

# Volumetric Calculations

## *I. Calculating Oil in Place by the Volumetric Method*

Oil in place by the volumetric method is given by:

$$N(t) = \frac{V_b \phi(p(t)) (1 - S_w(t))}{B_o(p(t))} \quad (1)$$

Where:

$N(t)$	= oil in place at time t, STB
$V_b$	= 7758 A h = bulk reservoir volume, bbl
7758	= bbl/acre-ft
A	= area, acres
h	= thickness, ft
$\phi(p(t))$	= porosity at reservoir pressure p, fraction
$S_w(t)$	= water saturation at time t, fraction
$B_o(p(t))$	= oil formation volume factor at reservoir pressure p, bbl/STB
$p(t)$	= reservoir pressure at time t, psia

## *II. Calculating Gas in Place by the Volumetric Method*

Gas in place by the volumetric method is given by:

$$G(t) = \frac{V_b \phi(p(t)) (1 - S_w(t))}{B_g(p(t))} \quad (2)$$

Where:

$G(t)$	= gas in place at time t, SCF
$V_b$	= 43,560 A h = bulk reservoir volume, ft <sup>3</sup>
43,560	= ft <sup>3</sup> /acre-ft
A	= area, acres
h	= thickness, ft
$\phi(p(t))$	= porosity at reservoir pressure p, fraction
$S_w(t)$	= water saturation at time t, fraction
$B_g(p(t))$	= gas formation volume factor at reservoir pressure p, ft <sup>3</sup> /SCF
$p(t)$	= reservoir pressure at time t, psia

## EPS-441: Petroleum Development Geology

### *Calculating Oil in Place by the Volumetric Method*

*Semester:*

*Homework #:*

*Name:*

*SS#:*

The following data are given for the Hout Oil Field:

Area	= 26,700 acres
Net productive thickness	= 49 ft
Porosity	= 8%
Average $S_w$	= 45%
Initial reservoir pressure, $p_i$	= 2980 psia
Abandonment pressure, $p_a$	= 300 psia
$B_o$ at $p_i$	= 1.68 bbl/STB
$B_o$ at $p_a$	= 1.15 bbl/STB
$S_g$ at $p_a$	= 34%
$S_{or}$ after water invasion	= 20%

Calculate the following:

- 1) Initial oil in place
- 2) Oil in place after volumetric depletion to abandonment pressure
- 3) Oil in place after water invasion at initial pressure
- 4) Oil reserve by volumetric depletion to abandonment pressure
- 5) Oil reserve by full water drive
- 6) Discuss your answers

**Solution:**

$$V_b = 7758 \times A \times h = 7758 \times 26,700 \times 49 = 10.15 \text{ MMM bbl}$$

1) The initial oil in place is given by:

$$N_i = \frac{V_b \phi (1 - S_{wi})}{B_{oi}}$$

Which yields:

$$N_i = \frac{10.15 \times 10^9 (0.08) (1 - 0.45)}{1.68} \approx 266 \text{ MM STB}$$

2) Oil in place after volumetric depletion to abandonment pressure is given by:

$$N = \frac{V_b \phi (1 - S_w - S_g)}{B_o}$$

Which yields:

$$N_1 = \frac{10.15 \times 10^9 (0.08) (1 - 0.45 - 0.34)}{1.15} \approx 148 \text{ MM STB}$$

3) Oil in place after water invasion at initial reservoir pressure is given by:

$$N = \frac{V_b \phi S_{or}}{B_o}$$

Which yields:

$$N_2 = \frac{10.15 \times 10^9 (0.08) 0.20}{1.68} \approx 97 \text{ MM STB}$$

4) Oil reserve by volumetric depletion

$$(N_i - N_1) = (266 - 148) \times 10^6 = 118 \text{ MM STB}$$

i.e. RF = 118/266 = 44%

5) Oil reserve by full water drive

$$(N_i - N_2) = (266 - 97) \times 10^6 = 169 \text{ MM STB}$$

i.e. RF =  $169/266 = 64\%$

6) Discussion of results:

For oil reservoirs under *volumetric control*, i.e. no water influx, the produced oil must be replaced by gas the saturation of which increases as oil saturation decreases. If  $S_g$  is the gas saturation and  $B_o$  the oil formation volume factor at abandonment pressure, then oil in place at abandonment pressure is given by:

$$N = \frac{V_b \phi (1 - S_w - S_g)}{B_o}$$

On the other hand, for oil reservoirs under *hydraulic control*, where there is no appreciable decline in reservoir pressure, water influx is either *edge-water drive* or *bottom-water drive*. In edge-water drive, water influx is inward and parallel to bedding planes. In bottom-water drive, water influx is upward where the producing oil zone is underlain by water. In this case, the oil remaining at abandonment is given by:

$$N = \frac{V_b \phi S_{or}}{B_o}$$

## EPS-441: Petroleum Development Geology

### *Calculating Gas in Place by the Volumetric Method*

*Semester:*

*Homework #:*

*Name:*

*SS#:*

The following data are given for the Bell Gas Field:

Area	= 160 acres
Net productive thickness	= 40 ft
Initial reservoir pressure	= 3250 psia
Porosity	= 22%
Connate water	= 23%
Initial gas FVF	= 0.00533 ft <sup>3</sup> /SCF
Gas FVF at 2500 psia	= 0.00667 ft <sup>3</sup> /SCF
Gas FVF at 500 psia	= 0.03623 ft <sup>3</sup> /SCF
S <sub>gr</sub> after water invasion	= 34%

Find the following:

- 1) Initial gas in place
- 2) Gas in place after volumetric depletion to 2500 psia
- 3) Gas in place after volumetric depletion to 500 psia
- 4) Gas in place after water invasion at 3250 psia
- 5) Gas in place after water invasion at 2500 psia
- 6) Gas in place after water invasion at 500 psia
- 7) Gas reserve by volumetric depletion to 500 psia
- 8) Gas reserve by full water drive; i.e. at 3250 psia
- 9) Gas reserve by partial water drive; i.e. at 2500 psia
- 10) Gas reserve by full water drive if there is one undip well
- 11) Discuss your answers

**Solution:**

$$V_b = 43,560 \times A \times h = 43,560 \times 160 \times 40 = 278.784 \text{ MM ft}^3$$

1) Initial gas in place is given by:

$$G_i = \frac{V_b \phi_i (1 - S_{wi})}{B_{gi}}$$

Which yields:

$$G_i = \frac{278.784 \times 10^6 (0.22) (1 - 0.23)}{0.00533} = 8860 \text{ MM SCF}$$

2) Gas in place after volumetric depletion to 2500 psia:

$$G_1 = \frac{278.784 \times 10^6 (0.22) (1 - 0.23)}{0.00667} = 7080 \text{ MM SCF}$$

3) Gas in place after volumetric depletion to 500 psia:

$$G_2 = \frac{278.784 \times 10^6 (0.22) (1 - 0.23)}{0.003623} = 1303 \text{ MM SCF}$$

4) Gas in place after water invasion at 3250 psia:

$$G_3 = \frac{278.784 \times 10^6 (0.22) (0.34)}{0.00533} = 3912 \text{ MM SCF}$$

5) Gas in place after water invasion at 2500 psia:

$$G_4 = \frac{278.784 \times 10^6 (0.22) (0.34)}{0.00667} = 3126 \text{ MM SCF}$$

6) Gas in place after water invasion at 500 psia:

$$G_5 = \frac{278.784 \times 10^6 (0.22) (0.34)}{0.03623} = 576 \text{ MM SCF}$$

7) Gas reserve by volumetric depletion to 500 psia:

$$G_i - G_2 = (8860 - 1303) \times 10^6 = 7557 \text{ MM SCF}$$

$$\text{i.e. RF} = 7557/8860 = 85\%$$

8) Gas reserve by water drive at 3250 psia (full water drive):

$$G_i - G_3 = (8860 - 3912) \times 10^6 = 4948 \text{ MM SCF}$$

$$\text{i.e. RF} = 4948/8860 = 56\%$$

9) Gas reserve by water drive at 2500 psia (partial water drive):

$$G_i - G_4 = (8860 - 3126) \times 10^6 = 5734 \text{ MM SCF}$$

$$\text{i.e. RF} = 5734/8860 = 65\%$$

10) Gas reserve by water drive at 3250 psia if there is one undip well:

$$\frac{1}{2}(G_i - G_3) = \frac{1}{2}(8860 - 3912) \times 10^6 = 2474 \text{ MM SCF}$$

$$\text{i.e. RF} = 2474/8860 = 28\%$$

## 12) Discussion of results:

The RF for volumetric depletion to 500 psia (no water drive) is calculated to be 85%. On the other hand, the RF for partial water drive is 65%, and for the full water drive is 56%. This can be explained as follows: As water invades the reservoir, reservoir pressure is maintained at a higher level than if there were no water encroachment. This leads to higher abandonment pressures for water-drive reservoirs. Recoveries, however, are lower because the main mechanism of production in gas reservoirs is depletion or gas expansion.

In water-drive gas reservoirs, it has been found that gas recoveries can be increased by:

1) Outrunning technique: Which is accomplished by increasing gas production rates. This technique has been attempted in Bierwang Field in West Germany where the field production rate has been increased from 50 to 75 MM SCF/D, and they found that the ultimate recovery increased from 69 to 74%.

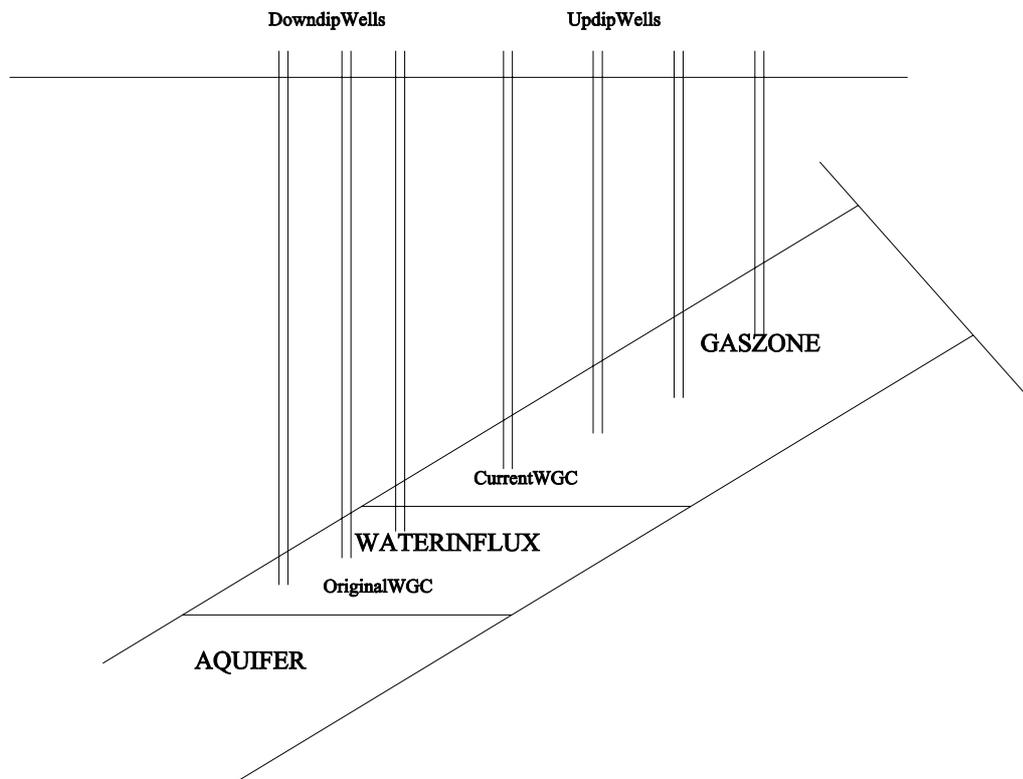
2) Coproduction technique: This technique is defined as the simultaneous production of gas and water, see Fig. 1. In this process, as downdip wells begin to be watered out, they are converted to high-rate water producers, while the updip wells are maintained on gas production. This technique enhances production as follows:

*First:* the high-rate downdip water producers act as a pressure sink for the water. This retards water invasion into the gas zone, therefore prolonging its productive life.

*Second:* the high-rate water production lowers the average reservoir pressure, allowing for more gas expansion and therefore more gas production.

*Third:* when the average reservoir pressure is lowered, the immobile gas in the water-swept portion of the reservoir could become mobile and hence producible.

It has been reported that this technique has increased gas production from 62% to 83% in Eugene Island Field of Louisiana.



**Fig. 1:** Cross section of a water-drive gas reservoir