CALIBRATION OF A 1-D BASIN MODEL FOR UPPER ASSAM BASIN, INDIA

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ABSTRACT

1-D modelling is concerned with thermal maturity, compaction, petroleum generation and expulsion in a single well. Using an input data comprising of stratigraphy, geothermics, maturity, lithology and kinetic parameters and organic richness of source rock, a 1-D model is able to predict, among other things, cumulative hydrocarbons generated, expelled oil and gas and burial and maturation history of rocks.

This paper presents the results of 1-D modelling of a deep well from Samdang oilfield of Upper Assam basin. Stratigraphic, thermal and lithological data available for the well were used. Kinetic parameters for immature and organically rich source rocks from Barail & Kopili Formation and Lakadong member of Sylhet Formation of the basin were determined using Rock Eval and OPTKIN software. GENEX software was used for modelling. The measured and modelled values of calibration parameters like Tmax, PI, HI and S1/TOC agreed very closely, thereby validating the input data. The model predicted that only C15+ hydrocarbons are generated and expelled by different source rocks in this well. The validated data are now being used for pseudo wells in the depocentres to determine the source rock maturity and hydrocarbon generation in the hydrocarbon kitchen.

KEYWORDS
1-D modelling, Upper Assam basin, kinetic parameters, hydrocarbon generation.

INTRODUCTION

Basin Modelling is a tool used by geoscientists to quantitatively describe complex geological systems. Basin models are used during exploration for prediction of amount of hydrocarbons generated, migrated and accumulated in a basin. Basin modelling can be done in one, two or three dimensions.

1-D modelling is concerned with thermal maturity, compaction, petroleum generation and expulsion in a single well. The outputs of 1-D models for several wells are used for creating 2-D and 3-D models. The input data required for a 1-D model are as follows.

- Stratigraphy i.e. depth and age of formation tops
- Geothermics i.e. measured temperature data or heat flow values for thermal calibration
- Maturity data for calibration of modelled maturity parameters e.g. Rock Eval Tmax or Vitrinite Reflectance
- Lithology type for compaction and
- Kinetic parameters to predict the amount of hydrocarbon generated from a source rock

The conversion of organic matter viz. kerogen to oil is considered a first order reaction (1), (2) & (3). The rate constant, k, of the reaction is given by the Arrhenius equation,
\[ k = A \exp(-E_a/RT) \]

where \( A \) is the frequency factor, \( E_a \) is the activation energy of the reaction, \( R \) is the universal gas constant and \( T \) is the temperature of reaction in Kelvin. The kinetic parameters refer to the set of activation energies, \( E_a \)'s and the frequency factor, \( A \), for a particular kerogen. It is generally assumed that a number of reactions, with different activation energies, take place simultaneously during the breakdown of kerogen, as shown below.

In a five fraction model (4),(5) considered here, degradation of kerogen results in three unstable fractions corresponding to oil viz. \( C_{15}^+ \), \( C_6-C_{14} \) and \( C_2-C_5 \) and two stable fractions, methane (\( C_1 \)) and coke. The three unstable factions further breakdown to produce methane. Thus, there are \( n \) parallel reactions for breakdown of kerogen and three parallel reactions for breakdown of each unstable fraction. The kinetic parameters for standard Type I, II and III kerogen are available in the literature, however, it is advisable to use the kinetic parameters for the kerogen from the basin being modelled, as these parameters give more accurate results.

Kinetic parameters for a source rock are measured in laboratory using Rock Eval (6). This is a pyrolysis instrument, which simulates the natural hydrocarbon generation process. In a standard cycle of the instrument, the source rock sample is first heated at 300\(^\circ\)C for 2 minutes to give \( S_1 \), hydrocarbons present in the rock. It is then heated from 300\(^\circ\)C to 600\(^\circ\)C at a rate of 25\(^\circ\)C/min to give \( S_2 \), residual hydrocarbon generation potential of the rock and \( T_{max} \), a maturity parameter. In addition, it also measures the total organic carbon (TOC) content of the rock and determines parameters like hydrogen index (\( HI = S_2 \times 100/TOC \)) and production index (\( PI = S_1/(S_1+S_2) \)). A source rock is considered organically rich if TOC is more than 2\% and immature to have generated any hydrocarbons if \( T_{max} < 435\(^\circ\)C \). In order to measure the kinetic parameters, the organically rich, immature source rock samples are pyrolysed in Rock Eval at three different heating rates (say, 2\(^\circ\)C/min, 5\(^\circ\)C/min and 15\(^\circ\)C/min) and the pyrolysis curves are used as an input to the kinetics software (1).

Typically, 1-D modelling is first carried out for a drilled well where sufficient data are available for calibration of various parameters. For example, depth and age of formation tops, measured temperature and lithology are generally known for a drilled well. Rock Eval analysis of source rocks yields additional data on their organic richness, maturity and hydrocarbon generation potential. However, since the drilled wells are generally on structural highs, away from hydrocarbon kitchens, the calibrated 1-D model is extended to pseudo wells in depocentres to determine the maturity and hydrocarbon generation in hydrocarbon kitchen. The output of a 1-D model includes the following: burial history curve of each formation, maturity of rocks, porosity of rocks, cumulative hydrocarbons generated, expelled oil and gas, gas:oil ratio, residual hydrocarbons, hydrogen index, production index and expulsion history of each source rock.

This paper describes the 1-D modelling carried out for a deep well in Samdang oilfield of Upper Assam basin.
EXPERIMENTAL

The Upper Assam basin has at least three potential source rocks belonging to Barail Formation (Oligocene), Kopili Formation (Upper to Middle Eocene) and Lakadong member of Sylhet Formation (Lower Eocene). Source rock samples were analyzed using Rock Eval 6 and organically rich and immature rocks (Table I) were selected from each of the formation for determination of kinetic parameters. The samples were extracted in dichloromethane to remove bitumen present in the rocks. Each sample was pyrolysed using Rock Eval 6 at three different heating rates, 2°C/min, 5°C/min and 15°C/min. The pyrolysis data were exported to OPTKIN (Beicip-Franlab, France) software and kinetic parameters viz. distribution of activation energies and the frequency factor were determined. The kinetic parameters along with the well data were used as an input to GENEX (also from Beicip-Franlab, France), the 1-D modelling software. Rock Eval analysis of source rocks from Samdang well was carried out and parameters Tmax, HI, PI and S1/TOC were used for calibrating the model.

RESULTS AND DISCUSSION

Input Data

In Upper Assam basin, the reservoirs are present in Girujan, Tipam and Barail Formation with Girujan also acting as a regional seal. Similarly, Lakadong member of Sylhet Formation is a prolific reservoir with Kopili Formation acting as a seal. Hydrocarbons are also being produced in increasing quantities from Langpar Formation. The Samdang well has been drilled to a depth of 4932 m in to the Langpar Formation of Paleocene age. The stratigraphic and lithologic data for the Samdang well is shown in Table II. Pressure and porosity data used for checking the compaction of sediments is shown in Table III. Measured temperature data used for thermal calibration of the model is shown in Table IV.

The kinetic parameters for the three source rocks viz. SMDBB, KTHKO and CBA7LK from Barail Formation, Kopili Formation and Lakadong member of Sylhet Formation respectively are shown in Figures 1, 2 & 3 respectively. Each of the source rocks shows a broad distribution of activation energies, typical of organic matter with significant terrestrial input. This is consistent with the fact that most of the oils in the basin are of terrestrial origin (7). A five fraction kinetic model, as described above, has been used.

The Barail Formation has been considered as a source as well as reservoir, Kopili Formation as a source and seal whereas Lakadong member of Sylhet Formation as source and reservoir for modelling purpose (Table V). In different formations of Upper Assam basin, organic poor strata alternate with organic rich strata. The source rock thickness considered here is the cumulated thickness of only the organic rich strata and is, therefore, less than the formation thickness. The initial TOC modeled here also corresponds to the organically rich strata only. The expulsion saturation is the fraction of pore volume that must be occupied by petroleum for expulsion to begin. Both initial TOC and the expulsion saturation have been determined by trial and error so that the present day HI, PI and S1/TOC match with the modelled values. The geochemical data from Samdang well, used for maturity, kinetic and expulsion calibration of the model, is shown in Table VI.
**Output Results**

Using the above input data, the 1-D basin model was prepared using GENEX. Figure 4 shows the burial history curve for modeled well. Erosion has not been considered during the entire sedimentation history of the basin as there is no evidence of significant erosion. Since no rock layer has experienced overpressure in this well, the fluid pressure is a function of burial and is equal to the hydrostatic pressure. Figure 5 shows the fluid pressure versus depth curve. The measured bottom hole pressure of 45.14 MPa (Table III) at a depth of 4712 m matches very closely with the modeled pressure. Due to compaction the porosity of each formation decreases with depth and follows the $1/Z$ law. The variation of porosity is different for different rocks and depends on its lithology. Figure 6 shows the variation of porosity versus depth as determined by the model. The measured value of porosity of 6% (Table III) at a depth of 4712 m matches closely with modeled value.

The present day measured temperatures are used for thermal calibration of the model. Any discrepancy between calculated and measured temperature is due to incorrect values of thermal conductivities, radiogenic heat flow and bottom heat flow. In this model, default values of radiogenic heat flow and thermal conductivity have been taken and bottom heat flow has been calculated after thermal calibration. The measured (Table IV) and calculated temperatures are in agreement as evidenced by the temperature versus depth curve (Figure 7), thus validating the thermal calibration. Using this thermal calibration, heat flow versus depth is calculated (Figure 8). A heat flow value of approximately 35 mW/m$^2$ is obtained at the bottom of the sedimentary column.

Variation of maturity parameter Tmax with depth (Figure 9) is used to check the accuracy of maturity thermal reconstruction and kinetic reconstruction. The measured Tmax values (Table VI) are in close agreement with values calculated by the model for both Kopili Formation and Lakadong member of Sylhet Formation. This confirms that both the thermal data for the well and the kinetic parameters determined for these source rocks are correct. However, there is a difference of about 7ºC in the measured and calculated Tmax values for Barail Formation. Since thermal data are same for both Barail Formation and deeper formations and a good match has been obtained for measured and calculated values of Tmax for the latter, the thermal data is accurate. Kinetic parameters have been determined separately for the source rocks from three formations and it is likely that kinetic parameters for Barail Formation are not very accurate. However, as we shall see later, this difference in Tmax values is insignificant for correctly modelling hydrocarbon generation.

HI is a measure of the residual hydrocarbon generation potential of the source rock at the level of thermal stress to which it has been exposed. Like Tmax, the variation of HI is different for source rocks with different kinetic parameters, for similar thermal stress. Thus, variation of HI with depth is used for checking the accuracy of both thermal reconstruction and the kinetic reconstruction. Figure 10 shows the modeled variation of HI with depth where measured values of HI (Table VI) have also been marked. It can be seen that model has been able to predict fairly accurately the actual HI values of the source rocks. The ratio $S_1$/TOC is used to reconstruct expulsion and organic richness. Figure 11 shows the plot of $S_1$/TOC versus depth. By trial and error, the expulsion saturation for the source rocks were set at 5%, 10%, 2% and 10% and initial TOC contents were set at 4.0%, 30.0%, 2.5% and 10% for Barail 1/3, Barail 4/8, Kopili and Lakadong source rocks respectively (Table V). Using these values of expulsion saturation
and initial TOC content, the modeled values of S_i/TOC match very closely with measured values of 11.1, 14.1 and 20.6 at depths of 3641m, 4190m and 4826m respectively (Table VI). PI is a further check on maturity, expulsion saturation and initial TOC content of the source rock. Figure 12 shows the variation of PI with depth. The measured values at three depths (Table VI) are also plotted. It can be seen that all the parameters have been correctly set resulting in close agreement between measured and calculated values.

Thus, it can be seen that the 1-D model has been properly calibrated using stratigraphic and lithological data, pressure and porosity data, thermal data, kinetic parameters specific to the source rocks and geochemical data. After calibration, the model is able to determine amount and type of hydrocarbons generated and expelled by the source rocks, generation and expulsion history of the source rock and the residual hydrocarbons present in the source rock.

Figure 13 shows the total hydrocarbons generated by each source rock. All the source rocks including the most mature Lakadong source rock (Tmax ~ 451°C) have generated only the C_{15+} fraction (denoted by blue color). Further cracking of C_{15+} fraction to lighter hydrocarbons has not yet taken place. Figure 14 shows the amount of hydrocarbons expelled by each source rock. Lakadong source rock has generated more than 32 mg/g and expelled around 29 mg/g of hydrocarbons. Kopili source rock has generated 3 mg/g and expelled around 2 mg/g of hydrocarbons. Barail has generated 8 mg/g and expelled 6 mg/g of hydrocarbons. Thus, even though Barail source rock is very rich with good hydrocarbon generation potential, it has not generated and expelled significant amount of hydrocarbons at this depth. Kopili source rock is neither organically rich nor does it have good hydrocarbon generation potential. Lakadong source rock has generated and expelled substantial amount of hydrocarbons. The difference of total and expelled hydrocarbons is the residual hydrocarbons that are still present in the rock. The S_i value, as measured by Rock Eval, corresponds to roughly half of the calculated residual hydrocarbons. This is because of evaporation losses before the measurement. Figure 15 shows the residual hydrocarbons for different source rocks which roughly match with half of determined S_i values (Table VI).

Expulsion history plot is particularly useful for explorationist as one can determine the amount and type of hydrocarbons expelled in different time slices. One of the important criteria for a trap to be filled up is that the trap formation must have taken place before the expulsion of hydrocarbons started. Thus, using this plot and history of trap formation, the amount of hydrocarbons accumulated in a trap can be determined. Figures 16, 17 & 18 show the history of expelled hydrocarbons for Lakadong, Kopili and Barail source rocks. The expulsion of hydrocarbons started about 23 MY back for Lakadong source rock and so far a cumulated amount of 29 mg/g of hydrocarbons have been expelled. Similarly, for Kopili and Barail Formations, expulsion started 8 & 9 MY back respectively and they have expelled 2 & 6 mg/g of cumulated hydrocarbons respectively.

CONCLUSIONS

A 1-D model has been prepared and calibrated for Assam basin using data from a deep well. The kinetic parameters for the three different source rocks of Assam basin namely Barail, Kopili and Lakadong have been determined using Rock Eval analysis and OPTKIN software. Stratigraphic, geochemical, pressure and temperature data for a deep well from Samdang area has been taken for thermal, maturity and hydrocarbon generation calibration. After running the model using GENEX software, parameters like heat flow, expulsion saturation, initial TOC of source rocks were
suitably determined. The 1-D model has now been calibrated and is able to correctly predict the amount of hydrocarbons generated and expelled from different source rocks and also the history of hydrocarbon generation and expulsion. Extending this model to pseudo wells in the depocentre of the basin will help in determining the maturity and hydrocarbon generation in the Kitchen area. The output 1-D model can be used to prepare 2-D and 3-D models.

REFERENCES


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Table I: Rock Eval analysis results of source rocks used for determination of kinetic parameters

<table>
<thead>
<tr>
<th>Sample</th>
<th>Formation</th>
<th>S1 (mg/g)</th>
<th>S2 (mg/g)</th>
<th>Tmax (ºC)</th>
<th>TOC (%)</th>
<th>HI</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMDBB</td>
<td>Barail</td>
<td>3.33</td>
<td>152.96</td>
<td>421</td>
<td>48.79</td>
<td>314</td>
<td>0.02</td>
</tr>
<tr>
<td>KTHKO</td>
<td>Kopili</td>
<td>0.70</td>
<td>33.61</td>
<td>412</td>
<td>15.78</td>
<td>213</td>
<td>0.02</td>
</tr>
<tr>
<td>CBA7LK</td>
<td>Lakadong</td>
<td>6.46</td>
<td>109.63</td>
<td>423</td>
<td>26.17</td>
<td>419</td>
<td>0.06</td>
</tr>
</tbody>
</table>
### Table II: Stratigraphic and Lithologic data for Samdang Well

<table>
<thead>
<tr>
<th>Age</th>
<th>Formation</th>
<th>Lithology</th>
</tr>
</thead>
</table>
| Pleistocene | Alluvium  | Sand – 80%  
Shale – 20% |
| Pliocene  | Dhekiajuli | Sand – 80%  
Shale – 20% |
|          | Namsang   | Sand – 60%  
Shale – 40% |
| Miocene   | Girujan   | Sand – 20%  
Shale – 80% |
|          | Tipam     | Sand – 90%  
Shale – 10% |
| Oligocene | Barail 1/3| Sand – 20%  
Shale – 80% |
|          | Barail 4/8| Sand – 85%  
Shale – 15% |
| Eocene    | Kopili    | Sand – 20%  
Shale – 60%  
Silt – 20% |
|          | Sylhet    | Shale – 70%  
Limestone – 30% |
|          | Lakadong  | Shale – 65%  
Sand – 25%  
Limestone – 10% |
| Palaeocene| Langpar   | Shale – 65%  
Sand – 30%  
Limestone – 5% |

### Table III: Porosity & Pressure Data for Samdang Well

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Pressure (MPa)</th>
<th>Porosity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4712.0</td>
<td>45.14</td>
<td>6.0</td>
</tr>
</tbody>
</table>

### Table IV: Thermal Data for Samdang Well

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Temp (ºC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2113.0</td>
<td>75.0</td>
</tr>
<tr>
<td>4565.9</td>
<td>124.4</td>
</tr>
</tbody>
</table>

### Table V: Source rock input data for Samdang Well

<table>
<thead>
<tr>
<th>Formation</th>
<th>Source Rock</th>
<th>Initial TOC (%)</th>
<th>Source Rock Thickness (m)</th>
<th>Expulsion Saturation (%)</th>
<th>Petroleum History</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barail 1/3</td>
<td>SMDBB</td>
<td>4.0</td>
<td>50</td>
<td>5.0</td>
<td>Source + Reservoir</td>
</tr>
<tr>
<td>Barail 4/8</td>
<td>SMDBB</td>
<td>30.0</td>
<td>120</td>
<td>10.0</td>
<td>Source + Reservoir</td>
</tr>
<tr>
<td>Kopili</td>
<td>KTHKO</td>
<td>2.5</td>
<td>15</td>
<td>2.0</td>
<td>Source + Seal</td>
</tr>
<tr>
<td>Lakadong</td>
<td>CBA7LK</td>
<td>10.0</td>
<td>64</td>
<td>10.0</td>
<td>Source + Reservoir</td>
</tr>
</tbody>
</table>

### Table VI: Geochemical data for Samdang Well

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>$S_1$ (mg/g)</th>
<th>$S_2$ (mg/g)</th>
<th>Tmax (ºC)</th>
<th>TOC (%)</th>
<th>$S_1$/ TOC</th>
<th>HI</th>
<th>PI</th>
</tr>
</thead>
<tbody>
<tr>
<td>3641</td>
<td>2.56</td>
<td>83.49</td>
<td>416</td>
<td>23.06</td>
<td>11.1</td>
<td>362</td>
<td>0.03</td>
</tr>
<tr>
<td>4190</td>
<td>0.22</td>
<td>2.26</td>
<td>429</td>
<td>1.56</td>
<td>14.1</td>
<td>146</td>
<td>0.09</td>
</tr>
<tr>
<td>4826</td>
<td>0.86</td>
<td>6.73</td>
<td>451</td>
<td>4.17</td>
<td>20.6</td>
<td>161</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Figure 1: Distribution of activation energies for source rock from Barail Formation

Figure 2: Distribution of activation energies for source rock from Kopili Formation

Figure 3: Distribution of activation energies for source rock from Lakadong member of Sylhet Formation

Figure 4: Burial history curve for Samdang well

Figure 5: Variation of modeled pressure with depth

Figure 6: Compaction of sediments of different lithologies with burial
Figure 7: Measured temperature used for thermal calibration

Figure 8: Heat flows calculated from thermal calibration

Figure 9: Variation of Tmax with depth used for maturity and kinetic calibration

Figure 10: Variation of HI with depth used for maturity and kinetic calibration

Figure 11: S1/TOC used for expulsion calibration

Figure 12: PI used for maturity & expulsion calibration
Figure 13: Total hydrocarbons generated by each source rock

Figure 14: Hydrocarbons expelled by each source rock

Figure 15: Residual hydrocarbons present in each source rock

Figure 16: Expulsion history of Lakadong source rock

Figure 17: Expulsion history of Kopili source rock

Figure 18: Expulsion history of Barail source rock