UNCERTAINTY EVALUATION OF DYNAMIC RESERVOIR PARAMETER
ON MODERN DECLINE TYPECURVE ANALYSIS

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Diajukan sebagai salah satu syarat untuk
mendapatkan gelar
SARJANA TEKNIK
pada Program Studi Teknik Perminyakan

PROGRAM STUDI TEKNIK PERMINYAKAN
FAKULTAS ILMU KEBUMIAN DAN TEKNOLOGI MINERAL
INSTITUT TEKNOLOGI BANDUNG
2008
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Disetujui oleh:
Dosen Pembimbing Tugas Akhir,
Tanggal……………………………..

(Dr. Ir. Taufan Marhaendrajana)
Abstract

Mostly modern decline typecurves analysis were developed using several assumptions such as radial model – cylindrical reservoir with the well in the center of reservoir, constant rock properties – homogeneous reservoir and isotropic, constant fluid properties, and radial composite model for water drive mechanism (edge water system). Unfortunately, in fact, many things did not meet the assumptions such as one of the assumptions is fluid properties, especially oil compressibility. Oil compressibility always changes as the pressure decrease during production, mainly if the pressure decrease below bubble point, there will be significant changes in oil properties. Consequently, that issue which is becoming one of the uncertainties in this method could lead an erroneous result in the analysis and interpretation of modern decline typecurves in reservoir fluid in-place calculation.

This paper focuses on evaluating oil compressibility at certain point of pressure which has significantly changes to improve the accuracy of reservoir fluid in place on modern decline typecurves analysis, Blasingame typecurve analysis, using RTA™ at certain condition of reservoir (undersatured, saturated, and combination) and certain driving mechanism of reservoir (solution gas drive and bottom-water drive), which had been simulated using CMG™.

Keywords: Bubble-Point Pressure, Initial Pressure, Oil Compressibility, Typecurve, IOIP (N)

*) Petroleum Engineering Student – Institut Teknologi Bandung

I. Introduction

Since JJ Arps introduced traditional decline curve analysis which defined as graphical procedure used for analyzing declining production rates and forecasting future performance of oil and gas wells, implicitly assume constant operating condition and derived from empirical – no theoretical basis – observations of the production performance of oil and gas wells, is still continuously improved from Fetkovich typecurve, which developing previous decline analysis was only applicable at boundary dominated flow became typecurves encompass entire production life by adding analytical equation to generate transient typecurve combined to boundary dominated typecurve, until become modern production decline typecurve which has been used not only for forecasting future performance of oil and gas wells but also calculating reservoir fluid in place and reservoir properties by incorporating the effect of flowing pressure in well performance analysis, using material balance time which can convert constant pressure solution into constant rate solution and combining production analysis and pressure transient analysis – using pressure transient theory (radius of investigation, transient flow, and boundary dominated flow)\(^7\).

Due to combining production analysis and pressure transient analysis, modern decline typecurves analysis used almost the same assumptions with that analysis which are homogeneous, isotropic and constant fluid properties. In fact, reservoir did not meet those assumptions. There are many uncertainties in the reservoir such as anistropic, heterogeneity, oil properties and dynamic condition of reservoir which always changes as the pressure decrease from initial pressure. Those uncertainties, especially oil properties – so-called dynamic reservoir parameter, could lead an erroneous in the analysis and interpretation of modern decline typecurves especially in calculating reservoir fluid in place.

II. Objective

The objectives of this paper are to:

1. To evaluate uncertainty of dynamic reservoir parameter, oil compressibility at several points of pressure to know its influence on application of modern decline typecurve analysis.
2. To determine which point of pressure that could improve result of modern decline typecurve analysis.
III. Basic Theory

Modern Production Decline typecurves analysis/interpretation, for example agarwal-gardner typecurve, blasingame typecurve (main concern), NPI typecurve, Flowing Material Balance and Transient typecurve, has been developed for more than a decade and used as an alternative tools to determine skin, reservoir property, fracture length and reservoir fluid in place.

Becoming alternative tool, modern production decline typecurves could be used to determine permeability of reservoir and skin by using transient match. Besides, modern production decline typecurve also can be used to determine either oil or gas in place and drainage area of reservoir by using boundary dominated match.

Basically, modern production decline typecurves analysis were developed by incorporating the effect of flowing pressure in performance analysis, using pressure transient theory – radius of investigation, transient flow and boundary dominated flow, and relying on the equivalence between constant rate and constant pressure solutions. Also, in modern production decline analysis introduced superposition in time which emerged material balance time.

Material balance time had improved the development of production decline analysis because it can work well to account the changing of flowing well pressure and can convert the constant pressure solution into constant rate solution which widely used in the field of well testing.

Principally, the concept of material balance time is defined as the ratio of cumulative production, Q, to instantaneous rate, q, see Equation 1:

\[ t_p = \frac{Q}{q} \]  

(1)

It is the value of the time that well would have to flow at the current rate in order to produce the same amount of fluid – that is why called material balance principle, see Figure 1.

Here, below (3.1 to 3.6), are the brief explanations about several modern production decline typecurves and one of dynamic parameter – oil compressibility.

3.1 Blasingame Typecurve

Blasingame typecurve was developed fetkovich typecurve, radial model Figure 2, to account for variations in bottom-hole pressure and changing gas PVT properties. This method uses a form of superposition time function, so-called material balance time which only requires one depletion stem for typecurve matching, harmonic stem – which represent boundary dominated flow to calculate fluid in place.

The used of superposition time had led an improvement of fetkovich typecurve. When the typecurves are plotted using blasingame’s superposition time function, the analytical exponential stem of the fetkovich typecurves becomes harmonic. Also blasingame typecurves allow depletion at constant pressure to appear as pseudo steady-state depletion at constant rate. In other words, the usage of material balance time forces boundary dominated data to fall only on the analytical harmonic stem. Further improvement of blasingame on fetkovich typecurves is introducing two additional typecurves, rate integral and rate integral derivative, which are plotted simultaneously to get unique match.

Blasingame typecurves have identical format with fetkovich typecurve. However, there are three differences:

1. Models are based on constant rate solution.
2. Exponential and Hyperbolic stems are absent only harmonic stem is plotted.
3. Rate Integral and Rate Integral – derivative typecurve are used to simultaneous typecurve.

The data which plotted on the blasingame typecurves are normalized rate \(\frac{q}{\Delta p}\) vs material balance time. Blasingame typecurves have three sets of typecurves, see Figure 3, as follows:

1. Rate Normalized
2. Rate Integral
3. Rate Integral Derivative

3.2 Water Drive Model

Model for reservoirs under the influence of active water encroachment can be classified as follows:

1. Steady State Models (Schiltuis)
2. Pseudo Steady-State Models (Fetkovich)
3. Single Phase Transient Models
   a. Infinite Aquifer
   b. Finite Aquifer
4. Modified Transient Models
   a. Moving Saturation Front Approximations
   b. Two Phase Flow Approximations

In this paper used single phase transient models which have several assumptions as follows:

- An Infinite acting aquifer with a stationary boundary.
- Radial composite model (radial edge water drive systems), see Figure 4.
- Ideal for very large aquifer of low to moderate mobility.
- Designed for Early-Time Analysis
- Water Influx is not calculated, reservoir material balance is not corrected.

3.3 Oil Compressibility

The coefficient of isothermal compressibility of oil, so called oil compressibility, has two different definitions divided by pressure. At pressure above the bubble-point pressure, the definition of oil compressibility is the same exactly as the coefficient of isothermal compressibility of gas. At pressure below bubble-point, an additional term must be added to the definition because there is gas evolve from oil.

The definition of oil compressibility above the bubble point pressure is the fractional change in volume of a liquid as pressure is changed at constant temperature, Equation 2:

$$c_o = -\frac{\frac{dV}{V} \cdot (\frac{1}{P_T})}{P_T}$$

(2)

The relationship of oil compressibility to pressure for typical black oil at constant temperature is shown in Figure 5. Black oil compressibility is slightly constant at pressure above the bubble-point except at pressure near the bubble-point. Figure 5 also shows the relationship of oil compressibility below the bubble-point. At pressure below the bubble-point where the situation is much different, the volume of reservoir liquid decreases as pressure is reduced because so many gas evolve from oil. Thus, at reservoir pressures below the bubble point, the total change in volume is the sum of change in liquid volume and the change in free gas volume which represented by Equation 3:

$$c_o = -\frac{1}{\rho_l} \left[ \frac{\frac{dV}{V} \cdot (\frac{1}{P_T})}{P_T} - \frac{1}{\rho_g} \left( \frac{\frac{dV}{V} \cdot (\frac{1}{P_T})}{P_T} \right) \right]$$

(3)

However, there is a discontinuity at the bubble point which indicated the evolution of the first bubble of gas causes a large shift in the value of compressibility.

Commonly, typecurves are developed with several assumptions. One of the assumptions is rock and fluid properties are constant, mainly for oil. In fact, fluid and rock properties are always change as fluid produced and pressure decreased, although rock properties are negligible because no significant change. Those assumptions could lead an erroneous to result of calculation, especially fluid in-place.

According to that problem, this paper evaluates the uncertainty of dynamic reservoir parameter, in this case is oil compressibility, to improve the quality of calculation result on using modern decline typecurve.

IV. Case Study

In order to evaluate the uncertainty of dynamic reservoir parameter, several data from simulated data cases were applied on modern decline typecurve analysis. In the application of each modern decline typecurve, those data have two models of driving mechanism (solution gas drive and bottom-water drive), three models of reservoir condition (saturated, under-saturated, and combination both of them) which determined by reservoir pressure whether above or below bubble-point and its minimum bottom hole pressure (BHP). Then, those data were evaluated at several points of pressure such as initial pressure and bubble point pressure. Due to oil compressibility has discontinuity at bubble point pressure, the uncertainty evaluation of dynamic reservoir parameter were done at the point in the range of discontinuity of oil compressibility. Eventually, from several uncertainty evaluation, there are several point could be inferred as point where should be evaluated.

All of simulated data were evaluated on modern decline typecurve analysis, Blasingame Analysis, using commercial software RTATM (Rate Transient Analysis) demo version which created by Fekete Associates Inc.

4.1 Simulated Data Cases

Models were created to evaluate the uncertainty of dynamic reservoir parameter on modern decline typecurve analysis.

Models used radial cylindrical reservoir with single well in the center of reservoir, see Figure 6, which generated by simulator CMG™. It used 500 grid blocks to model reservoir performance in ten-layer reservoir with homogeneous and isotropic, Figure 7 shows 3-D view of cylindrical reservoir model.

Models were divided into two models according to reservoir driving mechanism. Each reservoir driving mechanism was divided into three conditions of reservoir determined by reservoir pressure and bubble point pressure, as follows:

1. Under-saturated condition ($P_{res} = 3999 \text{ psi} > P_B = 2000 \text{ psi}$ with minimum BHP = $P_B = 2000 \text{ psi}$)
2. Saturated condition ($P_{res} = P_B$ – initially saturated = 3999 psi with minimum BHP = 600 psi)
3. Combination ($P_{Res} = 3999$ psi $> P_B = 2000$ psi with minimum BHP below bubble point pressure $= 600$ psi)

The pertinent data of reservoir rock and fluid properties are summarized below.

**Reservoir Rock Properties, Aquifer Properties, Fluid Properties, and Production Time.**

Reservoir Properties:
- Wellbore radius, $r_w = 0.25$ ft
- Drainage radius, $r_e = 740$ ft
- Net pay thickness, $h = 10$ ft
- Porosity ($\phi$), percent $= 20\%$
- SW,Irr , percent $= 20\%$
- Formation permeability $= 1$ mD
- Area, $A = 39.5$ acre
- Temperature, $T = 180$ F
- Rock compressibility, $1/\text{psi} = 3.647 \times 10^{-6}$
- Bubble Point (undersat’d’) $= 2000$ psi
- Bubble Point (sat’d) $= 3999$ psi
- Bubble Point (combination) $= 2000$ psi
- All layers were perforated (Figure 8)

Aquifer Properties:
- Porosity, ($\phi$) $= 20\%$
- Radius, ft $= 400$ ft
- Permeability, mD $= 1$ mD
- Thickness, ft $= 10$ ft
- Model carter – tracy (infinite acting)
- Leakage is allowed

Fluid Properties:
- Oil gravity, API $= 30$
- SG gas $= 0.7$
- Water salinity, ppm $= 50000$

Production parameter:
- Initial reservoir pressure, psi $= 3999$ psi
- Production time $= 3000$ days
- Minimum BHP (saturated) $= 600$ psi
- Min BHP (undersaturated) $= 2000$ psi
- Min BHP (combination) $= 600$ psi

**Modern decline typecurve analysis results:**

Production data and bottom-hole data were analyzed and calculated using modern decline typecurve analysis. The results of calculation are permeability, skin, area, and initial oil in place (IOIP). Results of modern decline typecurve analysis was compared to several point of pressure – initial - bubble point and point in the range of discontinuity of oil compressibility for undersaturated and combination and initial pressure (bubble-point) and point in the range of discontinuity of oil compressibility for saturated. Equation for calculation results of modern decline typecurve analysis, blasingame typecurve, can be seen at Appendix A.

The way to analyze production data using RTA™ is to move the data over the top of the “family of typecurves” which consist of three sets of typecurve – normalized rate, integral, and derivative until the data points match one of the typecurves as closely as possible. In attempting to obtain the best possible match, data point was moved and matched not only one typecurve but also consider three sets of typecurve (normalized rate, integral, and derivative).

**Solution Gas Drive**

**Undersaturated condition**

Production data history during 3000 days could be seen at Figure 9. Total compressibility was calculated with equation 4.

$$\frac{c_2}{c_1} = \frac{c_1}{c_2} + (c_2 \times S_n) = (c_1 \times S_n)$$

Oil compressibility which is one of the dynamic reservoir parameter changes as pressure decrease during production from initial to current pressure at bubble point and its changing influences application of modern decline curve, Figure 10 show the relationship of oil compressibility to pressure at several points.

Modern decline typecurves matched for solution gas drive at undersaturated could be seen at Figure 11. Basically, in solution gas drive models were quite easy to match the production data points over family of three sets typecurves because the same radial model. In solution gas drive mechanism, at undersaturated condition, there were evaluated at three points of pressure – initial, bubble, and in the middle between initial and bubble point. The results, Table 2, show to us that analysis done at initial and mid initial-bubble point (3000 psi) pressure had large differences or error between IOIP (N) from simulator output and modern decline analysis, see Figure 12.

So, the evaluation was done at bubble point. There was significant improvement of modern decline results, see Table 2 especially
IOIP (N) calculation had acceptable error (<10%) see Figure 12.

Table 1 – Dynamic parameter at Undersaturated condition for SGD

<table>
<thead>
<tr>
<th>Condition</th>
<th>Co</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>6.83E-06</td>
<td>1/psi</td>
</tr>
<tr>
<td>Bubble</td>
<td>1.37E-05</td>
<td>1/psi</td>
</tr>
<tr>
<td>Mid initial – bubble</td>
<td>9.11E-06</td>
<td>1/psi</td>
</tr>
</tbody>
</table>

Table 2 – Result of undersaturated condition for SGD

<table>
<thead>
<tr>
<th>Co</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubble - early</td>
<td>1.22E-05</td>
</tr>
<tr>
<td>Bubble - end</td>
<td>1.26E-04</td>
</tr>
<tr>
<td>Bubble - 0.1</td>
<td>1.62E-05</td>
</tr>
</tbody>
</table>

Saturated condition

Production data history for this condition could be seen at Figure 13. During production, oil compressibility changes from initial pressure (initially saturated) to current pressure, 600 psi. Figure 14 shows the discontinuity of oil compressibility where evaluated was done, see Table 3. Modern decline typecurve matched could be seen at Figure 15.

At saturated condition, the results were almost the same as at undersaturated. The analysis evaluated at the early and the end of discontinuity had large differences (error) between modern decline results, Table 4 and simulator output in IOIP (N), see Figure 16. The early discontinuity had higher results in IOIP and the end discontinuity had lower result in IOIP, see Table 4. So, the analysis was done in the range of discontinuity to get better results of calculation. After trial and error, there was a point which can improve results of calculation, had acceptable error (<10%) at IOIP (N), see Figure 16. That point was at the 1/10 of discontinuity length.

Table 3 – Dynamic parameter at saturated condition for SGD

<table>
<thead>
<tr>
<th>Condition</th>
<th>Co</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubble - early</td>
<td>1.22E-05</td>
<td>1/psi</td>
</tr>
<tr>
<td>Bubble - end</td>
<td>1.26E-04</td>
<td>1/psi</td>
</tr>
<tr>
<td>Bubble - 0.1</td>
<td>1.62E-05</td>
<td>1/psi</td>
</tr>
</tbody>
</table>

Table 4 – Result of Saturated condition for SGD

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>0.57</td>
<td>0.22</td>
<td>39.5</td>
</tr>
<tr>
<td>Bubble</td>
<td>0.57</td>
<td>0.21</td>
<td>3.4</td>
</tr>
<tr>
<td>0.1</td>
<td>0.57</td>
<td>0.23</td>
<td>20.4</td>
</tr>
</tbody>
</table>

Combination

Figure 17 shows production data history for solution gas drive at combination condition. Modern decline typecurve matched could be seen at Figure 18. The pressure changes from initial through bubble point until current pressure, 600 psi. However, the evaluations were evaluated at initial and bubble, see changes of dynamic reservoir parameter at Table 5.

At combination condition – the condition that came from undersaturated condition to saturated condition – had good results of analysis and calculation of IOIP (N) at initial pressure see Table 6 for result of calculation and Figure 19 for comparison or error - because modern decline result had approached the result from simulator output. It could be good analyzed at initial pressure because it has the same assumption with blasingame model.

Table 5 – Dynamic parameter at combination condition for SGD

<table>
<thead>
<tr>
<th>Co</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>6.84E-06</td>
</tr>
<tr>
<td>Bubble</td>
<td>1.37E-05</td>
</tr>
</tbody>
</table>

Table 6 – Result of combination condition for SGD

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CMG</td>
<td>1</td>
<td>0</td>
<td>39.5</td>
</tr>
<tr>
<td>Initial</td>
<td>0.46</td>
<td>1.34</td>
<td>22.5</td>
</tr>
<tr>
<td>Bubble - early</td>
<td>0.46</td>
<td>1.6</td>
<td>14.5</td>
</tr>
</tbody>
</table>
**Bottom Water Drive**

**Undersaturated condition**

Production data history for bottom water drive at undersaturated condition could be seen at Figure 20. The pressure changes from initial to bubble point as minimum BHP. The oil compressibility was evaluated at several points, Table 7. Figure 21 shows the discontinuity of oil compressibility and show the quarter of discontinuity where evaluation was done. Modern decline typecurve matched could be seen at Figure 22.

In the analysis of production data from bottom water drives, those data points were quite difficult to match data points all over three sets of typecurves especially derivative typecurve. However, normalized rate and integral typecurve were easy to match data points over those typecurves. The possibility of unmatched data points with typecurve came from the basic assumption of typecurve used radial composite model that represent edge-water drive system while simulated model using bottom water drive system.

At undersaturated condition, once again that the assumptions of constant fluid properties could lead an erroneous analysis and calculation results. Three points, initial, early bubble, quarter of bubble, and end of bubble, were evaluated and had large differences (error) results between modern decline and simulator in calculation of IOIP, see Table 8 and Figure 23. However, at the point – middle of discontinuity – had improved the analysis and calculation or had smaller errors in calculation of IOIP (N), see Figure 23.

### Table 7 – Dynamic parameter at undersaturated condition

<table>
<thead>
<tr>
<th></th>
<th>Co</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>6.83E-06</td>
<td>1/psia</td>
</tr>
<tr>
<td>Bubble - early</td>
<td>1.37E-05</td>
<td>1/psia</td>
</tr>
<tr>
<td>Bubble - end</td>
<td>2.32E-04</td>
<td>1/psia</td>
</tr>
<tr>
<td>Bubble - middle</td>
<td>5.69E-05</td>
<td>1/psia</td>
</tr>
<tr>
<td>Bubble - quarter</td>
<td>2.83E-05</td>
<td>1/psia</td>
</tr>
</tbody>
</table>

**Saturated Condition**

Production data history for bottom water drive at saturated condition could be seen at Figure 24 and modern decline type curve matched could be seen at Figure 25.

At saturated condition, the pressure changes from initial pressure, initially saturated due to the same with bubble point, were evaluated at initial pressure (bubble point) – the early, the quarter, the middle, and the end of discontinuity, see Table 9 for dynamic parameter data. The evaluation at the quarter of discontinuity had good results in IOIP (N) calculation which was showed by acceptable error - see Figure 26 and Table 10. The other evaluation had large differences with model, Figure 26.

### Table 8 – Results of undersaturated condition for BWD

<table>
<thead>
<tr>
<th></th>
<th>K (md)</th>
<th>S</th>
<th>A (ac)</th>
<th>N (MSTB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMG</td>
<td>1</td>
<td>0</td>
<td>40</td>
<td>215</td>
</tr>
<tr>
<td>Initial</td>
<td>0.53</td>
<td>0.53</td>
<td>114</td>
<td>1204</td>
</tr>
<tr>
<td>Bubble - early</td>
<td>0.53</td>
<td>0.75</td>
<td>73</td>
<td>768</td>
</tr>
<tr>
<td>Bubble - end</td>
<td>0.53</td>
<td>2</td>
<td>6</td>
<td>62</td>
</tr>
<tr>
<td>Bubble - middle</td>
<td>0.53</td>
<td>1.4</td>
<td>20</td>
<td>207</td>
</tr>
<tr>
<td>Bubble - quarter</td>
<td>0.53</td>
<td>0.98</td>
<td>46</td>
<td>484</td>
</tr>
</tbody>
</table>

### Table 9 – Dynamic parameter at saturated condition

<table>
<thead>
<tr>
<th></th>
<th>Co</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial - early</td>
<td>1.22E-05</td>
<td>1/psi</td>
</tr>
<tr>
<td>Initial - end</td>
<td>1.26E-04</td>
<td>1/psi</td>
</tr>
<tr>
<td>Bubble - mid</td>
<td>4.10E-05</td>
<td>1/psi</td>
</tr>
<tr>
<td>Bubble - quarter</td>
<td>2.30E-05</td>
<td>1/psi</td>
</tr>
</tbody>
</table>

### Table 10 – Result of Bottom water drive at saturated condition

<table>
<thead>
<tr>
<th></th>
<th>K (md)</th>
<th>S</th>
<th>A (ac)</th>
<th>N (MSTB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMG</td>
<td>1</td>
<td>0</td>
<td>39.5</td>
<td>172.3</td>
</tr>
<tr>
<td>Early</td>
<td>0.3</td>
<td>3.9</td>
<td>30.0</td>
<td>263.0</td>
</tr>
<tr>
<td>End</td>
<td>0.3</td>
<td>4.9</td>
<td>3.9</td>
<td>34.6</td>
</tr>
<tr>
<td>Mid</td>
<td>0.3</td>
<td>4.3</td>
<td>12.0</td>
<td>106.5</td>
</tr>
<tr>
<td>Quarter</td>
<td>0.3</td>
<td>4.0</td>
<td>19.9</td>
<td>174.3</td>
</tr>
</tbody>
</table>
Combination

Production data history for bottom water drive at combination condition could be seen at Figure 27 and modern decline type curve matched could be seen at Figure 28. The pressure changes form initial through bubble until minimum BHP at 600 psi. At combination condition was evaluated at initial pressure and bubble point – the early of discontinuity (see Table 11 for dynamic data parameter). The first evaluation, at initial pressure, had good result in calculation of IOIP (N) because had lowest error, see Table 12 and Figure 29. However, the second evaluation – bubble point, the early of discontinuity – also had large error in IOIP (N) calculation. At combination both of solution gas drive and bottom water drive had same point of evaluation which has good result.

Table 11 – Dynamic parameter for BWD at combination condition

<table>
<thead>
<tr>
<th></th>
<th>Co</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>6.80E-06</td>
<td>1/psi</td>
</tr>
<tr>
<td>Bubble point</td>
<td>1.37E-05</td>
<td>1/psi</td>
</tr>
</tbody>
</table>

Table 12 – Result of BWD at combination condition

<table>
<thead>
<tr>
<th></th>
<th>K (md)</th>
<th>S</th>
<th>A (ac)</th>
<th>N (MSTB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMG</td>
<td>1</td>
<td>0</td>
<td>40</td>
<td>215</td>
</tr>
<tr>
<td>Initial</td>
<td>0.6</td>
<td>3.7</td>
<td>21</td>
<td>220</td>
</tr>
<tr>
<td>Bubble</td>
<td>0.6</td>
<td>3.9</td>
<td>14</td>
<td>150</td>
</tr>
</tbody>
</table>

V. Conclusion

1. The evaluation has proven that the oil compressibility could lead erroneous results in IOIP calculation.
2. For solution gas drive at undersaturated condition, the evaluation at early-bubble point could improve IOIP (N) calculation.
3. For solution gas drive at saturated condition (initially saturated), the evaluation at 1/10 length of range discontinuity could improve IOIP (N) calculation.
4. For solution gas drive at combination condition, the evaluation at initial pressure yield good result on modern decline typecurves.
5. For bottom water drive at undersaturated condition, the evaluation at middle of discontinuity could improve IOIP and Area calculation.
6. For bottom water drive at saturated condition, the evaluation at initial pressure – the early discontinuity yield good results in drainage area calculation and at the quarter of discontinuity could improve IOIP (N) calculation.
7. For bottom water drive at combination condition, the evaluation at initial pressure – the early discontinuity yield good result in IOIP (N) calculation.

REFERENCES


Appendix A: Equation of Calculating Permeability, Skin, Volume, and Area for Each Typecurve

N in MBbls

Blasingame typecurve

1. Permeability

\[ \text{Permeability} = \left( \frac{\text{Blasingame typecurve}}{\text{A-1}} \right) \left( \frac{\text{205/6659 x M}}{\text{h}} \right) \left[ \text{ln} \left( \frac{\text{N}}{\text{V_{oil}}} \right) \right] - 0.5 \] (A-1)

2. Skin

\[ \text{Skin} = \left( \frac{\text{Blasingame typecurve}}{\text{A-2}} \right) \left( \frac{\text{0.0069 x 0.5 x 0.8 x \left( \frac{\text{N}}{\text{V_{oil}}} \right) \left( \text{ln} \left( \frac{\text{N}}{\text{V_{oil}}} \right) \right) - 0.8}}{\text{A-3}} \right) \] (A-2)

3. Area

\[ \text{Area} = \left( \frac{\text{Blasingame typecurve}}{\text{A-4}} \right) \left( \frac{\text{ln} \left( \frac{\text{N}}{\text{V_{oil}}} \right) \text{Acre}}{\text{A-5}} \right) \] (A-4)

4. Initial Oil In Place

\[ \text{Initial Oil In Place} = \left( \frac{\text{Blasingame typecurve}}{\text{A-6}} \right) \left( \frac{\text{ln} \left( \frac{\text{N}}{\text{V_{oil}}} \right) \text{Acre}}{\text{A-7}} \right) \] (A-6)
Figure 1 – Material balance principle.

Figure 2 – Radial Model.

Figure 3 – Blasingame typecurve.

Figure 4 – Radial Composite Model.

Figure 5 – The Relationship of oil compressibility to pressure both of above and below bubble point.

Figure 6 – Cylindrical reservoir model with single well in the center of reservoir.

Figure 7 – 3-D view of reservoir model.
Figure 8 – All layers were perforated

Figure 9 – Production data history for solution gas drive undersaturated condition.

Figure 10 – Oil compressibility relationship (only used the black and red curve).

Figure 11 – Blasingame typecurve analysis for undersaturated condition. (Solution Gas Drive)

Figure 12 – Comparison of error at undersaturated condition for SGD

Figure 13 – Production data history solution gas drive at saturated condition

Figure 14 – The discontinuity of oil compressibility and its parts.

Figure 15 – Blasingame typecurve analysis for saturated condition. (Solution Gas Drive)
Figure 16 – Comparison of error at saturated condition for SGD

Figure 17 – Production history for solution gas drive at combination condition.

Figure 18 – Blasingame typecurve analysis for combination condition. (Solution Gas Drive)

Figure 19 – Comparison of error for solution gas drive at combination condition

Figure 20 – Discontinuity of oil compressibility at bottom water drive.

Figure 21 – Production data history for bottom water drive at undersaturated condition.

Figure 22 – Blasingame typecurve analysis for undersaturated condition. (Bottom Water Drive)
Figure 23 – Comparison of error for bottom water drive at undersaturated condition

Figure 24 – Production data history for bottom water drive at saturated condition.

Figure 25 – Blasingame typecurve analysis for saturated condition. (Bottom Water Drive)

Figure 26 – Comparison of error for bottom water drive at saturated condition

Figure 27 – Production data history for bottom water drive at combination condition.

Figure 28 – Blasingame typecurve analysis for combination. (Bottom Water Drive)
Figure 29 – Comparison of error for BWD at combination condition