Unconventional Reservoir Geomechanics
Spring 2020

Homework 4: Permeability and Flow Mechanisms

Due May 11, 2020 00:00 PST

Instructions

This assignment focuses on understanding the relationships between permeability, pore pressure, effective stress, and pore size through analysis of laboratory data.

Part 1: Pressure-dependent permeability

a) Consider helium gas permeability measurements on a clay-rich, horizontal Eagle Ford sample from Heller et al. (2014) at pore pressures 1000-4000 psi (GP208 2020 HW4 permdata.txt). Calculate the effective stress parameter for permeability, χ, using the expression below (Unit 10, slide 10):

$$\chi = -\left(\frac{\partial \text{log} k/\partial P_p}{\partial \text{log} k/\partial P_c}\right)$$

What does the value of χ mean in terms of the relative sensitivity of permeability to changes in pore pressure and confining pressure? Hint: Find the change in log k with the change in P_p for P_c = 4000-6000 psi and take the average. Then, find the change in log k with the change in P_c for P_p = 1000-4000 psi and take the average.

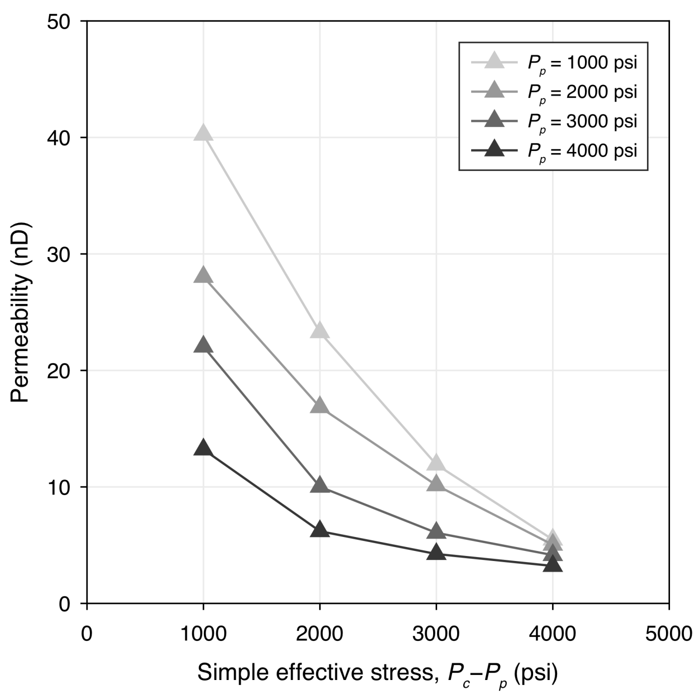

Figure 1: Permeability measurements on a clay-rich, horizontal Eagle Ford sample at various confining pressures and pore pressures. From Heller et al. (2014).

b) Plot the results from (a) with the x-axis as modified effective stress ($P_c - \chi P_p$). Then, plot the permeability data at lower pressure (250-750 psi) on the same plot (GP208 2020 HW4 lowppermdata.txt). Why do the low pressure data not necessarily follow the permeability-modified effective stress relationship?

Part 2: The Klinkenberg effect

a) Determine the magnitude of the Klinkenberg effect. First, find the permeability value of each low pressure curve at modified effective stresses 2000, 3000, and 4000 psi. Then, plot the permeability data at each effective stress as a function of inverse pore pressure ($1/P_p$) (e.g., Unit 10, slide 19).

b) For each effective stress, find the value of the permeability at infinite pore pressure, k_∞, and the Klinkenberg correction factor, K_b, using the expression below.

$$k_a = k_\infty \left(1 + \frac{K_b}{P_p}\right)$$

Part 3: Effective pore size

a) Use the expression below to calculate the effective slit pore width for each value of modified effective stress 2000-4000 psi using the following parameters:

$$w = \frac{16c\mu}{K_b} \left(\frac{2RT}{\pi M}\right)$$

Geometric factor, $c = 4$
Temperature, $T = 40$ °C
Molar mass, $M = 4$ g/mol
Pore pressure, $P_p = 500$ psi
Universal gas constant, $R = 8.3145$ J/mol°K

Find the viscosity, μ, of helium gas at the given pressure-temperature conditions from the NIST Chemistry WebBook (https://webbook.nist.gov/chemistry/fluid/).

b) Plot the effective slit pore width, w, as a function of effective stress. How does effective pore width vary with effective stress? Provide a physical explanation here. How do these values compare to the pore sizes observed in unconventional reservoir rocks (Unit 9)?

Part 4: Flow mechanisms

a) Under what conditions is slip flow important in gas production? Hint: Calculate the ratio of diffusive to viscous flux at 2000 psi effective stress (the ratio of the Klinkenberg corrected permeability to k_∞) as a function of pore pressure.

b) Calculate the mean free path, λ, as function of pore pressure for helium gas using the expression and parameters below.

$$\lambda = \frac{K_B T}{\sqrt{2}\pi d_m^2 P_p}$$

Temperature, T = 40 °C
Molecular diameter, d_m = 2.6e-10 m
Boltzmann's constant, K_B = 1.38064852e-23 $m^2kg/s^2{}^\circ K$

Use your answer to (e) to determine the value of the Knudsen number, Kn, as function of pore pressure at each effective stress. What does your answer signify in terms of the flow mechanisms active during the low pressure permeability measurements (Unit 10, slide 7)?