

RESERVOIR ENGINEERING FOR GEOLOGISTS

Part 5B – Material Balance for Oil Reservoirs

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Material balance calculations for oil reservoirs are more complex than for gas reservoirs. They must account for the reservoir volumes of the produced fluids and the effect of pressure depletion on the oil volume remaining in the reservoir. They must account for the formation, expansion, and production of solution gas. The calculations must also account for the expansion of the reservoir rock and formation water, since they have similar compressibility as oil. As noted in last month's article, typical compressibility ranges are:

- Rock: 0.2 to 1.5×10^{-6} kPa^{-1}
- Gas: 10^{-3} to 10^{-5} kPa^{-1} (Varies significantly with reservoir pressure.)
- Water: 0.2 to 0.6×10^{-6} kPa^{-1}
- Oil: 0.4 to 3×10^{-6} kPa^{-1}

Nonetheless, in theory, material balance calculations can provide an independent estimate for the original oil-in-place for a solution gas drive reservoir with sufficient production history.

Havlena and Odeh (1963) developed a useful graphical procedure for estimating the oil-in-place volume for a solution gas drive reservoir (see Figure 1). By rearranging the material balance equation so that the total withdrawals from the reservoir are grouped onto the y axis while all the expansion terms are grouped on the x axis, the correct oil-in-place value will generate a straight line trend on the graph. Thus the oil volume for a solution gas drive reservoir can be determined by successively iterating until a straight line is achieved. Upward curvature indicates that the value selected as the OOIP is too small. Downward curvature indicates that the selected value is larger than the true size of the oil deposit. Various formulations of the material balance equation can be sourced in any of the references cited.

Figure 2 presents a Havlena-Odeh plot for a solution gas drive reservoir with an OOIP of 49 MMSTB. The four points calculated from reservoir pressure measurements are in good agreement with the predicted trend based on the OOIP value. Inadequate pressure build-up time may be the reason that the third pressure measurement comes in slightly below the predicted trend line.

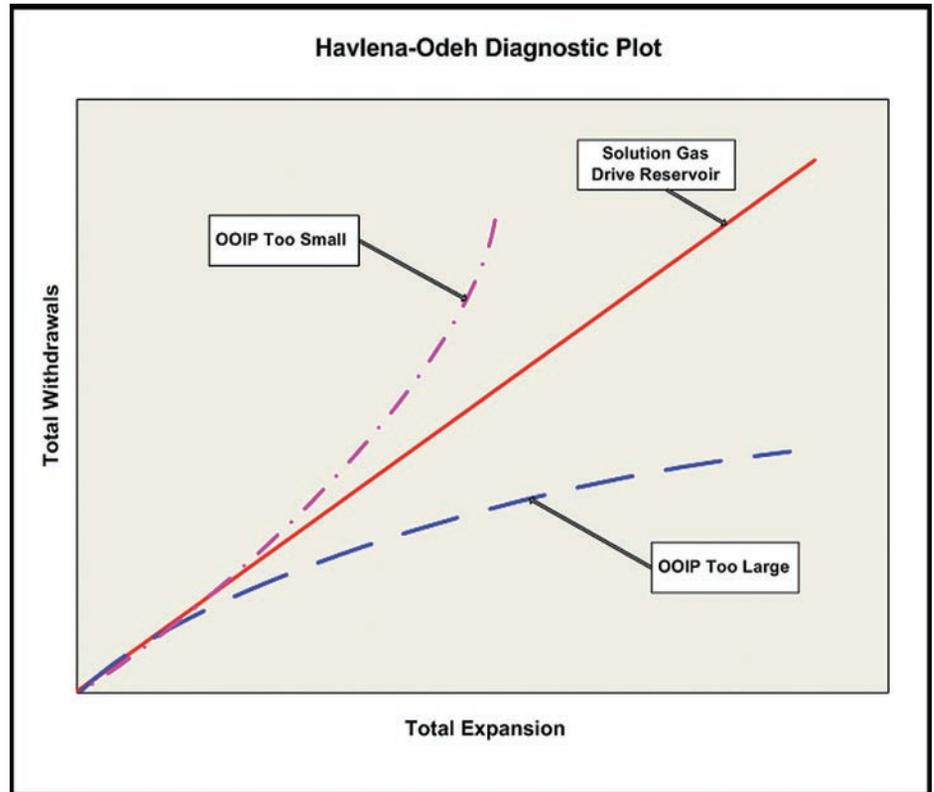


Figure 1. Gas Reservoir PIZ Material Balance Diagnostics.

When an oil deposit has a gas cap, the material balance calculations must also account for gas cap expansion and production. However, there are now too many unknowns to develop a unique solution by material balance alone. Estimating the oil-in-place in the presence of a gas cap first requires a volumetric estimate for the size of the gas cap. Then the size of the oil deposit can be estimated via material balance calculations.

Though it cannot independently determine the oil-in-place volume when a gas cap is present, the Havlena-Odeh plot can assist in confirming the consistency of the proposed solution. For every gas cap volume, there will be a corresponding oil-in-place volume that together result in a straight line pressure trend on the Havlena-Odeh plot. As before, upward curvature on the plot indicates that the OOIP value is too small; downward curvature that it is too large (Figure 3).

In practice, a table of values for OOIP is often set up and iteration performed on the ratio of the reservoir volume of the gas cap relative to the oil-in-

place (referred to as "m"). Now upward curvature on the Havlena-Odeh plot indicates that the "m" value (size of the gas cap) is too small relative to the selected oil volume. Downward curvature indicates that "m" (size of the gas cap) is too large (Figure 3).

Due to the fact the solution is non-unique many combinations of OOIP and "m" can be found that will mathematically match the reservoir production and pressure history. Mathematically successful solutions can range from:

- A large oil volume with a relatively small gas cap.
- A small oil volume with a relatively large gas cap.
- Multiple intermediate oil and gas cap volume combinations.

The dilemma can usually be resolved by using geological knowledge to identify the material balance solution(s) consistent with the reservoir's physical geometry. This consistency check provides the best chance of determining the correct magnitude of OOIP and OGIP.

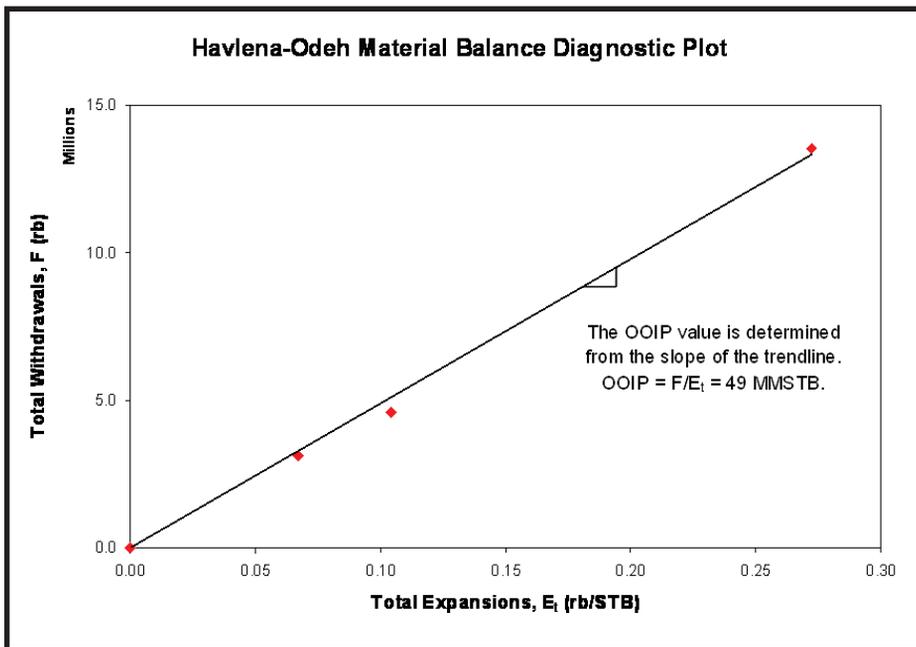


Figure 2. Multi-Well Gas Reservoir P/Z Plot.

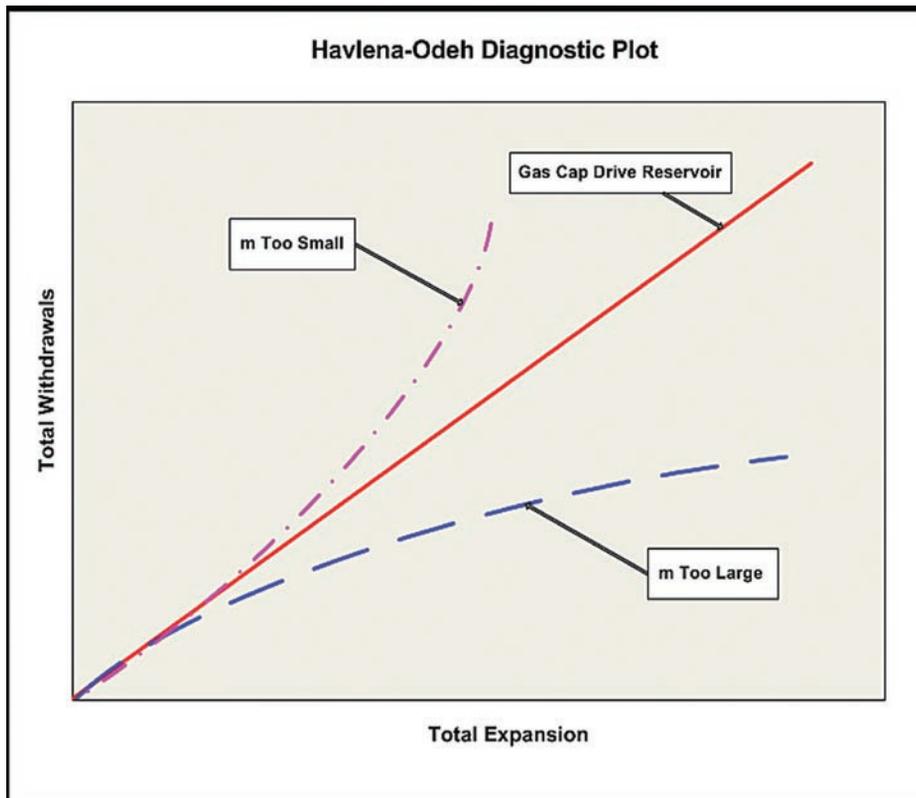


Figure 3. Multi-Well Gas Reservoir Pressure vs. Time Plot.

Geologic knowledge of the reservoir geometry is also essential when attempting to assess fluid influx into a reservoir. For example, water influx into a D-3 reef with an underlying aquifer could be assessed by periodically logging selected wellbores to determine and relate a rising oil-water interface to a water influx volume. Once the influx volume is estimated, in theory a material balance estimate for the original oil-in-place volume can be calculated. However, internal compartmentalization of the reef into multiple reservoirs may make the

task significantly more challenging than might be concluded from this article.

The Havlena-Odeh plot is also useful when fluid influx is suspected, as in possible inflow across a fault. In theory, measured reservoir pressures on a Havlena-Odeh plot will exhibit (Figure 4):

- A straight line for a volumetric (solution gas or gas cap) expansion reservoir provided the OOIP and OGIP values are correct.

- An upward curvature when there is pressure support due to fluid influx.
- A downward curvature when there is a pressure deficit.

The Havlena-Odeh plot cannot however, identify the reason for pressure support or the pressure deficit. Potential reasons for pressure support include:

- An unaccounted-for water injection/disposal scheme.
- Flow from a deeper interval via a fault or across a fault from an adjacent reservoir compartment. Note that the fluid can be any combination of oil, gas, and water.
- “U tube” displacement of the producing reservoir’s water leg by a connected reservoir. The connected reservoir is usually gas-bearing and may be undiscovered.
- Expansion of water. Due to the limited compressibility of water (0.2 to 0.6×10^{-6} kPa^{-1}) the water volume must be at least 10 times the reservoir oil volume for water expansion to provide pressure support. Thus the Cooking Lake aquifer underlying Alberta D-3 oil pools has the potential but water legs in clastic reservoirs are too small.

Potential reasons for a pressure deficit or downward curvature include:

- Later time interference from unaccounted-for producing wells.
- Rock compressibility in an overpressured reservoir.
- An inflow that gradually decreases over time, perhaps because of depletion or because flow across the fault decreases/ceases below a certain pressure threshold.

In cases where fluid inflow is suspected, knowledge of the reservoir geometry is an absolute requirement to limit the possible reasons for either an upward or downward curving trend.

Thus far, the discussion has been on the theoretical challenges to material balance analysis. In addition, a real world challenge is the scatter that is present in the pressure data. As with gas systems, oil well pressure data must first be correctly grouped into common reservoirs to generate reliable trends. But oil pressure data generally exhibits greater scatter because:

- Longer build-up times are required to extrapolate the pressure data to a reliable estimate of reservoir pressure, due to the increased viscosity of oil.

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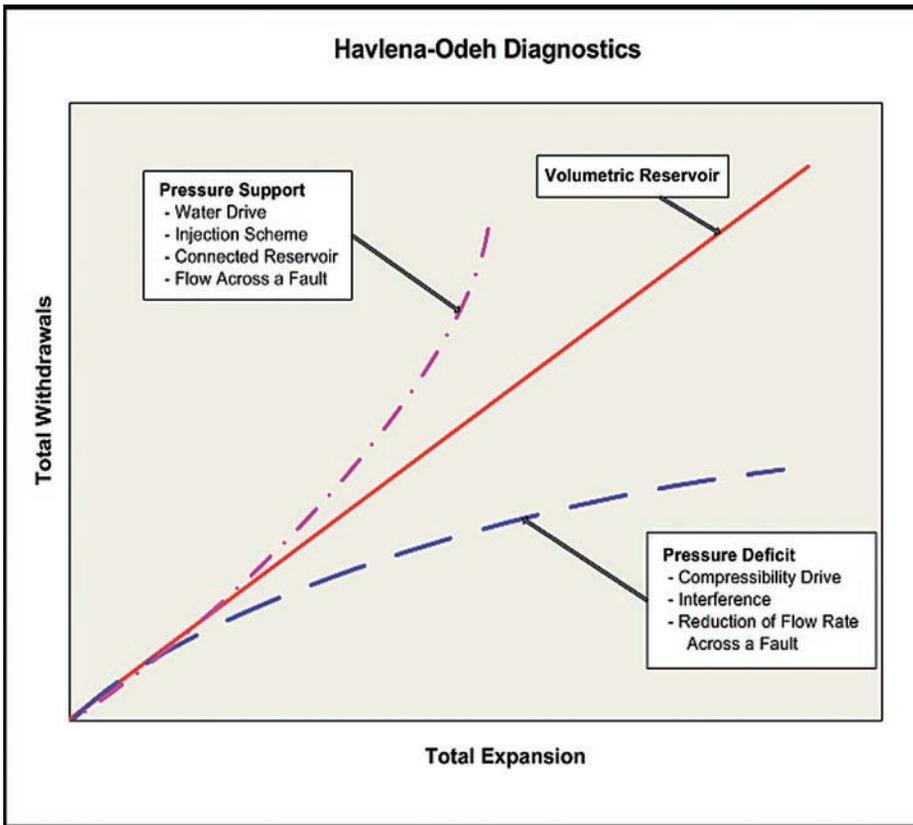


Figure 4. Single Well Gas Reservoir PIZ Plot.

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- Pressure gradients across the reservoir are more pronounced, due to the oil viscosity.
- Pressure differences in an oil column, due to the density of the oil, are sufficient to require careful correction to a common datum.
- Multiple perforation intervals and inadvertent commingling of intervals that were isolated by nature creates the potential for crossflow and further confuses the pressure data interpretation.

Other potential sources of error include:

- Thermodynamic equilibrium is not attained.
- PVT data that does not represent reservoir conditions.
- Uncertainty in the “m” ratio.
- Inaccurate production allocation.

Yet despite the foregoing theoretical and practical challenges, material balance analysis has proven its worth, with the accuracy of the analysis generally increasing as the reservoir is produced. In Fekete’s experience, the most reliable analyses are obtained by integrating the reservoir geology; fluid properties; and the well production, pressure, and completion histories into a consistent explanation.

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Look for our next article on “Well Test Interpretation/Pressure Transient Analysis” in the April issue of the Reservoir.

This article was contributed by Fekete Associates, Inc. For more information, contact Lisa Dean at Fekete Associates, Inc.



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