Steady State Permeability Measurements on Unconventional Reservoir Rock

Customer Need

Steady-state measurements have many advantages to unsteady state measurements, mainly that the interpretation of the data follows the basic form of Darcy's law and does not require complicated models or assumptions. There is additional value associated with performing these measurements with a fluid that is miscible with the residual oil in the core plugs[1].

Steady state permeability measurements were performed on a selection of unconventional reservoir plugs flowing decane through the sample at known water saturations. Measurements were performed at multiple flow rates with constant net confining stress.

Methods and Materials

Figure 1: The steady state permeability apparatus used in this example has the capacity to measure permeability on four 1" Ø core plugs simultaneously.

One-inch (1" Ø) core plugs of a fine-grain carbonate-rich rock with varying amounts of clay minerals (marls and argillaceous marls) were used in this example; 1.5" Ø samples can also be used. Samples were screened with Micro-CT at a resolution of 50µm removing any samples with cracks or flow barriers. Gas-filled porosity of the samples were measured with the GRI method after permeability tests and ranged from 0.02 to 0.12.

Samples were pressure saturated with decane at 150°F and 2000psi for several days prior to the permeability measurement. Water saturations were determined with low-field NMR T_2 relaxation measurements; water saturations ranged from 20-30%.

A bespoke steady state apparatus built specifically for unconventional reservoir rock measured permeability on four core plug samples simultaneously. Decane was flowed through plugs using very precise syringe pumps. A constant back pressure of 500psi was supplied across all samples; net confining stress was held constant at 3000psi. Samples were heated to 150°F to solubilize residual hydrocarbon in the decane. Samples were measured at multiple flow rates and linear regression[2] was used to calculate permeability values.

Results of the Analysis

Figure 2 shows pressure gradient data as a function of time at two different flow rates over 14 days for the first experiment. From early experimental data it was determined that samples reached steady state fairly quickly and the equilibration time was reduced. Subsequent samples took about one week for multi-rate permeability measurements.

PREMIER OILFIELD GROUP

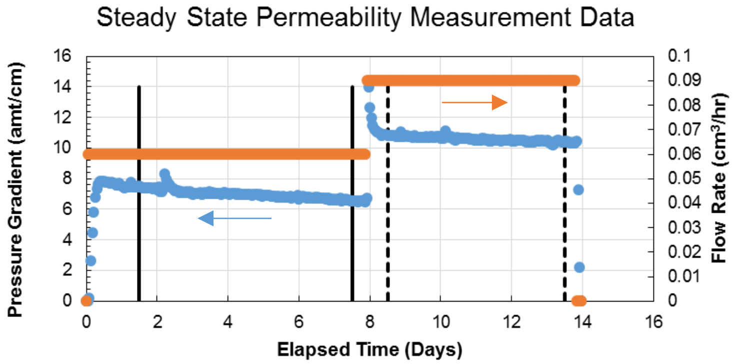

Figure 2: Data from the first steady state permeability test over 14 days. Blue Points are the pressure gradient and orange points are flowrate. Vertical black lines denote steady state region. Steady state was reached quickly justifying using one-week sample runs on subsequent samples.

A major advantage of measuring permeability at steady state with liquids was that compressibility and slippage were negligible allowing straightforward interpretations of pressure drop data.

Validation studies of this procedure found the steady state permeability method is accurate on one inch core plugs down to 10nD with greater than 95% reproducibility.

Pressure drop data from the measurements were inspected for quality and plotted in relation to flow rate with linear trend lines typically having correlation coefficients greater than 0.98. Figure 3 is an example plot showing the linear regression of pressure data. The measurements found that permeability values ranged from 30nD to 600nD with the majority of values clustering around 100-200nD.

> *"Validation studies of the steady state permeability method on unconventional reservoir rock found it reliable down to 10nD with reproducibility greater than 95%."*

Discussion

Steady-state permeability measurements were performed on one-inch diameter unconventional reservoir core plugs and a validation study proved the accuracy of the results. It was necessary plugs be screened with Micro-CT to eliminate samples with cracks or barriers to flow. Samples reached steady state fairly quickly; multiple point permeability measurements took about one week. Permeability ranged from 30-600nD for the selected samples.

Variations of this measurement are also available. Permeability can be measured with differing net confining stresses. Effluent from the sample can also be collected for geochemical analysis. The liquid used to measure permeability is not limited to decane, brine and dead oil from the field can also be used so long as there is equipment incompatibility.

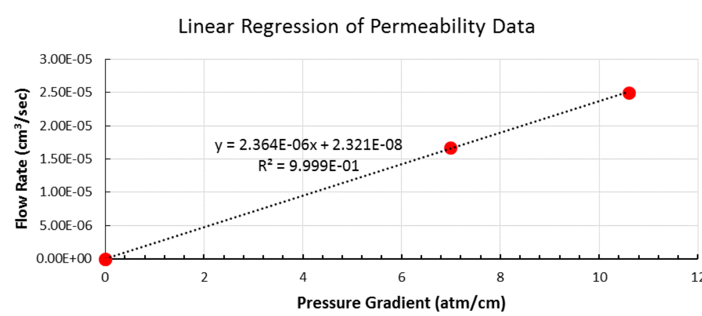

Figure 3: Example linear regression of permeability data from this study. Calculated permeability was 320nD.

References

(1) Chhatre, S. S. et al. *Petrophysics* **2015**, *56* (2), 116–124.

(2) McPhee, C. et al. I. *Dev. Pet. Sci.* **2015**, *64*.