PGE381L
Advanced Petrophysics
HW4

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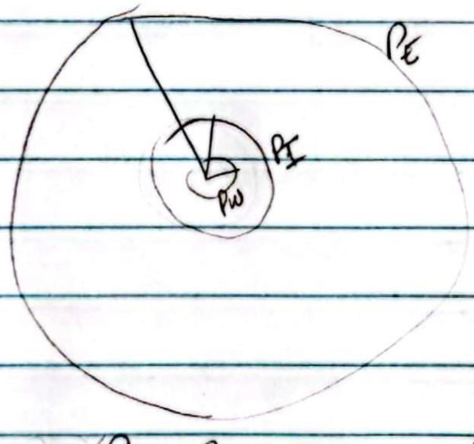
Question 1

$\phi = 15\%$ $K = 40\,mD$
$K_{IZ} = 5\,mD$
$\mu = 4\,cp$ $r_w = 0.3\,ft$ $r_{iz} = 1.3\,ft$
$h = 35\,ft$ $r_e = 1000\,ft$
$p_e = 5000\,psi$
$p_w = 2200\,psi$

$K_{eq} = ?$ $q_o = ?$

Cilindrical coords:



$$q \ln\left(\frac{r_e}{r_w}\right) = \frac{k}{\mu} 2\pi h (P_e - P_w)$$

$$q = \frac{1}{141.2} \frac{kh(P_e - P_w)}{\mu B \ln(r_e/r_w)}$$

$$(P_w - P_e) = \frac{141.2\, q\, \mu B \ln(r_e/r_w)}{kh}$$

a)

$$(P_w - P_e) = (P_w - P_I) + (P_I - P_e)$$

$$\frac{\ln r_e/r_w}{K_{avg}} = \frac{\ln r_I/r_w}{K_I} + \frac{\ln r_e/r_I}{K_e}$$

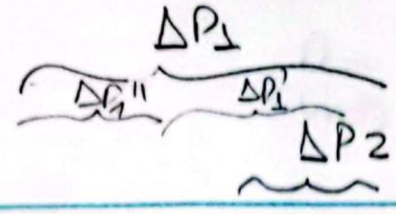
$$\frac{\ln 1000 - \ln 0.3}{K_{avg}} = \frac{\ln 1.3 - \ln 0.3}{5} + \frac{\ln 1000 - \ln 1.3}{40}$$

$$\boxed{K_{avg} = 17.66\ md}$$

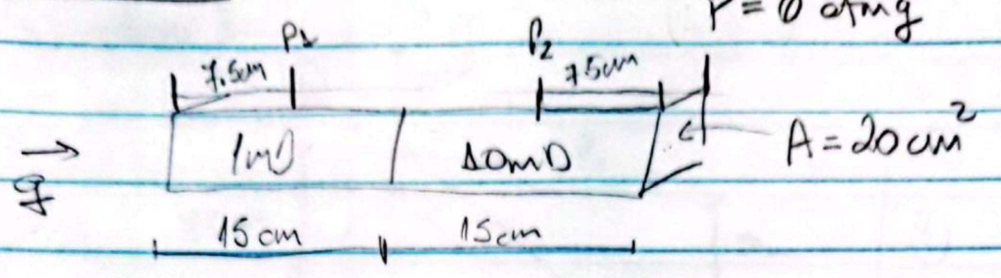
(b) $$q = \frac{1}{141.2} \frac{Kh(P_e - P_w)}{\mu \ln(r_e/r_w)}$$

$$q = \frac{1}{141.2} \cdot \frac{(17.66)(35)(2200-5000)}{(4)\ln(1000/0.3)}$$

$$\boxed{q = 377.69 \text{ rbpd}}$$



Question 2



$\mu = 1\,cp$ $\qquad q = 5\ cm^3/h \times \frac{h}{60min} \times \frac{min}{60s} = 0.00139\ cm^3/s$

$$q = \frac{kA}{\mu}\frac{\Delta P}{L}$$

$$\Delta P_2 = \frac{q \cdot \mu \cdot L}{k \cdot A} = \frac{(0.00139)(1)(7.5)}{(10^{-2})(20)}$$

$$\Delta P_2 = 0.521\ atm \Rightarrow \boxed{P_2 = 0.521\ atm}$$

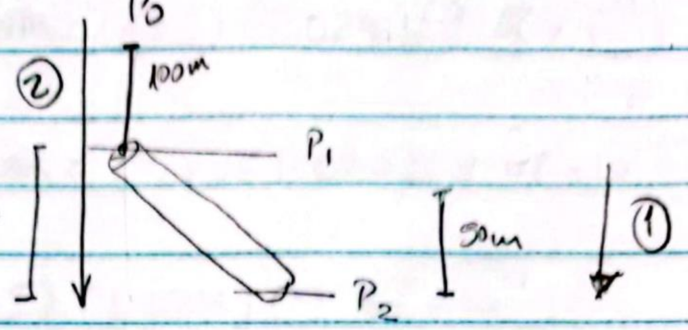
$$\Delta P_1 = \Delta P_1' + \Delta P_1''$$

$$\Delta P_1 = \frac{(0.00139)(1)(15)}{(10^{-2})(20)} + \frac{(0.00139)(1)(7.5)}{(10^{-3})(20)}$$

$$\boxed{\Delta P_1 = 0.625\ atm} \rightarrow \boxed{P_1 = 0.625\ atm}$$

Darcy units : $\Delta P_H = 0.433 \gamma z$

Question 3



$\Delta P_H = \rho g h \Rightarrow [Pa] = [\frac{kg}{m^3}] \cdot [9.81 \frac{m}{s^2}] [m]$

$[atm] = \frac{[Pa]}{101325} = \frac{1}{101325} \frac{g}{\cancel{cm^3}} \cdot \frac{kg}{1000g} \cdot \frac{10^6 \cancel{cm^3}}{m^3} \cdot 9.81 \cdot \frac{\cancel{cm} \cdot m}{100 \cancel{cm}}$

$[atm] = 0.00097 \gamma z = \underbrace{9.68 \times 10^{-4}}_{c} \gamma z$ ← g/cc ← cm

ⓐ Yes, there is flow downwards, because:

① $= 50 \times G_F$ < ② $= 175 \times G_F$.

Therefore, the flow through the porous media results in a pressure drop of 125 cm × GF. Where GF is the fluid gradient.

ⓑ Downwards.

c) $\Phi_1 @ \text{DATUM} = (175)(1.024)(9.68 \times 10^{-4})$

$\Phi_2 @ \text{DATUM} = (50)(1.024)(9.68 \times 10^{-4})$

$\Delta\Phi = (125)(1.024)(9.68 \times 10^{-4})$

$\Delta\Phi = 0.1239 \text{ atm}$

$$q = \frac{kA}{\mu L}\Delta\phi = \frac{(2)\cancel{(100)}(0.1239)}{(1.5)\cancel{(100)}} =$$

$\boxed{q = 0.165 \text{ cm}^3/\text{s}}$ $\quad V = \frac{0.165}{100} = 1.65 \times 10^{-3} \text{ cm/s}$

d) $$Re = \frac{V \rho D}{\mu} = \frac{(1.65 \times 10^{-3})\left[\frac{\text{cm}}{\text{s}}\right] \cdot (1.024)\left[\text{g/cm}^3\right] \frac{1}{16}[\text{mm}]}{1.5[\text{CP}]}$$

$$Re = (70.4 \times 10^{-6}) \frac{\cancel{\text{cm}}}{\cancel{\text{s}}} \cdot \frac{\cancel{\text{g}}}{\cancel{\text{cm}^3}} \times \cancel{\text{mm}} \times \frac{1}{\cancel{\text{cp}}} \frac{\cancel{\text{cm}}}{10\cancel{\text{mm}}} \times \frac{\cancel{\text{kg}}}{1000\cancel{\text{g}}} \times \frac{1000\cancel{\text{cp}}}{\cancel{\text{kg/ms}}}$$

$$\times 100 \frac{\cancel{\text{cm}}}{\cancel{\text{m}}}$$

$\boxed{Re = 7.04 \times 10^{-4} \ll 1}$

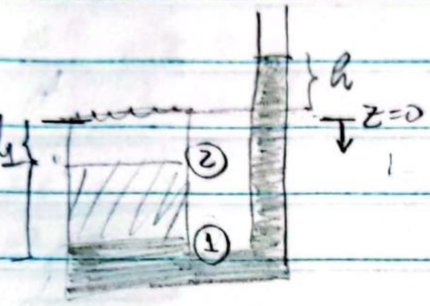
Thus, flow is laminar and Darcy's law is valid

4

a

$$q = -\frac{kA}{\mu}\frac{d\Phi}{ds} \qquad \frac{dV}{dh} = a$$

$$q = \frac{dV}{dt} = \frac{dV}{dh}\frac{dh}{dt} = a\frac{dh}{dt}$$



Φ_1 @ datum $= \rho g h$

Φ_2 @ datum $= 0$

$\Delta\Phi = \rho g h$

$$q = a\frac{dh}{dt} = -\frac{kA}{\mu}\frac{\rho g h}{L}$$

$$\boxed{\frac{dh}{dt} = -\frac{kA}{\mu a}\frac{\rho g h}{L}}$$

b

$$\int_{h_0}^{h}\frac{dh}{h} = \int -\frac{kA}{\mu a}\frac{\rho g}{L}\,dt$$

$$\Big[\ln(h)\Big]_{h_0}^{h} = -\frac{kA}{\mu a}\frac{\rho g}{L}\Delta t$$

$$\boxed{\ln\left(\frac{h}{h_0}\right) = -\frac{kA}{\mu a}\frac{\rho g}{L}\Delta t}$$

(c) $\ln\left(\frac{h}{h_0}\right) = -\frac{kA}{\mu a}\frac{\rho g}{L}\Delta t = -\frac{kR^2}{\mu r^2}\frac{\rho g}{L}\Delta t$

$h_0 = 100\,cm$

$Slope = -401.33 \times 10^6\ (1/s)$

$L = 10\,cm$

$D = 5\,cm \rightarrow R = 2.5\,cm$

$d = 1\,cm \rightarrow r = 0.5\,cm$

$\mu = 1\,cp$

$g = 981\,cm/s^2$

$\rho = 1.02\,g/cm^3$

$Sl = -\frac{kR^2}{\mu r^2}\frac{\rho g}{L}$

$$\boxed{k = -\frac{\mu r^2 L}{R^2 \rho g}}$$

UNITS :

$$[k] = cp \cdot \frac{\cancel{cm^2}}{\cancel{cm^2}} \cdot \cancel{cm} \cdot \frac{cm^3}{g} \cdot \frac{s^2}{\cancel{cm}} = 10^{-3} Pa \cdot s \cdot 10^{-9} \cancel{m^3} \cdot \frac{10^3}{kg} s^2$$

$$[k] = 10^{-6}\,m^2 \cdot \frac{D}{9.8 \times 10^{-13}} = 1.013 \times 10^6\,D$$

$$\Rightarrow \boxed{k = 0.163\,D}$$

```python
df = pd.DataFrame(
    { 't': [0,100,500,1000,2000,3000,4000,5000],
      'h': [100, 96.1, 82, 67,45, 30, 20, 13.5]
    })

h0 = 100
df['lnh'] = ln(df.h/h0)

r = 1/2
R = 5/2
rho = 1.02
g = 981
L=10
mu = 1


from scipy.stats import linregress as linreg
sl = linreg(df.t, df.lnh).slope

CNT = 1e-6/9.869233E-13
Kavg = - CNT * mu * r**2 / R**2 * L / rho / g * sl

print(f"Slope:{sl:.3e}       Permeability: {Kavg:.3f} D")

import matplotlib.pyplot as plt
plt.plot(df.t, df.lnh)
''
```

```
Slope:-4.013e-04       Permeability: 0.163 D
''
```