Reservoir Engineering II

Reserve Estimation Methods

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Reserve Estimation Methods

Reserve estimation methods may be classified as:

- **Analogical Methods.**
- **Volumetric Methods.**
- **Performance Methods.**

➢ Material Balance.

➢ Computer Simulation.

➢ Performance/Decline Trend Analysis.

Analogical Methods

Application: Used early in exploration and initial field development

Accuracy: Highly dependent on similarity of reservoir characteristics. Reserve estimates are often very general.

The analogy method is applied by comparing the following factors for the analogous and current fields or wells:

- Recovery Factor (RF),
- Barrels per Acre-Foot (BAF), and
- Estimated Ultimate Recovery (EUR)

Analogical Methods

Analogy is most useful when running the economics on a yet-to-be-drilled exploratory well. Care, however, should be taken when applying analogy technique.

For example, care should be taken to make sure that the field or well being used for analogy is indeed analogous. That said, a dolomite reservoir with volatile crude oil will never be analogous to a sandstone reservoir with black oil. Similarly, if your calculated EUR is twice as high as the EUR from the nearest 100 wells, you had better check your assumptions.

Volumetric Methods

Application: Used early in life of field.

Accuracy: Dependent on quality of reservoir description. Reserves estimates often high because this method does not consider problems of reservoir heterogeneity.

The volumetric method for estimating oil in place is based on log and core analysis data to determine the bulk volume, the porosity, and the fluid saturations, and on fluid analysis to determine the oil volume factor.

Volumetric Methods

Due mainly to gas evolving from the oil as pressure and temperature are decreased, oil at the surface occupies less space than it does in the subsurface.

Conversely, gas at the surface occupies more space than it does in the subsurface because of expansion.

This necessitates correcting subsurface volumes to standard units of volume measured at surface conditions.

Volumetric Methods

For any reservoir unit, the following fluid volumes can calculated by volumetric method:

1. **Interstitial water volume**

$$Interstitial\ water\ volume = 7758 \times Ah\emptyset \times S_{wc} \ \ldots\ldots.(1)$$

2. **Reservoir oil**

$$Reservoir\ oil\ volume = 7758 \times Ah\emptyset \times (1 - S_{wc}) \ \ldots\ldots.(2)$$

3. **Stock tank oil**

$$Reservoir\ oil\ volume = \frac{7758 \times \ Ah\emptyset \ \times \ (1 - S_{wc})}{B_o} \ \ldots\ldots.(3)$$

Volumetric Methods

For oil reservoirs under volumetric control, there is no water influx to replace the produced oil, the pressure gradually decrease till it reach the bubble point pressure.

the saturation of gas increases as the oil saturation decreases. If S_g is the gas saturation and B_o is the oil volume factor at abandonment, then at abandonment conditions:

Reservoir oil

$$Reservoir\ oil\ volume = 7758 \times Ah\emptyset \times (1 - S_{wc} - S_g) \ \ldots\ldots.(4)$$

Stock tank oil

$$Reservoir\ oil\ volume = \frac{7758\times \ Ah\emptyset \ \times \ (1-S_{wc}-S_g)}{B_o} \ \ldots\ldots.(5)$$

Volumetric Methods: Oil Reservoirs

For an oil reservoir, or for the oil column of an oil reservoir with a gas cap, oil initially in place (OIIP) may be calculated as:

$$OIIP = N_i = \frac{7758\phi_o(1 - S_{wc})A_o h_{no}}{B_{oi}} \quad .... \quad (6)$$

N_i = oil initially in place, STB.
7758 = (unit conversion constant) barrels in an acre foot (1 acre=4046.85642 m^2 ≅4047 m^2).
ϕ_o = average porosity in the oil zone, fraction.
S_{wc} = connate water saturation in the oil zone, fraction.
A_o = area of the oil zone, acres.
h_{no} = average net oil pay, feet.
B_{oi} = average initial formation volume factor, bbl/STB.

Volumetric Methods: Oil Reservoirs

Solution gas dissolved in the oil at initial reservoir conditions may be calculated as:

$$G_{Si} = N_i R_{si} \qquad .....(7)$$

where:

G_{Si} = solution gas initially in place, scf.

R_{si} = average initial solution gas/oil ratio, scf/STB.

Volumetric Methods: Oil Reservoirs

Oil formation volume factor can be calculated by applying Standing's correlation, if both oil specific gravity and gas specific gravity are available:

$$B_o = 0.9759 + 0.000120\left[R_s\left(\frac{\gamma_g}{\gamma_o}\right)^{0.5} + 1.25(T-460)\right]^{1.2} \quad \text{......(8)}$$

where:

T = temperature, °R.

γ_o = specific gravity of the stock-tank oil, 60°/60°.

γ_g = specific gravity of the solution gas.

Volumetric Methods: Oil Reservoirs

Example:

An oil reservoir exists at its bubble-point pressure of (3,000 psia) and temperature of (160°F). The oil has an API gravity of (42°) and gas-oil ratio of (600 scf/STB). The specific gravity of the solution gas is (0.65). The following additional data are also available:

- Reservoir area = 640 acres.
- Average thickness = 10 *ft*.
- Connate water saturation = 0.25
- Effective porosity = 15%.

Calculate the initial oil in place in STB.

Volumetric Methods: Oil Reservoirs

Solution:

Step 1. Determine the specific gravity of the stock-tank oil

$$API = \frac{141.5}{\gamma_o} - 131.5$$

$$\gamma_o = \frac{141.5}{42 + 131.5} = 0.8156$$

Step 2. Calculate the initial oil formation volume factor by applying Standing's equation

$$B_o = 0.9759 + 0.000120\left[600\left(\frac{0.65}{0.8156}\right)^{0.5} + 1.25(160)\right]^{1.2} = 1.396\ bbl/STB$$

Step 3. Calculate the initial oil in place

$$OIIP = N_i = \frac{7758(0.15)(1 - 0.25)(640)(10)}{1.396} = 4001260.74\ STB$$

Volumetric Methods: Recovery calculation

The Recovery represent the oil produced in STB that can be expressed mathematically as:

$$N_p = N_i - N$$

$$N_p = 7758 \times Ah\emptyset \left[\left(\frac{1 - S_{wc}}{B_{oi}} \right) - \left(\frac{1 - S_{wc} - S_g}{B_o} \right) \right]$$

$$N_p = 7758 \times Ah\emptyset \left[1 - \left(\frac{1 - S_{wc} - S_g}{1 - S_{wc}} \right) \left(\frac{B_{oi}}{B_o} \right) \right]$$

Recovery factor represent the fraction of total oil that has been produced:

$$R_f = \frac{N_p}{N_i}$$

Volumetric Methods: Recovery calculation

Example:

Use the information in the previous example to calculate the recovery factor at 2900 psia if you know that Bo =1.4 at 2900 psia and the saturation pressure is equal to 2400 psia.

Volumetric Methods: Recovery calculation

Solution:

Step 1: calculate oil in place at 2900 psi

$$N = \frac{7758 \times Ah\emptyset\,(1-S_{wc})}{B_o}$$

$$N = \frac{7758 \times 640 \times 10 \times 0.15 \times (1-0.25)}{1.4}$$

N=3,989,828 STB

Step 2: calculate oil produced at 2900 psi

$$N_p = N_i - N$$

$$N_p = 4{,}001{,}260 - 33{,}989{,}828$$

$$N_p = 11{,}432 \text{ STB}$$

Step 3: calculate oil recovery factor at 2900 psi

$$R_f = \frac{N_p}{N_i}$$

$$R_f = \frac{11{,}432}{4{,}001{,}260}$$

$$R_f = 0.00288 = 0.288\%$$

Volumetric Methods: Gas Reservoirs

For a nonassociated gas reservoir, or for a gas cap, free gas initially in place may be calculated as:

$$G_{Fi} = \frac{43560\phi_g(1 - S_{wc})A_g h_{ng}}{B_{gi}}$$

where:

G_{Fi} = free gas initially in place, scf.
43560 = (unit conversion constant) cubic feet in an acre foot.
ϕ_g = average porosity in the free gas zone, fraction.
S_{wc} = connate water saturation in the free gas zone, fraction.
A_g = area of gas cap or gas reservoir, acres.
h_{ng} = average net thickness of gas cap or gas reservoir, feet.
B_{gi} = average initial formation volume factor, ft^3/scf.

Volumetric Methods: Gas Reservoirs

Condensate (also called distillate) in the vapor phase at initial reservoir conditions (but measured as a liquid at surface conditions) may be calculated as:

$$R_{ci} = \frac{C_i}{C_{Fi}} \quad => \quad C_i = C_{Fi} R_{ci}$$

where:

C_i = condensate (distillate) initially in place, STB.
R_{ci} = initial condensate/gas ratio (CGR), STB condensate/MMscf.
C_{Fi} = free gas initially in place, MMscf.

Volumetric Methods: Gas Reservoirs

Example:

The following data are given for the Bell Gas Field:

- Area = 160 acres.
- Net productive thickness = 40 *ft*.
- Porosity = 22%.
- Connate water = 23%.
- Initial gas FVF = 0.00533 ft^3/SCF.

Find the gas initially in place.

Solution:

Calculating initially gas in place

$$G_{Fi} = \frac{43560(0.22)(1-0.23)(160)(40)}{0.00533} = 8860\ MMSCF$$

Note: Each "M" is equal 10^3, So "MM" equals 10^6.