Research Summary

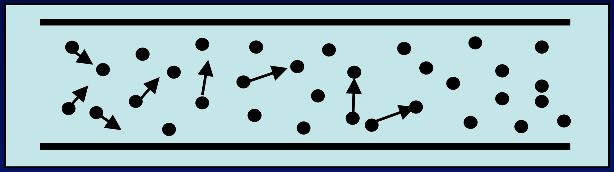
Dual-Mechanism Gas Flow in Naturally Fractured Source Rocks

Osman Apaydin & Erdal Ozkan
Colorado School of Mines

Flow Regimes in

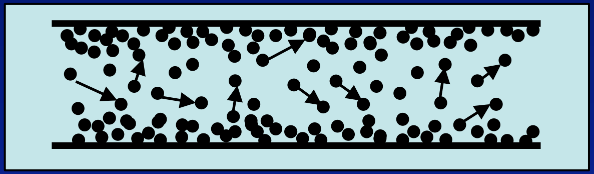
FLOW REGIMES IN POROUS MEDIA

High Velocity Flow (Forcheimer's Equation)



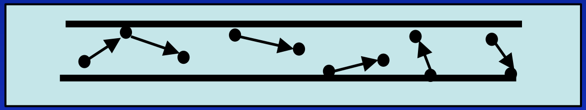
Non-Linear Flow
High *p*, *v*, & *k*
Macro-pores and fractures

Moderate Velocity, No-Slip Flow (Darcy's Law)



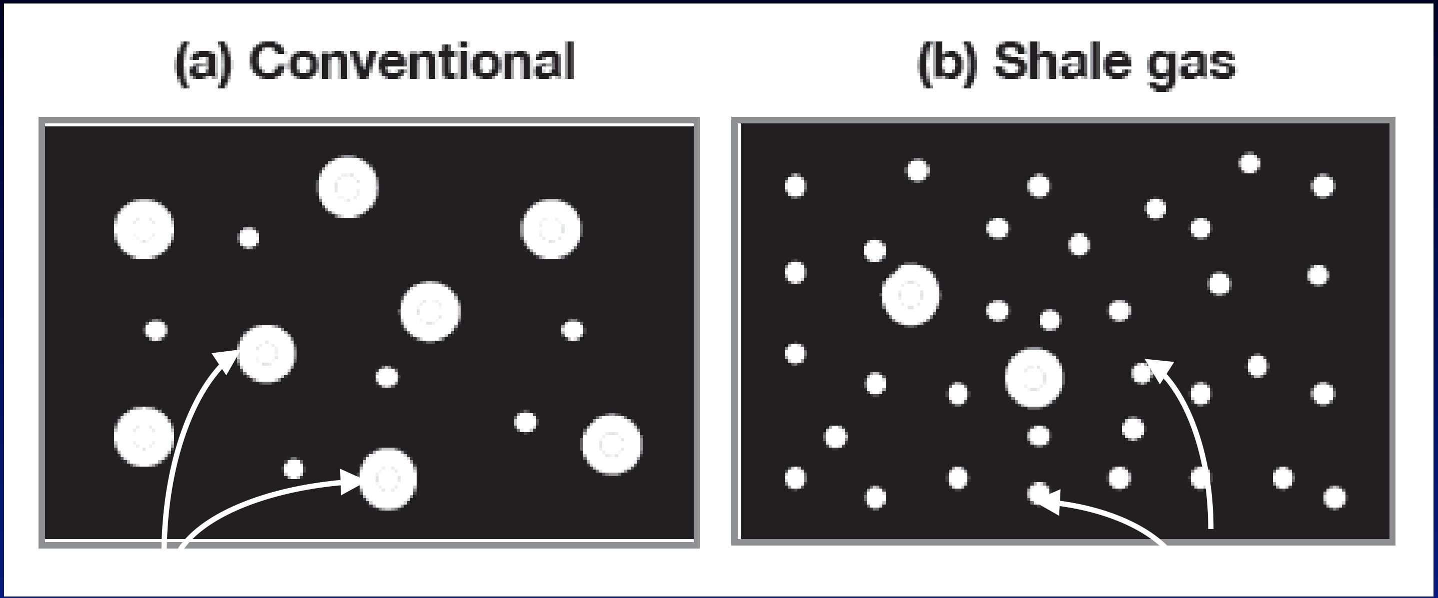
Linear and Laminar Flow
Moderate *p*, *v*, & *k*
Micro-pores

Low Velocity, Slip Flow (Klinkenberg effect)



Non-Linear Flow
Low *p*, *v*, & *k*
Core measurements, nano-pores,

Conventional vs. Unconventional



Micro-pores
(Darcy Flow)

Nano-pores
(Slip Flow)

Conventional Oil and Gas

$$d_{pore} \geq 1\ \mu m$$

$$k \geq 1\ md$$

Tight Oil and Gas

$$1\ \mu m \geq d_{pore} \geq 10^{-1}\ \mu m$$

$$1\ md \geq k \geq 1\ \mu d$$

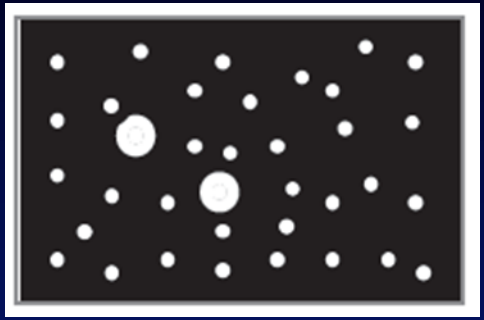
Shale Oil and Gas

$$10^{-1}\ \mu m \geq d_{pore} \geq 10^{-2}\ \mu m$$

$$1\ \mu d \geq k \geq 10^{-3}\ \mu d$$

Dual-Mechanism Flow in Source Rocks

Total Flow Velocity is the Sum of Darcy and Slip Velocities



$$v_{prm} = \frac{k_m}{\mu_g}\left(\frac{\partial p_m}{\partial r}\right)$$ Darcy velocity

$$v_{srm} = \frac{M_g D_g}{\rho_g}\left(\frac{\partial C_m}{\partial r}\right) = c_g D_g \left(\frac{\partial p_m}{\partial r}\right) \qquad D_g = \frac{31.57}{\sqrt{M_g}} k^{0.67}$$

Slip velocity from Fick's law. (Ertekin et al., 1986)

$$v_{rm} = v_{prm} + v_{srm} = \frac{k_{am}}{\mu_g}\left(\frac{\partial p_m}{\partial r}\right)$$

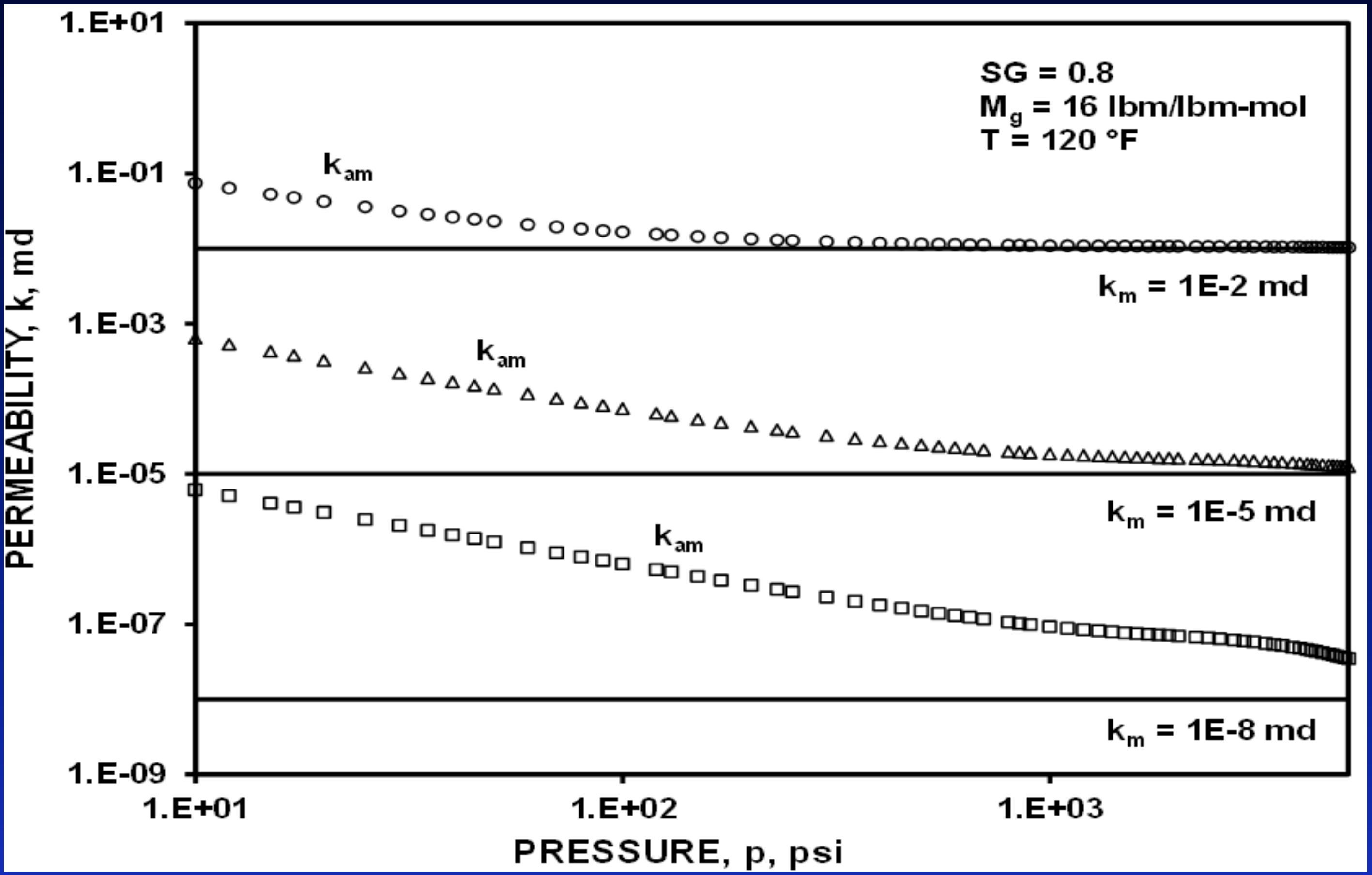
Sum of the radial components of the velocity

$$k_{am} = k_m\left(1 + \frac{b_{am}}{p_m}\right) \qquad b_{am} = \frac{D_g \mu_g c_g p_m}{k_m}$$

Similar to Klinkenberg (1941) but function of pressure

Dual-Mechanism Flow in Source Rocks

Contribution of diffusive flow to the apparent matrix permeability



Dual-Mechanism Flow in Source Rocks

Combined effect of slip flow and stress-dependent natural fracture permeability on pressure responses.