Challenges of Reserves Estimate
(tight and unconventional reservoirs)

By: Saad Ibrahim, P.Eng.
Calgary, Canada

For information:
www: petromgt.com
2015

Petro Management Group
Quality Petroleum Engineering Consultants

- Reservoir Studies (Conventional/Simulation)
- Well Test Planning and Analysis
- Waterflood Design & Performance Monitoring
- Production Optimization
- Performance Evaluation of MFHW’s (PTA, RTA, Numerical)
- Reserves and Economic Evaluations
- **Complete frac design/optimization (Gohfer/KAPPA software)**
- Government Submissions
- Customized course contents
- Expert Witness
Full Well Frac Design and Optimization Services:

- **Geological**
  - Mineral contents
  - Natural fractures
  - Core/Sweet spots

- **Geo-mechanical**
  - Poisson’s ratio
  - Young’s modulus
  -Britleness Index

- **Reservoir Performance**
  - DFIT and PTA
  - RTA
  - Reservoir parameters

Geological Data → Goffersoftware → Well Fracability → Optimum Frac Design → KAPPA software

**Tight/Unconventional Oil and Gas**

**Agenda:**

- Introduction
- Reservoir characteristics of conventional vs. tight/unconventional
- Conventional methods of estimating reserves
- Methods used for tight/unconventional reserves estimate
- Case study
- Closing comments
Reserves Booking is Critical to E&P

- Share holders
- Managers/supervisors
- Even the employees...

Why Reserves Estimate has been a Challenge?

Because....

- It relies on interpretations
- Reservoir engineering is not an accurate science
- Reserve's estimate is dependant on available technology
- Tight/unconventional reservoirs are more difficult to evaluate
- It depends on what the boss wants...(political)
- You need a good crystal ball!
Waterfall of Reserves Estimate

- Definitions
- Classification
- NI-51 Policy
- Technical Calculations
- Reporting

**Tight and Unconventional Oil and Gas**

- Tight gas/oil sands
- Shale Gas
- shale oil and oil shale!!
- CBM
Hoadley (Glauconite) is a gas play but with high liquid yield.
Permeability Terminology

Conventional vs. Tight/unconventional

Schematic geology of natural gas resources

Source: US Department of Energy Study
Conventional vs. Tight/unconventional

Conventional:
- Localized structural trap
- Source rock separate from reservoir
- Permeability > 0.1 md
- Reservoir as a tank
- Hydrocarbons & rock are non-reactive
- Classic methods used to estimate reserves
  - Decline analysis and PTA
  - Static Material balance
  - Volumetric method
- Long history available
- Relatively homogeneous
- Boundary dominated (P.S.S)

Tight and unconventional:
- Large and continuos
- Hydrocarbons generated from within
- Permeability in micro & nano darcy
- Does not act as a tank
- Hydrocarbons & rock are reactive
- Reserves are estimated using:
  - Rate Transient Analysis (RTA)
  - Analogs fields
  - Advanced numerical methods
- Large number of wells required
- Short history available
- Heterogeneous and natural fractures
- Transient dominated

Infinite-acting (transient or non-stabilized)

- Pressure wave does not reach reservoir boundaries, it takes a long time:
  - Transient could be dominated by linear/bilinear flow regimes
  - Radial flow might not be observed, depends on the perm.

Where:

\[ r_{\text{inv}} = \frac{k t}{948 \phi \mu c_l} \]

*\( r_{\text{inv}} \): Radius of investigation ft
Pseudo Steady State (P.S.S.) - stabilization

- Pressure wave reaches all reservoir boundaries (P.S.S): it could take a long time:
  - Montney (k = 0.01 md) - takes over 1 year
  - Shale gas (k=0.001 - 0.0001 md) - takes at least 3 to 4 yrs

Reserves Techniques for Conventional Reservoirs

- Volumetric calculations
- “Static” Material balance
- Decline analysis
- Pressure transient analysis (PTA) - well testing
"Static" Material Balance

Requirements:
- Good “static” pressure history
- Reservoir acts like a tank
- Production of at least 10% of total reserves

Consistency of Volumetric OOIP/OGIP

Volumetric (Geology) vs. Material Balance (engineering)
Type Curve Analysis (DCA)
(by Arps in 1945)

General formula:

\[ q_t = \frac{q_i}{(1 + bD_i t)^b} \]

<table>
<thead>
<tr>
<th>Type</th>
<th>Rate</th>
<th>Remaining Reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exponential</td>
<td>[ q_t = q_i \cdot e^{-D_i t} ]</td>
<td>[ Q_t = \frac{1}{D_i} (q_i - q_t) ]</td>
</tr>
<tr>
<td>Hyperbolic</td>
<td>[ q_t = \frac{q_i}{(1 + bD_i t)^b} ]</td>
<td>[ Q_t = \left[ \frac{q_i}{D_i (1 - b)} \right] \left[ \frac{q_i}{q_t} \right]^{1-b} ]</td>
</tr>
<tr>
<td>Harmonic</td>
<td>[ q_t = \frac{q_i}{(1 + D_i t)} ]</td>
<td>[ Q_t = \left( \frac{q_i}{D_i} \right) \ln \left( \frac{q_i}{q_t} \right) ]</td>
</tr>
</tbody>
</table>

Where:
- \( D_i \): Initial decline constant
- \( q_i \): Initial producing rate
- \( q_t \): Producing rate at time “t”
- \( Q_t \): Cumulative production at time “t”
- \( b \): Exponent

Use of Exponential Decline Curve

Decline Constant (\( D_i \)):
\[ D_i = \ln \left( \frac{q_1}{q_2} \right) / \text{time} \]

Decline rate (\( P \)), %:
\[ P = 1 - e^{-D_i t} \]
Main Assumptions in Decline Analysis

- Well is producing at or near capacity
- Well is producing at a constant BHFP
- Well is producing under boundary-dominated conditions (P.S.S)
- Reservoir acts like a tank model

Abuse of Decline Curve Analysis!

Use of transient data will yield errors:

- **Early transient flush production** data will yield limited reserves (low)
- Use of **transient after flush production** data will yield optimistic reserves, as “b” could higher than a value of 1.
Hyperbolic Decline Curve Analysis During Transient (b>1.0)

- Non-unique solution, with reserves varying from 5.7 Bcf (b = 1.2) to 12.5 Bcf (b = 1.4), during transient dominated flow.
- Use of well types could be appropriate in the presence of long production history, reaching P.S.S (boundary dominated flow).

Reserves Techniques for Tight/unconventional Reservoirs

- Improved decline curve analysis techniques
- Rate Transient Analysis (RTA)
  - Fetkovich Type Curve
  - Blasingame Type Curves
  - Flowing material balance
  - Normalized rate (Agrawal)
- Analog fields - well types
- Modelling (history matching of production/pressure history)
- Numerical techniques
Performance Evaluation Tools Besides RTA

Facts:
RTA tools are reliable, but it take a longs time to perform and requires pressure data.....

Reality:
My boss wants me to finish my reserves evaluation for 200 wells in one week, how about decline curve analysis (DCA)?

Evolution of Decline Analysis

- Initially introduced by Johnson and Bollens [1928]
- Improved by Arps in 1945 (fixed decline constant)
- More improvements of decline curve analysis.....
Why Need to Use Newer DCA Methods?

- The decline analysis by Arps, should only be applied when production is stabilized; when P.S.S is reached.
- Arps assumes that the values “b” and “D” are constants for the full production history, which might not be appropriate for tight formations, as transient flow can last for months if not years.
- For instance, for shale gas, initial decline in the 1st year is usually 60% to 80%. Subsequent decline rate could be 5% to 10%/yr.
- Transient flow regime could last for several years, during which hyperbolic decline analysis will yield a value of “b” over 1.
- Fetkovich (1990) indicated that a value of $b > 1$ should not be used for reserves determination (SPE 116731).
- New decline curve analysis techniques to allow the analysis of transient data.

Evolution of Decline Curve Analysis

- Arpes ($b = 0$ to $1$)
- Super Hyp./Harm ($b = > 1$)
- Duong’s Method (DM)
- Power Law Exp. (PLE)
- Modified Hyperbolic (MH)
- Stretched Exponential Production Decline (SEPD)
Power Law Loss-Ratio (ILK et al - 2008) or Power Law Exponential (PLE)

Since the Contacted Reservoir Volume, is believed to increase with time, Ilk introduced a non-hyperbolic decline, where the values the of the decline constant “D” and “b” (Arps) change with time and were replaced by the parameters $D_i$, $D_\infty$, and $n$, as follow:

$$D = D_\infty + D_i t^{-(1-n)}$$

$$R = \frac{D_\infty}{D_i \cdot t^{(n-1)}}$$

Where:

- $D_i$: Decline constant at initial time
- $D_\infty$: Decline constant at infinite time
- $n$: Time exponent
- $R$: Power law loss-ratio ($D_\infty / D_i$)

Stretched Exponential Production Decline (SEPD)

The stretched exponential decline was introduced by Valko (SPE 134231). The “SEPD” method is similar to the PLE method but without the constraining variable $D_\infty$.

$$q = q_i \exp\left[ -D_\infty t - D_i t^n \right]$$

Valko (2008) defined $D_i$ as $(1/\zeta)$:

$$q(t) = q_i \exp\left[ -(t / \tau)^n \right]$$

Where:

- $\zeta$: Characteristic time function for SEPD model

The “SEPD” method seems to yield reasonable results for production history longer than 3 years.
Duong Decline Method

Graph production rate normalized to cumulative production ($q/G_P$) vs time on a Log-Log graph, will yield a linear trend

- $m$: slope of the line ($m>1$ for unconventional - $m<1$ for conventional)
- $a$: Intercept of the line at time value of 1
- Target for $R>0.95$ for good results

**Barnett Shale – Johnson County**

Middle profiles:
- $b = 1.18 - 1.3$
- Duong
- Terminal decline @5%

Ref: John Lee - U of H
Forecast Comparison of **Duong** vs. **SEPD** Methods
At Different Production Durations

- Forecast by **Duong** is reasonable even at only **6 months** of production history.
- Forecast by **SEPD** becomes reasonable after **3 yrs** of production history.

**Summary of DCA Techniques**

- The **Exponential decline** (constant % decline) has been traditionally used when PSS is reached; i.e for short transient flow experienced in relatively good formation permeabilities (Arps).
- **Hyperbolic** (b value up 1) and **Harmonic** (b=1) tools can be used if decline rate is not constant. However, **super Hyperbolic/Harmonic** (b>1), can be used to match transient data, but **should not be used for reserve determination** or unrealistically high reserves will result.
- Newer DCA tools seem to yield reasonable reserves for tight/unconventional reservoirs, even when PSS is not reached:
  - **Power Law Exponential Decline** (PLE)
  - **Stretched Exponential Production Decline** (SEPD). Both PLE, SEPD are good for production history over 3 years, for tight/unconventional wells.
  - **Modified hyperbolic** (switch from hyperbolic to Arps when annual decline rate is approx. 5%), yields good results using "segmented decline tool".
  - **Duong’s** Method yields reasonable results for short production history < 1 year.
Case Study

Arps vs Power Law Loss-Ratio

Sources: Canadian International Petroleum Conference - Paper 2009 -159

Comparison of Arps vs Power Law Loss-Ratio

A study was performed to compare analysis results of Arps vs. Power Law techniques, for 4 wells

- Power Law tends to yield a slightly better match of both early and late-time data, but let’s compare the results.....
Results Comparison of Arps vs. Power Law

<table>
<thead>
<tr>
<th>Well</th>
<th>b</th>
<th>$q_i$ (Mscf/d)</th>
<th>$q_i$ ($10^3$ m$^3$/d)</th>
<th>n</th>
<th>$\dot{q}_f$ (Mscf/d)</th>
<th>$\dot{q}_f$ ($10^3$ m$^3$/d)</th>
<th>$D_f$</th>
<th>$D_{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.488</td>
<td>309.6</td>
<td>8.8</td>
<td>0.5278</td>
<td>375</td>
<td>10.6</td>
<td>0.0109</td>
<td>7.4E-05</td>
</tr>
<tr>
<td>2</td>
<td>1.4</td>
<td>127.0</td>
<td>3.6</td>
<td>0.3442</td>
<td>200</td>
<td>5.7</td>
<td>0.1176</td>
<td>3.6E-05</td>
</tr>
<tr>
<td>3</td>
<td>1.2</td>
<td>50.3</td>
<td>1.4</td>
<td>0.2184</td>
<td>120</td>
<td>3.4</td>
<td>0.3136</td>
<td>3.3E-05</td>
</tr>
<tr>
<td>4</td>
<td>1.6</td>
<td>25.6</td>
<td>0.7</td>
<td>0.3552</td>
<td>50</td>
<td>1.4</td>
<td>0.2624</td>
<td>1.2E-05</td>
</tr>
</tbody>
</table>

Discrepancy of EUR Arps vs. Power Law

<table>
<thead>
<tr>
<th>Well</th>
<th>Arps Decline EUR (MMscf)</th>
<th>Arps Decline EUR ($10^6$ m$^3$)</th>
<th>Power Law EUR (MMscf)</th>
<th>Power Law EUR ($10^6$ m$^3$)</th>
<th>Discrepancy of EUR Arps vs. Power Law</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1546</td>
<td>43.8</td>
<td>1499</td>
<td>42.2</td>
<td>+3.8%</td>
</tr>
<tr>
<td>2</td>
<td>380</td>
<td>10.8</td>
<td>233</td>
<td>6.5</td>
<td>+64.5%</td>
</tr>
<tr>
<td>3</td>
<td>389</td>
<td>11.0</td>
<td>339</td>
<td>9.6</td>
<td>+14.7%</td>
</tr>
<tr>
<td>4</td>
<td>215</td>
<td>6.1</td>
<td>113</td>
<td>3.2</td>
<td>+90.3%</td>
</tr>
</tbody>
</table>

Note:
The higher the value of “b” over 1, the higher the discrepancy of the EUR between Arps and the Power Law techniques.

Reserves Techniques for Tight/unconventional Reservoirs

- Improved decline curve analysis techniques
- Rate Transient Analysis (RTA)
  - Fetkovich Type Curve
  - Blasingame Type Curves
  - Flowing material balance
  - Normalized rate (Agrawal)
- Analog fields - well types
- Modelling (history matching of production/pressure history)
- Numerical techniques
Techniques of Analysis

**Rate Transient Analysis (RTA)**
- Constant flowing Press
- \( q \) (matched)
- \( P_{wh} \) (input)

**Pressure Transient Analysis (PTA) or Well Testing**
- Constant Rate
- \( q \) (input)
- \( P_{wf} \) (matched)

- Constant BHFP
- Declining production rate
- Sparse and inaccurate/noisy pressure data; usually WHFP
- Long period of production data
- Constant production rate
- Declining BHFP
- Accurate and frequent measurements
- Short test duration

---

**Fetkovich Type Curve (Rate vs. Time)**

One of the first generation of type curve matching of production history, which is based on decline analysis technique.

**Limitations:**
- It is based only on production data; pressure history is excluded
- It assume the BHFP is constant during the production life of the well, which is unrealistic
- Usually yield optimistic value of OOIP/OGIP
Fetkovich Type Curve (Rate vs. Time)

**Transient Depletion**

Transient data will yield:
- $K$
- $S$

Depletion data (P.S.S) will yield:
- Drainage area or
- Reservoir radius ($r_e$)

**Analytical Type Curve Solution**

$$q_{dt} = \frac{q(t)}{q} = q_b \left[ \ln \left( \frac{t}{r_e^2} \right) - \frac{1}{2} \right]$$

**Empirical Type Curve Solution**

$$q_{dt} = \frac{q(t)}{q} = \frac{1}{1 + b(t - t_0)^{1/5}}, \text{ for } b > 0$$

$$q_{dt} = \frac{q(t)}{q} = \frac{1}{b(t - t_0^2)}, \text{ for } b = 0$$

Boundary-dominated regime (P.S.S) is confirmed when the data shows a linear trend with a negative unit slope (slope = -1)

**Blasingame Type Curves**

**Concept:**

- Analyze both BHFP and production data
- Producing rates are normalized to the draw down $q/(P_i - P_{wf})$, which represents the well initial productivity index, $P.I$
- Normalized production rate history is plotted against Normalized cumulative production/production rate $(N_p/q)*$
- Boundary-dominated regime (P.S.S) is confirmed when the data shows a linear trend with a negative unit slope (slope = -1)
- Drainage area is then determined from the matching of production data during P.S.S regime

* Material balance pseudo time - $N_p/q = \text{Bbl/(Bbl/day)} = \text{time}
Use of Blasingame Type Curves

Method:

- WHFP’s are converted to BHFP’s
- Well P.I.’s are plotted against producing time on a log-log plot
- Overlay production data on Blasingame type-curve and obtain a match
- Determine k, s from transient data and the drainage area from the P.S.S. data

Concept of Flowing Material Balance (Gas)

During P.S.S:

- Decline in BHFP and static reservoir pressure are equal
- BHFP are converted into static pressure to estimate OGIP from the P/z plot
Reserves Techniques for Tight/unconventional Reservoirs

- Improved decline curve analysis techniques
- Rate Transient Analysis (RTA)
  - Fetkovich Type Curve
  - Blasingame Type Curves
  - Flowing material balance
  - Normalized rate (Agrawal)
- Analog fields - well types
  - Modelling (history matching of production/pressure history)
  - Numerical techniques

Reserve Estimates by Well Type

- Commercial software:
  - Harmony (Fekete)
  - Citrine (KAPPA)

Literature suggests the early hyperbolic decline \( (b>1) \) be switch, when the annual decline rate reaches \( \approx 5\% \), to the following:
- Exponential decline \( (b=0) \) - **Modified exponential**
- Hyperbolic decline \( (b \approx 0.4 \text{ to } 0.5 \text{ gas and } 0.3 \text{ for oil}) \) - **Modified hyperbolic**
Liquid Yield - Montney

Montney Field Comparison

Source: National Bank from various company’s presentations

Probability of Reserves Estimated by Analogy (Horn River - B.C)

Source: AER
Type Wells - Shale Gas (USA)

Typical Production Profile (shale gas)
(Eagle Ford - USA)

Source: Drilling info, Dec. 2013, by Hughes GSR Inc.

Source: DOE - USA
How to Identify Flow Regimes?

- **Production history**
  - Log-log graph of production vs material balance time

- **Pressure history**
  - Diagnostic derivative plot
Identification of Flow Regimes (production data only)

MBT: Material balance time - \( N_p/q = \text{Bbl/(Bbl/day)} \) = time

Flow Regimes for MFHW’s

- Inner zone or Stimulated Reservoir Volume (SRV):
  - Bilinear flow
  - Main Linear
- Transition
- Outer zone (non-simulated reservoir volume or Contacted Reservoir Volume CRV):
  - Compound Linear
  - Transition
- Reservoir dominated (boundaries)

<table>
<thead>
<tr>
<th>Play</th>
<th>Time of START of &quot;Linear&quot; flow (months)</th>
<th>Time of END of &quot;Linear&quot; flow (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett</td>
<td>6</td>
<td>36</td>
</tr>
<tr>
<td>Fayetteville</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Haynesville-LA</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Haynesville-TX</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Marcellus</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Woodford</td>
<td>4</td>
<td>16</td>
</tr>
</tbody>
</table>

Source: John Lee

Source: Dr. Blasingame
Identification of Flow Regimes
(pressure derivative plot)

1.3 yrs flow period (12,000 hrs) - k = 1.0 md

P.S.S* of only the SRV

Case Study

Barnett Gas Shale (Denton)
Objectives of study:
- Reserves estimate
- Optimize Hz well spacing
- Determine formation parameters
- Compare well performance: frac techniques of open hole vs cased

Analysis Step-by-Step

Procedures:
- Flow regime diagnoses
  - Pressure Derivative plot
  - Rate vs time (log-log plot)
  - Square Root of time vs pressure plot
- Rate Transient Analysis (RTA)
  - Fetkovich, Blasingame, and Agarwal type curves
  - Flowing material balance
- Decline analysis
  - Arps
  - Power Law Loss-ratio
- History matching of production/pressure data (analytical)
- Numerical output
Production/Pressure History

Well “A”

Decline rate during 1st year = 76%

Identification of Flow Regimes

(Pressure Derivative/Diagnostic Plot)

Well “A”

Pressure history is dominated by “Linear flow geometry”
Identification of Flow Regimes
(Use of Production History)

Well “A”

Mixed fracture conductivity is evident (finite and infinite)

Identification of Flow Regimes
(Pressure vs $\sqrt{\Delta t}$ time)

Well “A”

Average fracture half-length ($X_f$) could be estimated from slope of the line, during linear flow
Est. of drainage area from production history (SRV)

Use estimated OGIP to improve the match of the production/pressure history
Normalized Rate-Cumulative (Agarwal)

Well “A”

OGIP = 4.3 Bcf

Flowing Material Balance (Excluding Desorption)

Well “A”

OGIP = 3.4 Bcf
**Flowing Material Balance**

(INCLUDING DESORPTION)

Well “A”

OGIP = 4.2 Bcf

Include shale properties; Langmuir volume constant and density

**Power Law Exponential (PLE)**

Well “A”

EUR = 3.6 Bcf

Abandonment rate = 100 Mscf/d

Remaining production life = 22.7 years
Decline Analysis (hyperbolic)

Well “A”

Excessive EUR is obtained from decline analysis; Nearly 83.3% higher than the Power Law Exponential (PLE)

\[ \text{EUR} = 6.6 \text{ Bcf} !! \]
\[ b = 1.6 \]
\[ \text{Remaining prod life} = 73 \text{ yrs} !! \]

Abandonment rate = 100 Mscf/d

Match Comparison
(Power Law vs. ARPS)

Better match is obtained by the Power Law of both early and late time rate data
Excellent match is achieved, placing confidence in results.

**Summary of Results**

<table>
<thead>
<tr>
<th>Method</th>
<th>OGIP</th>
<th>EUR (Bcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fetkovich Type Curve</td>
<td>4.2</td>
<td>n/a</td>
</tr>
<tr>
<td>Blasingame Type Curve</td>
<td>4.1</td>
<td>n/a</td>
</tr>
<tr>
<td>Normalized Rate-cumulative (Agarwal)</td>
<td>4.3</td>
<td>n/a</td>
</tr>
<tr>
<td>Flowing Material Balance (no desorption)</td>
<td>3.2</td>
<td>n/a</td>
</tr>
<tr>
<td>Flowing Material Balance (with desorption)</td>
<td>4.2</td>
<td>n/a</td>
</tr>
<tr>
<td>History Matching (analytical)</td>
<td>4.6</td>
<td>n/a</td>
</tr>
<tr>
<td>Power Law Loss-Ratio</td>
<td>n/a</td>
<td>3.6</td>
</tr>
<tr>
<td>Decline Analysis (hyperbolic b = 1.6)</td>
<td>n/a</td>
<td>6.6</td>
</tr>
</tbody>
</table>

- Average OGIP (excluding the case with no desorption) = 4.28 Bcf
- Gas EUR: Power Law = 84.1 % - Decline analysis = 154% !!
**Why Numerical Modelling?**

**Benefits:**

- Can account for reservoir heterogeneity (variable values of porosity, permeability and pay thickness)
- Can account for odd reservoir geometry; use actual contour maps instead of a square/rectangular shape
- Account for both transient and P.S.S flow regimes
- Visually can recognize the drainage area from isobaric animation of SRV and CRV

**Numerical Modelling of Well’s “A” and “B” (Permeability Distribution)**

The pressure drop; after 4 yrs of production, has only affected the area of the reservoir that has been fraced.
Pressure Profile (after 4 yrs of Production)

Hz well spacing of 487 m is too large to allow efficient depletion of the Barnett shale.
This conclusion is consistent with the well spacing commonly used in the Horn River (Canada), between 200 m to 300 m.
Source: Topaze software

Modelling a Heterogeneous Formation

How to estimate CRV for heterogeneous reservoir?
Summary of Reserves Definitions

1. **Stimulated reservoir volume (SRV):**
   For short production periods and tight formations; production is restricted to the stimulated zone

2. **Contacted reservoir volume (CRV):**
   For long production periods and relatively better formation permeability. Production contribution is from a portion of the reservoir larger than the SRV

3. **P90 ......P50......P10:** Proved, Probable and Possible reserves
   - **P90:** the larger of SRV and CRV
   - **P50:** Based on reasonable well spacing to produce economic reserves
   - **P10:** Based on optimistic well spacing to produce economic reserves
Production Forecasts/Reserves

- **SRV (P90):** reflects the most conservative reserves estimate
- **CRV (P50):** reflects the most likely recoverable reserves, based on a reasonable production period and a reasonable drainage area
- **CRV (P10):** reflects an optimistic recoverable reserves, assuming an optimistic drainage area (use \( b >> 1.0 \))

**Closing Comments**

- The tighter the formation is, the longer it takes to confirm the EUR (SRV vs CRV)
- Production profile prediction could be generated based on analogous wells, but with caution...
- Decline curve analysis should be used with caution during transient, or unrealistically high reserves will be the outcome
- The combination of various evaluation techniques; PTA and RTA, DFIT, and numerical combined with micro-seismic/tracer survey can improve reserves estimate
Thank You

How to contact us ??

- E-mail: saad@petromgt.com
- Phone: (403) 216-5100
- Cell: (403) 616-8330
- Fax: (403) 216-5109
- Address: #401, 100 - 4th Ave. S.W.
  Calgary, Alberta, Canada T2P 3N2