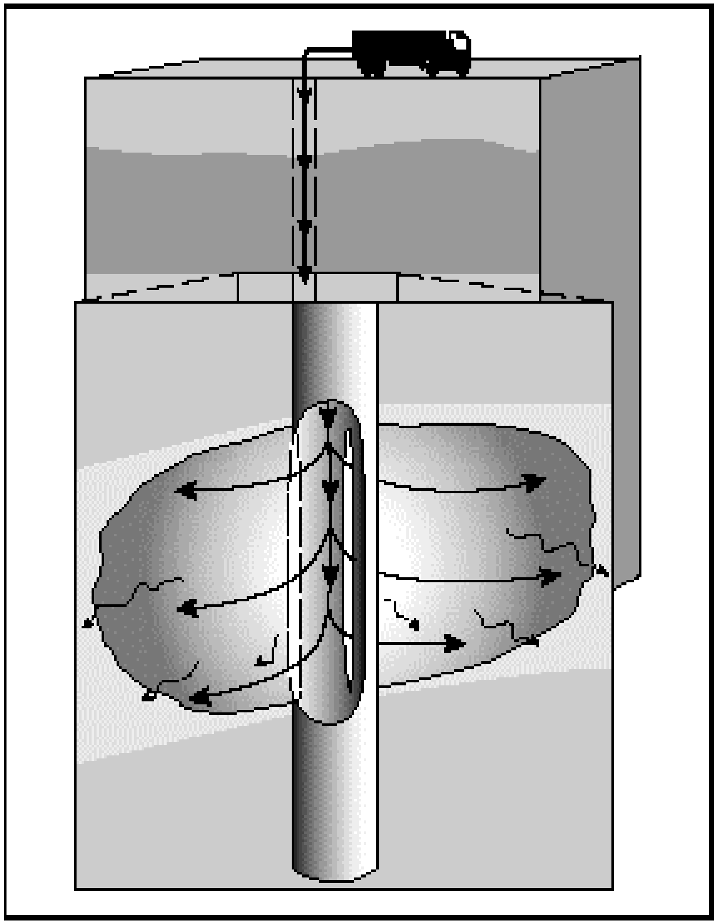


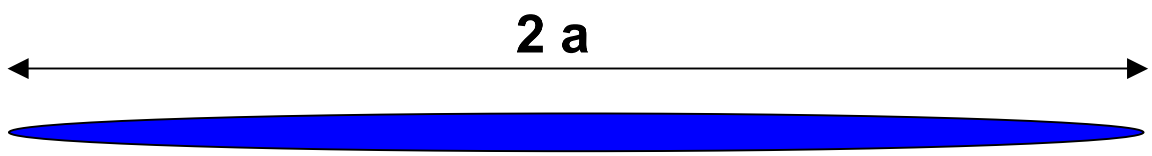
Figure 5-2. Cross-sectional view of a propagating fracture.

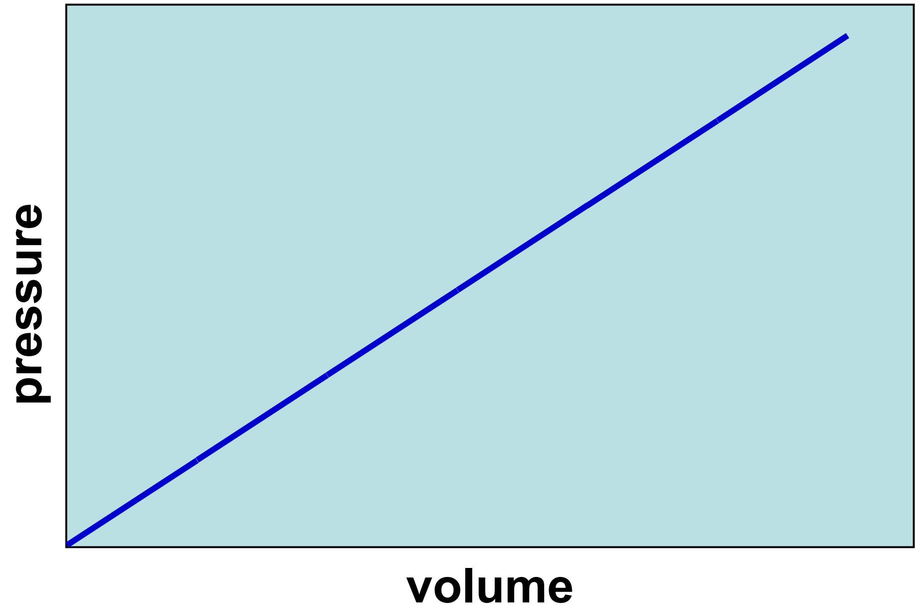
Review of Hydraulic Stimulation Technology

R. Jung, F. Rummel

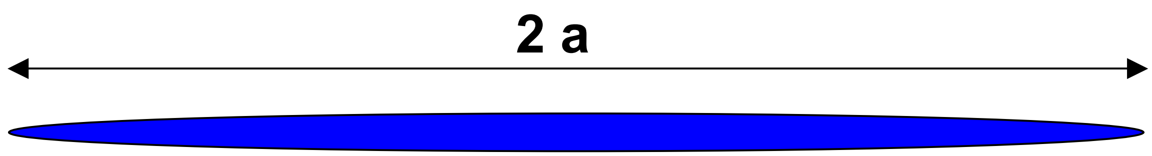
ENGINE Workshop 3
Ittingen 29./30.06.2006

Mechanical properties of fractures





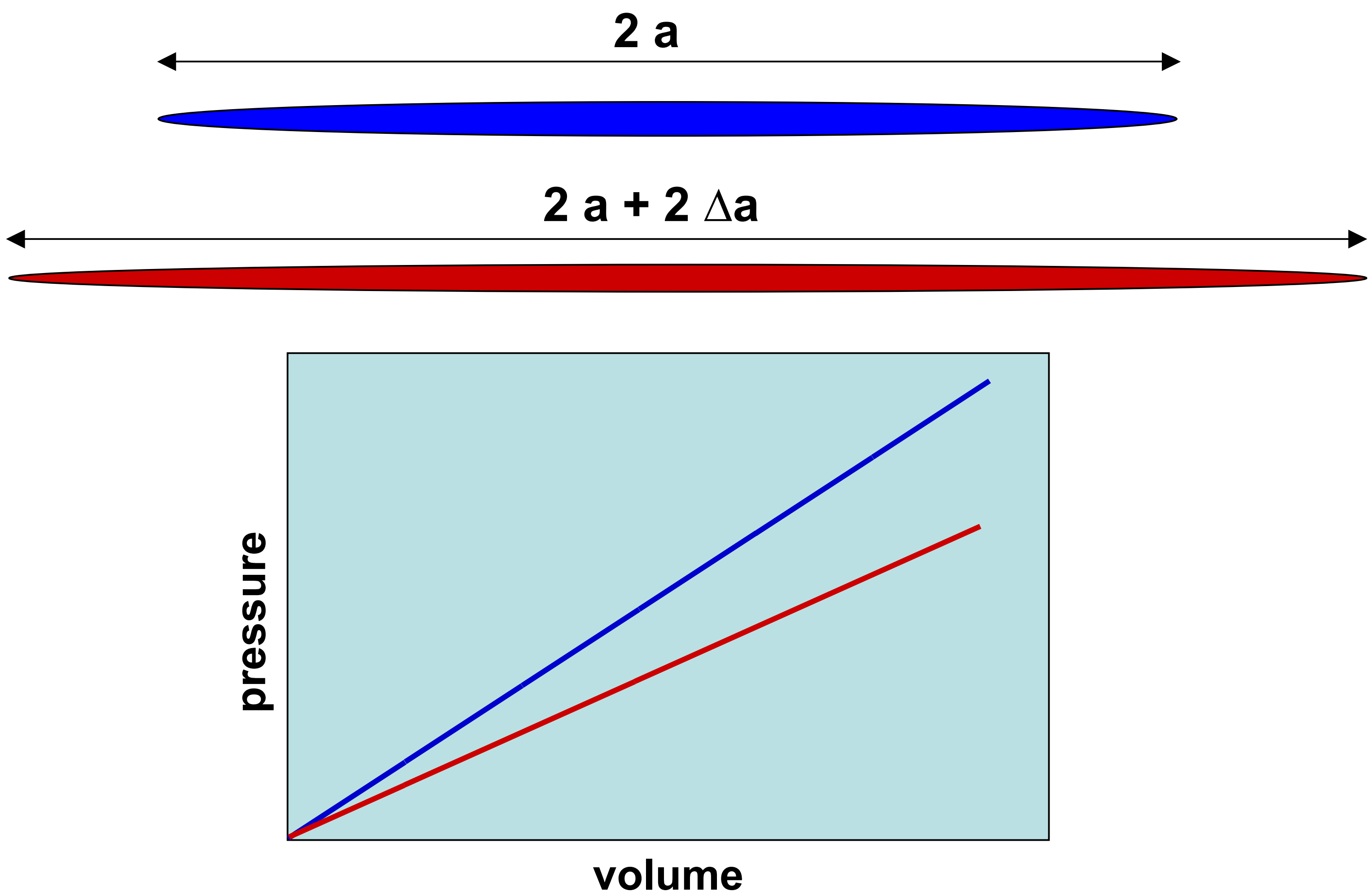
Mechanical properties of fractures



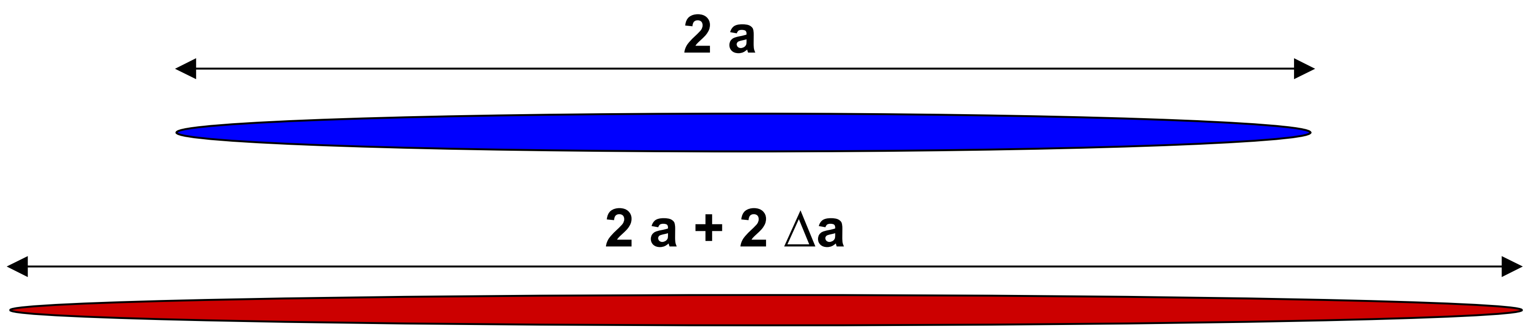
2a	dw/dp	dV/dp
[m]	[mm/bar]	[m³/bar]
1	0.003	$3 \cdot 10^{-6}$
10	0.03	0.003
100	0.3	3
1000	3	3000
in contact	0.001-0.01	

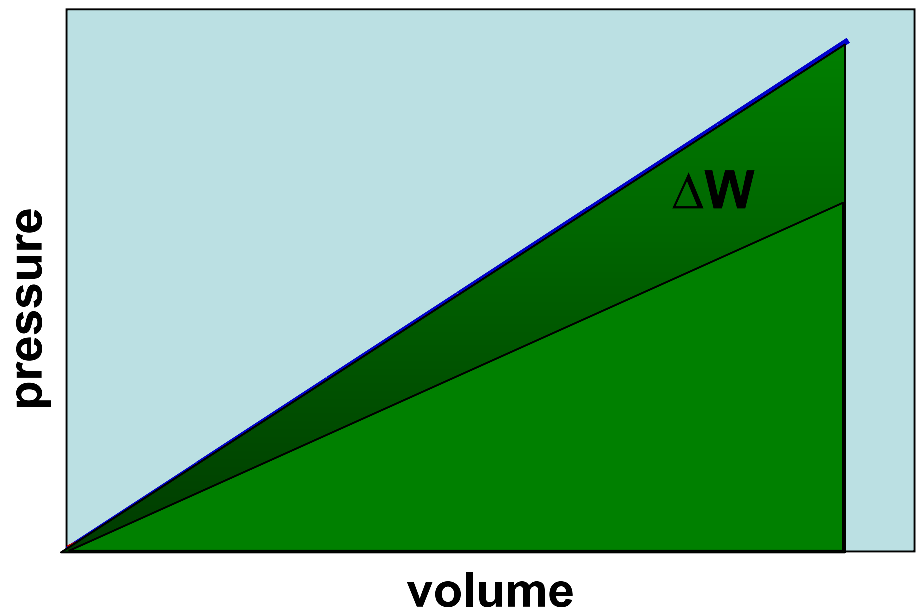
E = 50 GPa

Mechanical properties of fractures



Fracture propagation





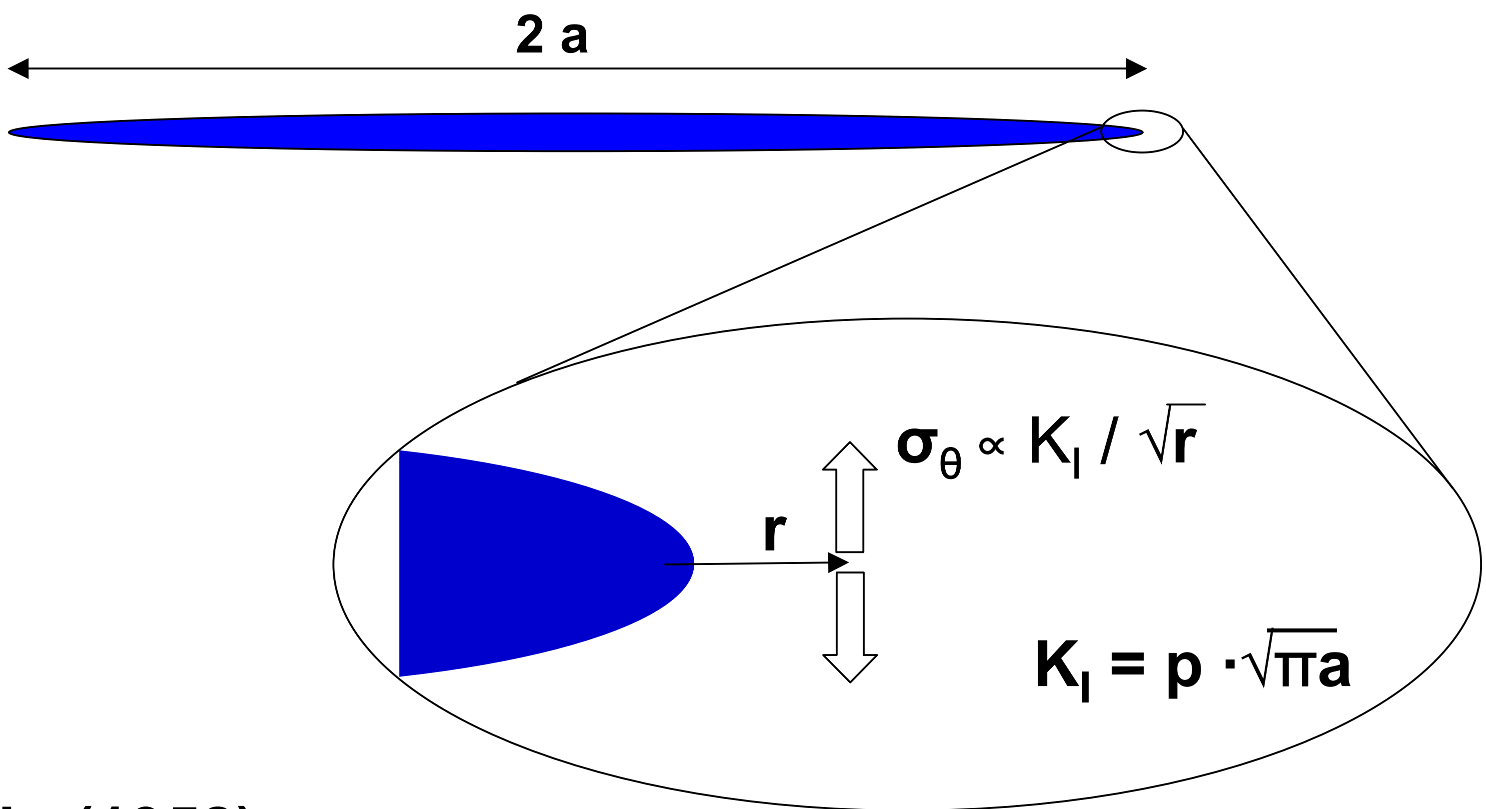
Griffith (1921)

$$\Delta W \geq 2\ \Delta a \cdot \gamma$$

γ : surface energy

$\gamma = 10 – 100\ J/m^2$

Fracture propagation



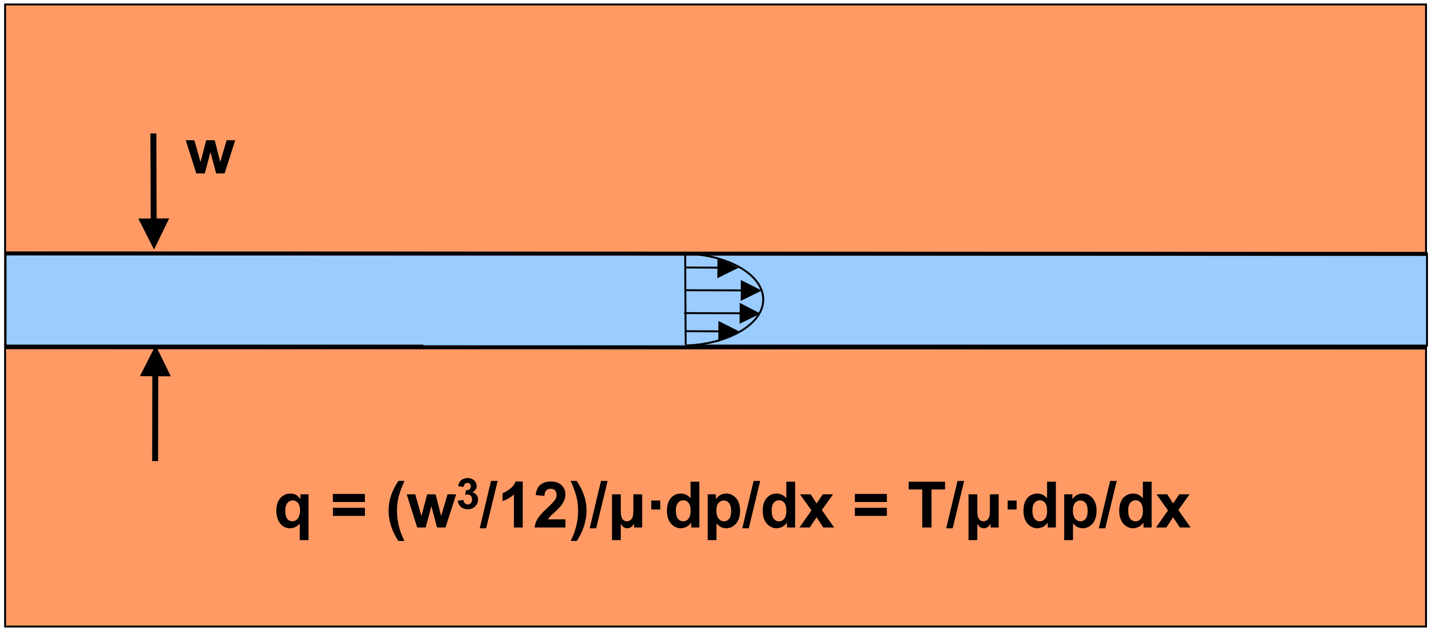
Irvin (1958)

$$K_I = K_{IC}$$

K_{IC}: fracture toughness

$K_{IC} = 1\ \text{MPa}\cdot\text{m}^{1/2}$

fluid flow in fractures

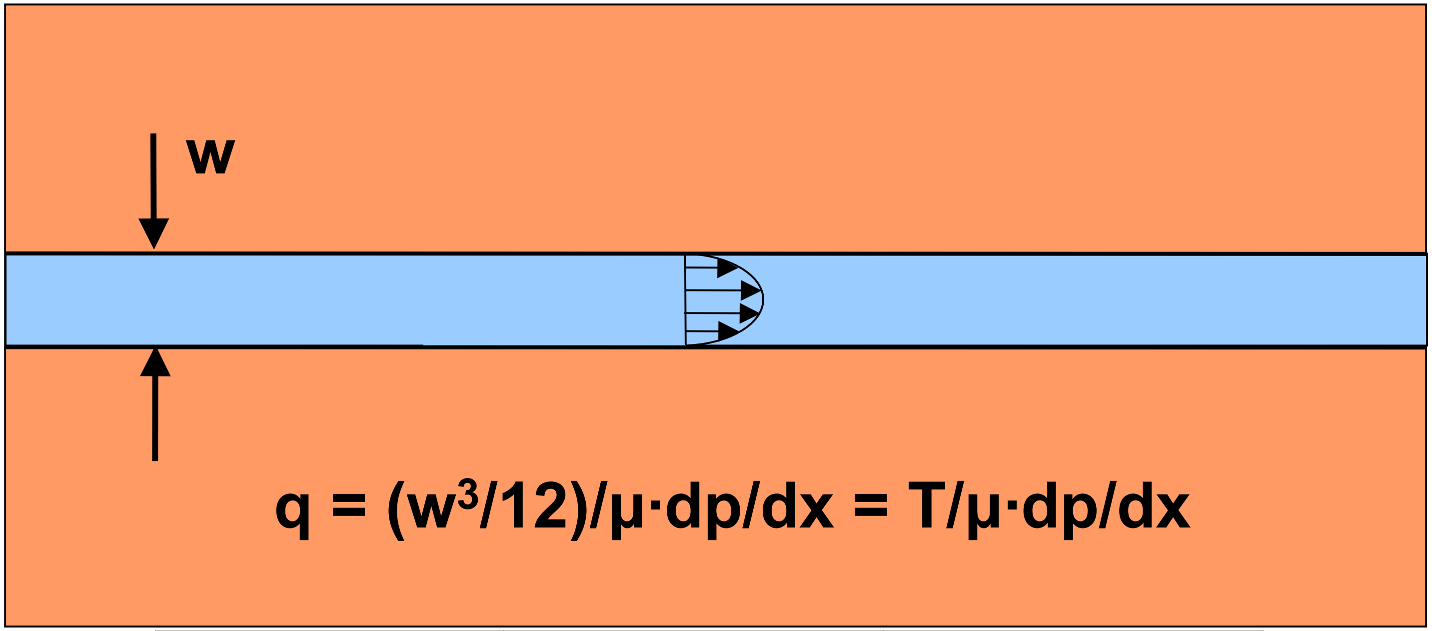


$$q = (w^3/12)/\mu \cdot dp/dx = T/\mu \cdot dp/dx$$

T : fracture transmissibility

μ : viscosity

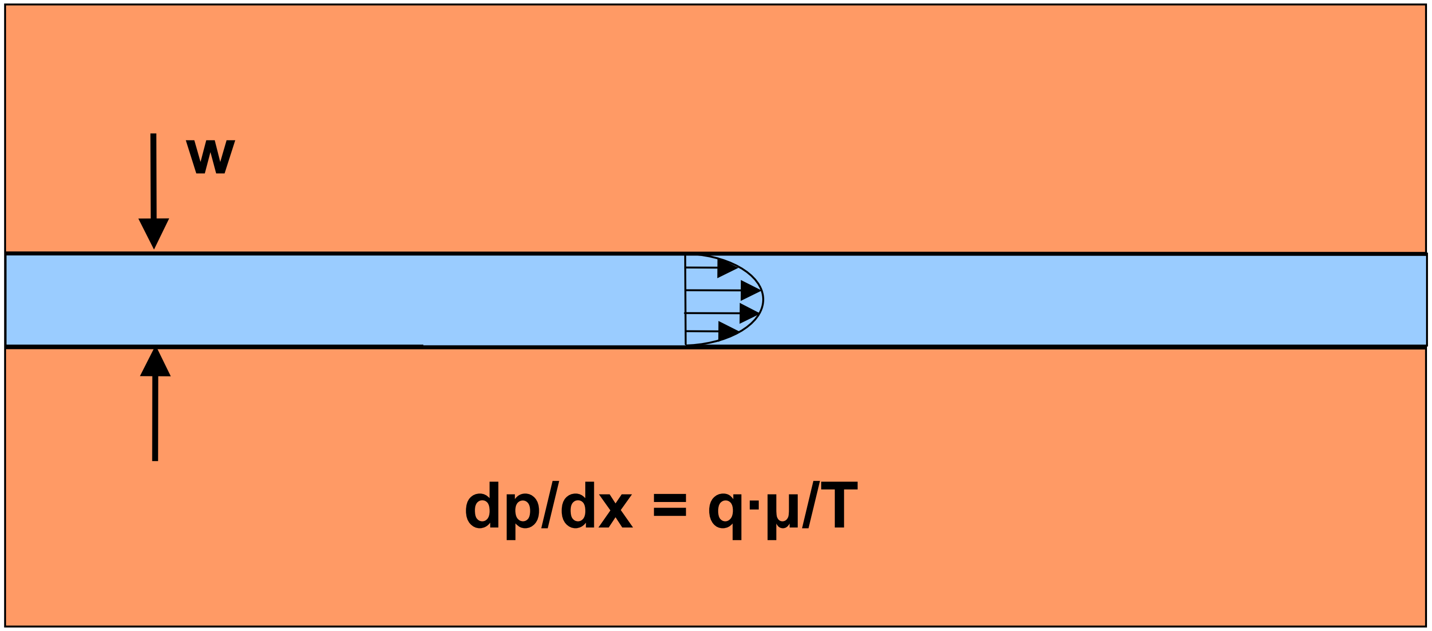
fluid flow in fractures



$$q = (w^3/12)/\mu \cdot dp/dx = T/\mu \cdot dp/dx$$

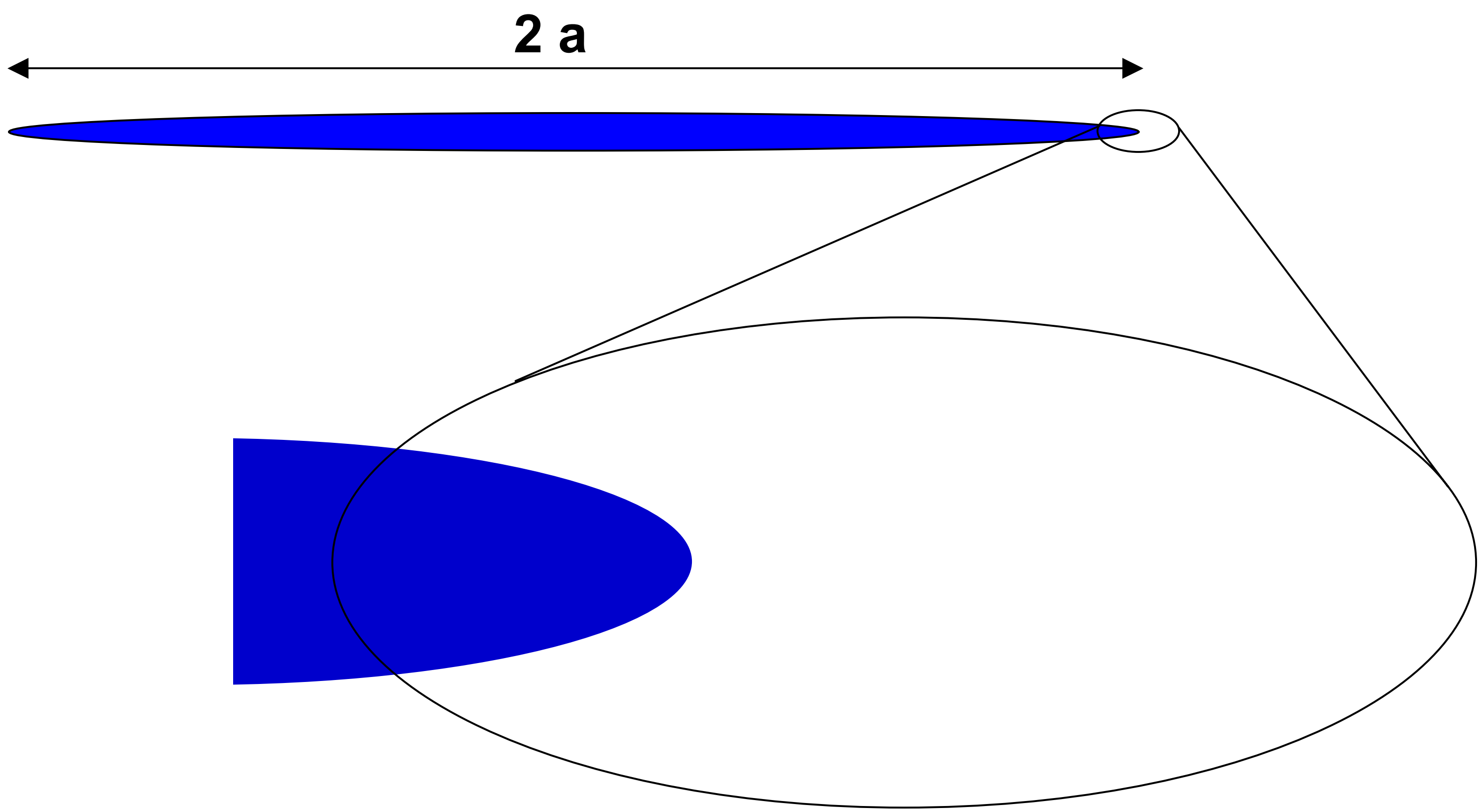
w	T	T
[mm]	[m³]	[D·m]
0.01	10^{-16}	10^{-4}
0.1	10^{-13}	0,1
1	10^{-10}	100
10	10^{-7}	10^{5}
Porous aquifer	10^{-11}	10

fluid flow in fractures



w	q	dp/dx
[mm]	[l/(s·m)]	[bar/m]
0.01	1	10^5
0.1	1	100
1	1	0.1
10	1	10^{-4}

fluid flow in fractures



High gradients at the fracture tip

Hydrodynamic fracture models

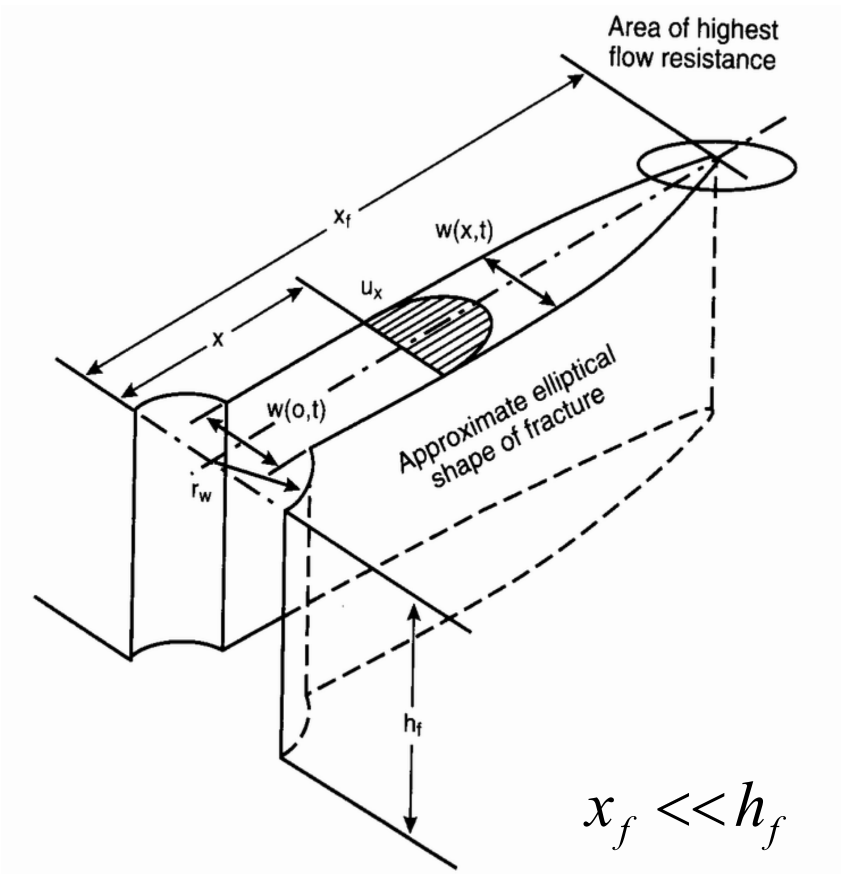


Figure 16-8

Khristianovich, Zheltov, Geertsma, de Klerk (KGD)
Model Geometry

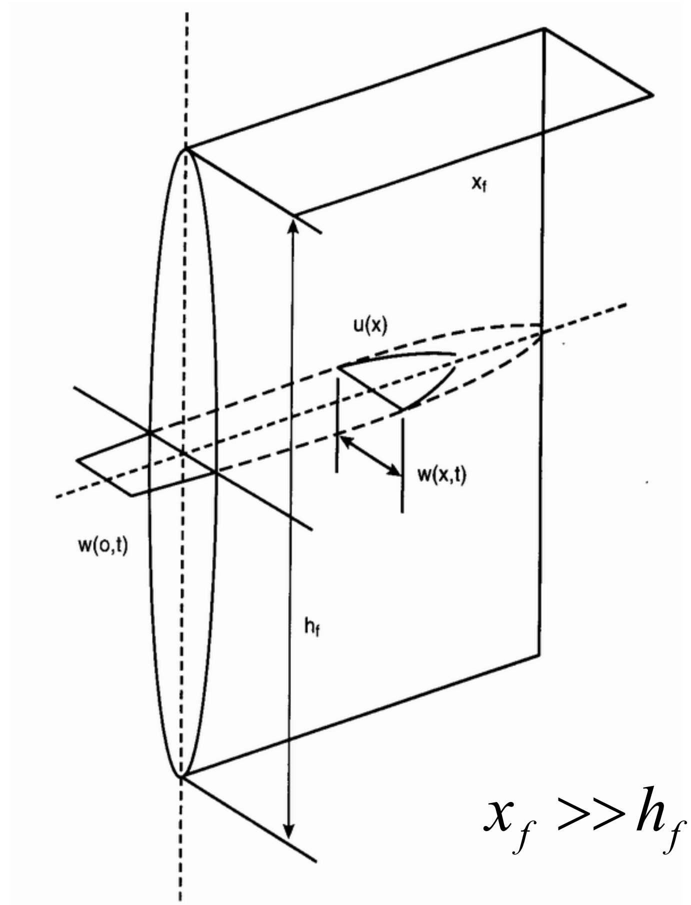


Figure 16-7

Perkins, Kern, and Nordgren (PKN)
Model Geometry

Hydrodynamic fracture models

KGD fracture model (1955, 1969)

$$\overline{w} = 2{,}27 \cdot \left[\frac{q_i \cdot \mu \cdot (1-\nu) \cdot x_f^2}{G \cdot h_f} \right]^{1/4} \left(\frac{\pi}{4} \right)$$

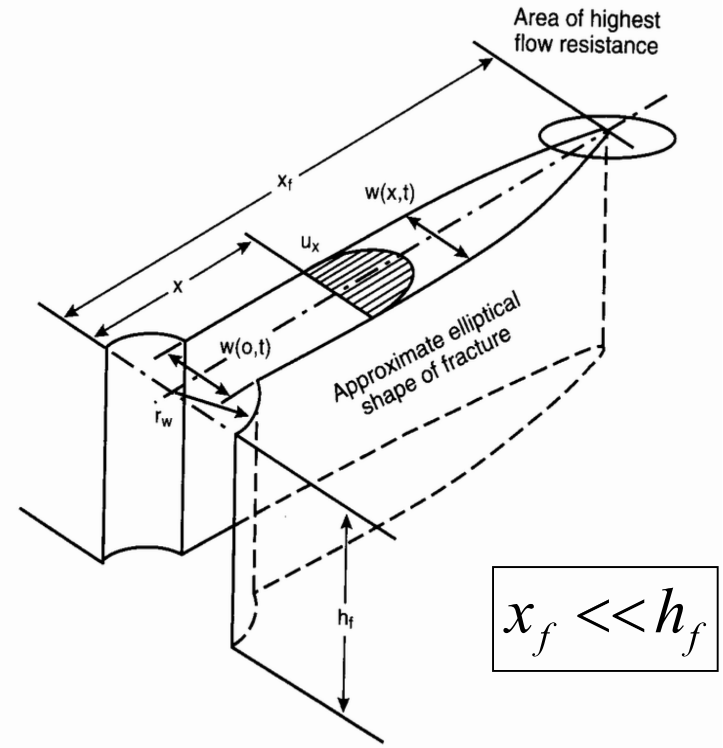


Figure 16-8
The KGD model geometry.

$$x_f << h_f$$

$$G = \frac{E}{2 \cdot (1+\nu)}$$

- G = elastic shear modulus, Pa
- q_i = injection rate, m³/s
- μ = apparent viscosity, Pa·s
- E = Young‘s modulus, Pa
- ν = Poisson’s ratio
- x_f = fracture half length, m
- h_f = Fracture height, m

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Hydrodynamic fracture models

PKN fracture model

$$\overline{w} = 2{,}31 \cdot \left[\frac{q_i \cdot \mu \cdot (1-\nu) \cdot x_f}{G} \right]^{1/4} \left(\frac{\pi}{4} \cdot \gamma \right)$$

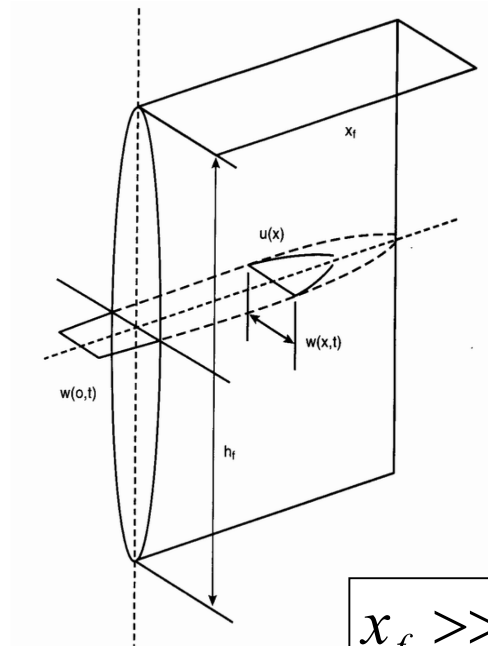


Figure 16-7
The PKN model geometry.

$$x_f >> h_f$$

G = elastic shear modulus, $G = \frac{E}{2 \cdot (1+\nu)}$

q_i = injection rate

μ = apparent viscosity

E = Young's modulus (10^7 - 2×10^5 psi)

ν = Poisson's ratio (0,15 - 0,4)

x_f = fracture half length

γ = geometry factor app. 0,75

q_i = injection rate, bpm

μ = apparent viscosity, cp

G = elastic shear modulus, psi

x_f = fracture half length, ft

Hydrodynamic fracture models

Comparision with static fracture models

2a	Griffith	KDG
[m]	w_c, [mm]	w_c, [mm]
1	0.025	0.4
10	0.075	1.2
100	0.25	4
1000	0.75	12

$q = 1\ l/(s \cdot m)$ water

Fluid losses

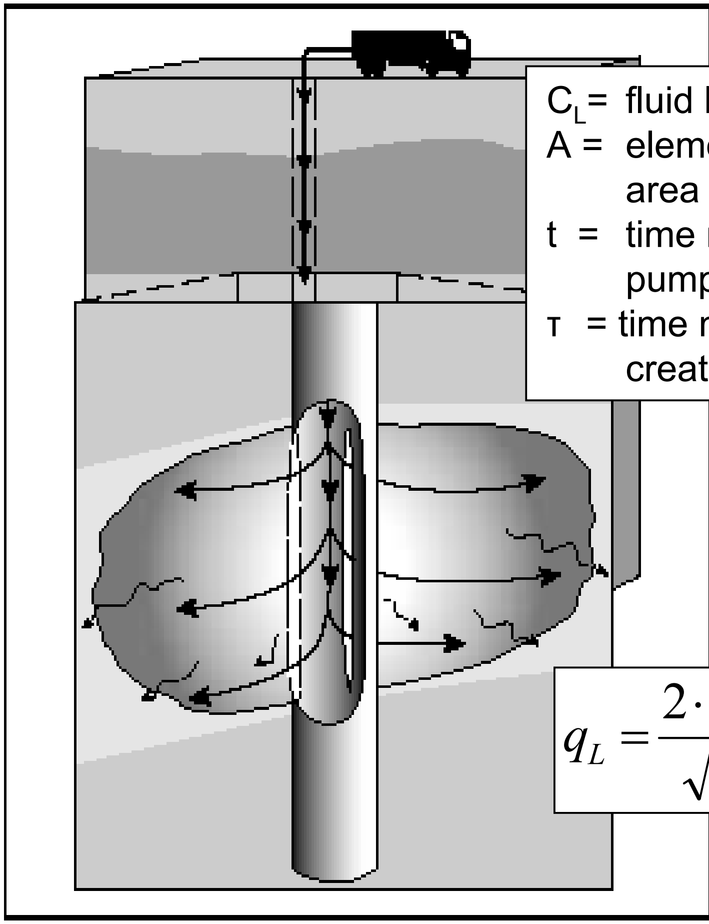


Figure 5-2. Cross-sectional view of a propagating fracture.

C_L = fluid loss coefficient
A = element of fracture area
t = time measured from pump start
τ = time measured from creation of A

$$q_L = \frac{2 \cdot C_L \cdot A}{\sqrt{t-\tau}}$$

Fluid losses

Volume injected = created fracture volume + fluid leak off

$$V_i = V_f + V_L$$

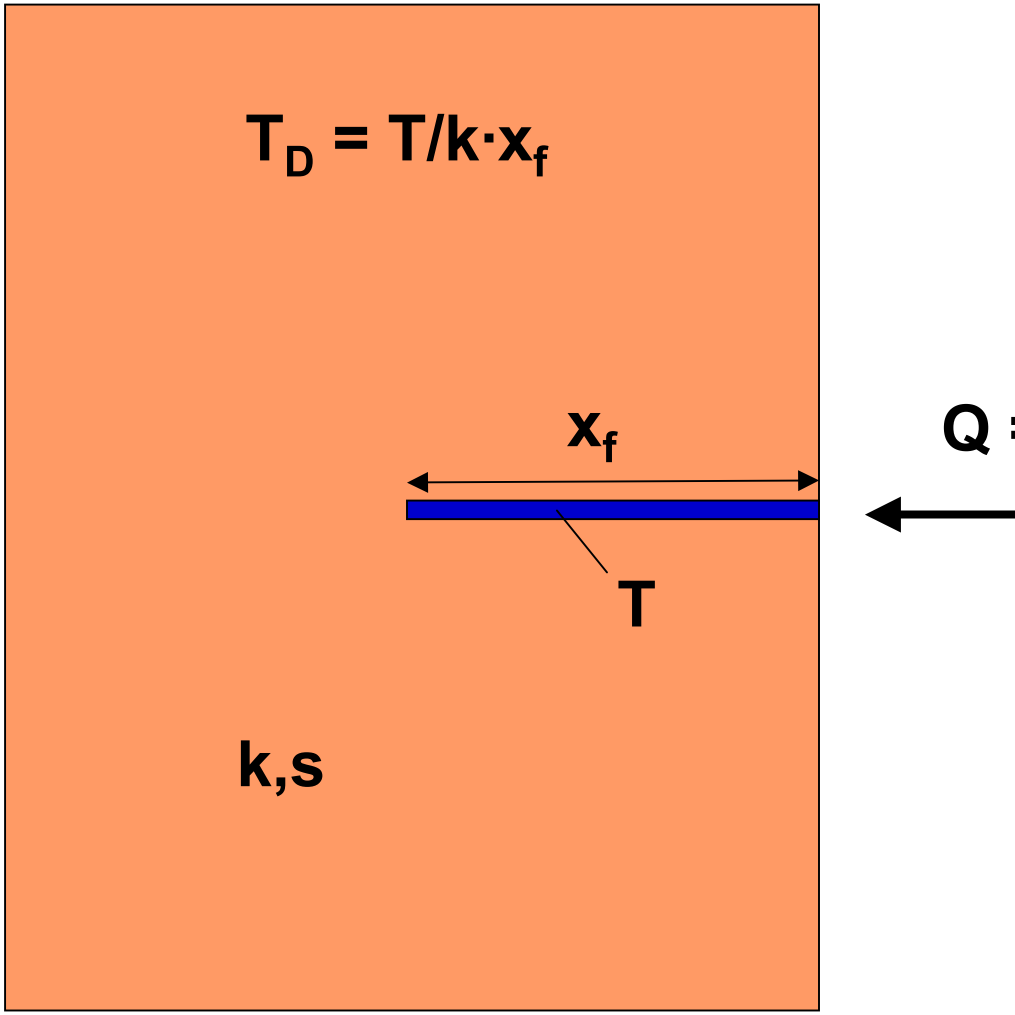
$$q_i \cdot t_i = A_f \cdot \overline{w} + K_L \cdot C_L \cdot (2 \cdot A_f) \cdot r_p \cdot \sqrt{t_i}$$

q_i = injection rate
t_i = injection time
A_f = fracture area
$\overline{w}$ = average fracture width
C_L = leakoff coefficient
r_p = ratio of net to fracture height
K_L = $\frac{1}{2} \cdot \left[\frac{8}{3} \eta + \pi \cdot (1 - \eta) \right]$ (Nolte)

η = fluid efficiency = $\frac{V_f}{V_i}$

V_{pad} = pad volume not carrying proppants

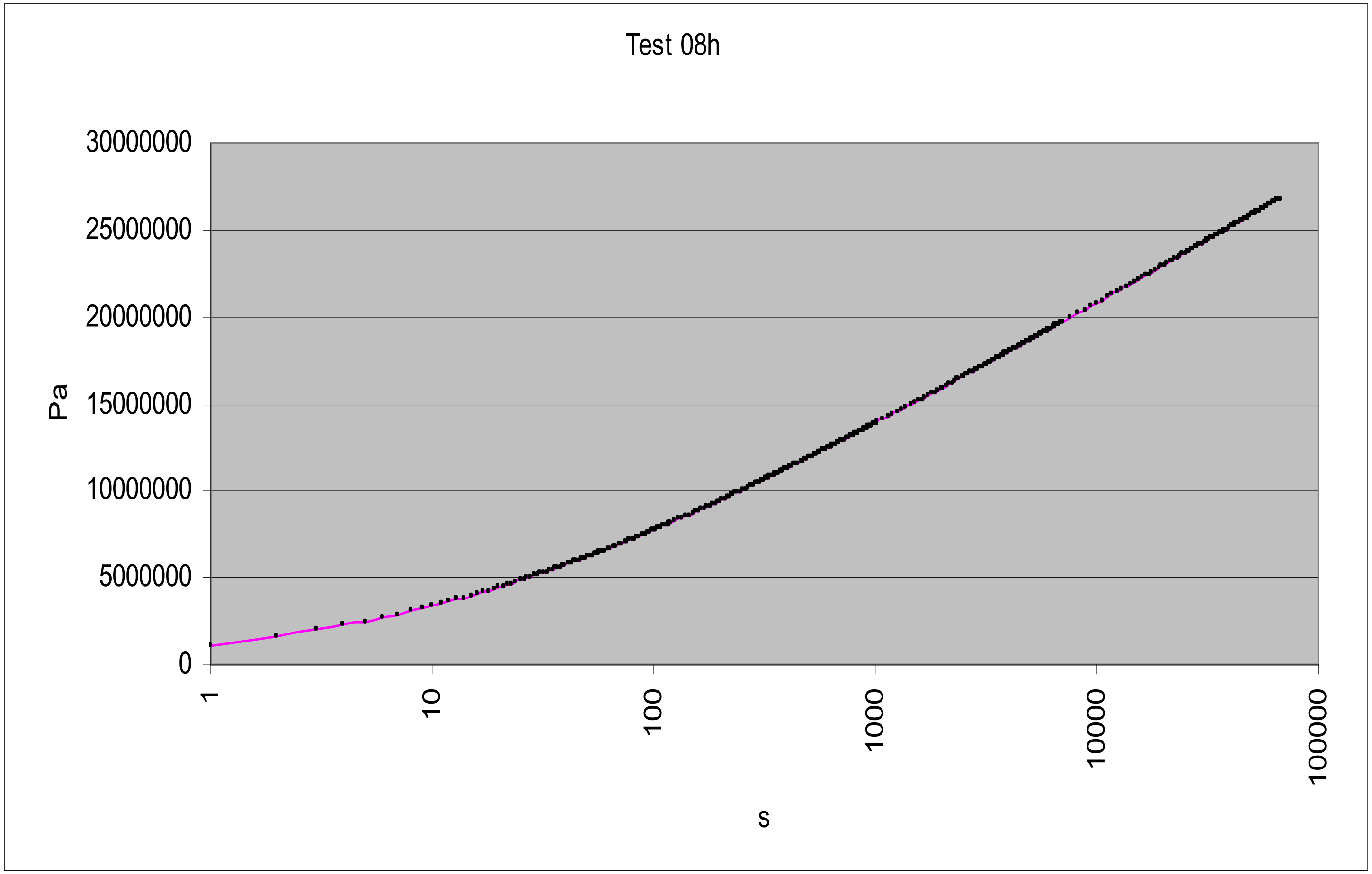
post frac tests



$Q = 0.1\ l/(s \cdot m)$

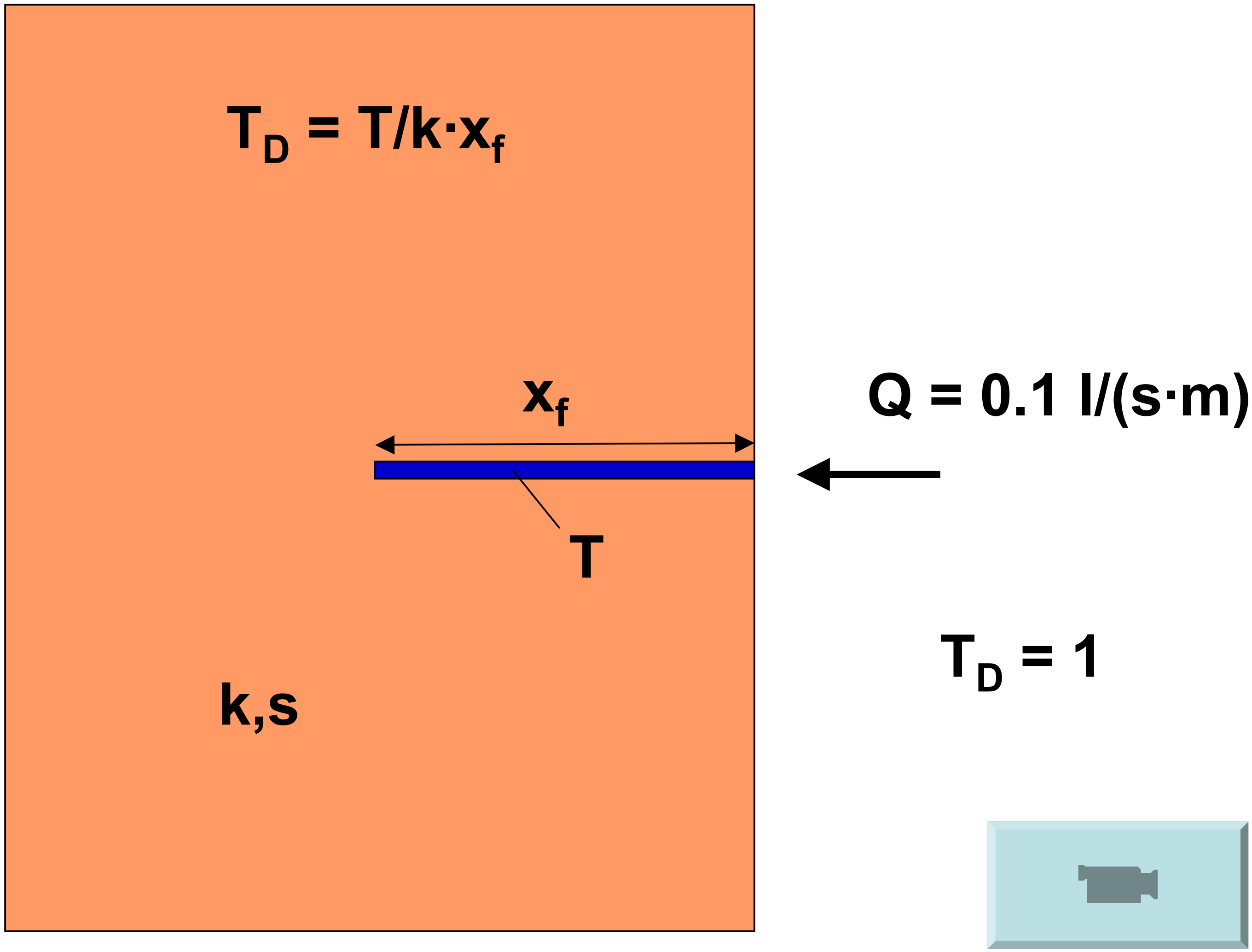
$T_D = 0.1$

post frac tests

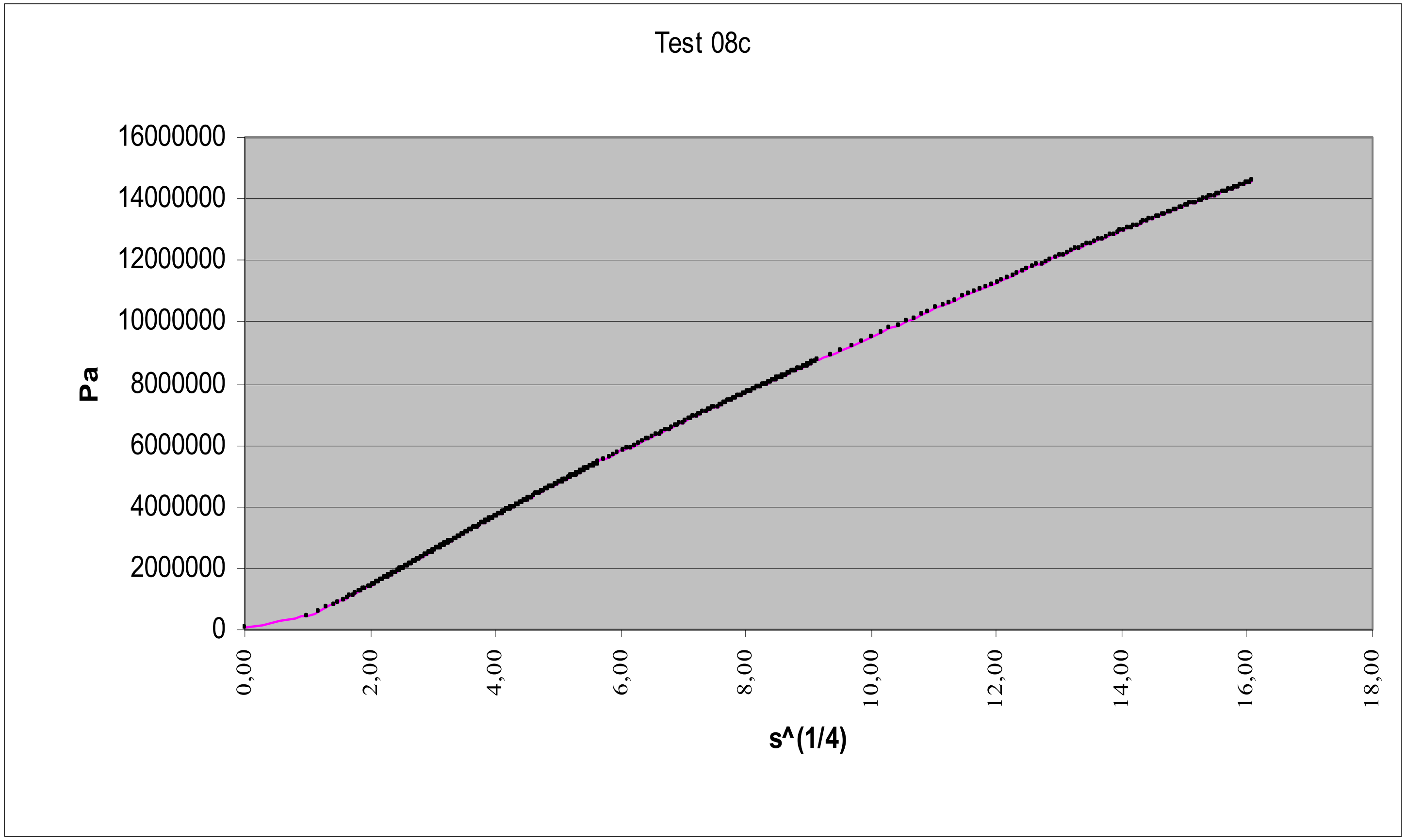


$T_D = 0.1$

post frac tests

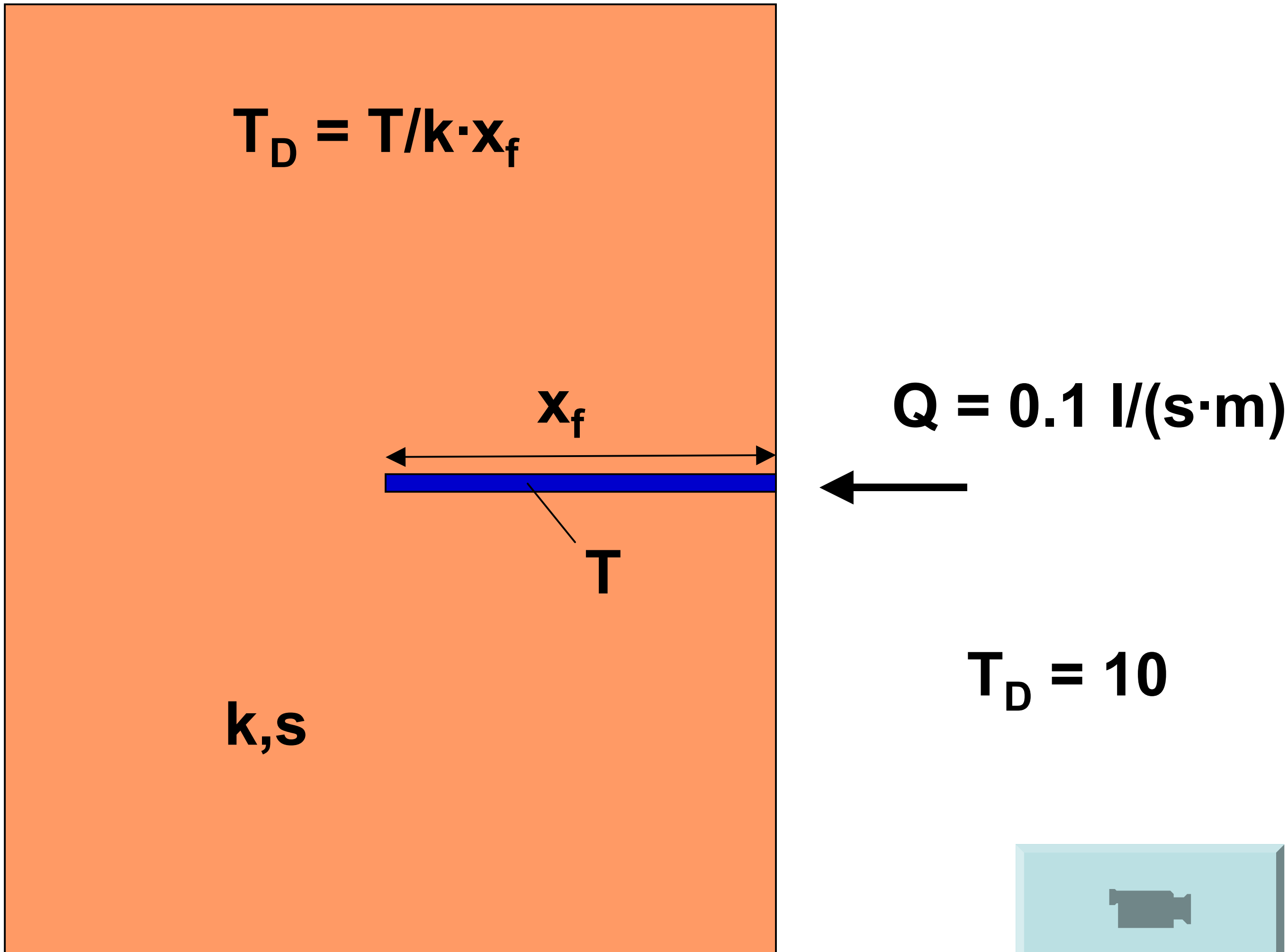


post frac tests

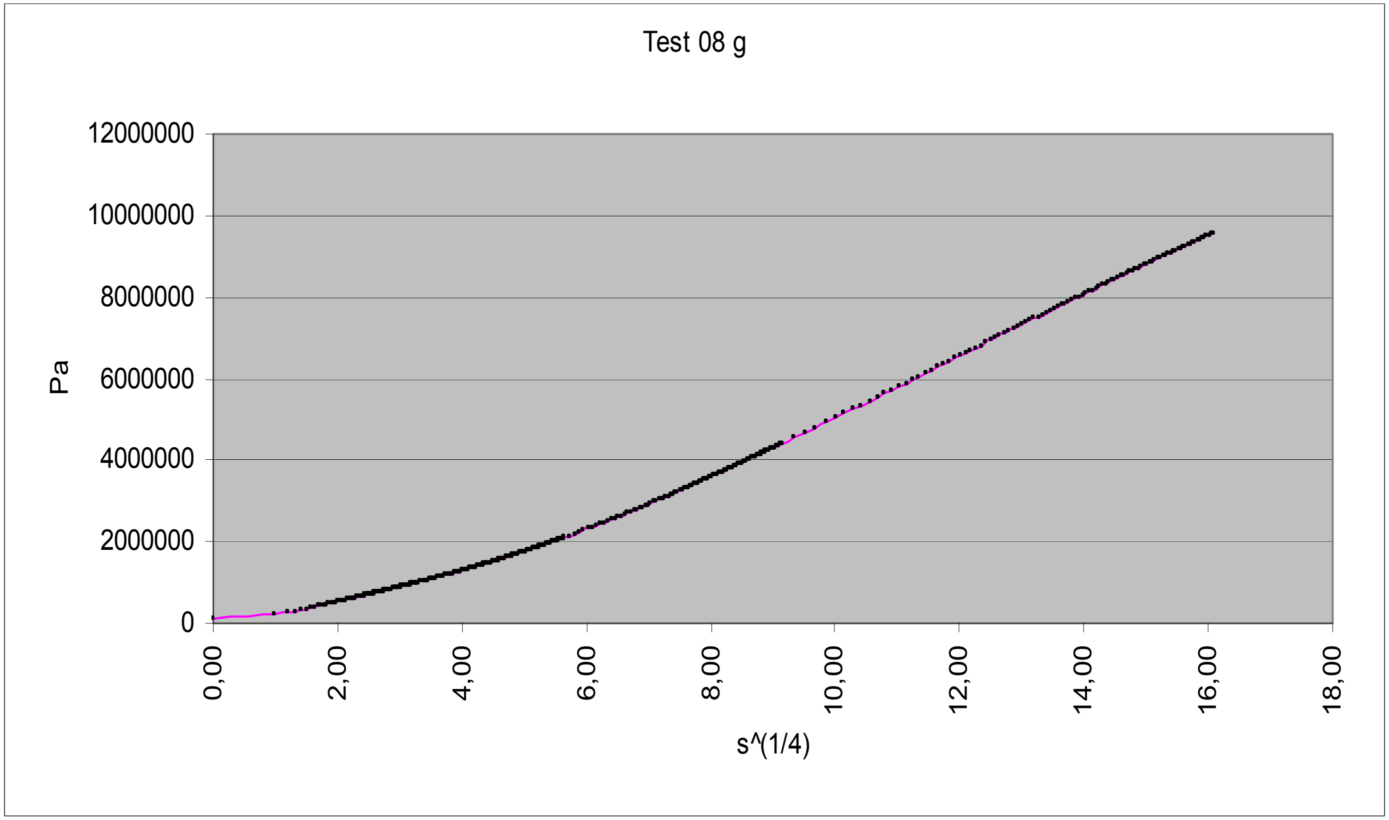


$T_D = 1$

post frac tests



post frac tests



$T_D = 10$