A Radial Core Analysis Design for Multi-Phase Flow in Tight Porous Media

S. Kryuchkov*, Perm Inc, Calgary, AB, Canada
skryuchkov@perminc.com
A. Kantzas, Perm Inc., Calgary, AB, Canada
Lilly Yu, Perm Inc., Calgary, AB, Canada

Introduction

Standard geometry of a core used in permeability measurements is a cylinder with the fluid flowing along the axis of this cylinder. What if all the available cores were sampled vertically? Does it mean that measurement of horizontal permeability is out of the question? If permeability of the core is low and it is of some standard size (with the length of the cylinder being several times the radius) permeability measurement can take substantial time. Cutting a slab of the core could be a solution.

A procedure of saturating the core that is based on the propagation of condensation front is also discussed here. It will require creation of the temperature gradient within the core. Is the linear configuration the best one for performing this procedure in a controlled way?

As an answer to the above questions we utilized a geometry that is not standard in permeability measurement. A permeameter / flooding system was build based on radial flow of fluid. As experiments have shown this geometry does provide substantial advantages in answering the above questions in a positive way. It allows to measure horizontal permeability in the vertically cut core, it shortens the measurement time in tight cores, and it provides ease of control of temperature gradient for the condensation core saturation procedure.

Theory and/or Method

A cylindrical hole is drilled in the center of the core. Top and bottom are pressed against flanges with appropriately designed O-rings / gasket. Produced fluid is collected at the perimeter on the outside of the cylinder. If needed, heat source or sink can be placed at the axis of the cylinder allowing for creation of radial temperature gradient.

Permeability measurements were performed in a steady-state regime. So, equation for radial pressure distribution in a fluid under the assumption of the axial uniformity will be

$$\frac{\partial}{\partial r}\frac{r\rho k}{\eta}\frac{\partial P}{\partial r}=0$$

with the boundary condition of

$$2\pi rh\frac{\rho k}{\eta}\frac{\partial P}{\partial r}\bigg|_{r=R_1}=Q_m$$

If k, η, and ρ do not depend on pressure this equation simplifies to

$$\frac{\partial}{\partial r}\frac{r\partial P}{\partial r}=0\,,$$

which can be easily integrated with the above boundary condition. If the parameters depend on pressure we arrive at the same (linear) equation by introducing a pseudo-pressure function $\Psi(P)=\int_{P_0}^{P}\frac{P}{P_0}\frac{\rho k\eta_0}{\rho_0 k_0\eta}dP$ (for non-ideal gas it becomes $\Psi(P)=\int_{P_0}^{P}\frac{P}{P_0}\frac{k}{k_0}\frac{Z_0\eta_0}{Z\eta}dP$):

$$\frac{\partial}{\partial r}\frac{r\partial\Psi}{\partial r}=0$$

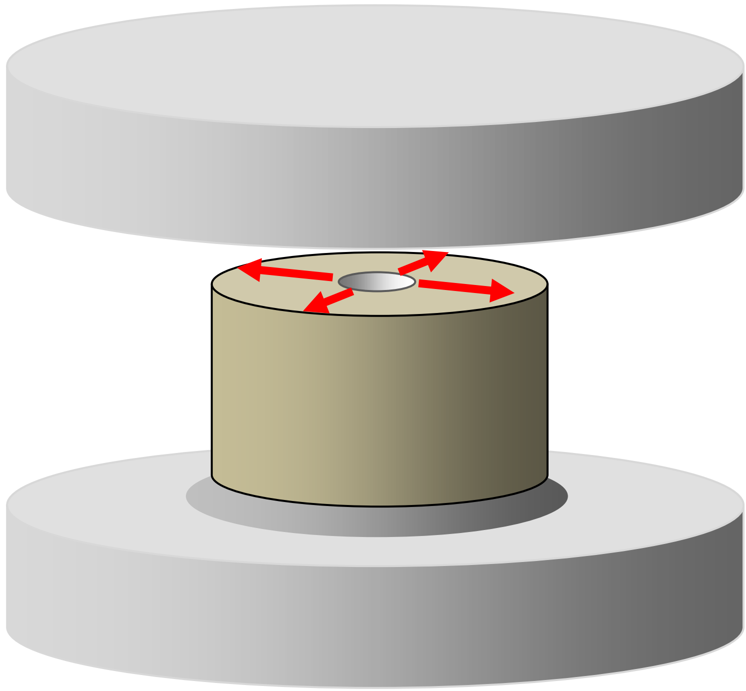

Figure 1: Schematic of test setup.

As a result the pressure (or pseudo-pressure) changes as logarithm of the radius.

Results

Helium was used for gas permeability measurements. Under the conditions of the tests it is very close to ideal gas in its properties. Figure 2 shows how flow rate changes in accordance with theoretical formula, which allows us to calculate gas permeability of the core. Measurements at different average pressure leads to varying gas permeability values. Correlating those to a straight line allows to extrapolate permeability to liquid state according to the Klinkenberg's correction formula (see graph at the RHS of Fig.2).

Measurement of relative permeabilities is also possible on this system. Bringing the samples to different level of saturation with water is a preparation step. After that the procedure of permeability measurement does not need any modifications. Figure 3 presents the results of such measurements.

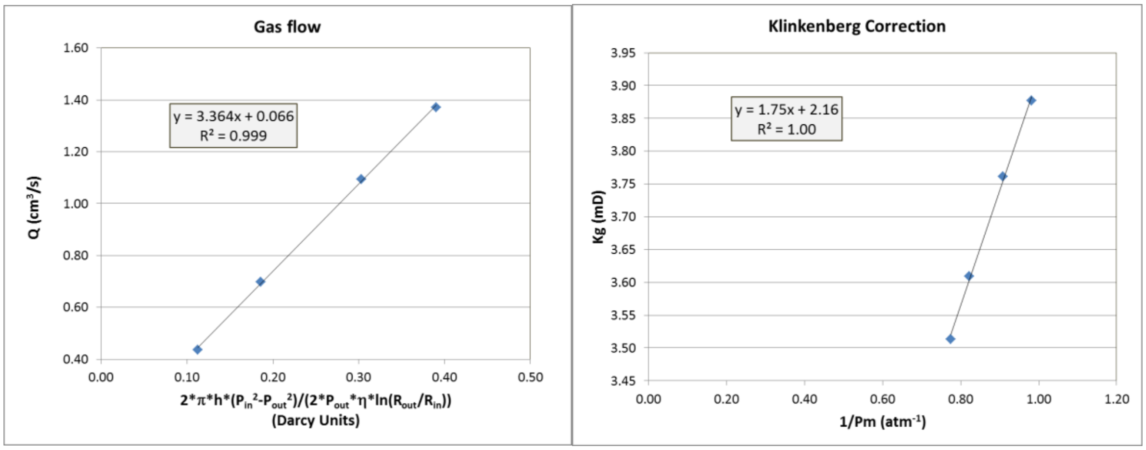

Figure 2. Example permeability

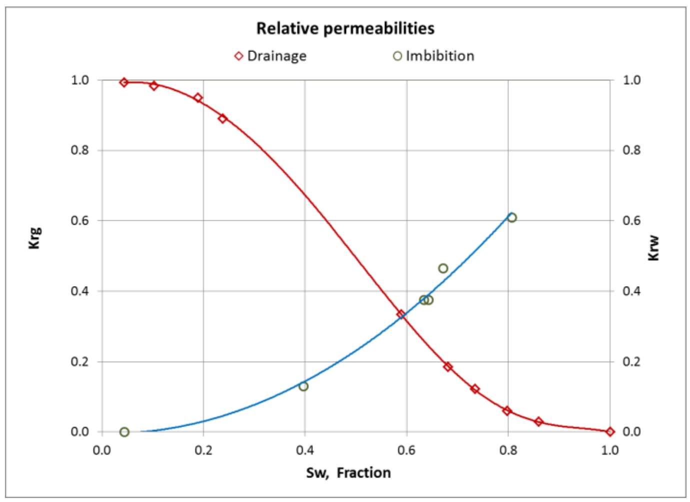

Figure 3. Example relative permeability

Conclusions

Advantages of radial configuration of permeameter were discussed. Experimental results show that this is a very useful configuration, which allows to measure horizontal and vertical permeability on the same core. Relatively low permeability also becomes measureable as the measurement time is shortened. Bringing the core to intermediate state of saturation and consecutive relative permeability measurements are also possible in this system.

Additional application of such a system can be creation of radial temperature gradient needed for saturation of core as a result of vapor condensation in the porous medium.