WELL TEST INTERPRETATION MODELS

NEAR WELLBORE EFFECTS	RESERVOIR BEHAVIOUR	BOUNDARY EFFECTS
Wellbore Storage	Homogeneous	Infinite extent
Skin	Heterogeneous	Specified Rate
Fracture	-2-Porosity	Specified Pressure
Partial Penetration	-2-Permeability	Leaky Boundary
	-Composite	
Horizontal Well		
EARLY TIMES	MIDDLE TIMES	LATE TIMES

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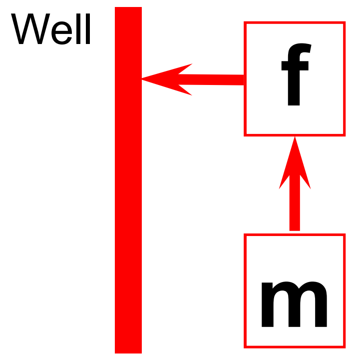
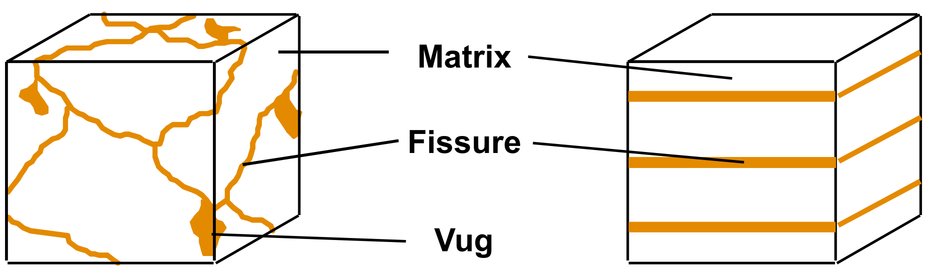
DOUBLE POROSITY BEHAVIOUR





	FISSURED	LAYERED
m	matrix	least permeable medium
f	fissures	most permeable medium

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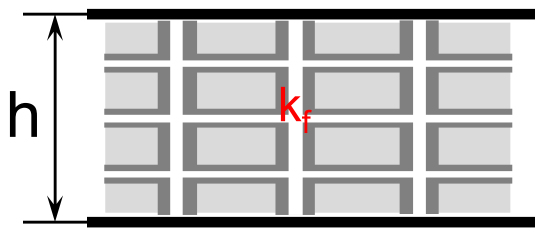
DOUBLE POROSITY BEHAVIOUR

Concentration of *f* or *m* : V_f (or V_m) = $\dfrac{\text{Volume of } f \text{ (or } m)}{\text{Total Bulk Volume}}$ $\qquad V_f + V_m = 1$

Porosity of *f* or *m* : ϕ_f (or ϕ_m) = $\dfrac{\text{Pore Volume of } f \text{ (or } m)}{\text{Volume of } f \text{ (or } m)}$ $\qquad \phi = \phi_f V_f + \phi_m V_m$

FISSURED

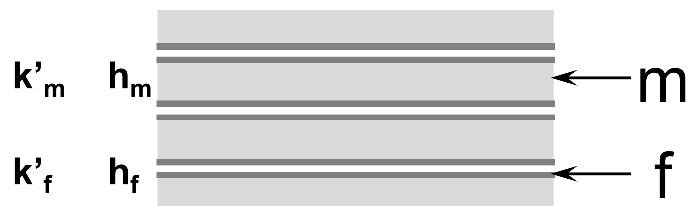


$V_m \approx 1 \qquad (V_f << V_m)$

$\varphi_f \approx 1 \qquad \phi = V_f + \phi_m$

"Fissure" porosity (<0.01%)

LAYERED



$$V_f = \frac{h_f}{h_f + h_m} \qquad V_m = \frac{h_m}{h_f + h_m}$$

$$k_f h = k'_f h_f \qquad k_f = k'_f \frac{h_f}{h} = k'_f V_f$$

$$k_m h = k'_m h_m \qquad k_m = k'_m \frac{h_m}{h} = k'_m V_m$$

Effective vs intrinsic permeabilities

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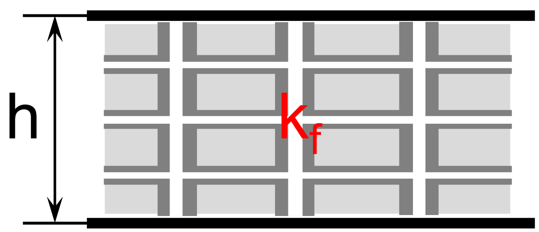
DOUBLE POROSITY BEHAVIOUR

Storativity ratio ω:

$$\omega = \frac{(\phi V c_t)_f}{(\phi V c_t)_f + (\phi V c_t)_m} = \frac{(\phi V c_t)_f}{(\phi V c_t)_{f+m}}$$

FISSURED



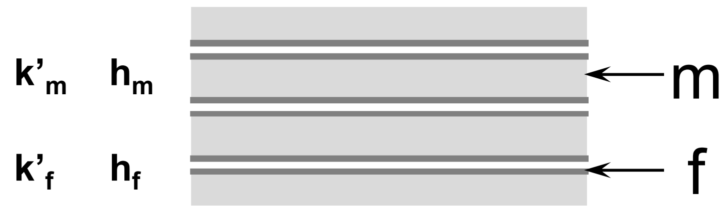
$$V_m \approx 1 \quad (V_f << V_m); \qquad \varphi_f \approx 1; \qquad (c_t)_f \approx (c_t)_m$$

$$\omega \cong \frac{V_f}{V_f + \varphi_m} \cong \frac{V_f}{\varphi_m} \cong \frac{0.003}{0.3} = 0.01$$

Single phase: ω = 0.01 - 0.02

Multiphase: ω = 0.1 - 0.2

LAYERED



$$\omega \cong \frac{h_f \varphi_f}{h_f \varphi_f + h_m \varphi_m}$$

ω = 0.1 - 0.2

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DOUBLE POROSITY BEHAVIOUR

Interporosity Flow Coefficient λ :

$$\lambda = \alpha r_w^2 \frac{k_m}{k_f}$$

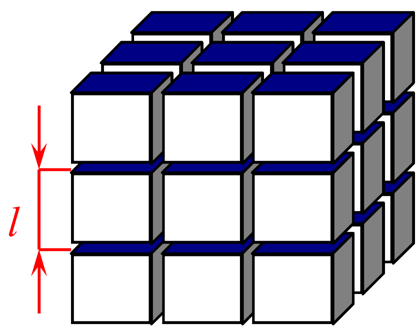
α: geometric coefficient:

$$\alpha = \frac{4n(n+2)}{l^2}$$

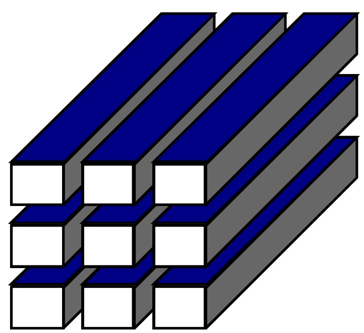
n: number of directions of planes defining a matrix block

l : characteristic length of a matrix block

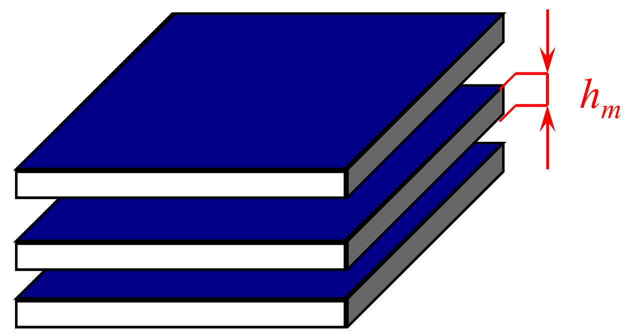
n=3 $\alpha = \frac{60}{l^2}$



n=2



n=1 $\alpha = \frac{12}{h_m^2}$



$$10^{-3} > \lambda > 10^{-7}$$

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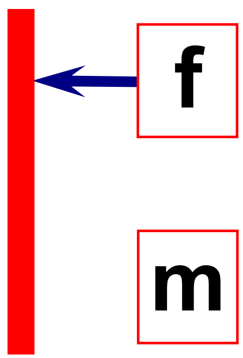
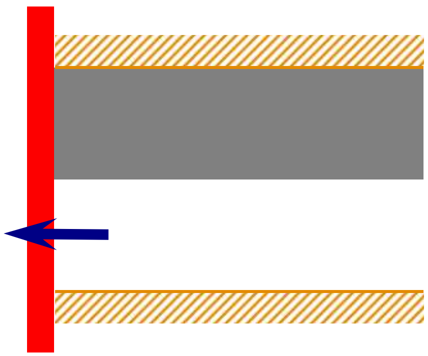
DOUBLE POROSITY BEHAVIOUR

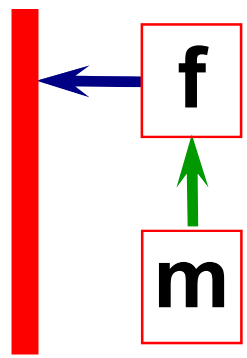
(1) EARLY TIMES



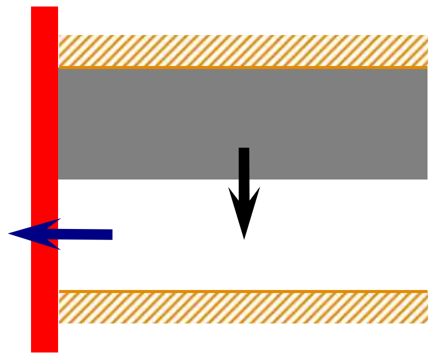
Flow from most
permeable medium only



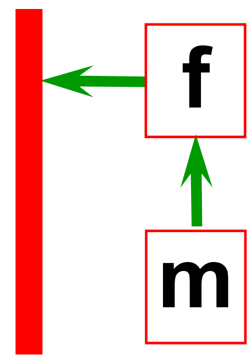
(2) TRANSITION



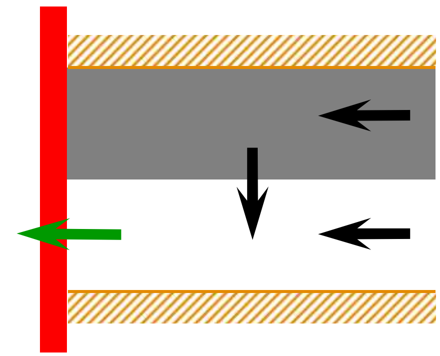
Recharge from least
permeable medium



(3) LATER TIMES



Flow from both
medium together



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Double Porosity Behaviour

$$\tilde{p}_{wD}\left(C_{D_{f+m}}, S, s\right) = \frac{1}{s\left[\ sC_{D_{f+m}} + \dfrac{1}{Skin + \dfrac{K_0\left(\ \sqrt{s\,f(s)}\ \right)}{\sqrt{s\,f(s)}\,K_1\left(\ \sqrt{s\,f(s)}\ \right)}}\ \right]} = \frac{1}{s\left[\ sC_{D_{f+m}} + \dfrac{1}{\ln \dfrac{2}{e^{\gamma}\sqrt{s\,f(s)e^{-2Skin}}}}\ \right]}$$

$$s' = s\,C_{D_{f+m}} \quad (call\ \ it\ \ s) \Rightarrow \overline{p_{wD}\left[\left(\frac{t_D}{C_D}\right)_{f+m}\right]} = \frac{1}{C_{D_{f+m}}}\tilde{p}_{wD}\left(s' C_{D_{f+m}}\right)$$

γ Euler's constant ($e^{\gamma}=1.78$)

$$\tilde{p}_{wD}\left[\left(C_D e^{2\,Skin}\right)_{f+m}, s\right] = \frac{1}{s\left[\ s + \dfrac{1}{\ln \dfrac{2}{e^{\gamma}\sqrt{s\,f(s) \big/ \left(C_D e^{2\,Skin}\right)_{f+m}}}}\ \right]}$$

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Double Porosity Behaviour

Early times: $f(s) \approx \omega$ $\qquad \tilde{p}_{wD} \approx \tilde{p}_{wD_f} = \dfrac{1}{s\left[\, s + \dfrac{1}{\ln \dfrac{2}{e^{\gamma}\sqrt{s \big/ \left(C_D e^{2\,Skin}\right)_f}}}\,\right]}$

Late times: $f(s) \approx 1$ $\qquad \tilde{p}_{wD} \approx \tilde{p}_{wD_{f+m}} = \dfrac{1}{s\left[\, s + \dfrac{1}{\ln \dfrac{2}{e^{\gamma}\sqrt{s \big/ \left(C_D e^{2\,Skin}\right)_{f+m}}}}\,\right]}$

Intermediate times: $s\, f(s) \approx \lambda\, C_{D_{f+m}}$ $\qquad \tilde{p}_{wD} \approx \dfrac{1}{s\left[\, s + \dfrac{1}{\ln \dfrac{2}{e^{\gamma}\sqrt{\lambda\, e^{-2\,Skin}}}}\,\right]}$

$p_D, \dfrac{t_D}{C_D}, C_D e^{2\,Skin}, \omega, \lambda\, e^{-2\,Skin}$ Independent variables (Bourdet and Gringarten, 1980)

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DOUBLE POROSITY BEHAVIOUR

Parameter	Early Times	Later Times
Medium	f	$f+m$
Permeability-thickness	$k_f h$	$k_f h$
Storativity	$(\phi V c_t)_f\, h$	$(\phi V c_t)_{f+m}\, h$
Dimensionless pressure	$p_D = \dfrac{k_f h}{141.2 qB\mu}\Delta p$	*Same*
Dimensionless time	$t_{Df} = \dfrac{0.000264 k_f}{(\phi V c_t)_f \mu r_w^2}\Delta t$	$t_{Df+m} = \dfrac{0.000264 k_f}{(\phi V c_t)_{f+m} \mu r_w^2}\Delta t$
Dimensionless wellbore storage	$C_{Df} = \dfrac{0.8936 C}{(\phi V c_t)_f h r_w^2}$	$C_{Df+m} = \dfrac{0.8936 C}{(\phi V c_t)_{f+m} h r_w^2}$
Skin	S	S
$\dfrac{t_D}{C_D}$	$\dfrac{t_{Df}}{C_{Df}} = 0.000295\, \dfrac{k_f h}{\mu}\dfrac{\Delta t}{C}$	$\dfrac{t_{Df+m}}{C_{Df+m}} = \dfrac{t_{Df}}{C_{Df}} = 0.000295\,\dfrac{k_f h}{\mu}\dfrac{\Delta t}{C}$
$C_D e^{2S}$	$\left(C_D e^{2S}\right)_f = \dfrac{0.8936\, C e^{2S}}{(\phi V c_t)_f h r_w^2}$	$\left(C_D e^{2S}\right)_{f+m} = \dfrac{0.8936\, C e^{2S}}{\left(\phi V c_t\right)_{f+m} h r_w^2} = \omega\left(C_D e^{2S}\right)_f$
$PM = \left(\dfrac{p_D}{\Delta p}\right)_{match}$	$\dfrac{k_f h}{141.2 qB\mu}$	*Same*
$TM = \left(\dfrac{t_D / C_D}{\Delta t}\right)_{match}$	$0.000295\, \dfrac{k_f h}{\mu}\dfrac{1}{C}$	*Same*
λ	λe^{-2S}	*Same*

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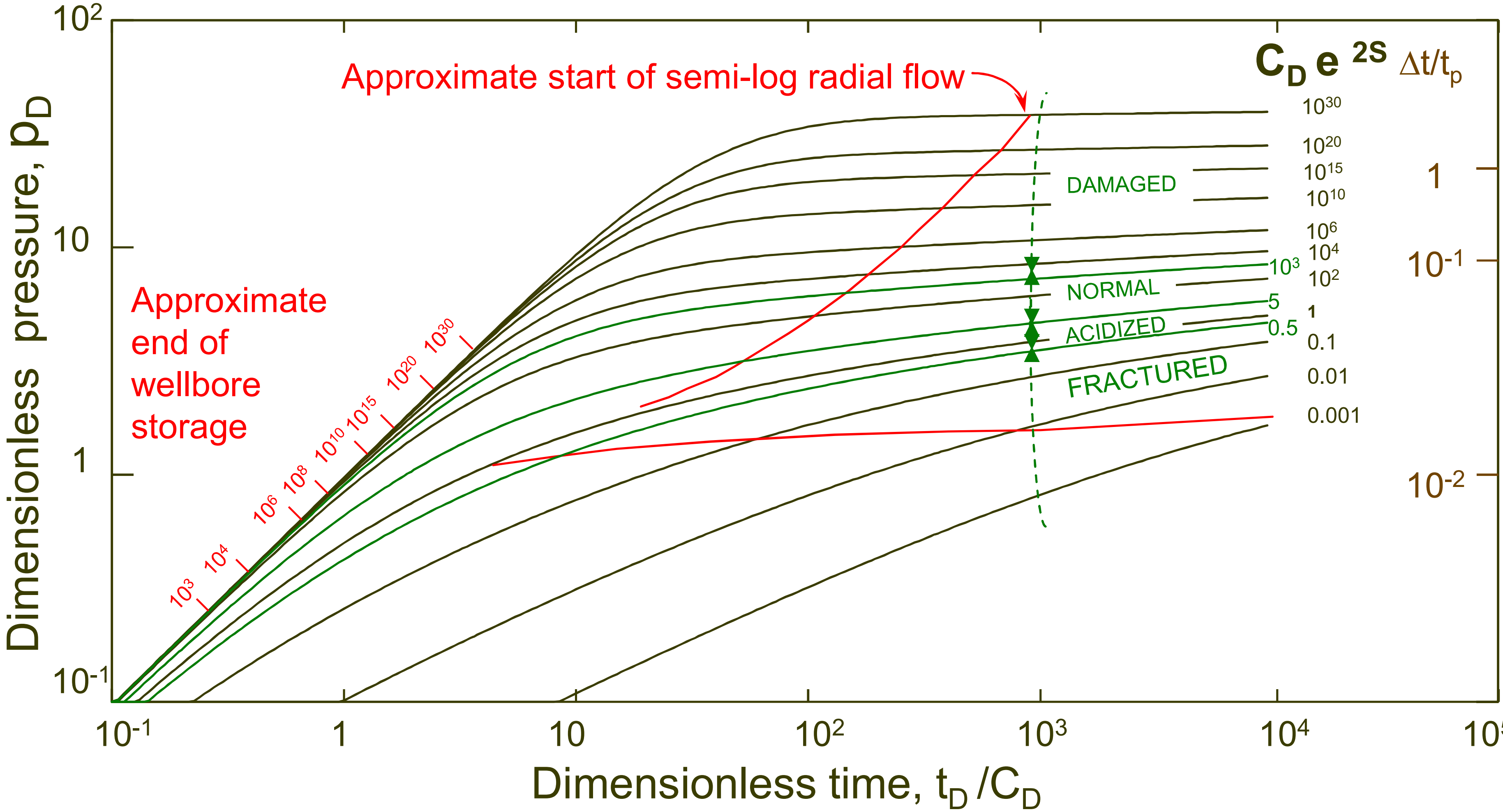
EARLY AND LATER TIMES DOUBLE POROSITY BEHAVIOUR:
Wellbore Storage and Skin Type curve



$$p_D = \frac{kh}{141.2\,\Delta q\,B\,\mu}\Delta p \qquad \frac{t_D}{C_D} = 0.000295\frac{kh}{\mu\,C}\Delta t \qquad C_D\,e^{2S} = \frac{0.8936}{\phi\,c_t h r_w^2}C\,e^{2S}$$

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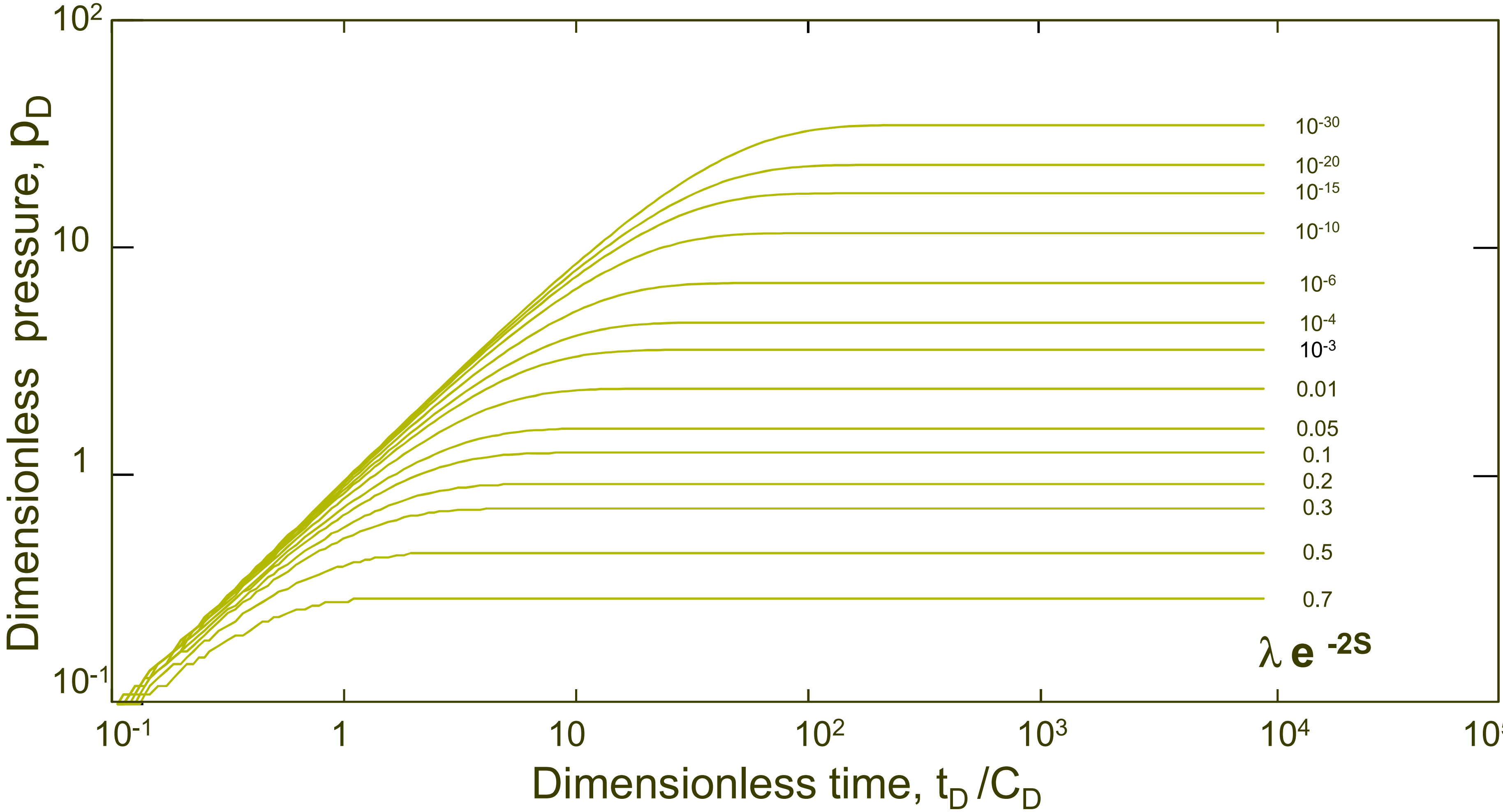
INTERMEDIATE TIMES DOUBLE POROSITY BEHAVIOUR:
λe^{-2S} Transition Type Curve



$$p_D = \frac{kh}{141.2 \Delta q B \mu} \Delta p \qquad \frac{t_D}{C_D} = 0.000295 \frac{kh}{\mu C} \Delta t \qquad \lambda e^{-2S} = \alpha r_w^2 \frac{k_m}{k_f} e^{-2S}$$

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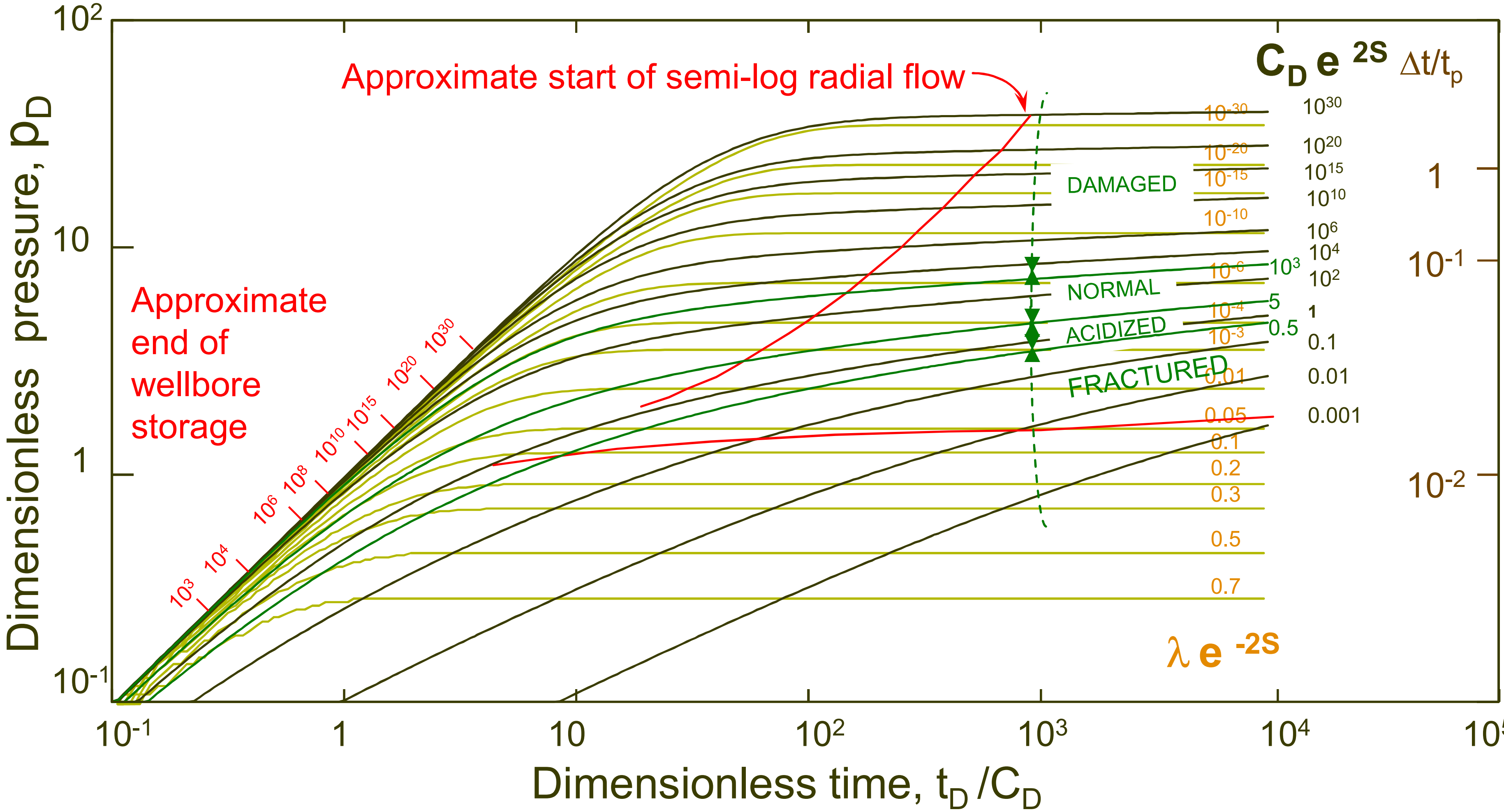
Drawdown Type Curve for a Well with Wellbore Storage & Skin, in a Reservoir of Infinite Extent with Double Porosity Behaviour (Restricted Interporosity Flow)



SPE 9293 Type Curve

$$p_D = \frac{kh}{141.2 \Delta q B \mu} \Delta p \qquad \frac{t_D}{C_D} = 0.000295 \frac{kh}{\mu C} \Delta t \qquad C_D e^{2S} = \frac{0.8936}{\phi c_t h r_w^2} C e^{2S}$$

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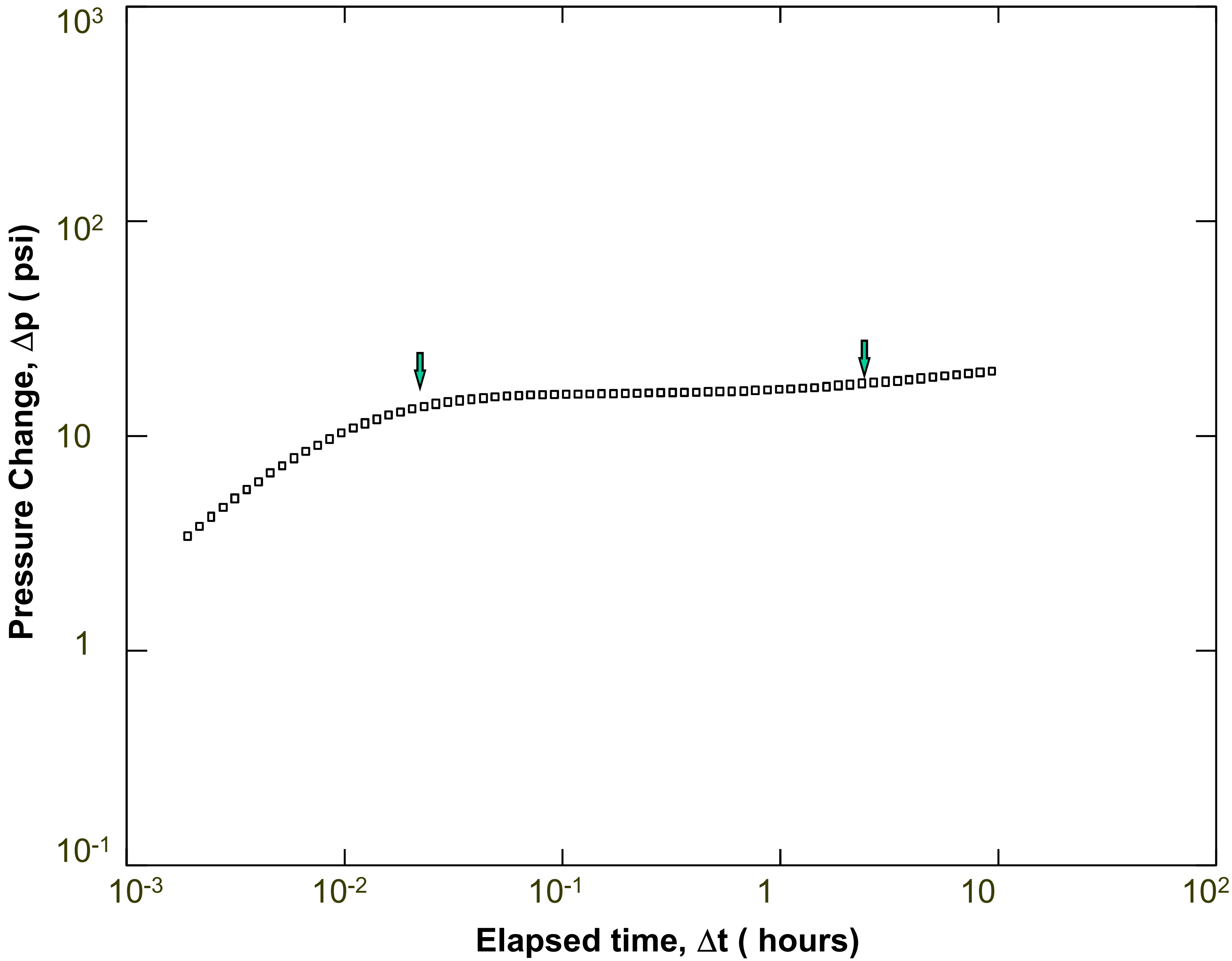

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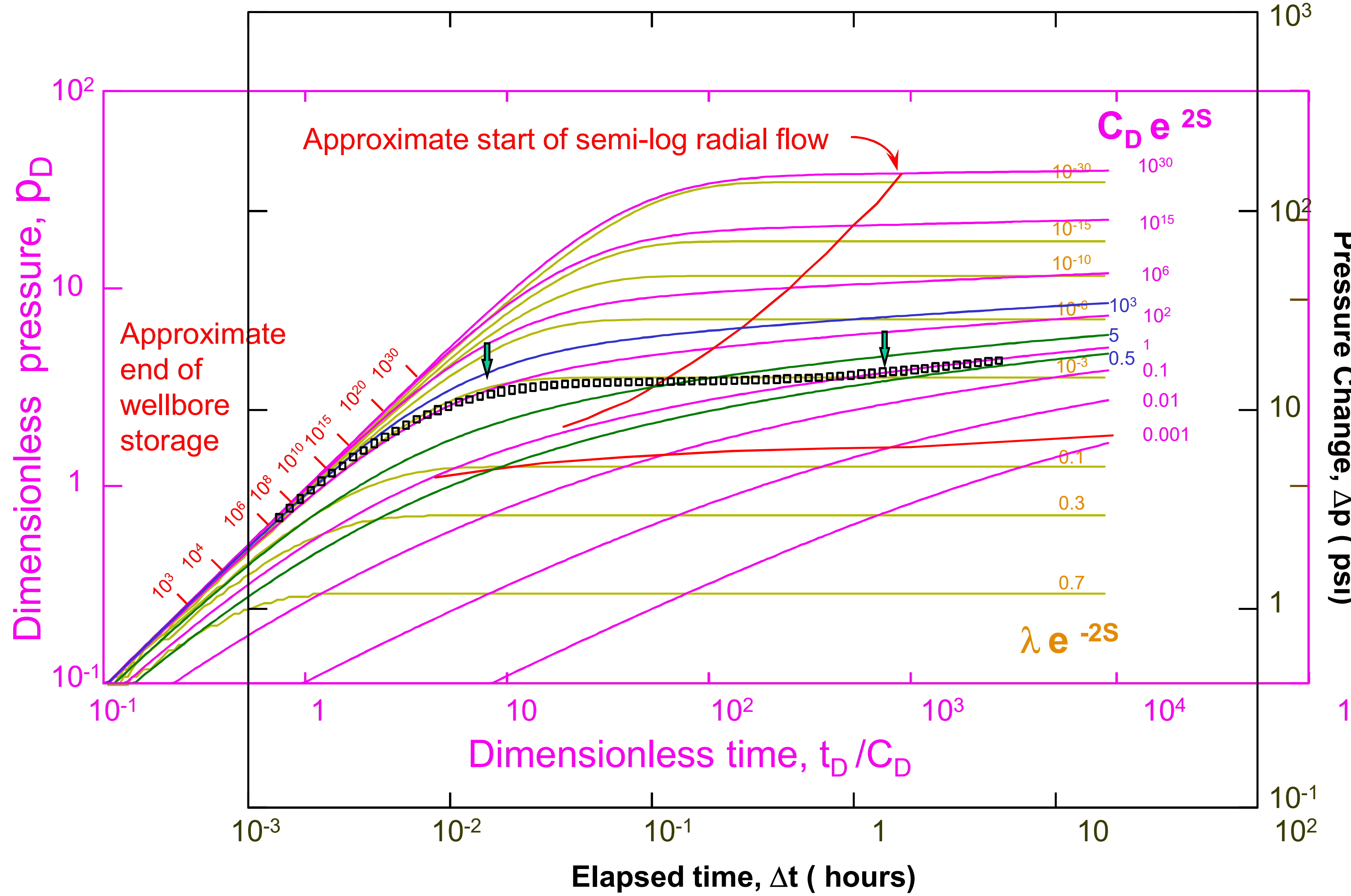

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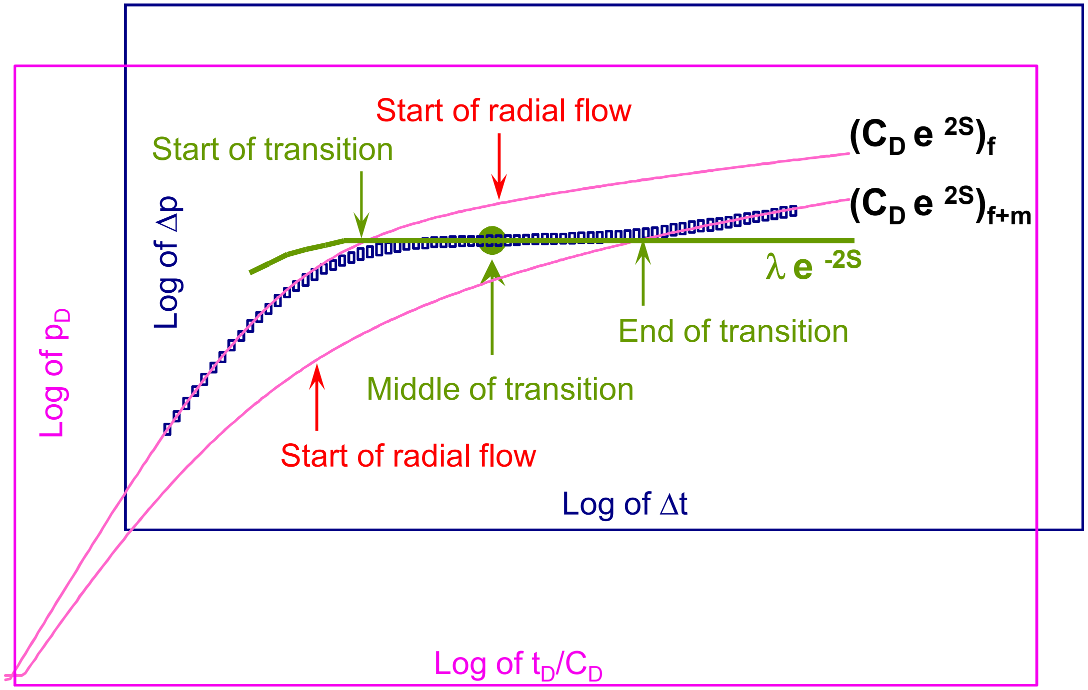

PRESURE MATCH:

$$PM = \left(\frac{p_D}{\Delta p}\right)_{match}$$

TIME MATCH:

$$TM = \left(\frac{t_D / C_D}{\Delta t}\right)_{match}$$

CURVE MATCHES:

$$\left(C_D\, e^{2S}\right)_f$$

$$\left(C_D\, e^{2S}\right)_{f+m}$$

$$\lambda e^{-2S}$$

$$kh = 141.2\,\Delta q B \mu\, \mathrm{PM}$$

$$C = 0.000295 \frac{kh}{\mu}\left(\frac{1}{\mathrm{TM}}\right)$$

$$\omega = \frac{\left(C_D e^{2S}\right)_{f+m}}{\left(C_D e^{2S}\right)_f}$$

$$S = 0.5 \ln \frac{\left(C_D e^{2S}\right)_f}{C_{Df}} = 0.5 \ln \frac{\left(C_D e^{2S}\right)_{f+m}}{C_{Df+m}}$$

$$\lambda = \left(\lambda e^{-2S}\right) e^{2S}$$

$$C_{Df} = \frac{0.8936\,C}{\left(\phi V c_t\right)_f h r_w^2} \qquad \left(\phi V c_t\right)_f = \frac{\omega}{1-\omega}\left(\phi c_t\right)_m$$

$$C_{Df+m} = \frac{0.8936\,C}{\left(\phi V c_t\right)_{f+m} h r_w^2} \qquad \left(\phi V c_t\right)_{f+m} = \frac{1}{1-\omega}\left(\phi c_t\right)_m$$

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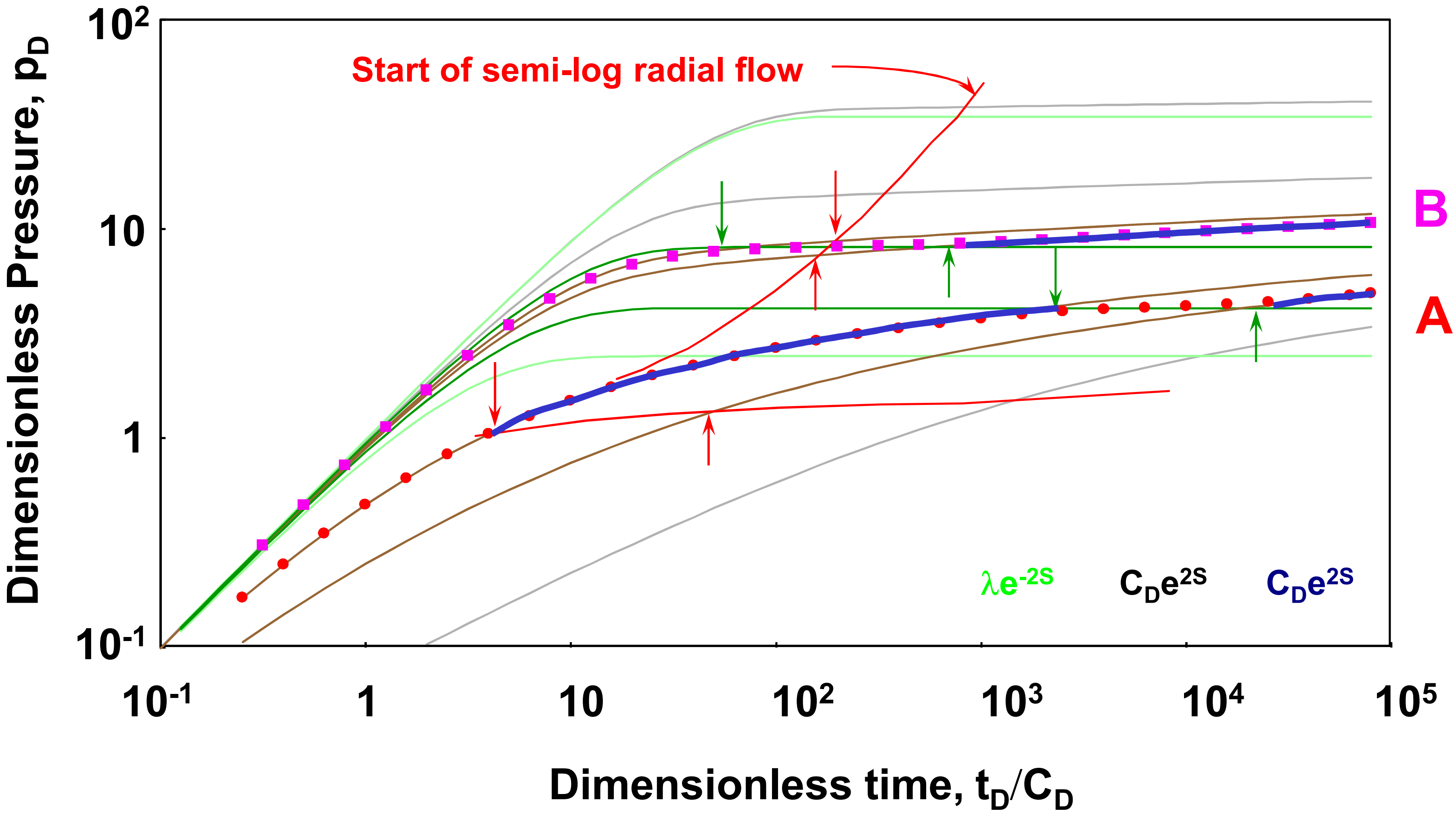

↓ Start of radial flow on fissure medium $(C_De^{2S})_f$ curve

↑ Start of radial flow on total system $(C_De^{2S})_{f+m}$ curve

↓ Start of transition on fissure medium $(C_De^{2S})_f$ curve

↑ End of transition on total system $(C_De^{2S})_{f+m}$ curve

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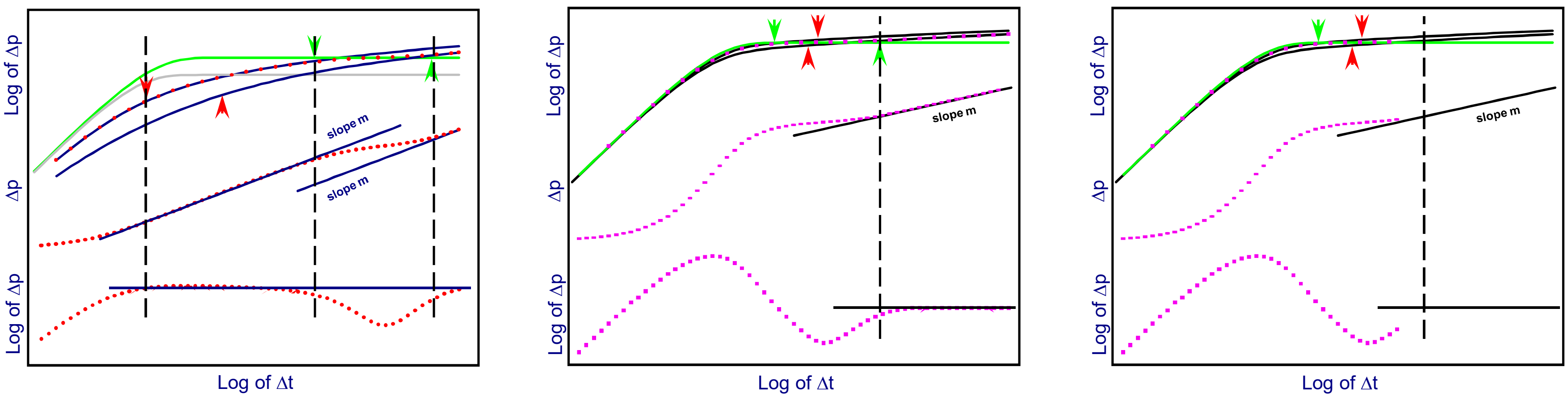
Existence of double porosity semi-log straight lines (drawdown)

1st line: Data must match $(C_De^{2S})_f$ — after the start of radial flow on (f) before the start of transition

2nd line: Data must match $(C_De^{2S})_{f+m}$ — after the end of transition after the start of radial flow on (f+m)

POSSIBILITY OF:

2 straight lines | 1 straight line | 0 straight line



DEPENDING UPON: **condition of well & behaviour of fluid**

	$(C_De^{2S})_f$	$(C_De^{2S})_{f+m}$	λe^{-2S}
i.e.:	$S, (c_t)_f$	$S, (c_t)_{f+m}$	S, k_m

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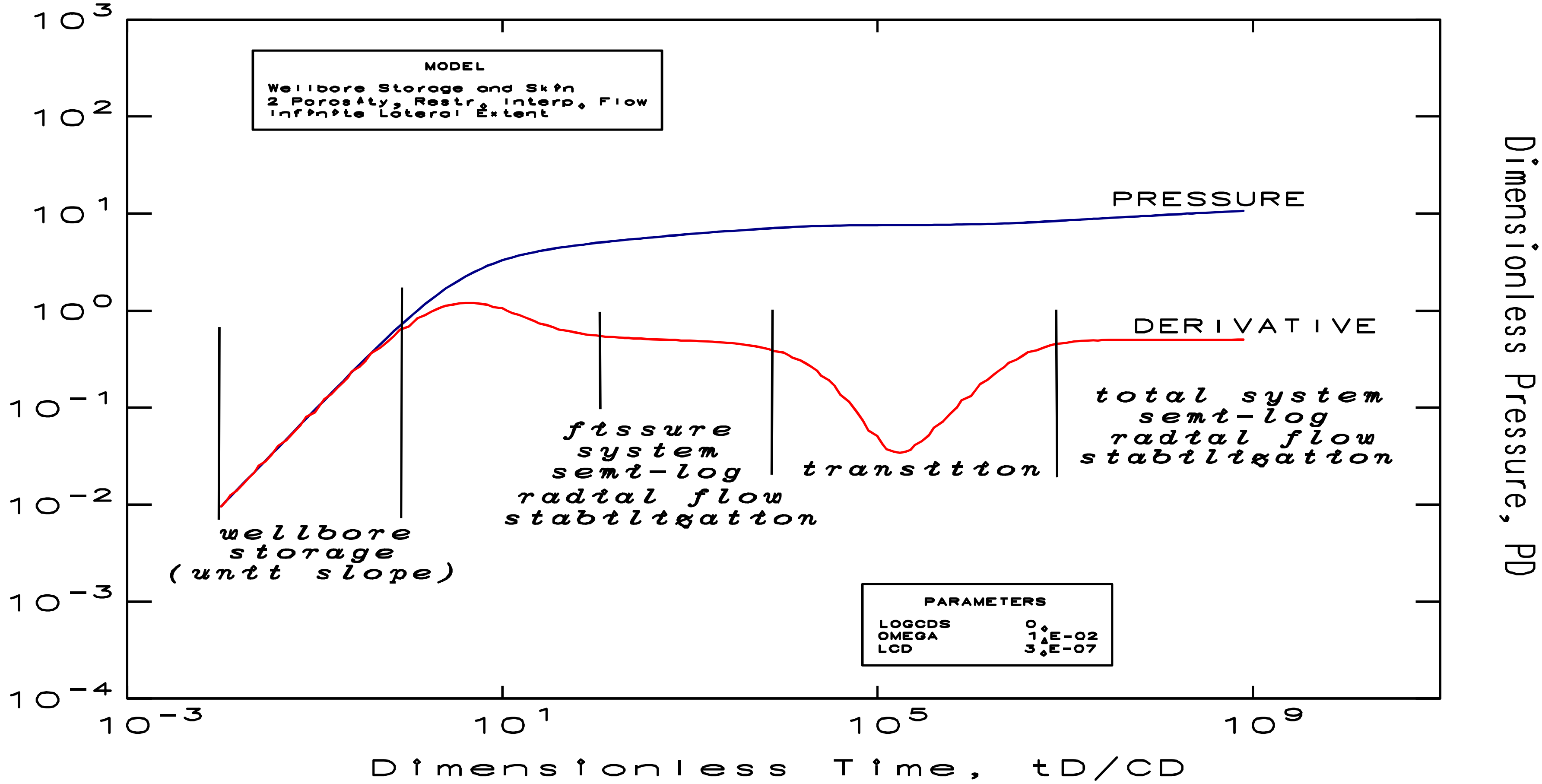

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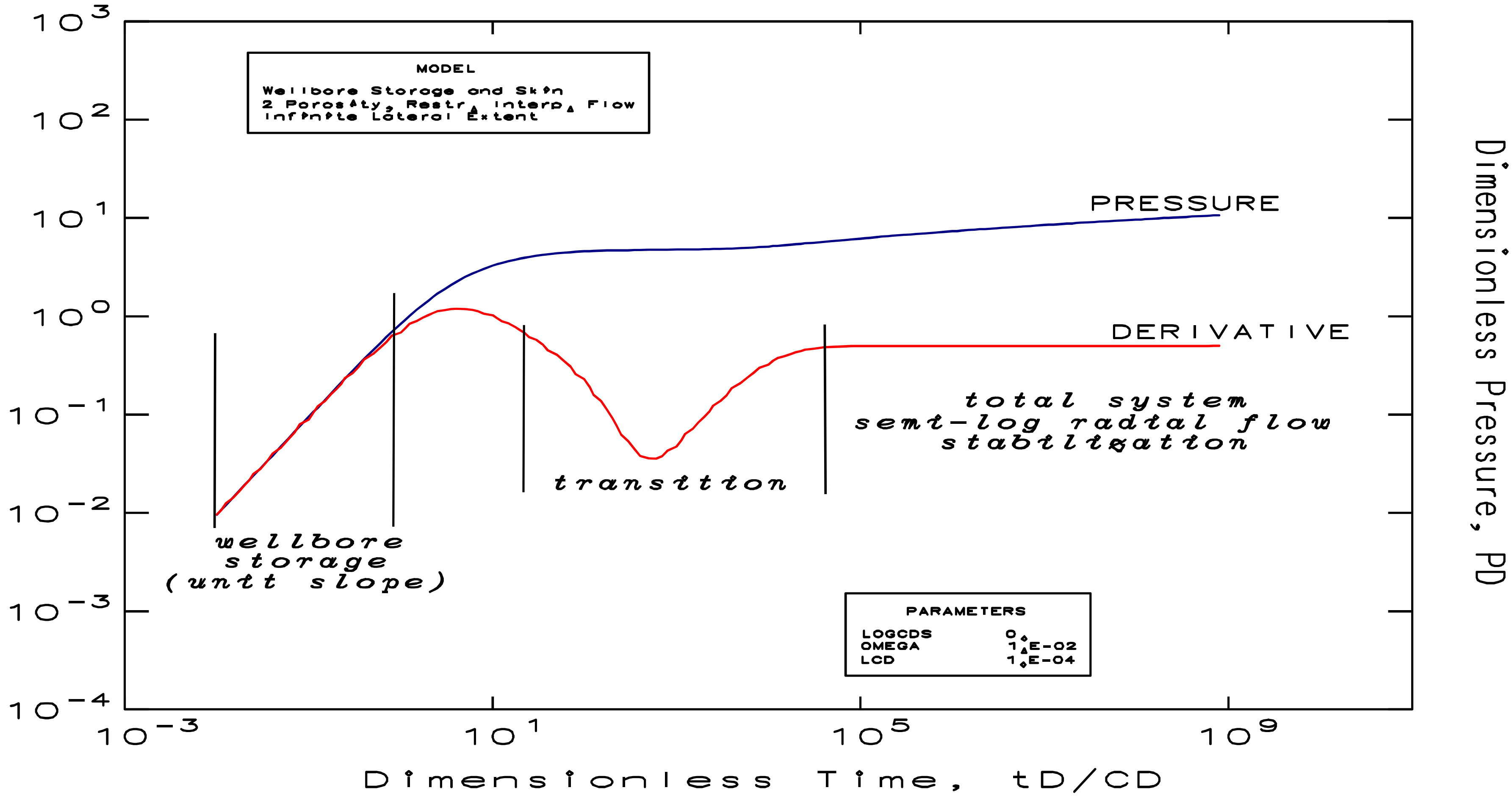

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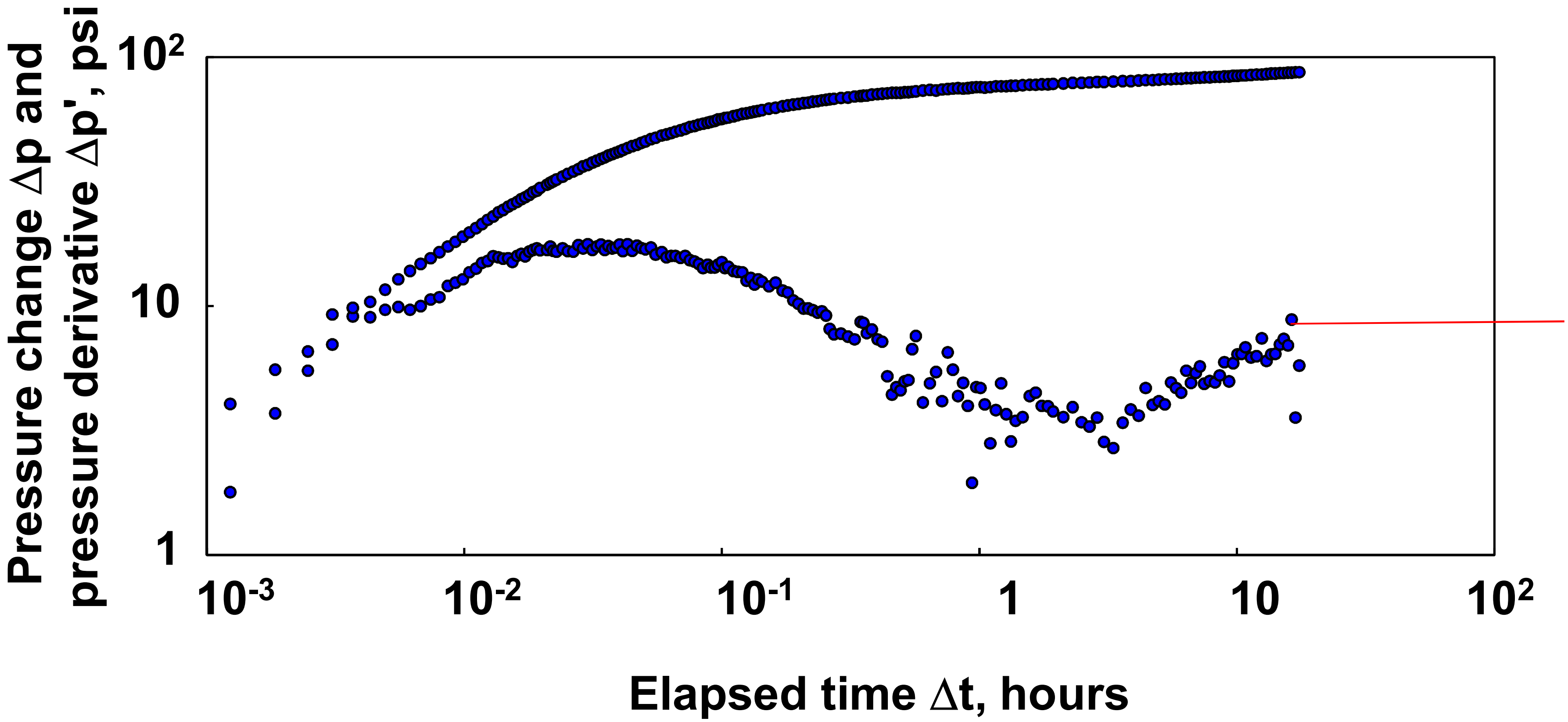
EXAMPLE OF DOUBLE POROSITY BEHAVIOUR



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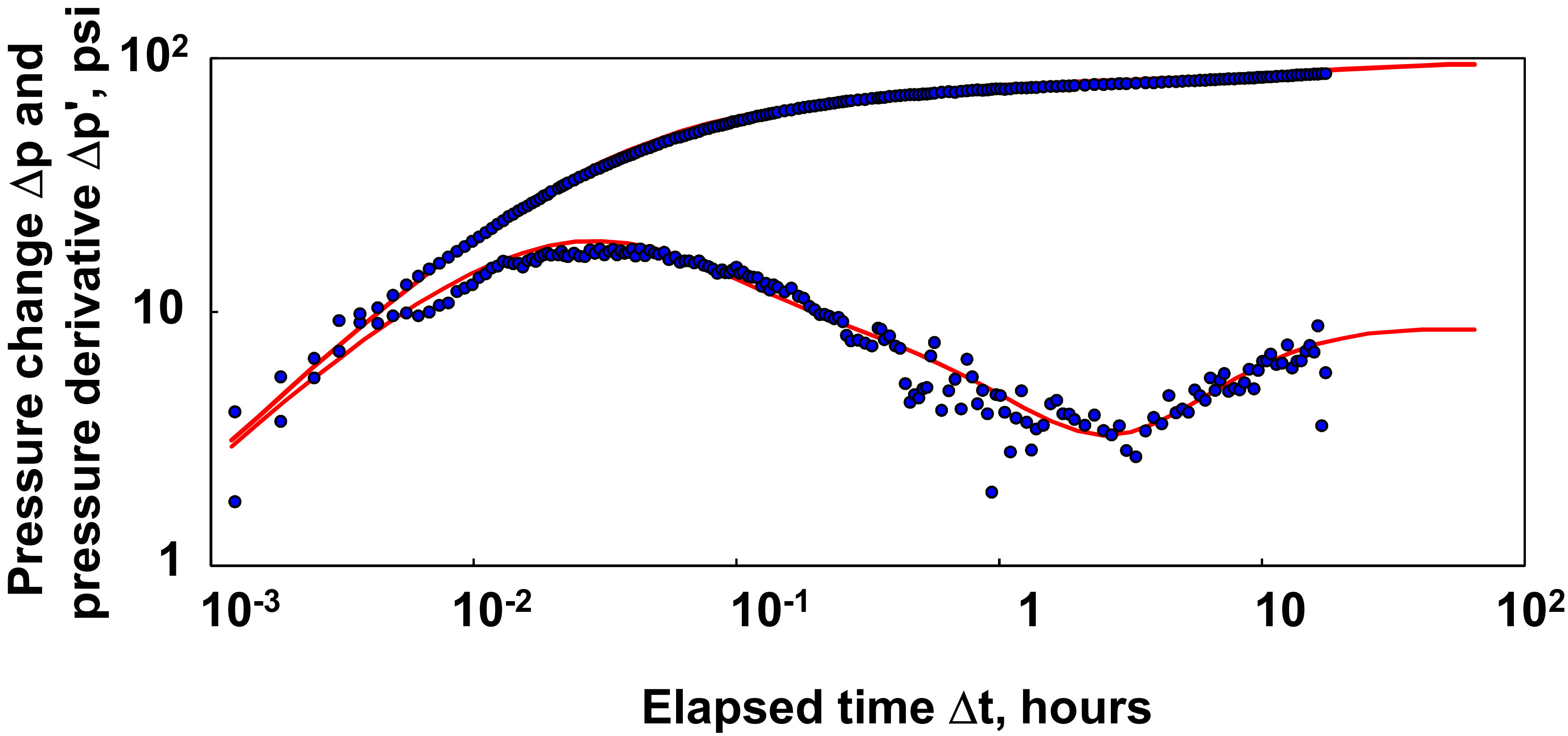
EXAMPLE OF DOUBLE POROSITY BEHAVIOUR



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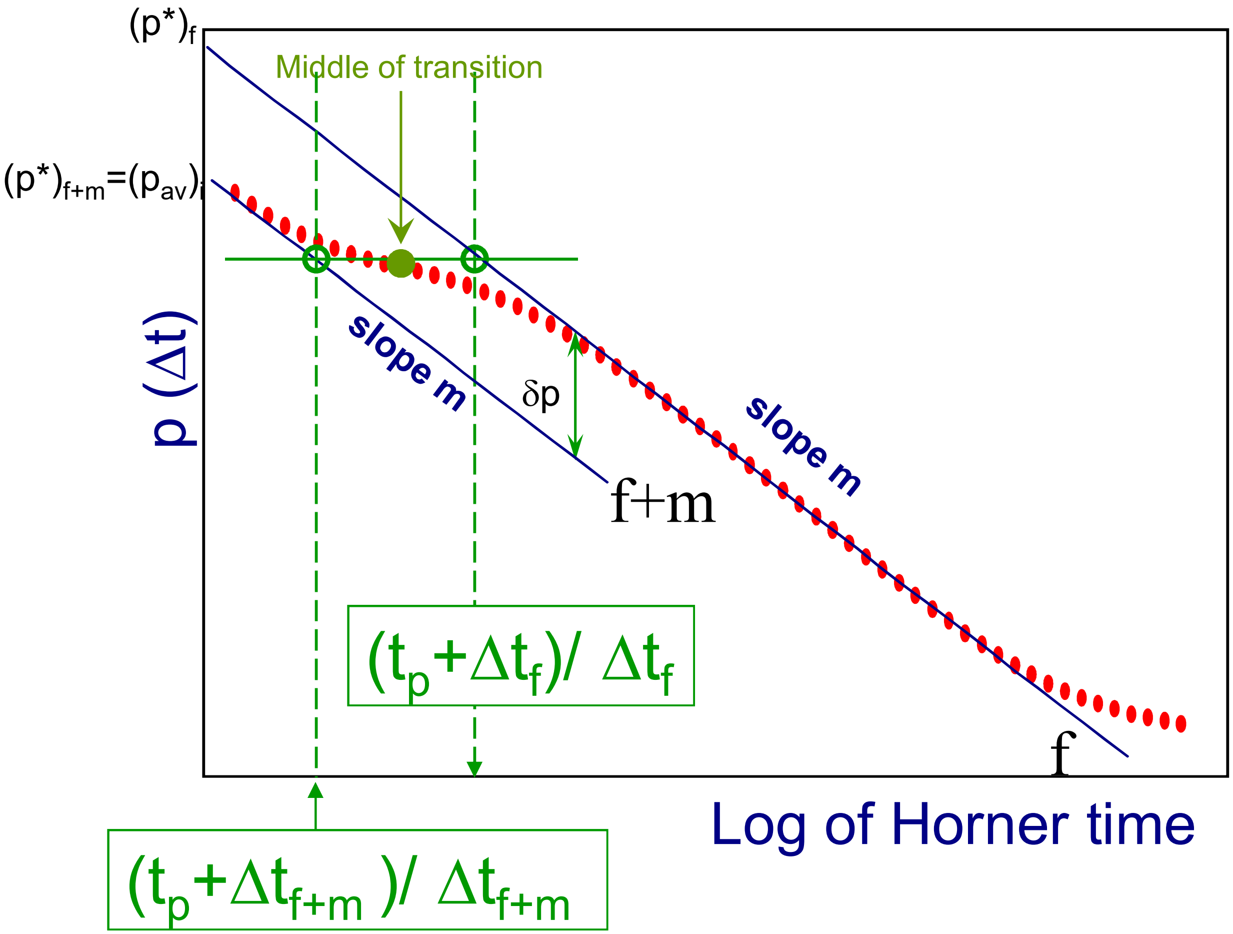
DOUBLE POROSITY SEMI-LOG Horner ANALYSIS



Radial flow (f) and (f+m) lines:

m δp

Transition line:

$(\Delta t)_f$ $(\Delta t)_{f+m}$

$$kh = 162.6\ \Delta q\ B\mu \frac{1}{m} \qquad \omega = 10^{-\delta p / m}$$

$$\lambda = \frac{(\phi V c_t)_f\ \mu\ r_w^2}{0.000264\ \ \gamma\, k_f\, (\Delta t_f)} = \frac{(\phi V c_t)_{f+m}\ \mu\ r_w^2}{0.000264\ \ \gamma\, k_f\, (\Delta t_{f+m})} \qquad \gamma = 1.78\ \textit{Exponential of Euler constant}$$

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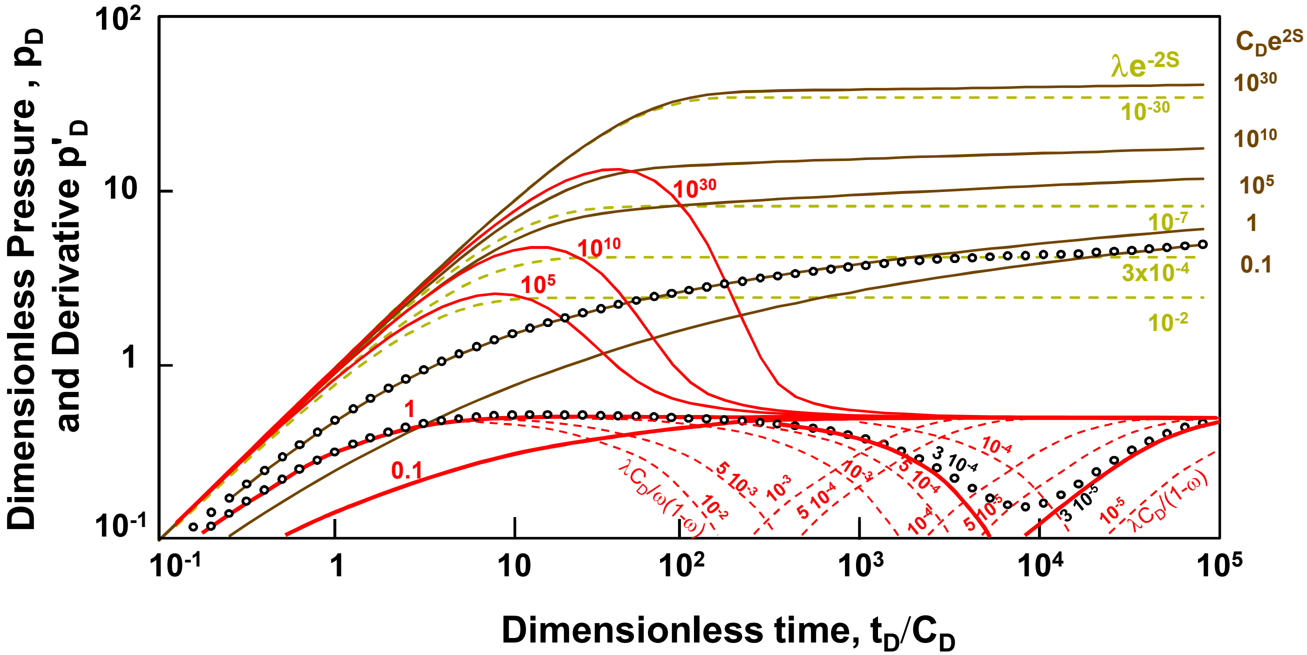

PRESSURE MATCH:

$$PM = \left(\frac{p_D}{\Delta p}\right)_{match}$$

TIME MATCH:

$$TM = \left(\frac{t_D/C_D}{\Delta t}\right)_{match}$$

CURVE MATCHES:

$$\left(C_D\, e^{2S}\right)_f$$

$$\left(C_D\, e^{2S}\right)_{f+m}$$

$$\frac{\lambda\left(C_D\right)_{f+m}}{1-\omega} \qquad \frac{\lambda\left(C_D\right)_{f+m}}{\omega\,(1-\omega)}$$

$$kh = 141.2\,\Delta q B \mu\, \text{PM}$$

$$C = 0.000295\,\frac{kh}{\mu}\left(\frac{1}{\text{TM}}\right)$$

$$\omega = \frac{\lambda\left(C_D\right)_{f+m}/(1-\omega)}{\lambda\left(C_D\right)_{f+m}/\omega(1-\omega)} \longrightarrow C_{Df+m} = (1-\omega)\, C_{Dm} \longrightarrow S = 0.5\ln\frac{\left(C_D\, e^{2S}\right)_{f+m}}{C_{Df+m}} = 0.5\ \ln\frac{\left(C_D\, e^{2S}\right)_f}{C_{Df}}$$

$$\lambda = (1-\omega)\left(\lambda\left(C_D\right)_{f+m}/(1-\omega)\right)/\left(C_D\right)_{f+m}$$

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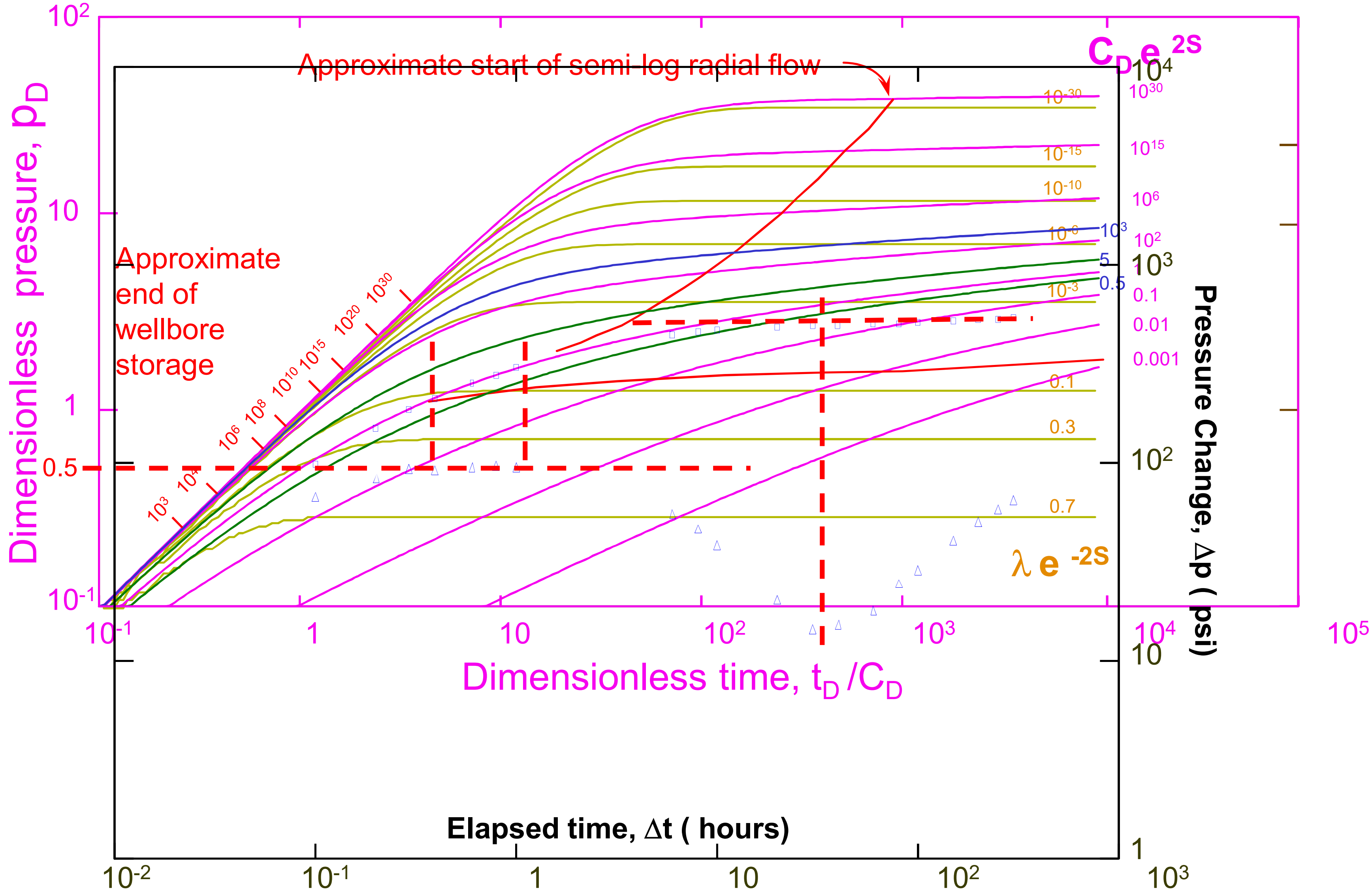

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DOUBLE POROSITY BEHAVIOUR

	Fissured	Multilayered	Homogeneous
DAMAGED	C normal	C normal	C normal 0.01 Bbl/psi
$(C_De^{2S})_f > 10^3$	S > - 3.5	S > - 3.5	S > 0
ACIDISED	C 10-100 Times normal	C normal	C normal
$0.5 < (C_De^{2S})_f < 5$	S as low as - 7	S as low as - 7	S as low as - 4
FRACTURED	C normal	C normal	C normal
$(C_De^{2S})_f < 0.5$	S ≈ - 5.5	S ≈ - 5.5	S ≈ - 5.5

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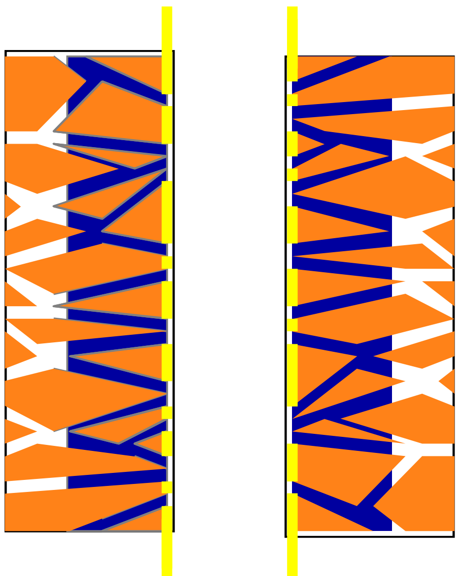
DOUBLE POROSITY BEHAVIOUR

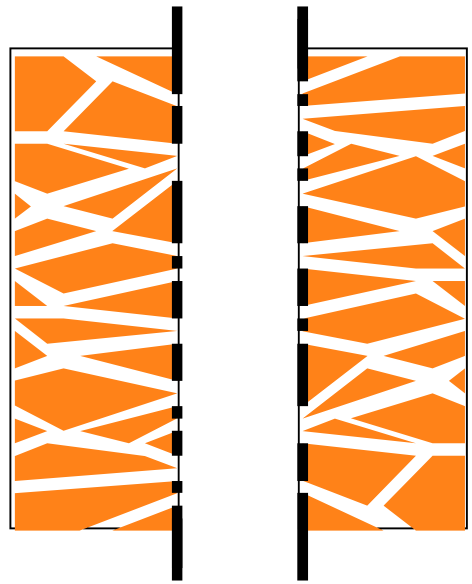
Damaged



Fissures Plugged

C normal
S > - 3.5
Skin = -3.5 = "Geo-skin"

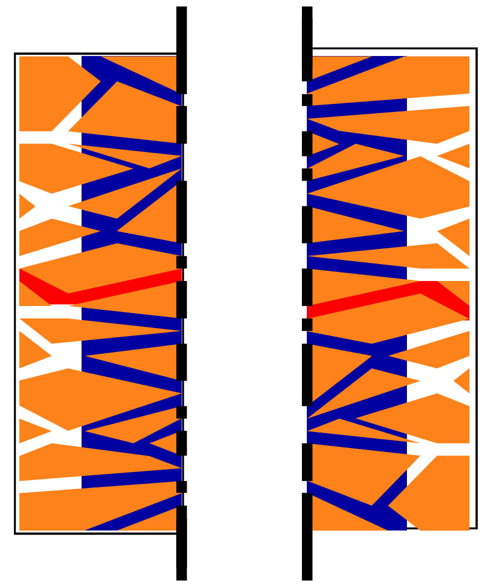
Acidised



Fissures Cleaned Open

C 10-100 normal
S as low as - 7
Skin = Geoskin - 4

Fractured



Fracture propagates along existing fissures

C normal
S ≈ - 5.5

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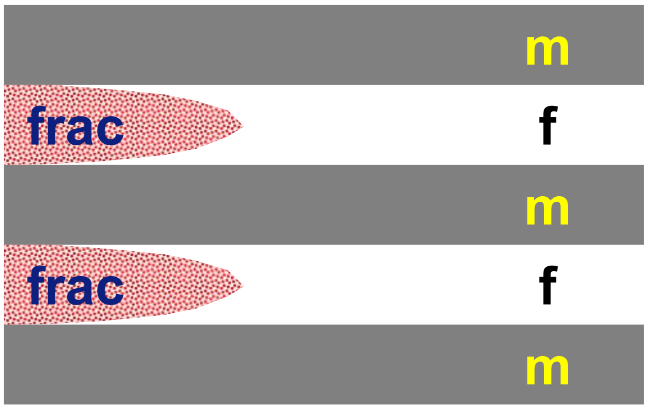
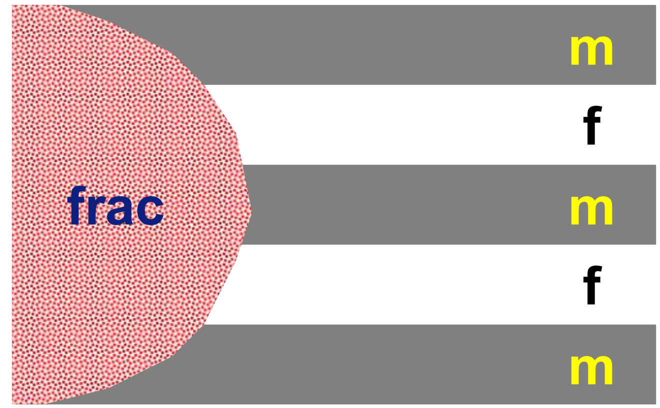
DOUBLE POROSITY BEHAVIOUR

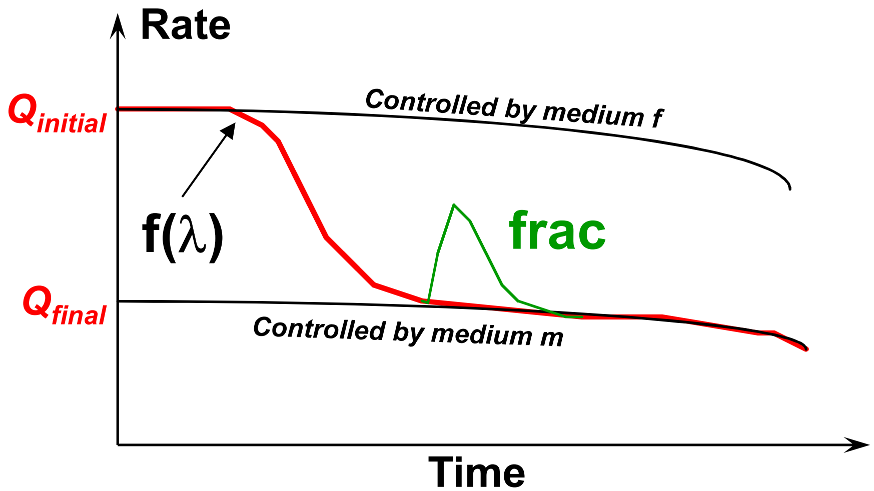
Need to improve the least permeable medium:

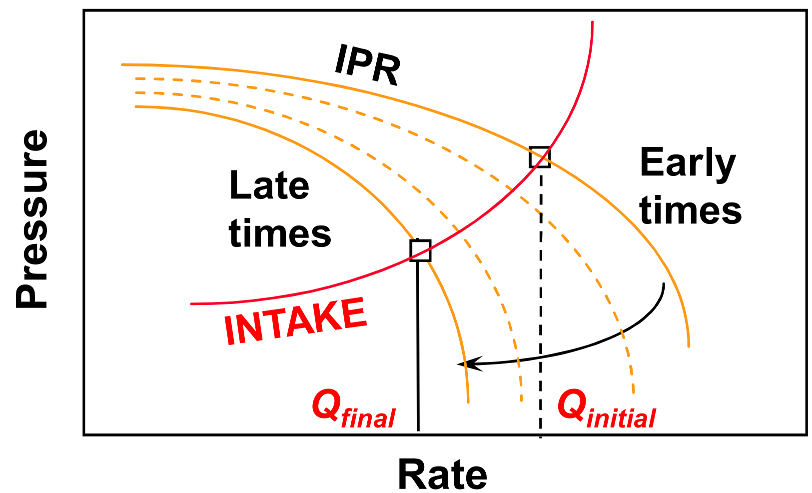




No improvement

Significant improvement





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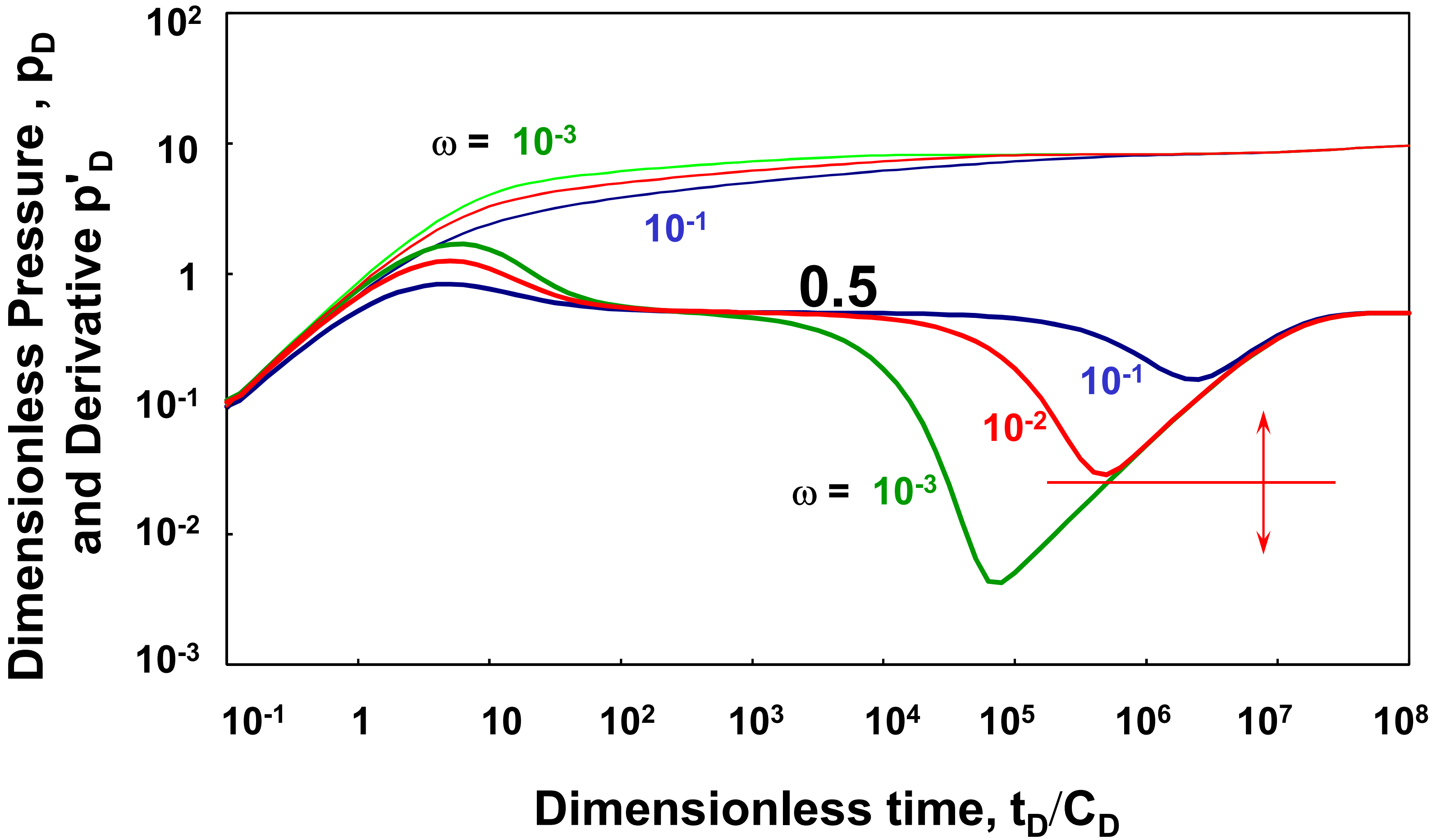
INFLUENCE OF ω



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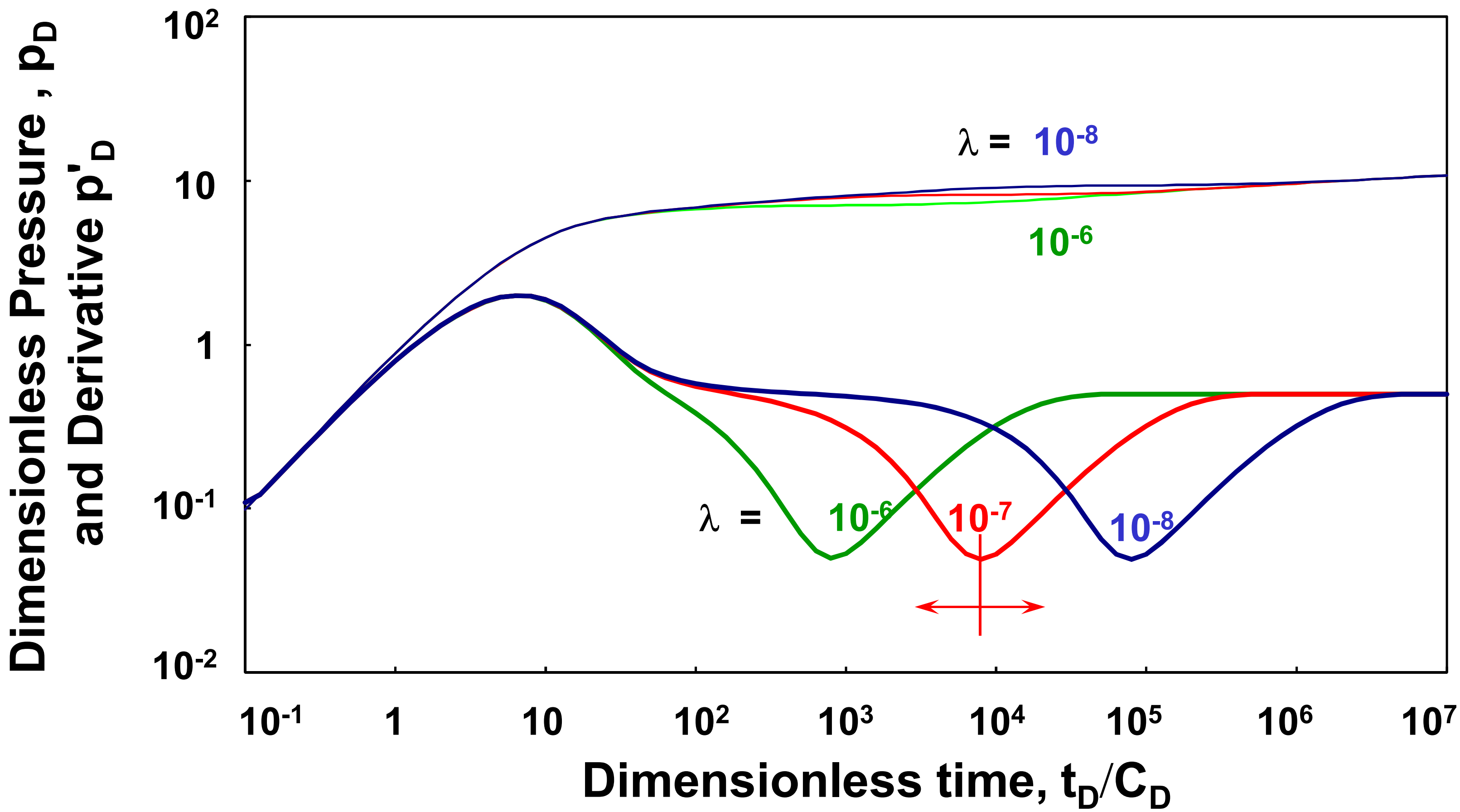
INFLUENCE OF λ



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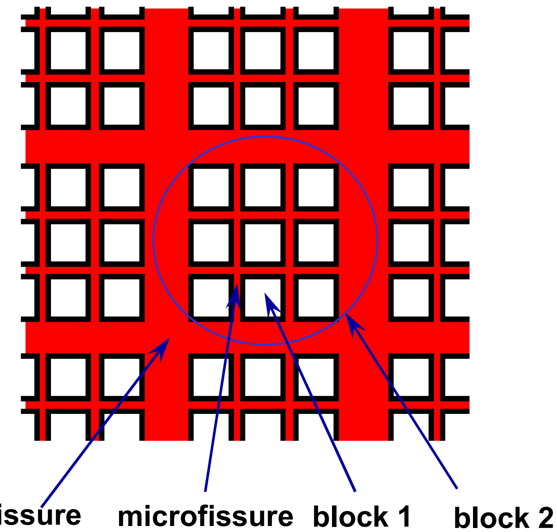
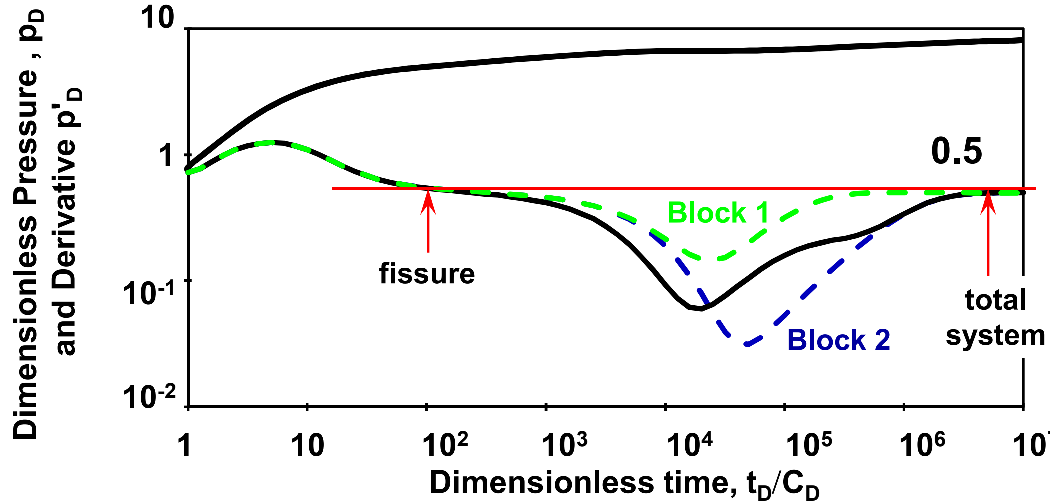
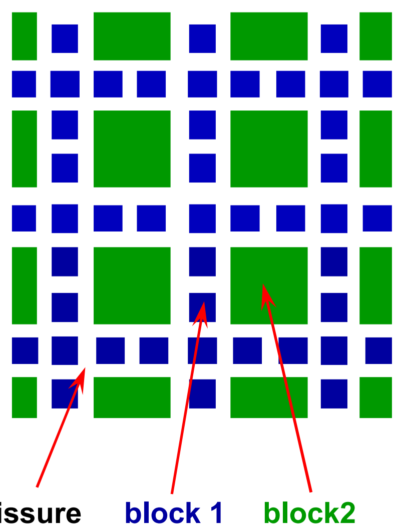
TRIPLE POROSITY RESERVOIR BEHAVIOUR



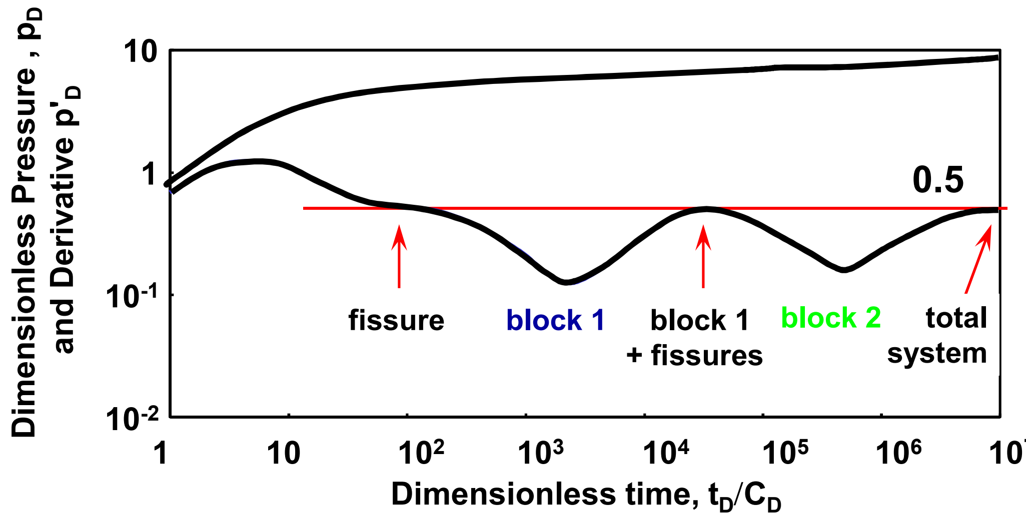
Fissured matrix blocks



OR



Two block sizes



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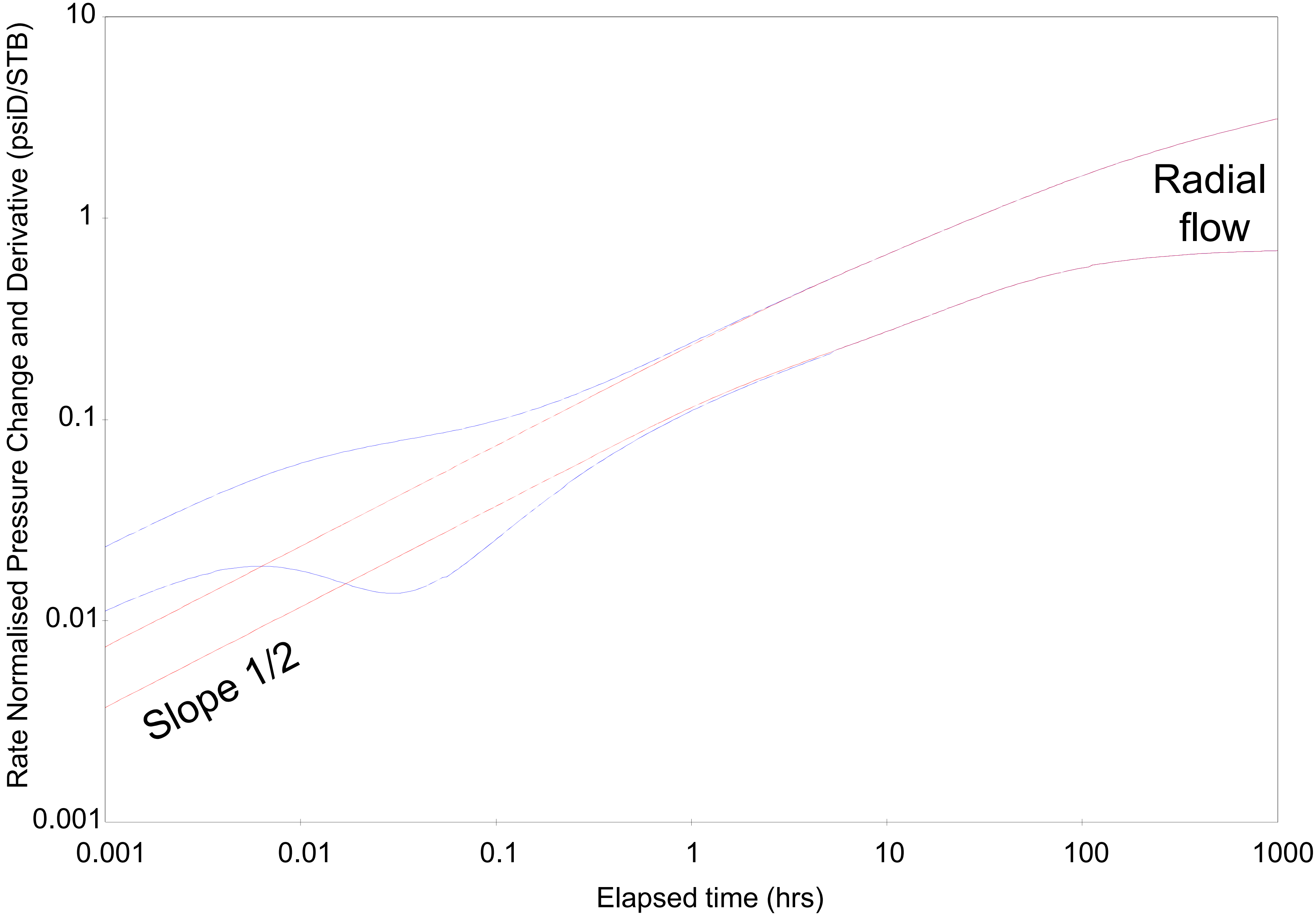
FRACTURED WELL



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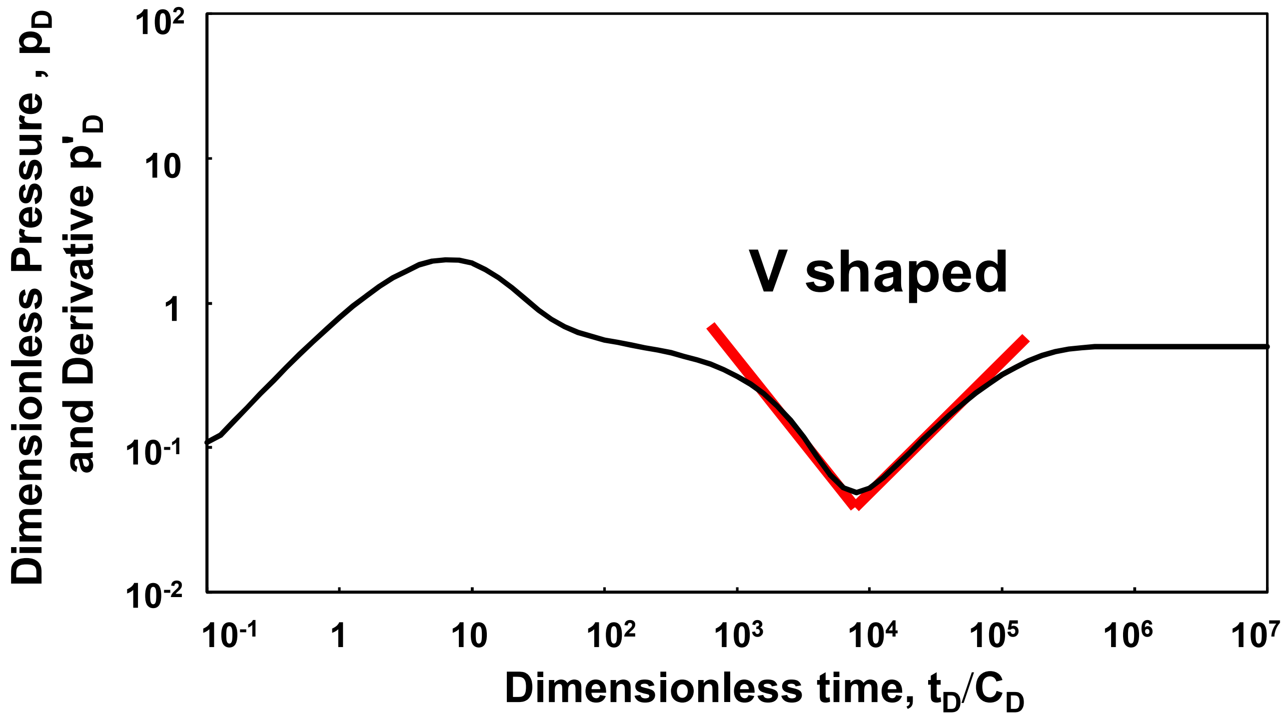
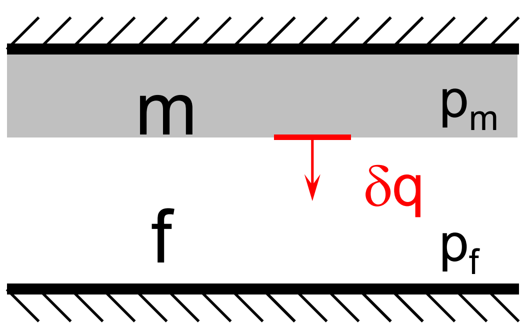
RESTRICTED INTERPOROSITY FLOW





"Warren & Root" (Soc. Pet. Eng. J., Sept. 1963) **or**
"Pseudo-steady state interporosity flow" solution

$$\delta q = \alpha \frac{k_m}{\mu}\left(p_m - p_f\right)$$

Interporosity flow / unit interface area / unit time

Independent of block shape

Barenblatt and Zeltov Soviet Physics Doklady (1960) Vol.5

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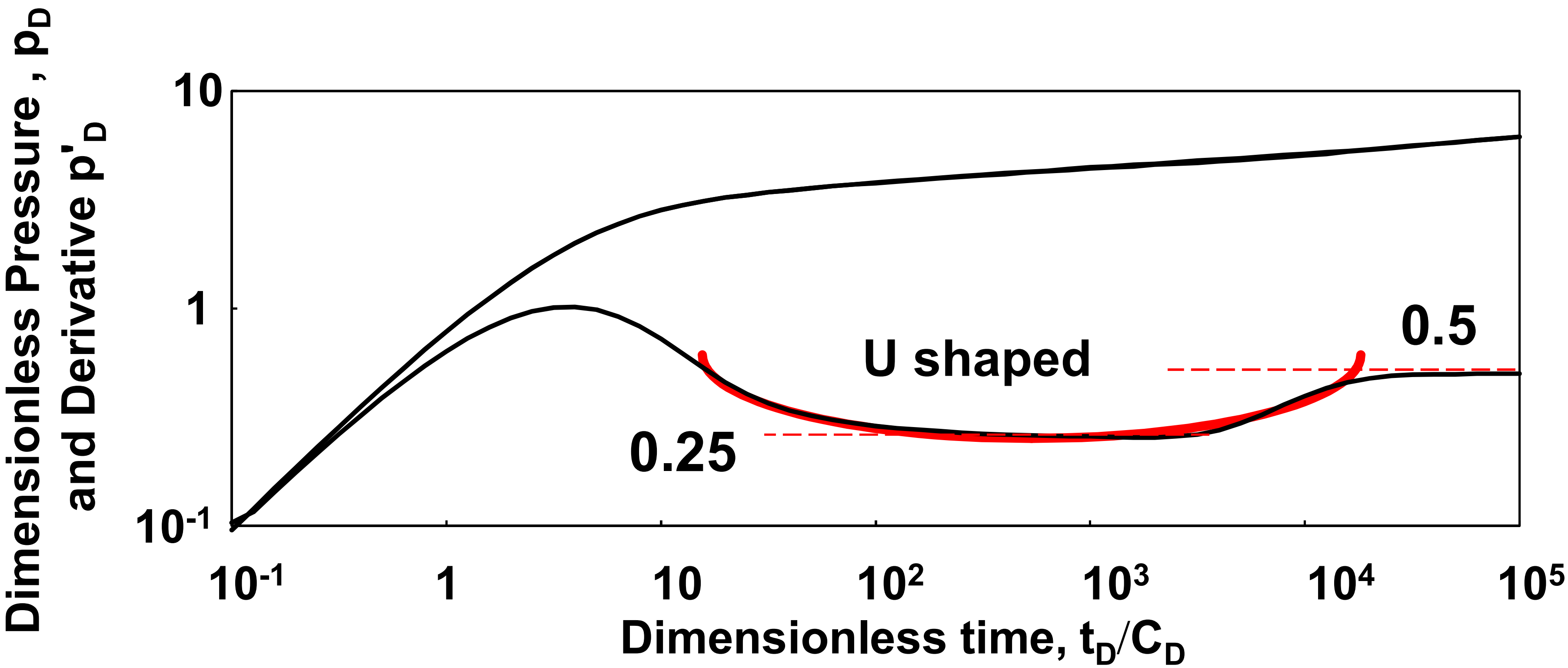
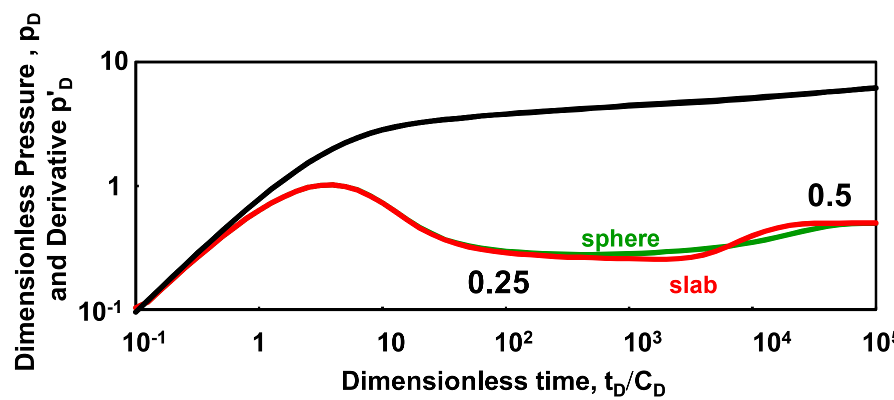
UNRESTRICTED INTERPOROSITY FLOW



"Transient interporosity flow" solution

Dependent of matrix block shape



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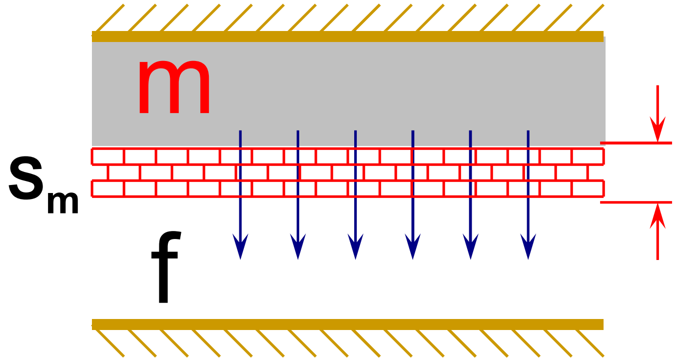
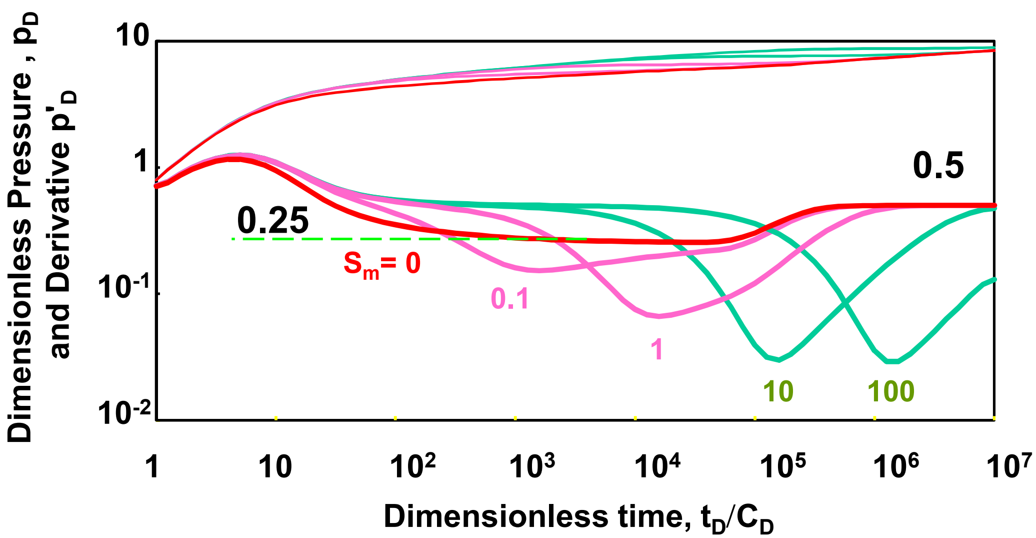
INTERPOROSITY SKIN

Moench Water Resour. Res. 20(7) July 1984

Cinco-Ley, Samaniego V. and Kucuk SPE14168 60th ATCE Las Vegas (Sept 1985)



$$S_m = \frac{k_m}{r_m}\frac{h_s}{k_s}$$



Warren and Root
pseudo-steady-state
interporosity flow solution

Transient interporosity flow solution

$$\lambda = \frac{12}{h_s^2} r_w^2 \frac{k_s}{k_f}$$

(does not give access to the matrix block size)

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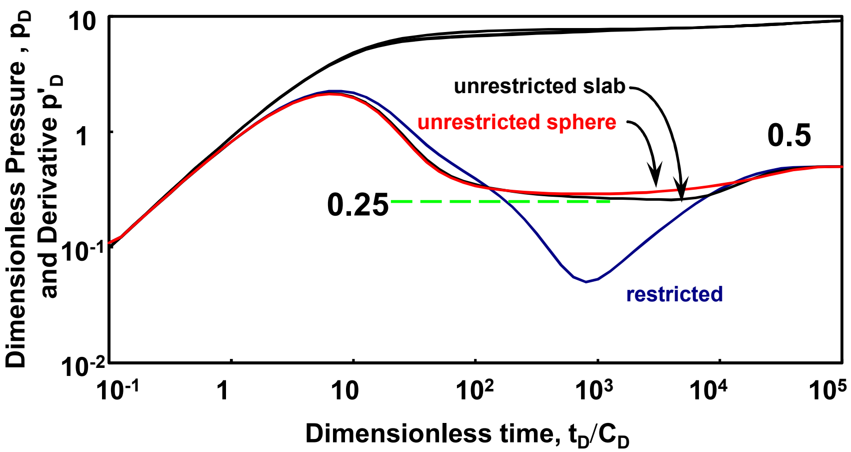
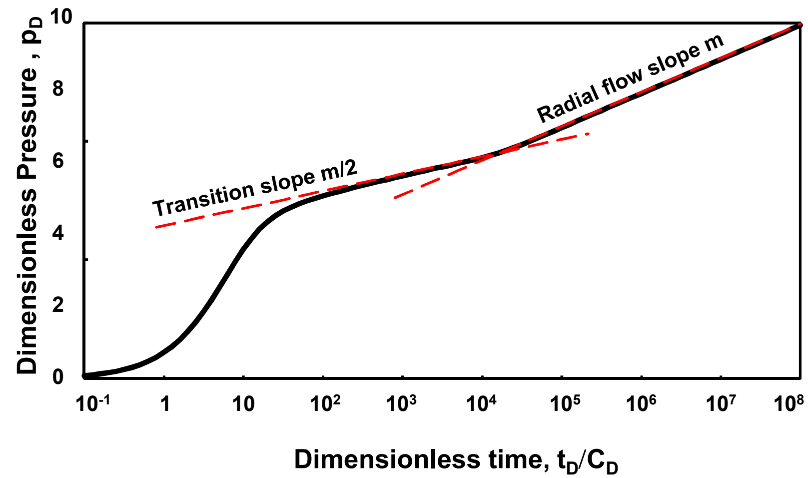
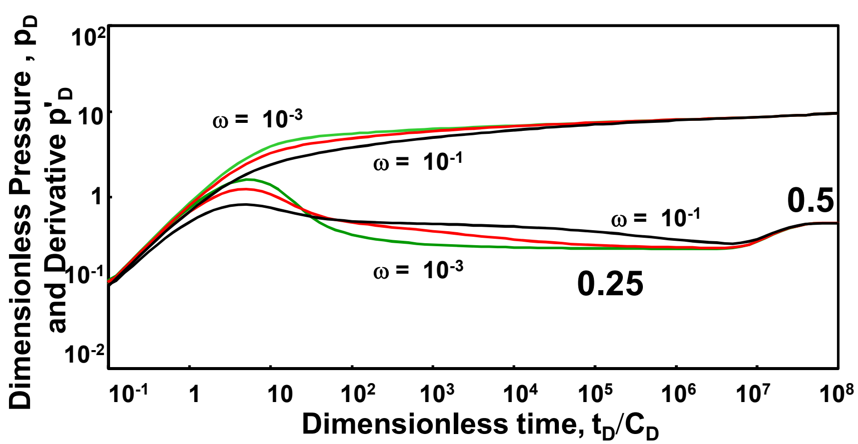
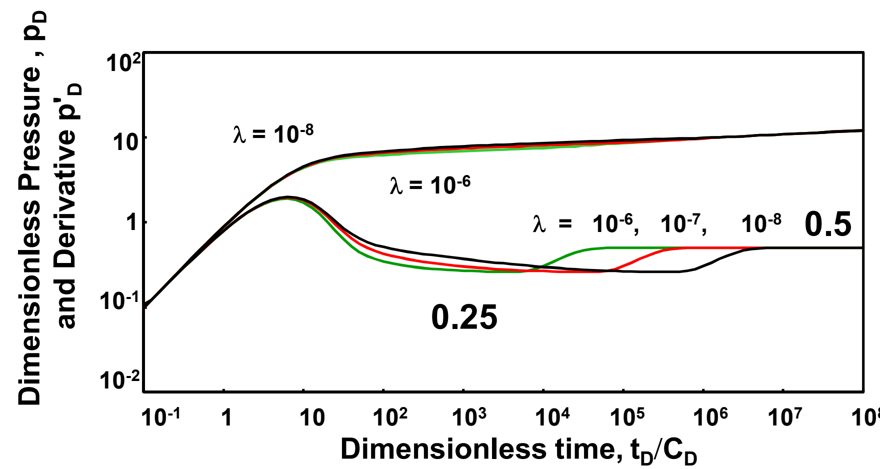
UNRESTRICTED INTERPOROSITY FLOW









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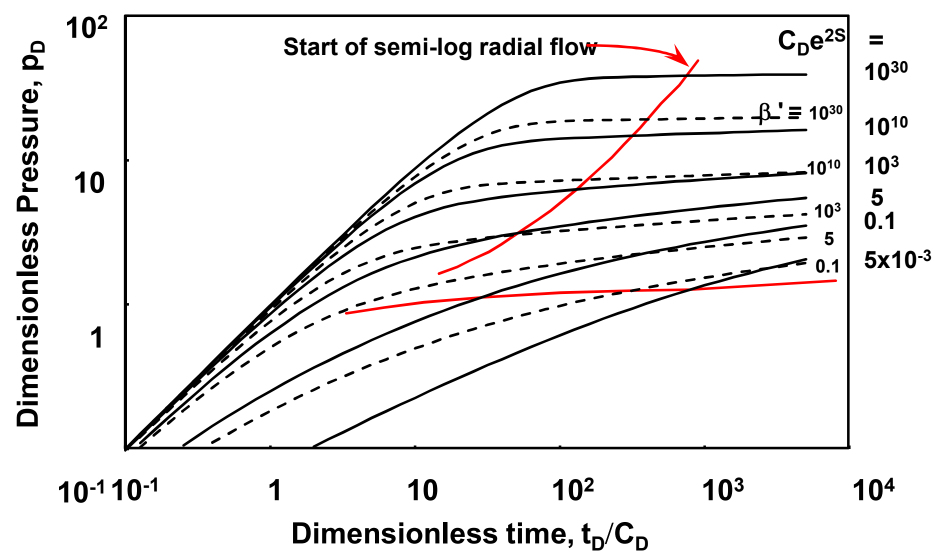
Drawdown Type Curves for a Well with Wellbore Storage & Skin, in a Reservoir of Infinite Extent with Double Porosity Behaviour (Unrestricted Interporosity Flow)

$$\beta' = \delta' \frac{\left(C_D e^{2S}\right)_{f+m}}{\lambda e^{-2S}}$$

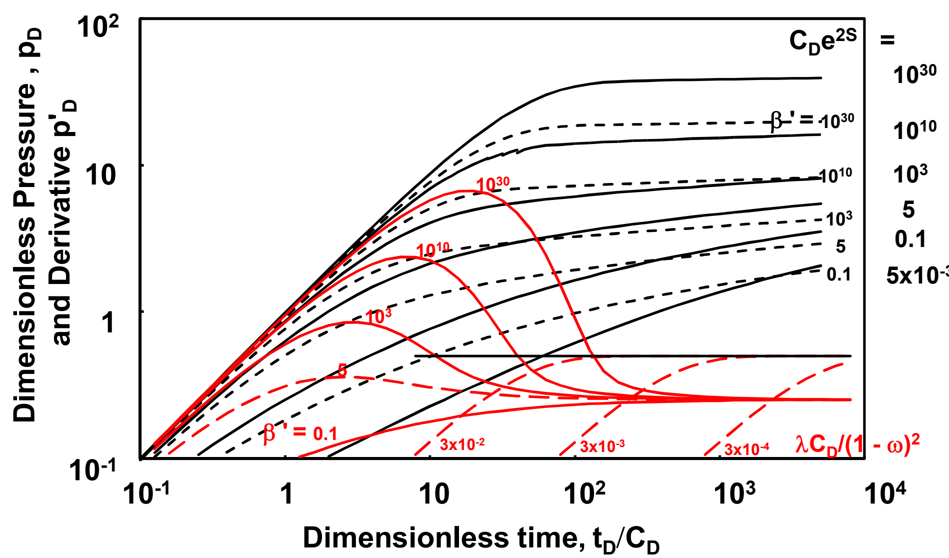


Slab matrix blocks:

$\delta' = 1.89$

Sphere matrix blocks:

$\delta' = 1.05$



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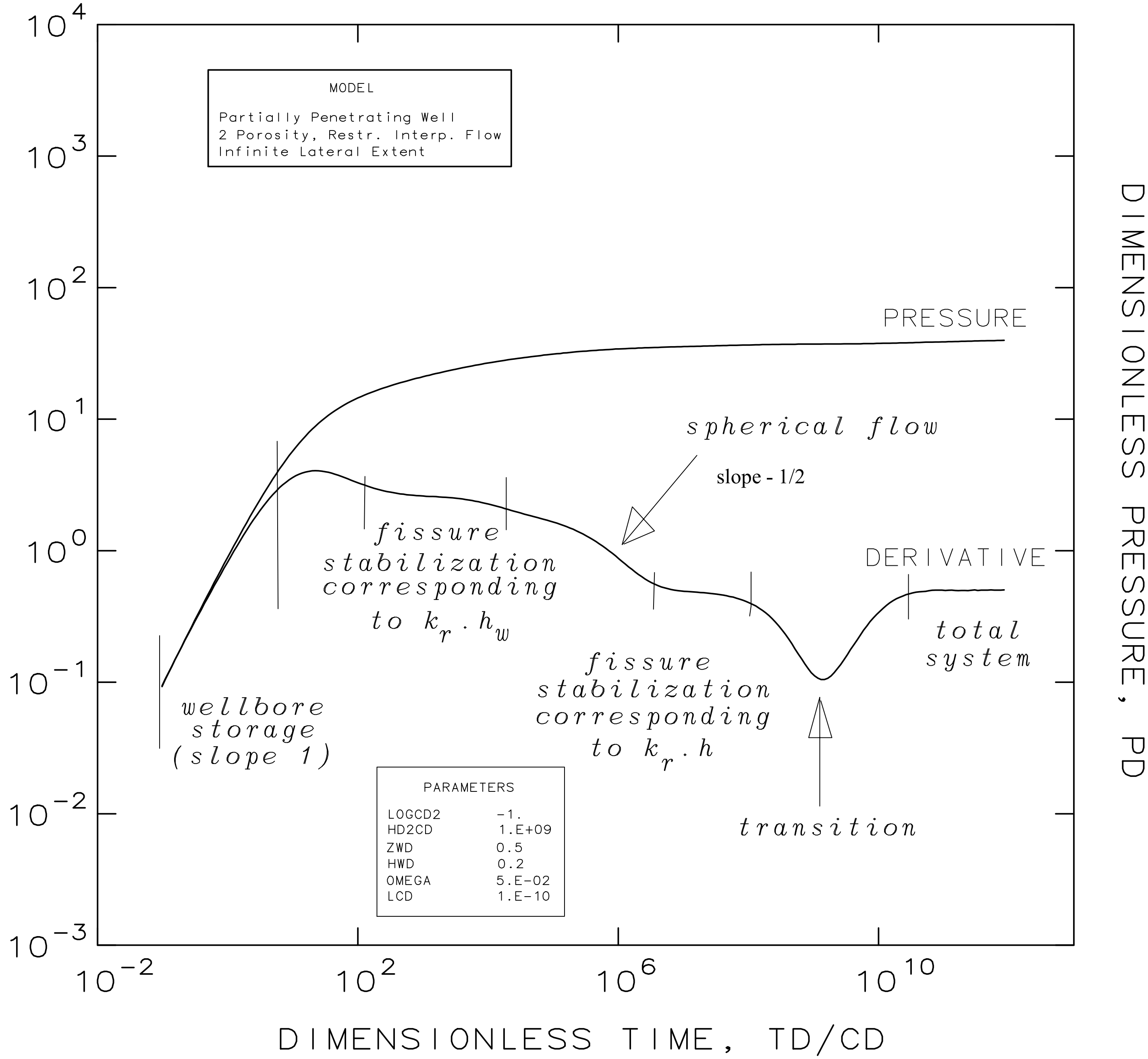
WELL WITH LIMITED ENTRY



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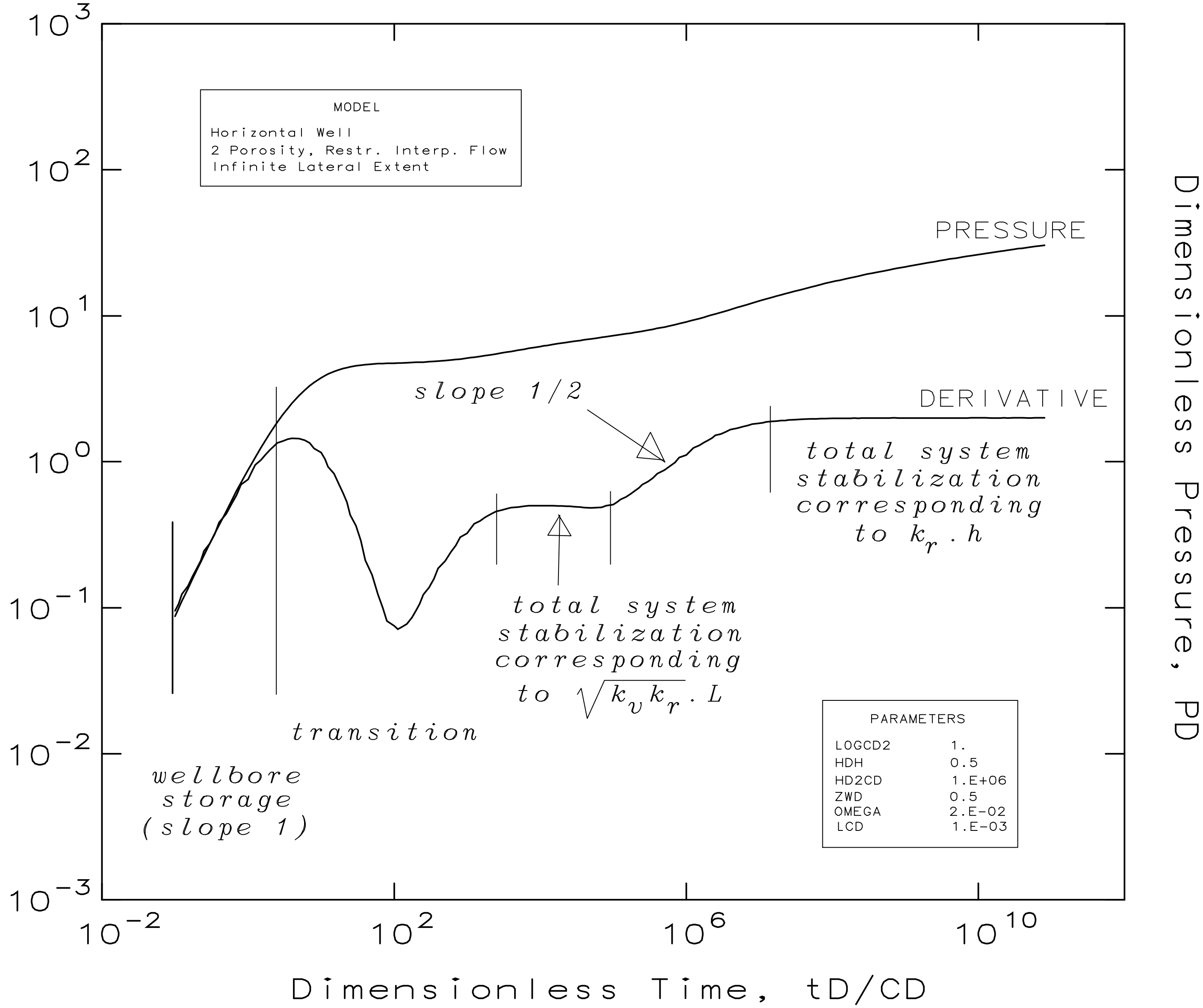
HORIZONTAL WELL



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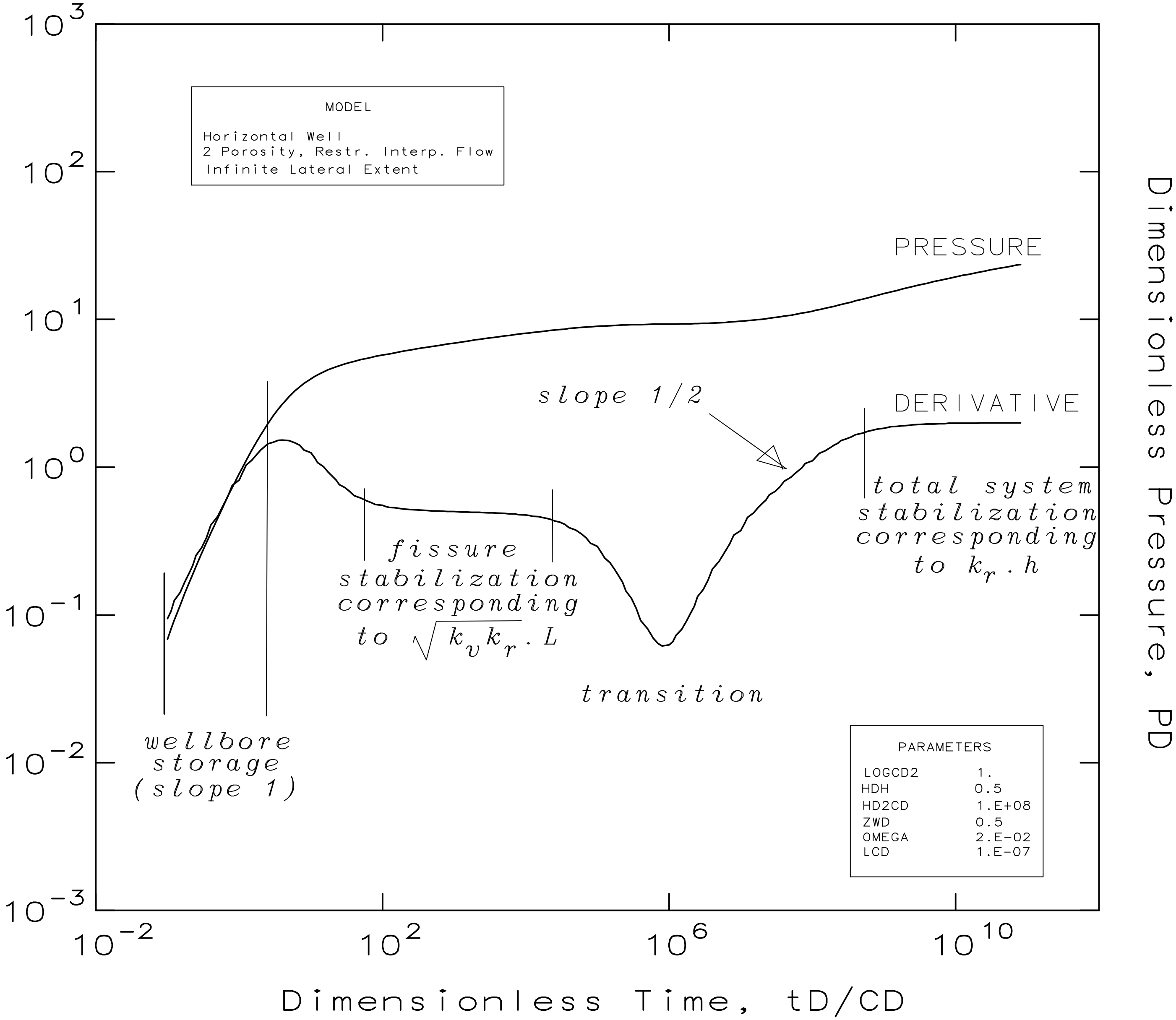
HORIZONTAL WELL



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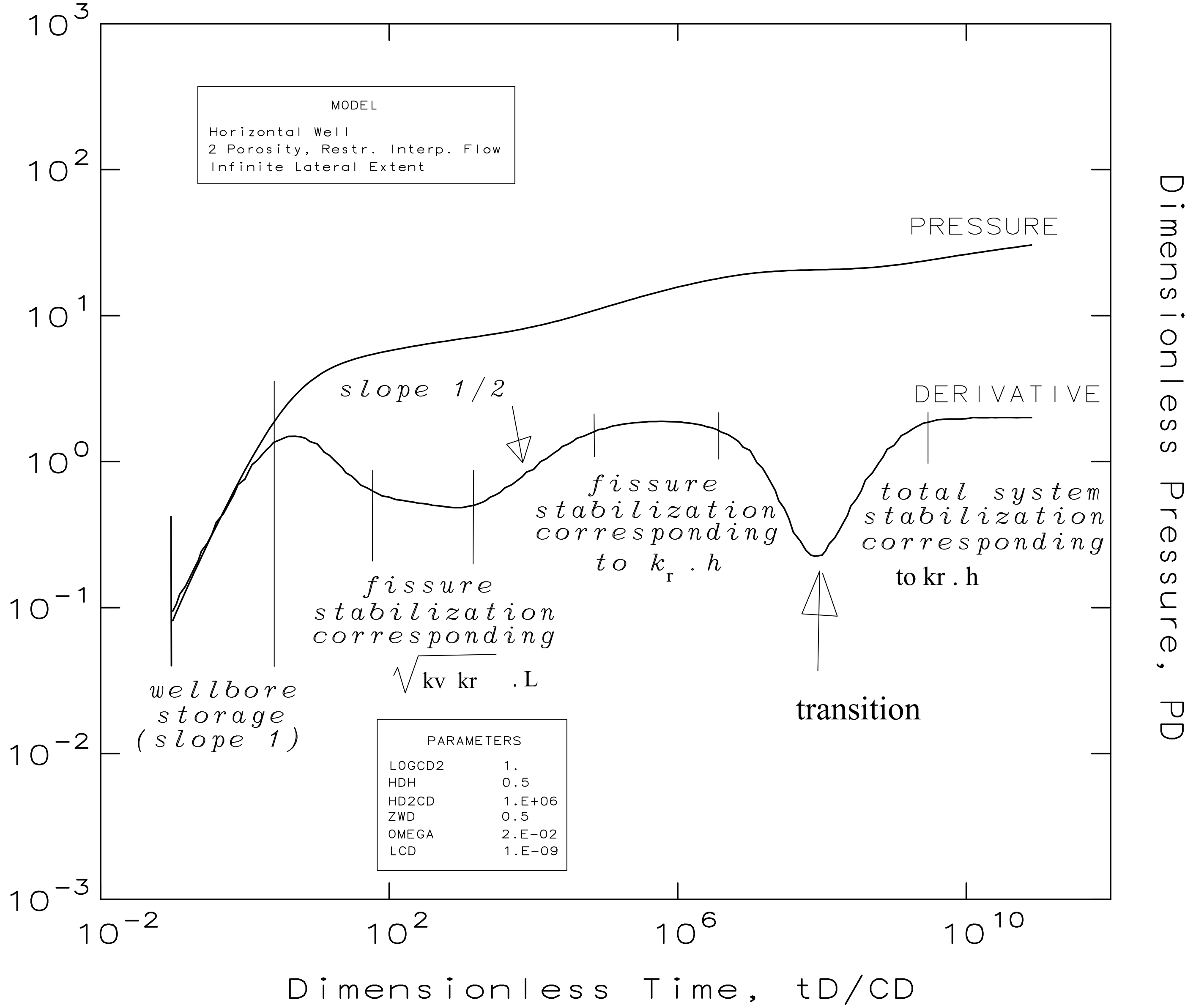
HORIZONTAL WELL



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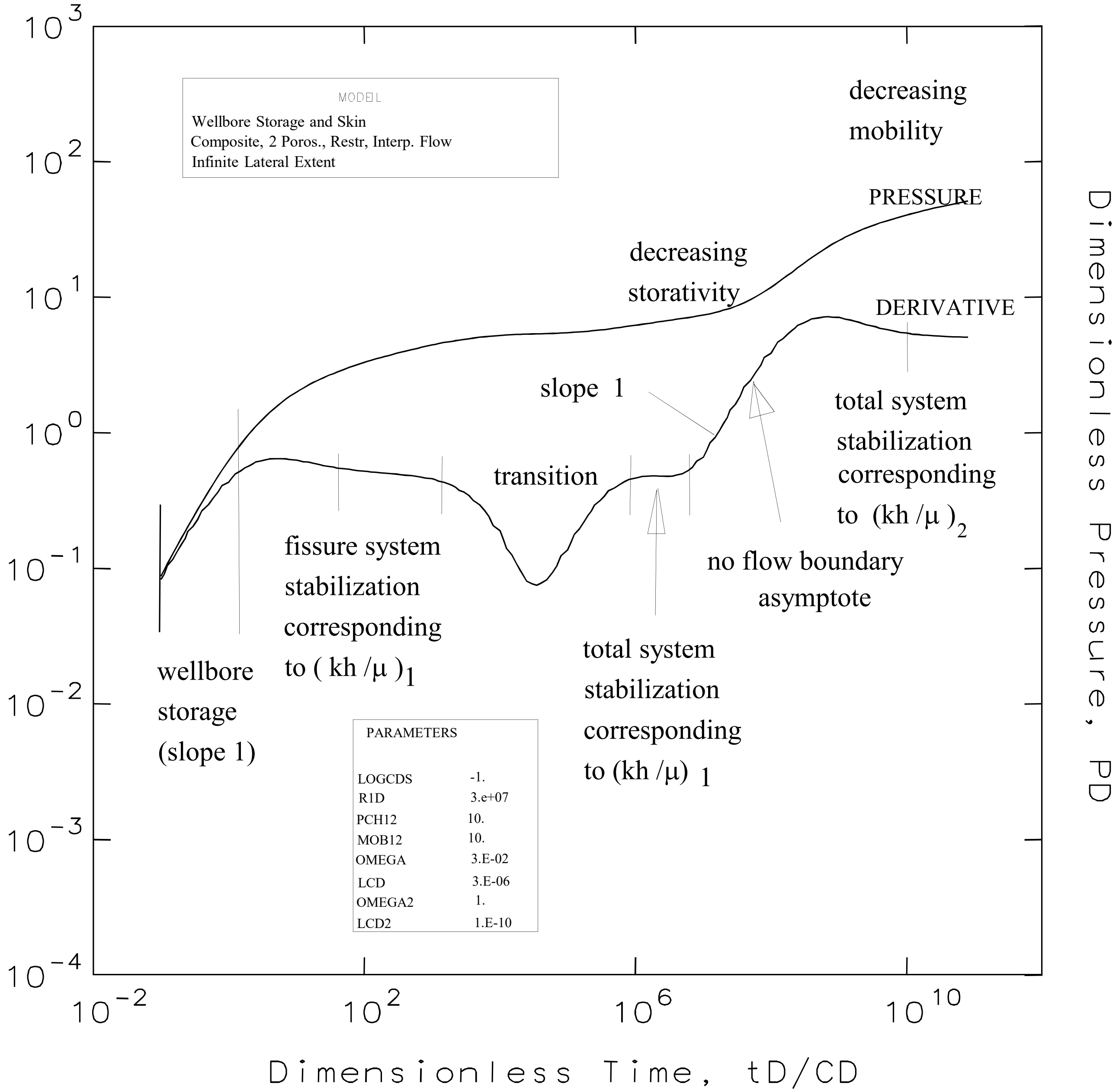
COMPOSITE BEHAVIOUR



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