarios where it is not applicable, we end up creating a distorted petrophysical characterization. It may be noted that in the above example, the so called tortuosity coefficient \( a \) has a value of unity with Simandoux model while \( a = 0.62 \) with Indonesian equation. Plot-2 gives ample demonstration for the fact that the different models can be calibrated only for the respective \( R_t \) regime and porosity range as discussed earlier vis-a-vis the \( R_m \) value. Table-2 is illustrative of the behavior of the Indonesian and modified Simandoux equation at different \( R_t \) values of 0.11, 0.55 and 1.0 \( \Omega M \) (arbitrary data under assumed conditions of same \( R_i \) and \( \phi_{\text{eff}} \)).

<table>
<thead>
<tr>
<th>( R_t )</th>
<th>( \phi_{\text{eff}} )</th>
<th>( V_{sh} )</th>
<th>Indonesian</th>
<th>Modified Simandoux</th>
<th>Modified Simandoux</th>
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<td>0.5</td>
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<td>1.0</td>
<td>27.24</td>
<td>0.17</td>
<td>0.21</td>
</tr>
</tbody>
</table>

Table-2:
Application of Saturation Models – Indonesian vs Simandoux

Respective plots are shown below: Plot-3: Indonesian equation for different \( R_e \) regimes

![Plot-3](image)

Plot-4: Modified Simandoux equation for different \( R_e \) regimes \((a = 0.62)\). Simandoux model shows a different magnitude trends at differing \( R_e \) and \( V_a \) values.

![Plot-4](image)

Modified simandoux at low \( R_e \) and \( a =1 \) gives nearly the same trend as Indonesian with \( a =0.62 \). Indonesian being applied in wrong \( R_e \) regime demands arbitrary modification to the so called tortuosity constant \( a \).
Re-processing the same sand with a non-linear Shale Function

It is clear from the above discussion that the formation under discussion could have been correctly evaluated using the Simandoux model with \( a = 1 \) instead of \( a = 0.62 \) demanded by the Indonesian equation. \( R_\text{sh} \) used in the above analysis had been 2.4\( \Omega \)m and the conventional processing had used the gamma-ray index as shale function. Data reprocessed with the \( R_\text{sh} \) defined earlier for Simandoux model and the non-linear shale function using Gamma Ray Index (GRI) viz.,

\[
f(V_\text{sh}) = 0.33[2^{GRI} - 1]
\]

is shown in plot-6. Original zone parameters adopted in the region \( a = 0.62, m = 2.15 \) and \( n = 2 \) have been used.

Plot 6

The Simandoux curve without any cosmetic truncation has matched well in poor reservoir but has given improved hydrocarbon content of the order of 10% during intervals 1067-1074m and 1078-1080m. Also, as explained earlier, the change of \( a \) from 0.62 to 1.0 causes the Simandoux output to match the Indonesian \( S_w \) output for \( a = 0.62 \) with an increase of nearly ten percent. This object had produced 24500M\(^3\)/d gas on conventional testing and was the first of its kind in cretaceous sand. Obviously, little field experience must have been there when the sand underwent conventional evaluation as explained earlier with Indonesian equation.

2. Sandstone PX2: Interval CBAA-CBCA

Plot-7 depicts conventional processing in contrast to Simandoux equation without the cosmetic truncation of \( S_w \) in shale. Parameters used are \( R_\text{sh} = 1.4, a = 0.81, m = 2 \) and \( n = 2 \).

Plot 7

Truncation is visible between \( S_w \_\text{Indo} \) and \( S_w \_\text{Ref} \). Simandoux curve apparently overshoots \( S_w \_\text{Ref} \) more than that of Indonesian equation because of the use of average \( R_\text{sh} \) selected for Indonesian equation. Plot-8 depicts the same formation evaluation using \( R_\text{shw} \) i.e. \( R_\text{sh} \) of the respective model for \( S_w = 1 \) and \( \phi_p = 0 \).

Plot 8

It can be inferred from the curves that the average \( S_w \) of the zone is not affected by the use of \( R_\text{shw} \) and so the net pay for any interval shall not be affected. Truncation can be dispensed with and parameters \( a, m \) and \( n \) can be adjusted over wet zones without the risk of fudging the model in the wrong place. Further, it is evident that the use of \( a = 0.81 \) in fact serves only to make the Indonesian equation output equal to that of modified Simandoux at \( a = 1 \) when formation water resistivity is low. On the other hand if we argue that the formation characteristics demanded \( a = 0.81 \) or 0.62, then the formation evaluation using Simandoux suggests the possibility of increase of reserves to the tune of ten percent. In fact the merging of \( S_w \) curves of the Indonesian equation for \( a < 1 \) less than 1 with that of modified Simandoux for \( a = 1 \) for the low \( R_\text{w} \) regime suggest the premises of the origin of the Indonesian equation i.e. Indonesian equation is meant for fresh water formations where the Simandoux may be failing.

Conclusions

Present study leaves us with the following conclusions:

1. In low \( R_\text{w} \) regimes modified Simandoux equation is preferred to Indonesian equation. Also it may be noted that the Simandoux model provides ample scope for customization using non-linear \( V_\text{sh} \) relations, \( R_\text{sh} \) and \( a, m, n \) values.

2. Ascribing \( a < 1 \) to a formation with Indonesian equation lacks any physical connotation in terms of
tortuosity or any other physical characteristic of the formation.

3. First choice in low $R_s$ regimes must be Simandoux model and its variants so that wrong calibration of other models such as Indonesian in terms of $a$, $m$ and $n$ as well as conflict with laboratory studies are avoided.

4. Need for truncation in most cases arise out of incompatibility of $\phi_f$ with average $R_d$ and $\phi_o$ implicit in the model anatomy. Truncation of $S_o$ in shaly segments where $\phi_{eff} = 0$ and calibration of the model in wrong place can be avoided if average $R_{sh}$ can be replaced by $R_{sh0}$ i.e. $R_{sh}$ at $S_o=1$ and $\phi_{eff} = 0$.

5. Use of Indonesian equation in low $R_s$ regime with $a = 0.62$ instead of modified Simandoux equation leads to under estimation of reserves by nearly 10%.

6. Present scenario of the use of softwares which are based on inversion modeling suggests that the concept of $R_{sh0}$ to replace $R_d$ and the need for incorporating a cut off ($\phi_{d0}$) for the effective porosity to avoid irrational cosmetic truncation are yet to gain attention.

References


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Certification

Opinions expressed in this paper are of the author only and ONGC owes no responsibility whatsoever.