PRESSURE LOG-LOG ANALYSIS

NEAR WELLBORE EFFECTS

- Wellbore Storage
- High Conductivity Fracture
- Low Conductivity Fracture

RESERVOIR BEHAVIOUR

- Homogeneous Behaviour
- Double porosity Behaviour

BOUNDARY EFFECTS

- Closed reservoir
- Constant Pressure

EARLY MISCONCEPTIONS ON LOG-LOG PRESSURE ANALYSIS

Robert C. Earlougher Jr. and Keith M. Kersch (Marathon Oil Co.) SPE 4488 48th ATCE Las Vegas (Sept. 1973)

Occasionally, insufficient transient test data are available for analysis using semi-logarithmic plotting methods. This usually happens when data collection stops before wellbore storage (afterflow) has become negligible. Under those circumstances, the semi-logarithmic straight line does not develop, and common semi-logarithmic analysis methods cannot be used. When such methods cannot be used, the engineer either obtains no information from the test or must use the available, short-time data to estimate reservoir characteristics. This paper presents a technique for the approximate analysis of such short-time transient test data. The method applies to buildup, falloff, drawdown, and injectivity tests when wellbore storage effects are important. *It should not be used* if data can be analysed by more conventional, semi-logarithmic plotting methods.

Henry J. Ramey, Jr. (Stanford U.) SPE 5878 46th Annual California Regional Meeting Long Beach, Ca. (Apr. 1975)

After a few years of further experience, it was found that in all successful cases of log-log type curve analysis, there was a sufficient portion of the semi-log straight line evident to permit conventional analysis. If only the unit slope straight line and a small portion of the transition toward the semi-log straight line were available, it was possible to find a match between field data and the Agarwal, Al-Hussainy and Ramey type curves in almost any position on the graph. It now appears that the most important use of the type curve is as a diagnostic device to determine the start of the semi-log straight line. Type curve matching should be done in emergency or as a checking device.

Henry J. Ramey, Jr. (Stanford U.) JPT(June 1992)

The log-log type curves described for the first time in the Earlougher 1977 monograph were considered controversial by the SPE Board of Directors. An early SPE board decision was not to publish full-scale log-log type curves because this would indicate SPE approval of log-log type curves or a particular type curve. Fortunately, this decision was reversed.

MODEL IDENTIFICATION IN LOG-LOG PRESSURE ANALYSIS

Wellbore storage

$$\Delta p = \frac{\Delta qB}{24C}\Delta t$$

$$\log\Delta p = \log\Delta t + \log\frac{\Delta q B}{24C}$$

Early time unit slope log-log straight line

Infinite conductivity fracture

$$\Delta p = 4.06\frac{\Delta qB}{hx_f}\sqrt{\frac{\mu}{\phi c_t k}}\sqrt{\Delta t}$$

$$\log\Delta p = \frac{1}{2}\log\Delta t + \log 4.06\frac{\Delta q B}{h x_f}\sqrt{\frac{\mu}{\varphi c_t k}}$$

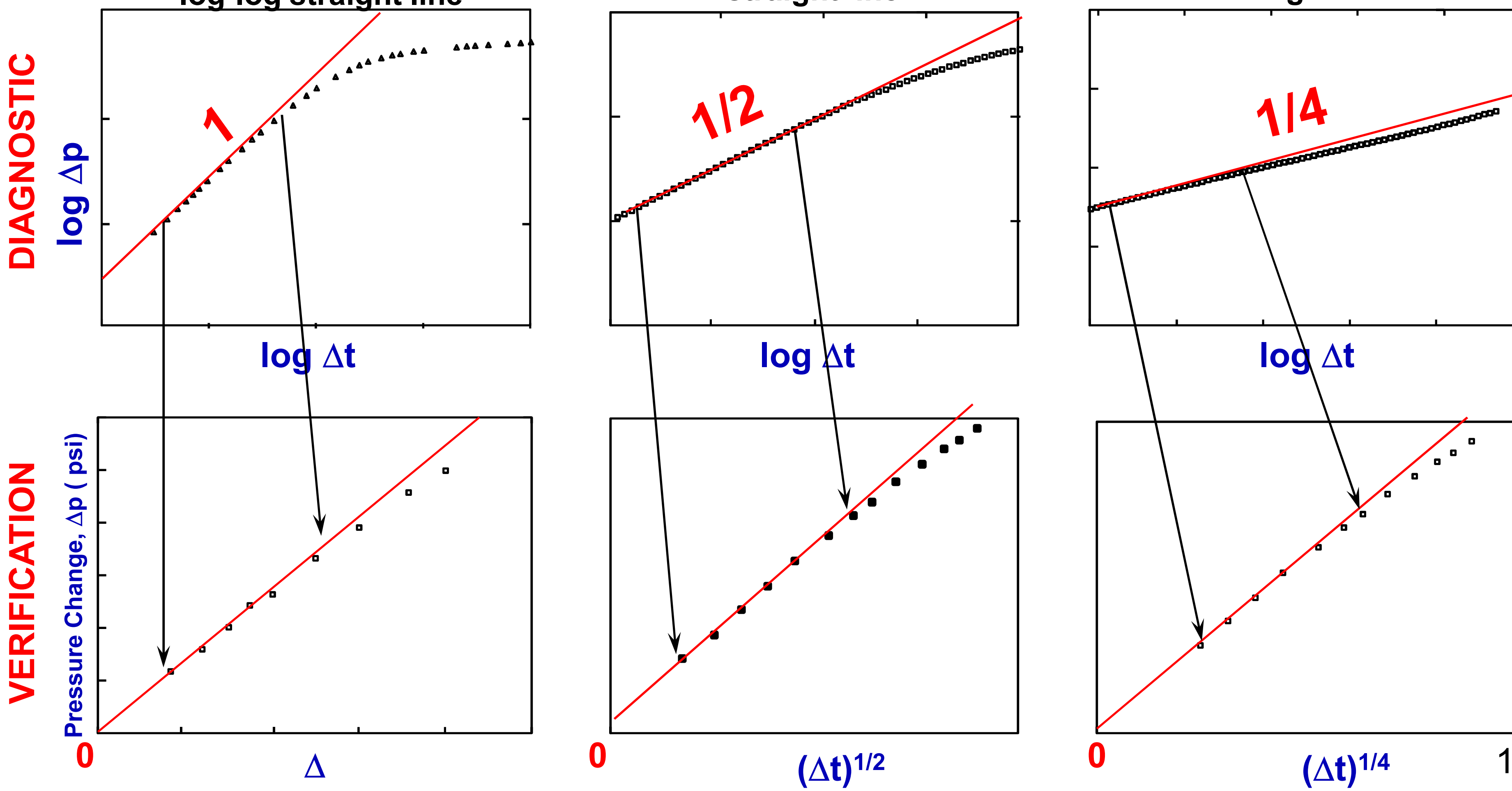
Early time half-unit slope straight line

Finite conductivity fracture

$$\Delta p = 44.1\frac{\Delta qB\mu}{h\sqrt{k_f w_f}\,\sqrt[4]{\phi\mu c_t k}}\sqrt[4]{\Delta t}$$

$$\log\Delta p = \frac{1}{4}\log\Delta t + \log 44.1\frac{\Delta q B\mu}{h\sqrt{k_f w_f}\,\sqrt[4]{\varphi\mu c_t k}}$$

Early time quarter-unit slope straight line



MODEL IDENTIFICATION IN LOG-LOG PRESSURE ANALYSIS

Homogeneous BEHAVIOUR

Smooth-shaped curve at middle times

$$\Delta p = 162.6 \frac{\Delta q B \mu}{kh}\left(\log \Delta t + \log \frac{k}{\phi \mu c_t r_w^2} - 3.23\right)$$

Double porosity BEHAVIOUR

S-shaped curve at middle times

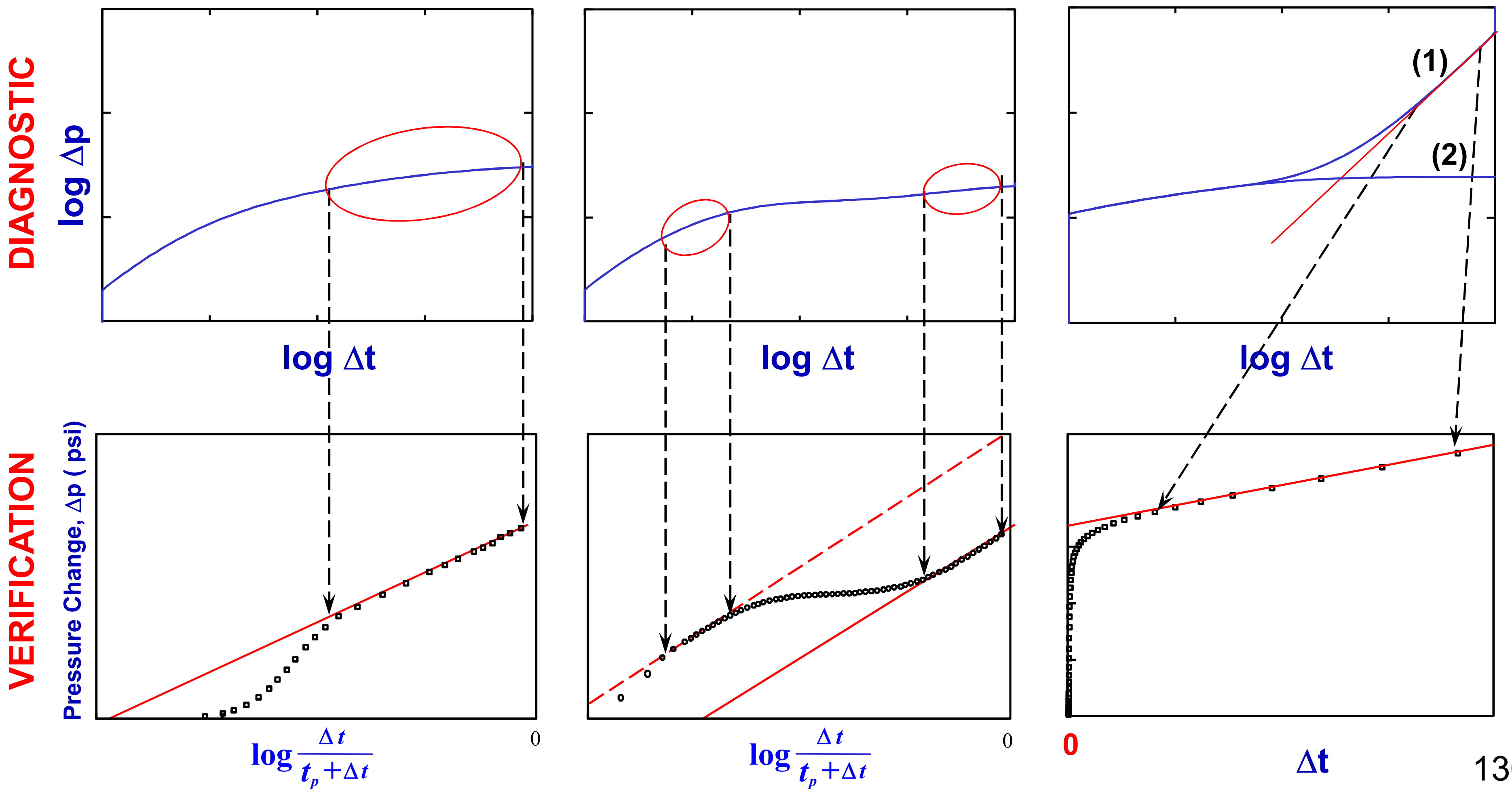
(1) Closed rectangle

Asymptotic to unit slope straight line at late times

(Drawdowns only)

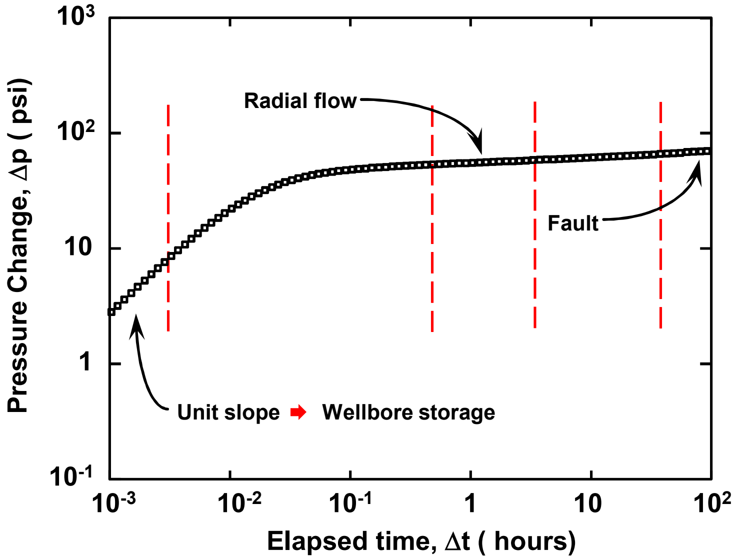
(2) Constant pressure

Stabilised pressure at late times

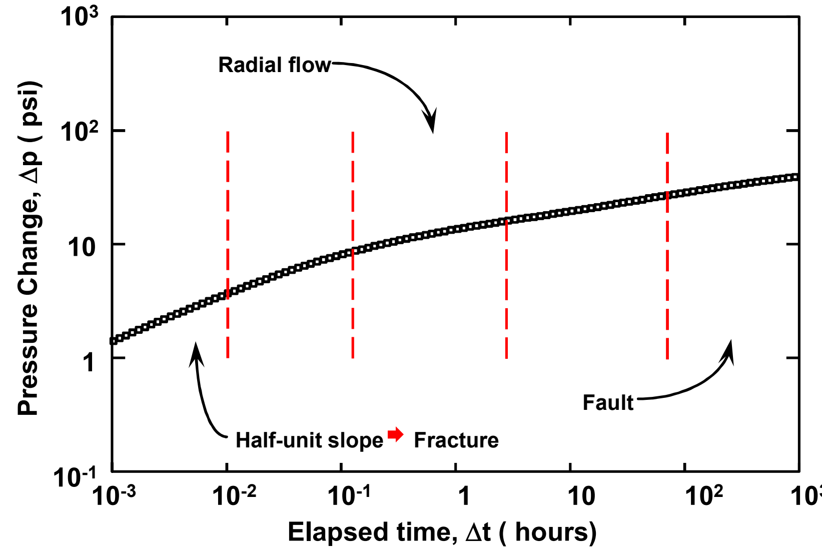


MODEL IDENTIFICATION IN LOG-LOG PRESSURE ANALYSIS

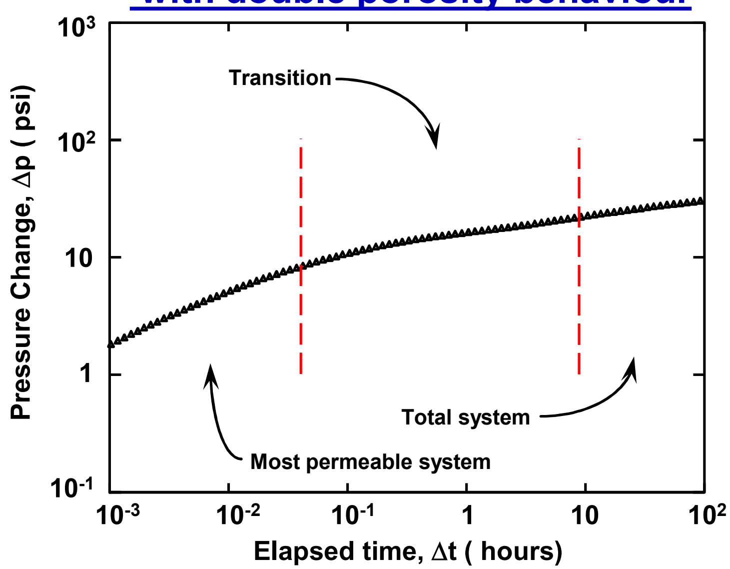
wellbore storage in a reservoir with homogeneous behaviour and a fault



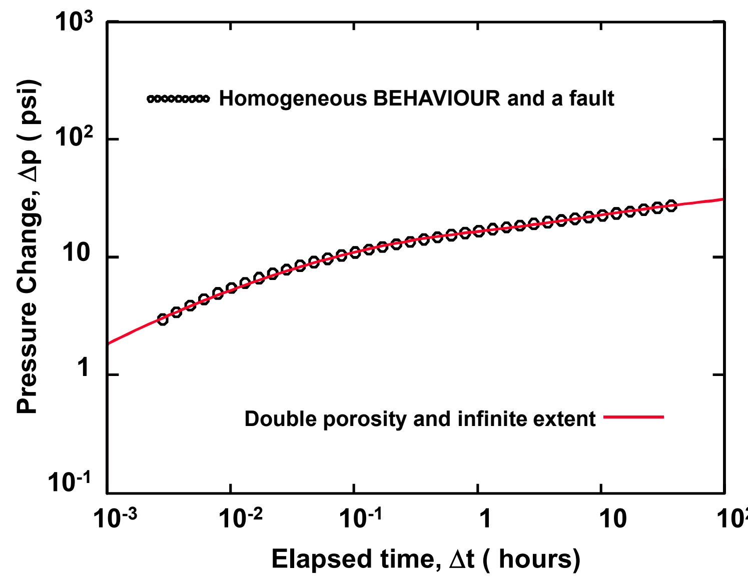
high conductivity fracture in a reservoir with homogeneous behaviour and a fault



wellbore storage in an infinite reservoir with double porosity behaviour



Example of non-uniqueness



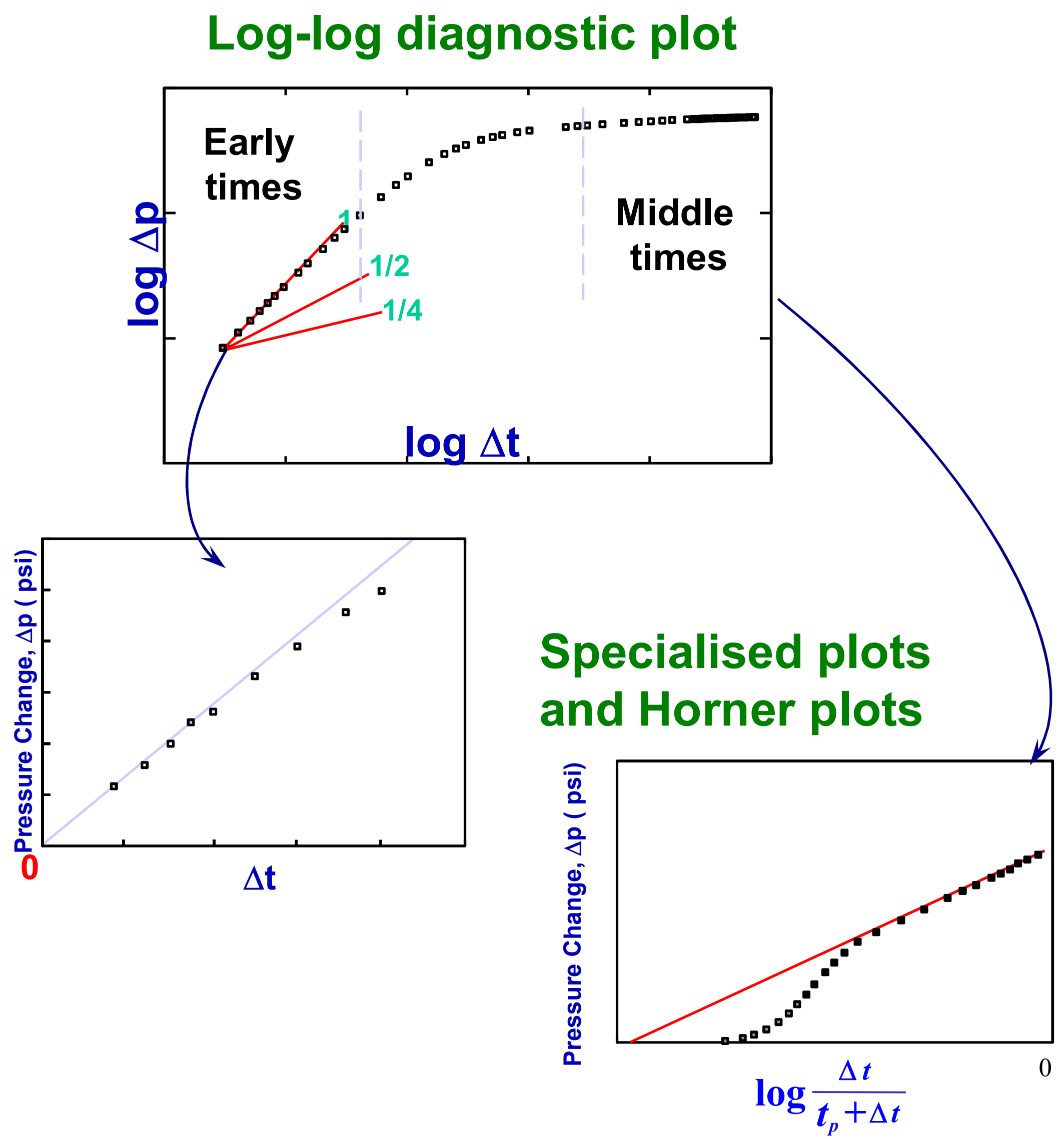
TYPE CURVE ANALYSIS PROCESS

(1) INVERSE PROBLEM

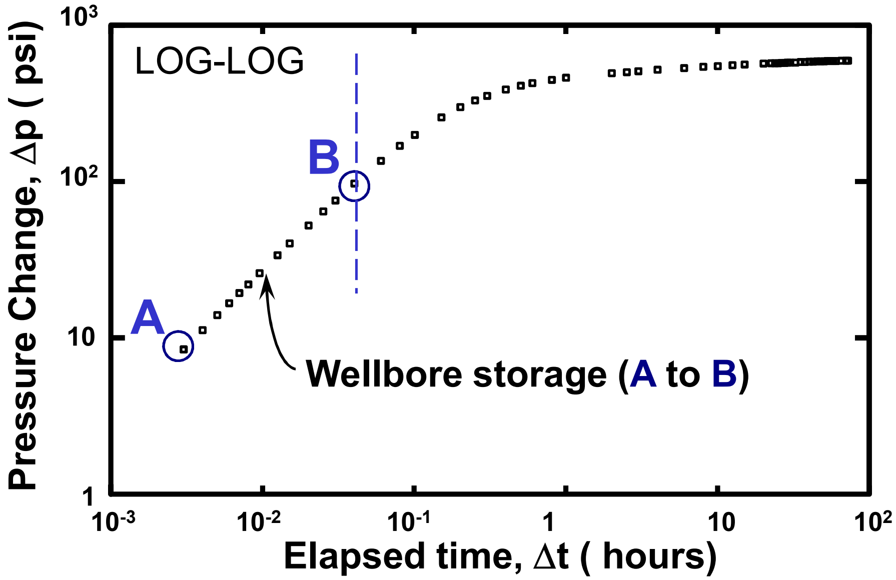
IDENTIFY FLOW REGIMES ON LOG-LOG PLOT

↓

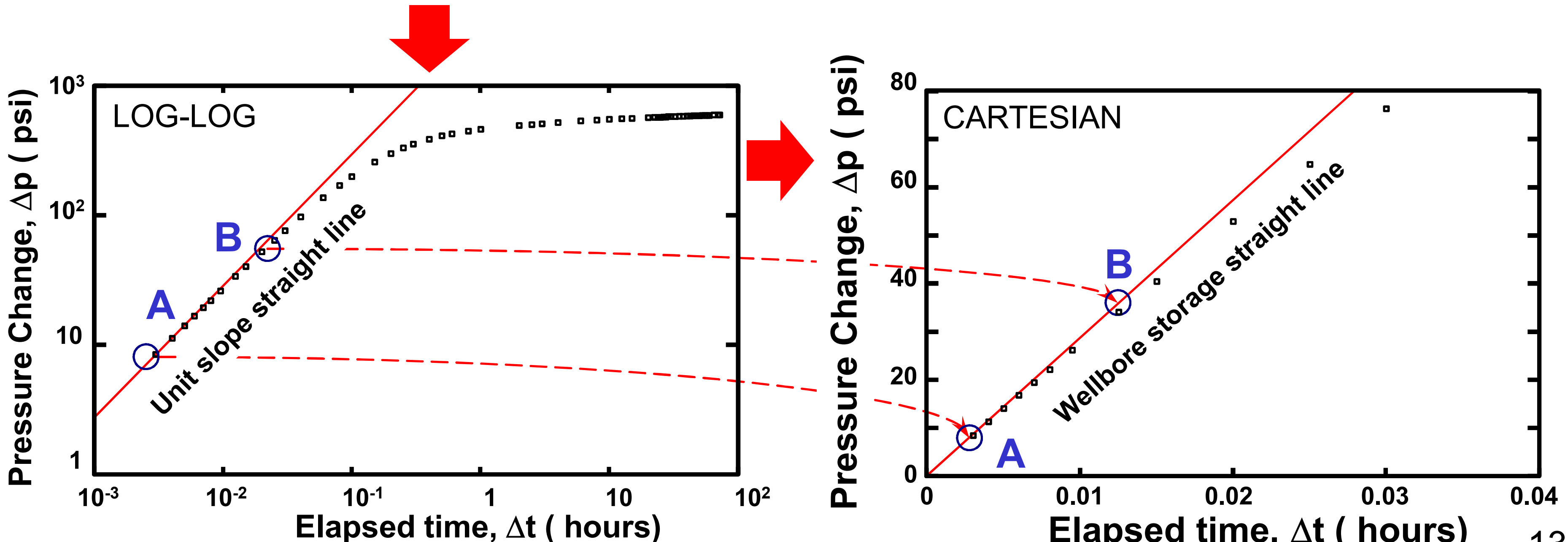
VERIFY FLOW REGIMES ON SPECIALISED PLOTS



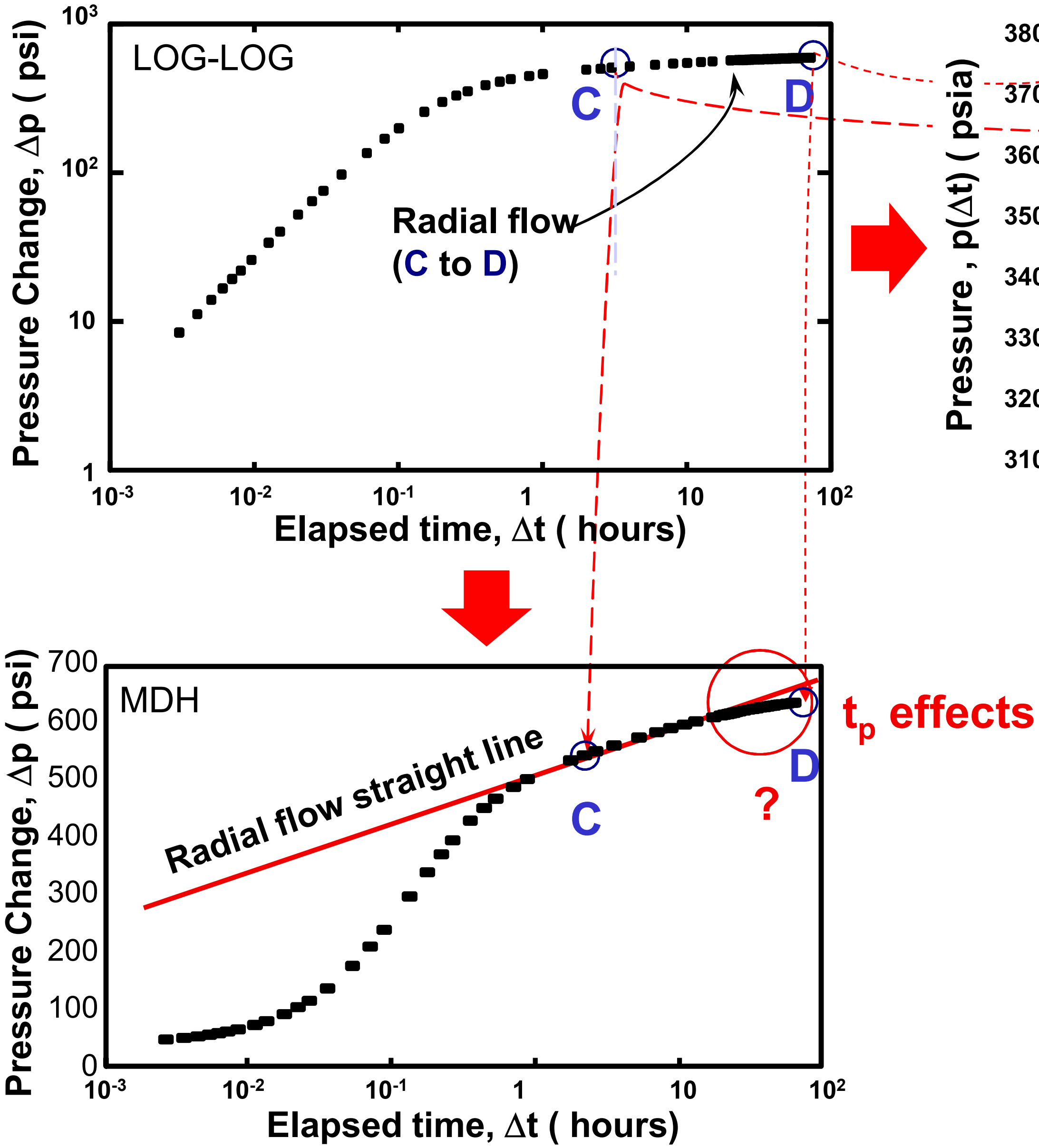
Verification of the flow regimes



1: Wellbore storage

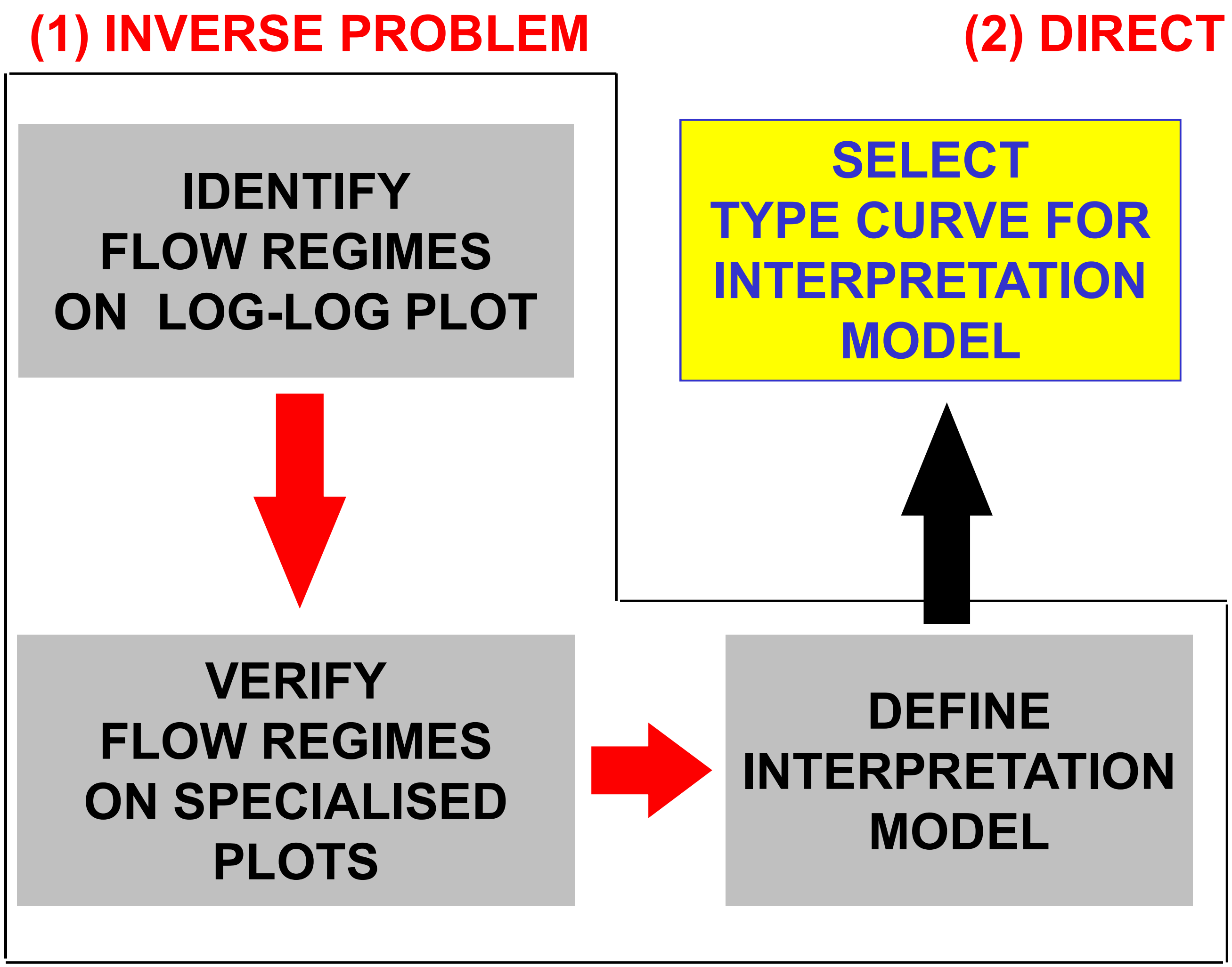


Verification of the flow regimes

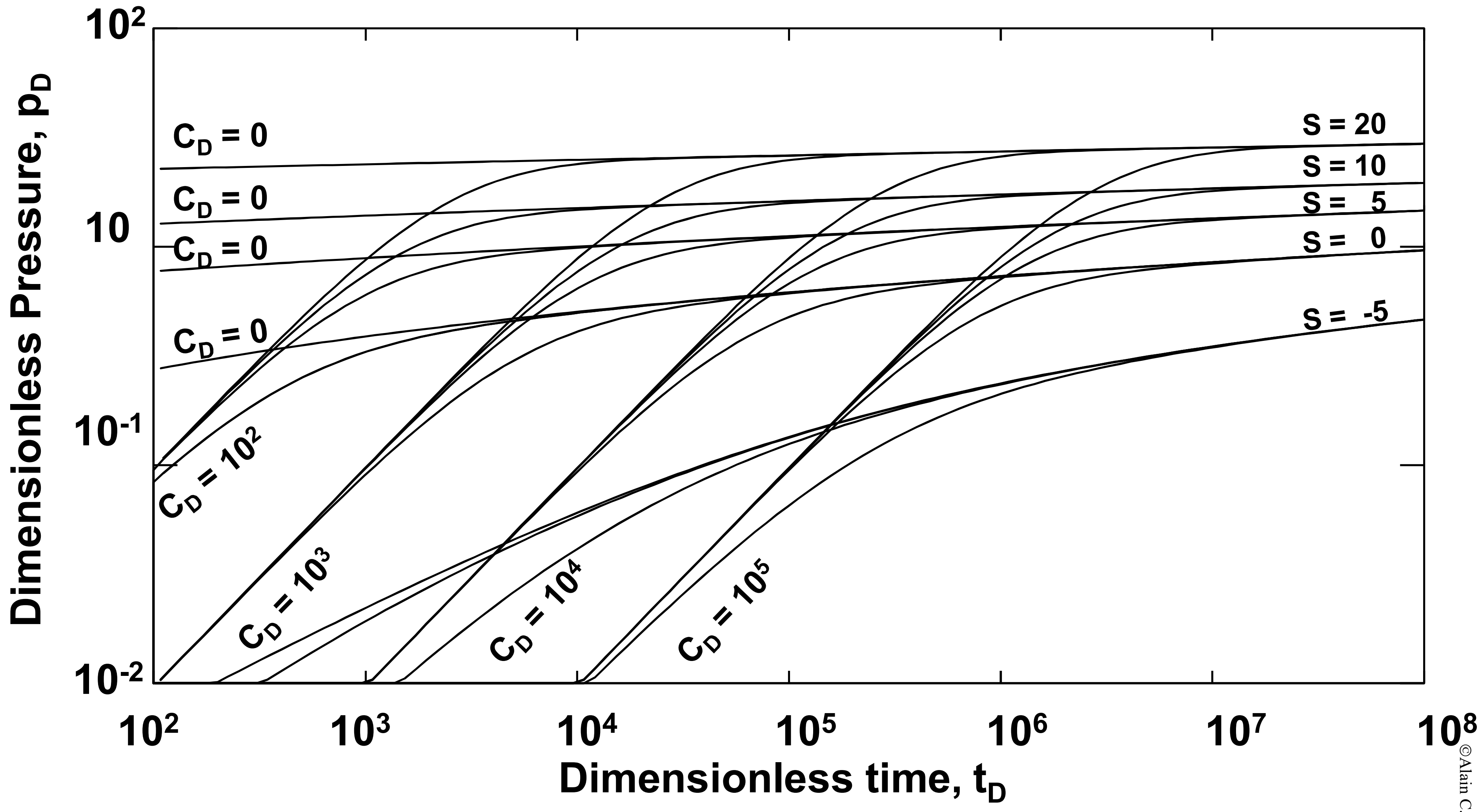


2: Radial Flow

TYPE CURVE ANALYSIS PROCESS



Drawdown Type Curve for a Well with Wellbore Storage & Skin, in a Reservoir of Infinite Extent with Homogeneous Behaviour

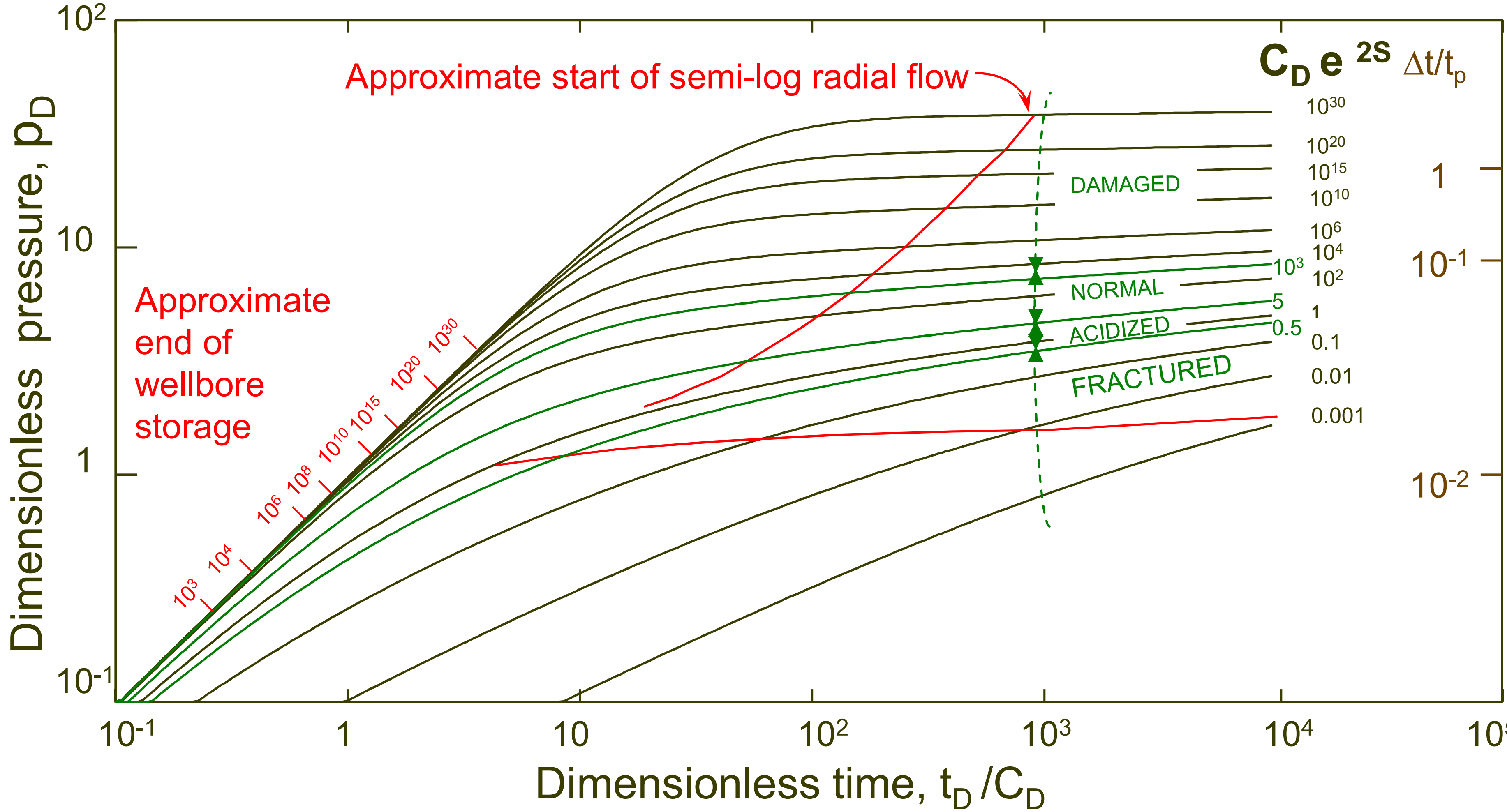


Ramey's Type Curve:

$$p_D = \frac{kh}{141.2 \Delta q B \mu} \Delta p \qquad t_D = \frac{0.000264\, k}{\phi \mu\, c_t r_w^2} \Delta t \qquad C_D = \frac{0.8936\, C}{\phi\, c_t h r_w^2} \qquad (S)$$

Dimensionless parameters, non-unique match

Drawdown Type Curve for a Well with Wellbore Storage & Skin, in a Reservoir of Infinite Extent with Homogeneous Behaviour

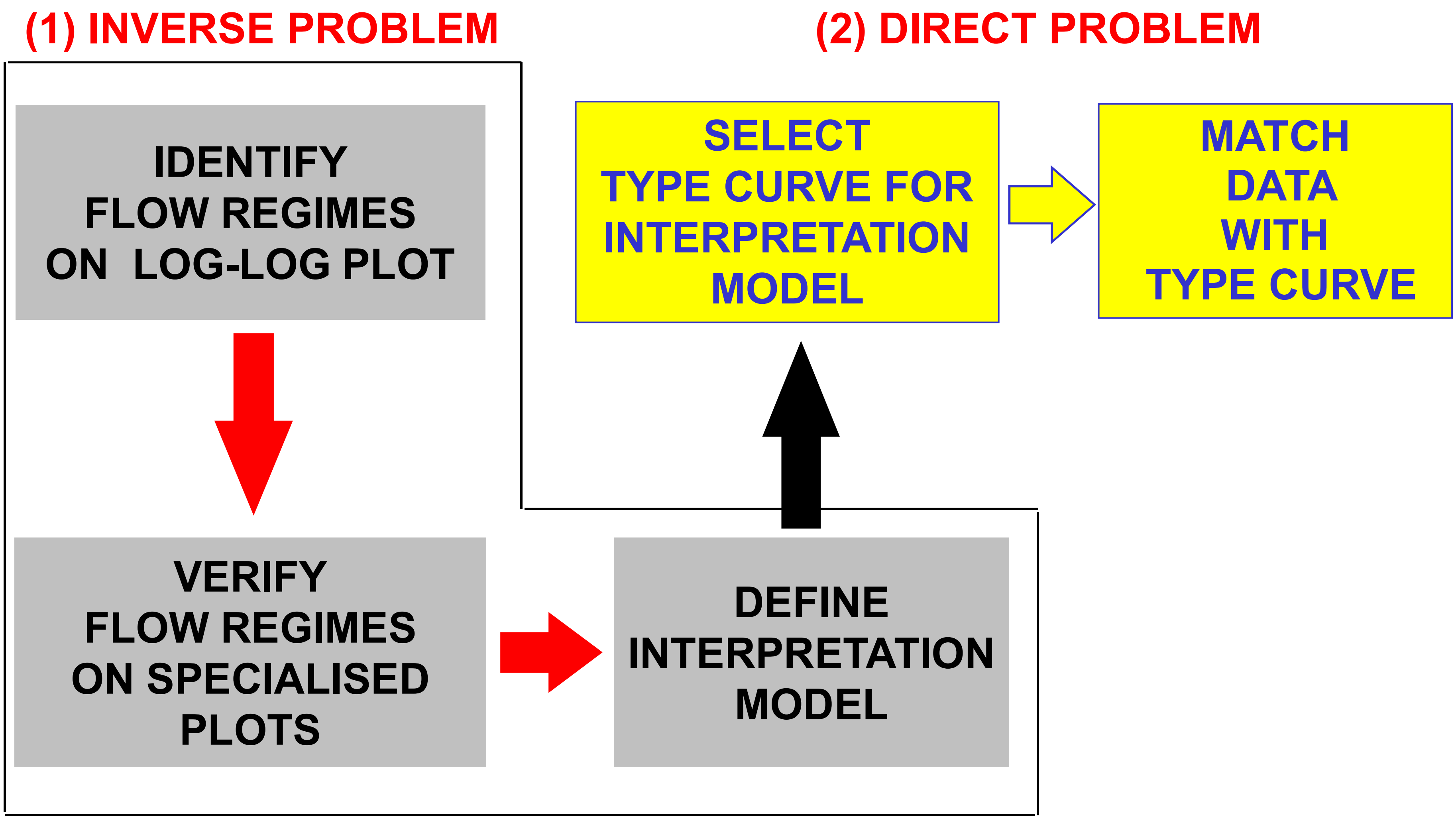


SPE 8205 Type Curve:

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

Independent variables, unique match

TYPE CURVE ANALYSIS PROCESS



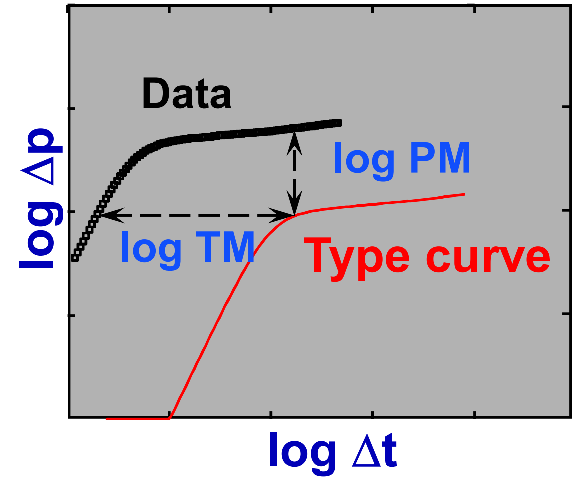
TYPE CURVE MATCHING

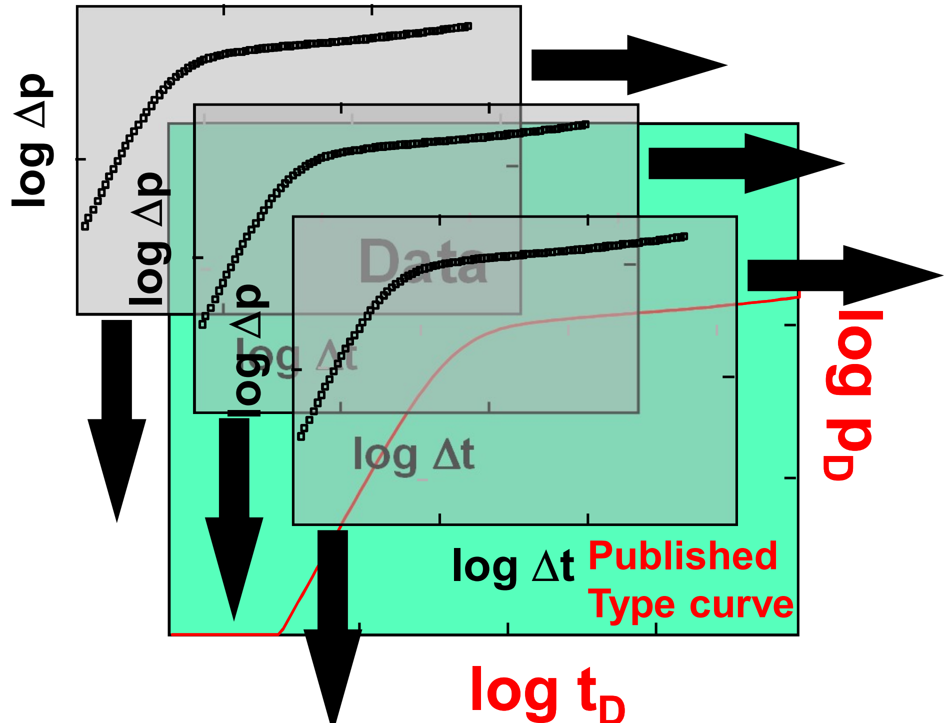
p_D = PM Δp

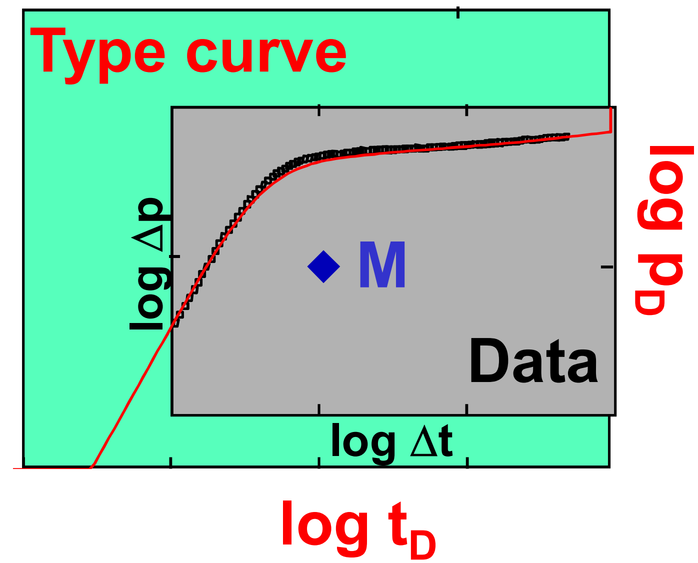
t_D = TM Δt

$\log p_D = \log \Delta p + \log PM$

$\log t_D = \log \Delta t + \log TM$







"Match Point"

M = (p_D , t_D) = $(\Delta p , \Delta t)$

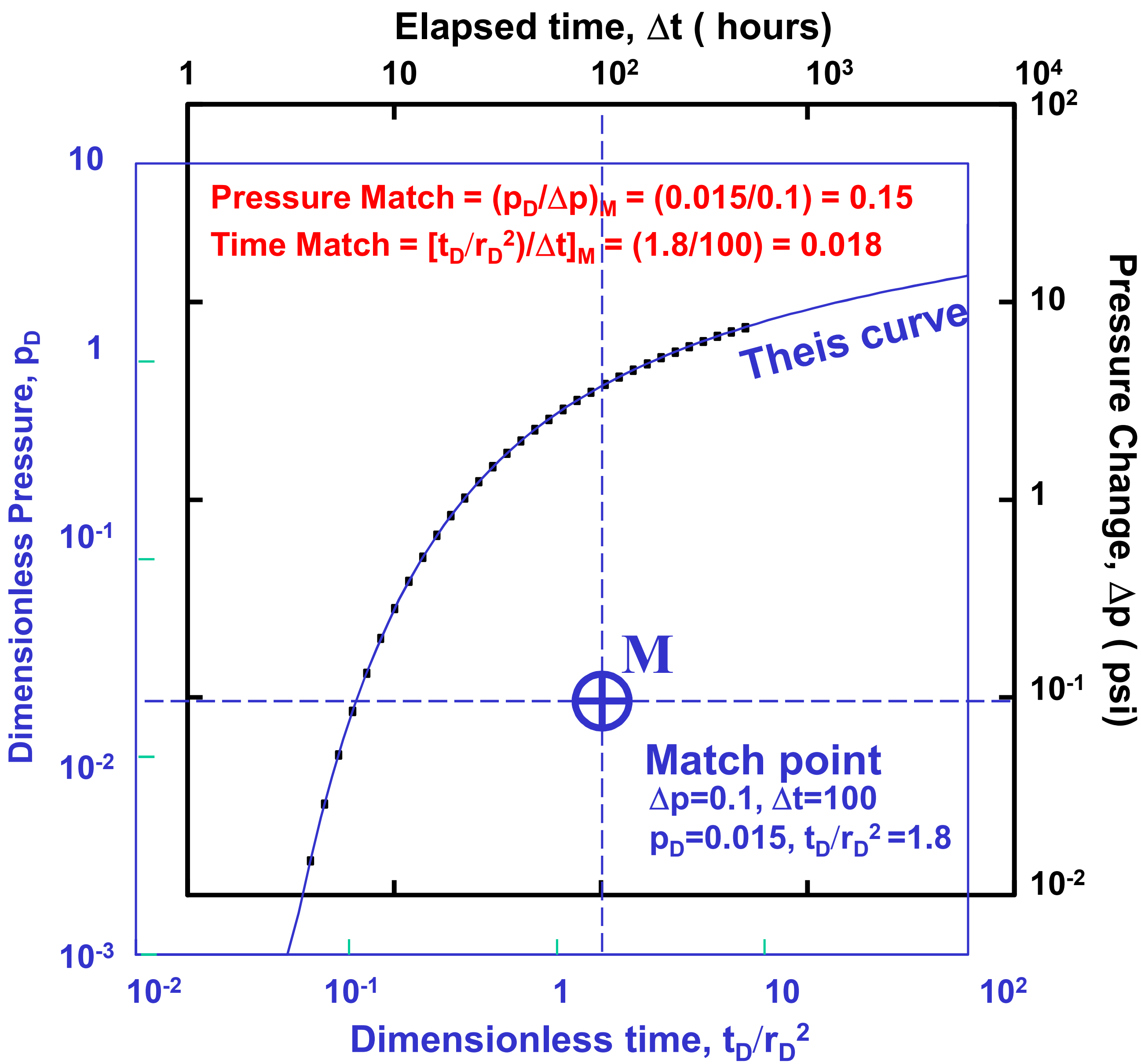
"Pressure Match"

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

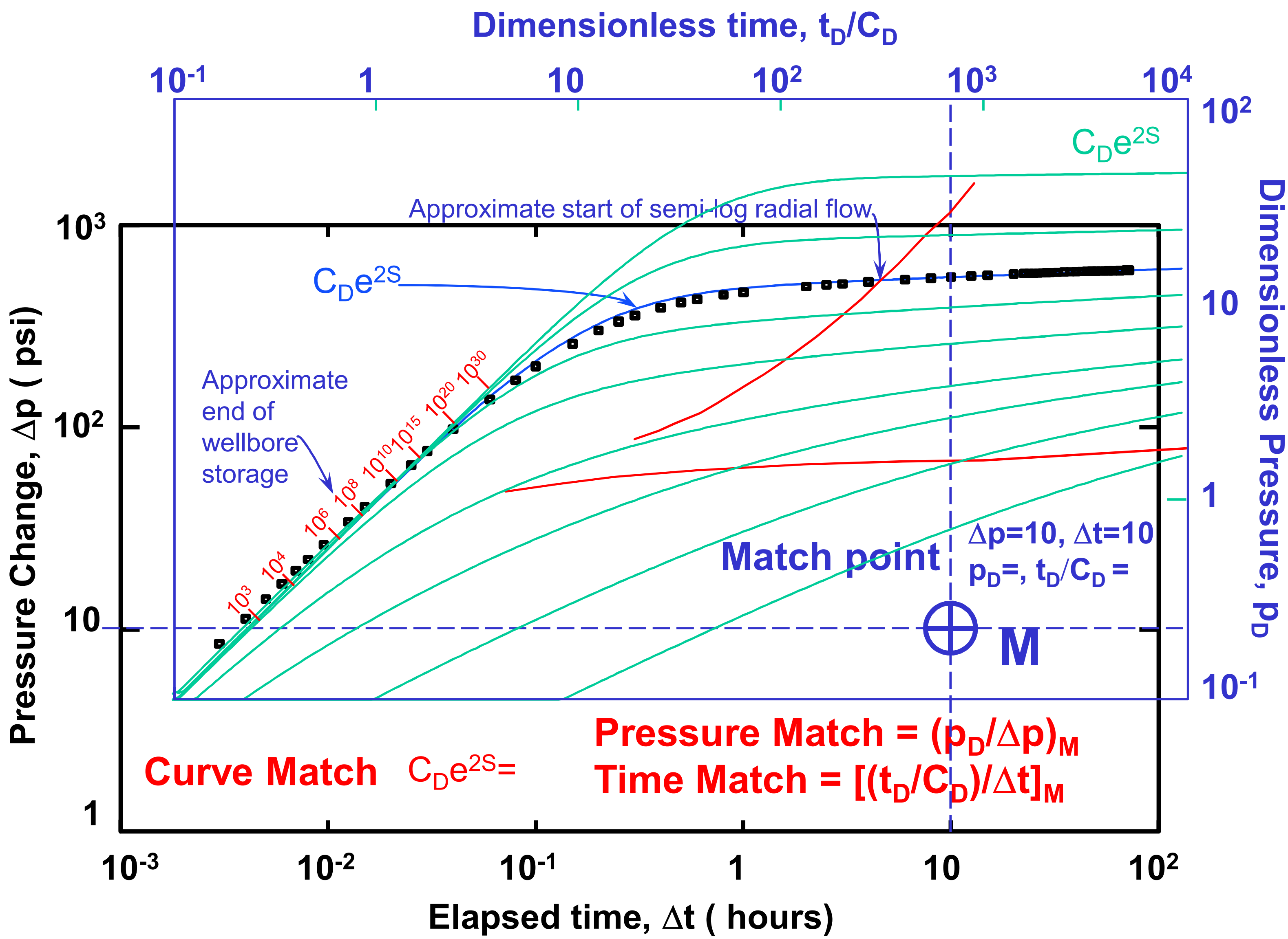
"Time Match"

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

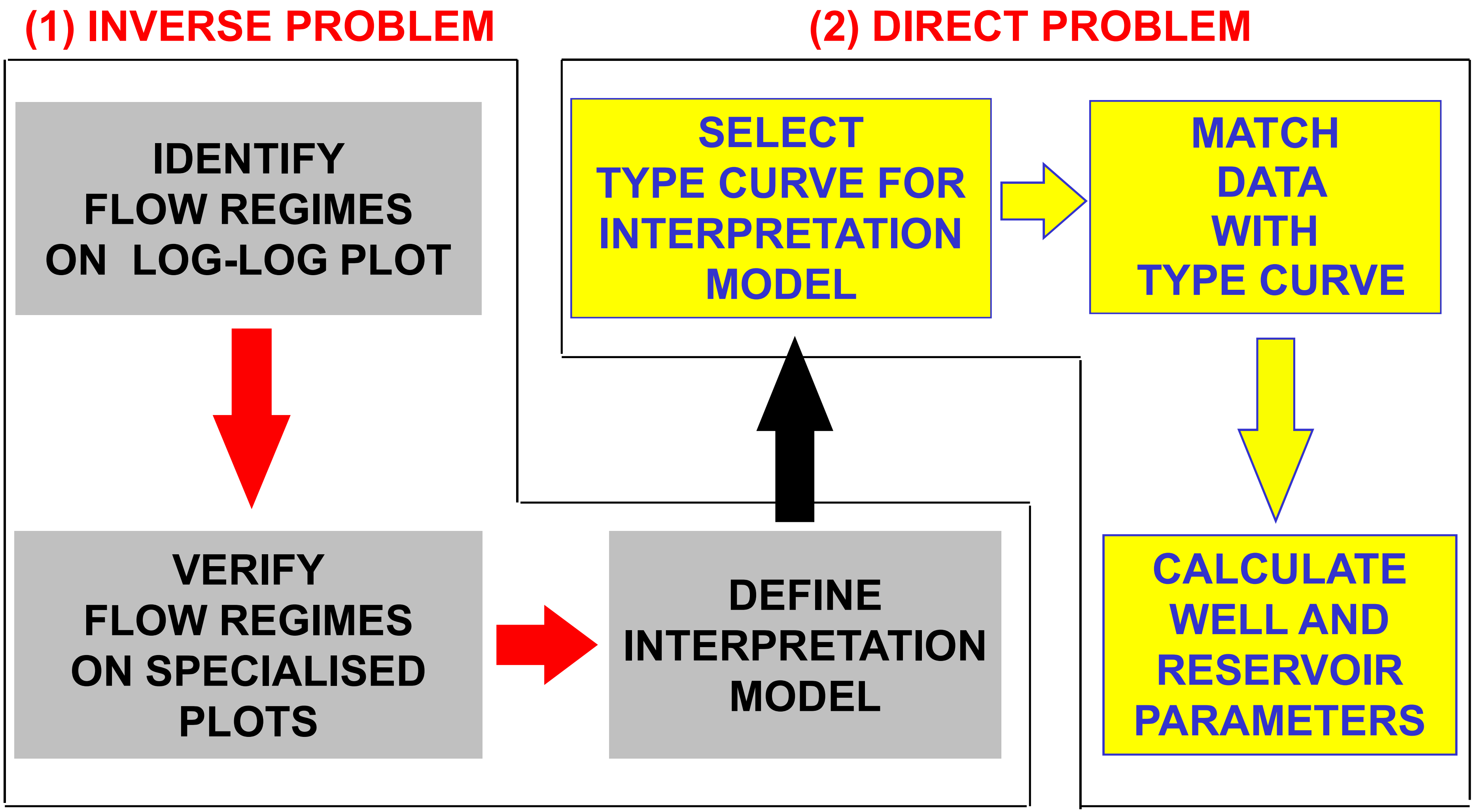
Type Curve match for an Observation Well in a Reservoir of Infinite Extent with Homogeneous Behaviour



Preliminary Type Curve Match for a Well with Wellbore Storage and Skin in a Reservoir of Infinite Extent with Homogeneous Behaviour



TYPE CURVE ANALYSIS PROCESS



Calculation of interpretation model parameters

- **Log-log analysis yields <u>ALL</u> the model parameters: kh, C and S**

$$\frac{kh}{\mu}\text{, mD.ft} = 141.2\ qB\ (\text{PM})$$

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

$$S = 0.5\ln\frac{\left(C_D\,e^{2S}\right)_{\text{match}}}{0.8936\,C/\phi\,c_t h r_w^2}$$

- **Cartesian specialized analysis yields C**

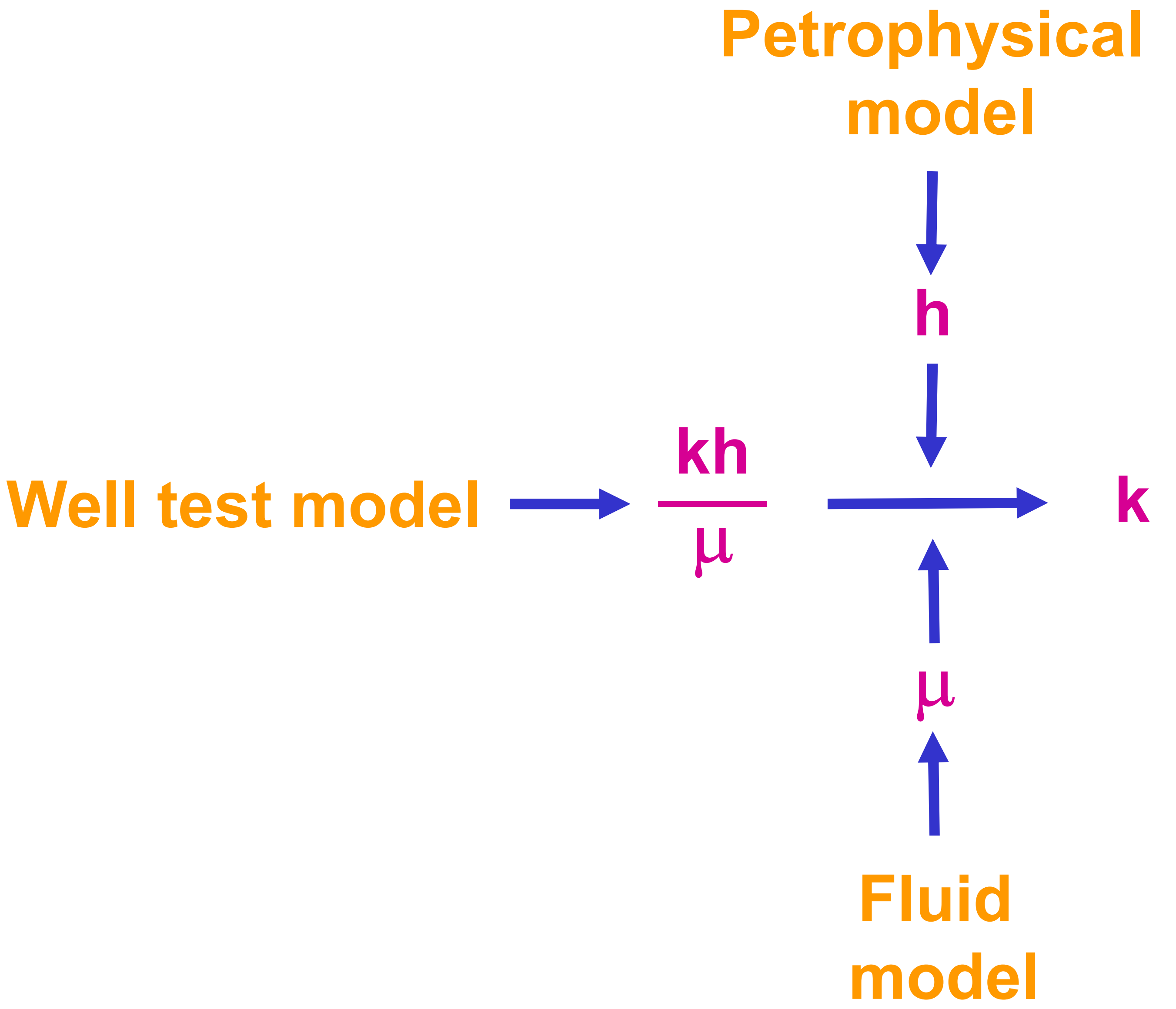
$$C\text{, Bbl / psi} = \frac{\Delta qB}{24\ m_{\text{WB}}}$$

- **Horner analysis yields kh, S and $\bar{p}_i$**

$$\frac{kh}{\mu} = 162.6\,\frac{\Delta qB}{m}$$

$$S = 1.151\left(\frac{p_{1\text{hr}} - p(\Delta t = 0)}{m} - \log\frac{k}{\phi\mu c_t r_w^2} + \log\frac{t_p + 1}{t_p} + 3.23\right)$$

Calculation of k from $\frac{kh}{\mu}$



Definition of h

Horizons	Lithology Zones	Gross Thickness	True Vertical Depth (Relative)	Fluid in Zone	Mean Zonal Properties	Gross Reservoir	Net Reservoir	Gross Pay	Net Pay
Formation Top	Anhydrite	1	1m	None	No ϕ_{eff} Zero K	0	0	0	0
		1	2m			0	0	0	0
		1	3m			0	0	0	0
		1	4m			0	0	0	0
		1	5m			0	0	0	0
Reservoir Top	Sand	1	6m	Mostly oil	High ϕ_{eff} High K	1	1	1	1
		1	7m			1	1	1	1
		1	8m			1	1	1	1
	Shale	1	9m	Bound water	No ϕ_{eff}	1	0	1	0
	Sand	1	10m	Mostly oil	High ϕ_{eff} High K	1	1	1	1
		1	11m			1	1	1	1
		1	12m			1	1	1	1
Oil-Water Contact		1	13m	High water, low oil		1	1	0	0
	Shale	1	14m	Bound water	No ϕ_{eff}	1	0	0	0
		1	15m			1	0	0	0
		1	16m			1	0	0	0
	Sand	1	17m	Mostly water	High ϕ_{eff} High K	1	1	0	0
		1	18m			1	1	0	0
		1	19m			1	1	0	0
		1	20m			1	1	0	0
		1	21m			1	1	0	0
		1	22m			1	1	0	0
Reservoir Base	Shale	1	23m	Bound water	No ϕ_{eff} Zero K	0	0	0	0
		1	24m			0	0	0	0
		1	25m			0	0	0	0
		1	26m			0	0	0	0
Formation Base		1	27m			0	0	0	0

ϕ_{eff} = effective porosity
K = permeability

Gross Thickness, m: 27	**Gross Reservoir, m: 17**	**Net Reservoir, m: 13**	**Gross Pay, m: 7**	**Net Pay, m: 6**	

Net-to-Gross Ratio for Simulation: 13/27=0.48	**Net-to-Gross Ratio for Reserves, using gross thickness: 6/27=0.22**	**Net-to-Gross Ratio for Reserves, using gross reservoir: 6/17=0.35**	**Net-to-Gross Ratio for Reserves, using gross pay: 7/6=0.86**

Core Lab
RESERVOIR OPTIMIZATION

Verification of the interpretation model

- **Consistency**

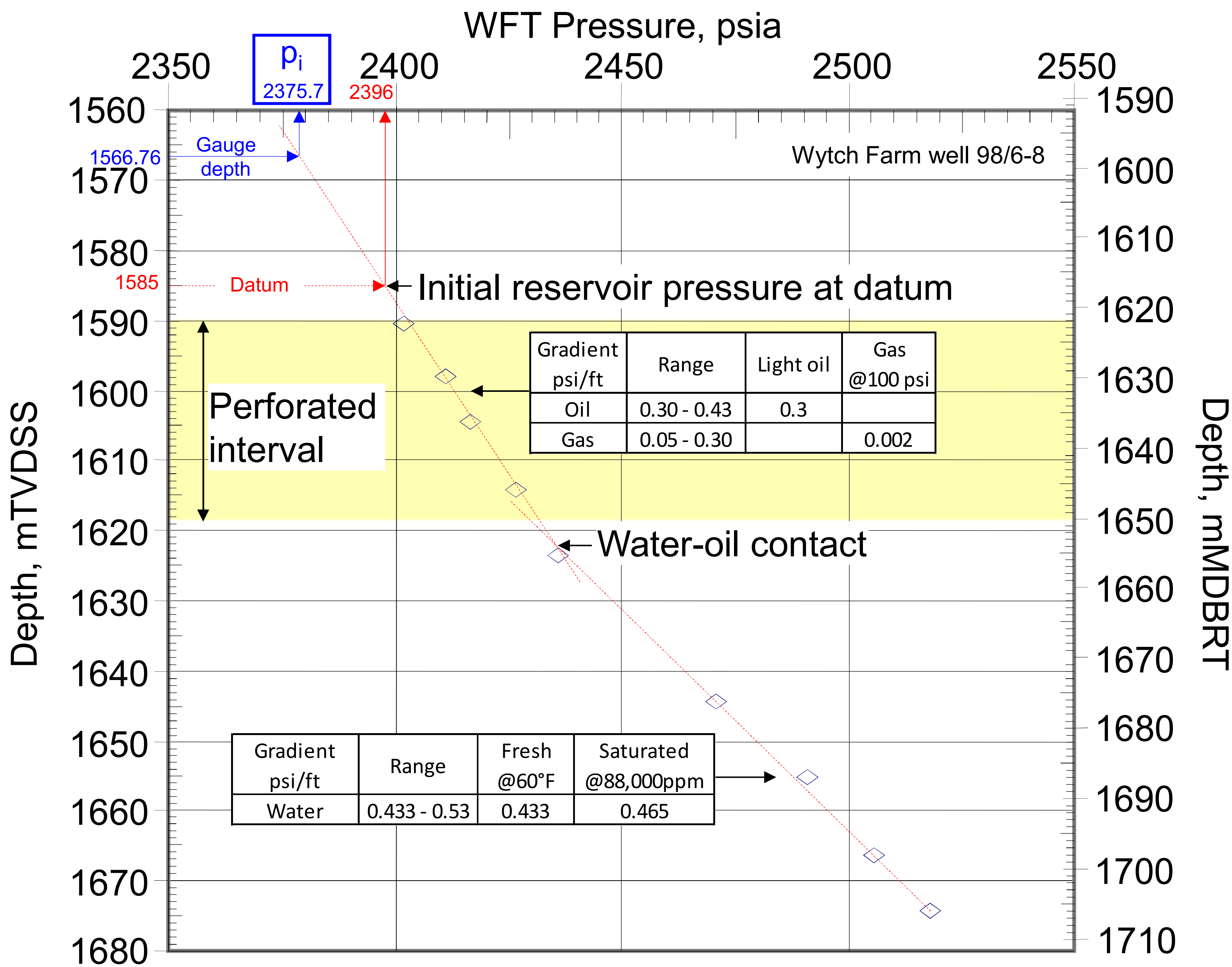
  - Start and end of flow regimes on log-log and straight-line plots

  - Acceptable difference between log-log and straight-line analyses :

kh	± 10%
C	± 10%
S	± 0.5

This is a tolerance, NOT a measure of uncertainty

Initial pressure at gauge depth



Gradient psi/ft	Range	Light oil	Gas @100 psi
Oil	0.30 - 0.43	0.3	
Gas	0.05 - 0.30		0.002

Gradient psi/ft	Range	Fresh @60°F	Saturated @88,000ppm
Water	0.433 - 0.53	0.433	0.465

Depth in practice

Measured depth (MD) or along hole depth (AHD)

References:

- Mean Sea Level (MSL)
- Rotary Table (RT)
- Drill Floor (DF)
- Kelly Bushing (KB)
- Sea Bottom (SB)
- Ground Level (GL)
- Lowest Astronomical Tide (LAT) (legal datum offshore Australia)

True vertical depth (TVD)

TVDSS =TVD minus elevation above MSL
of depth reference point of the well (KB in the US and DF in most places)

Verification of the interpretation model

- **Consistency**

  - Start and end of flow regimes on log-log and straight-line plots

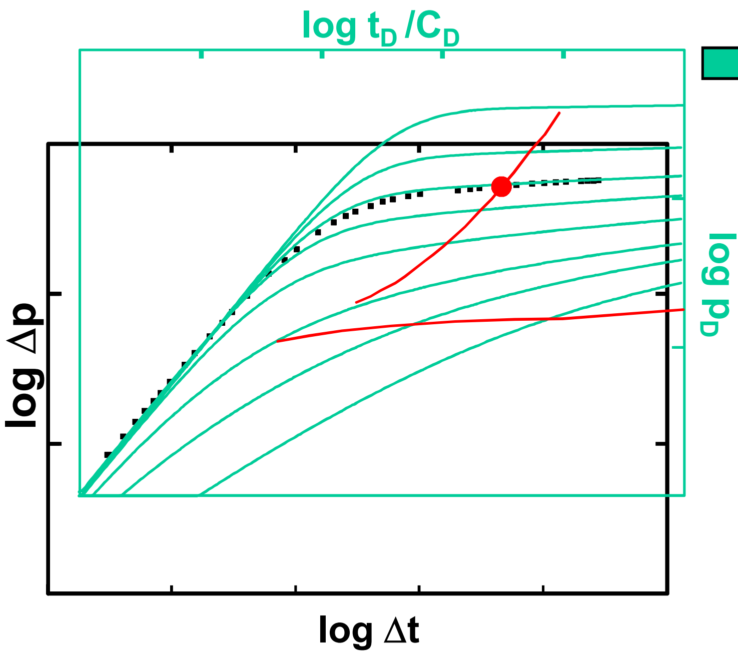
  - Acceptable difference between log-log and straight-line analyses:

kh	± 10%
C	± 10%
S	± 0.5

- **Log-log match**

Iteration on manual type curve matching

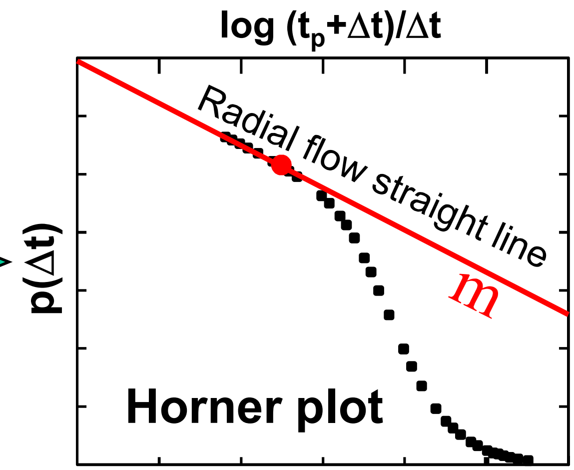
1. **Preliminary** log-log match



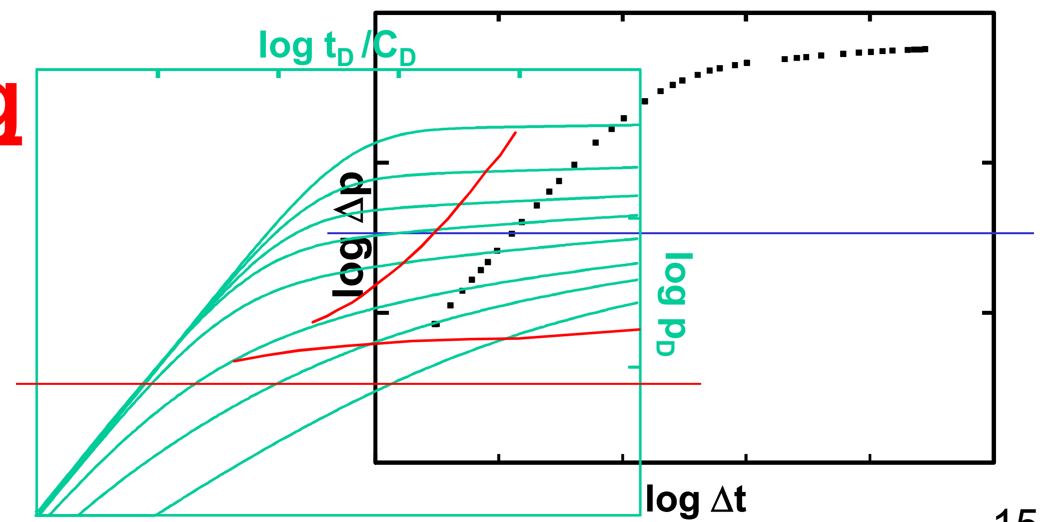
2. Find start of semi-log straight line

3. Draw semi-log straight line and find slope m

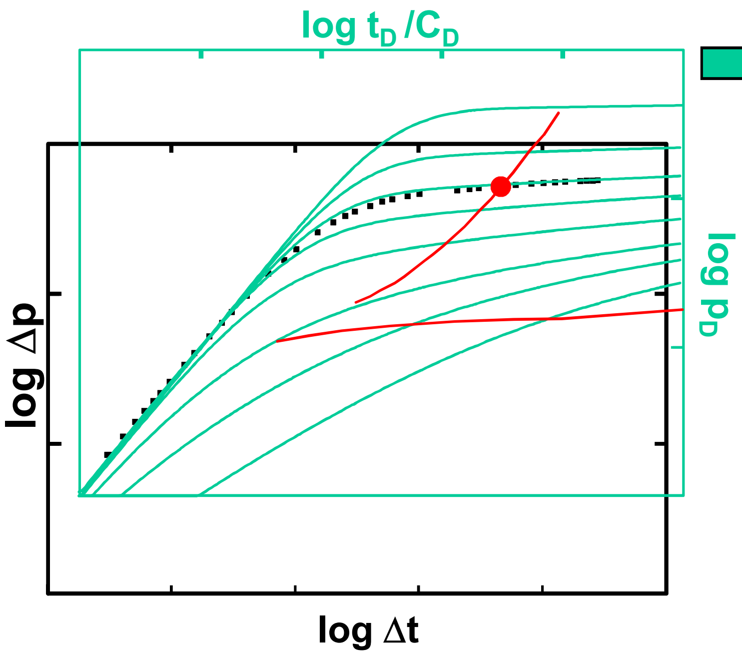
4. Calculate pressure match PM = 1.151/m



5. **Final** log-log match
- Select Δp
- Calculate p_D= ΔpxPM



1. **Preliminary** log-log match



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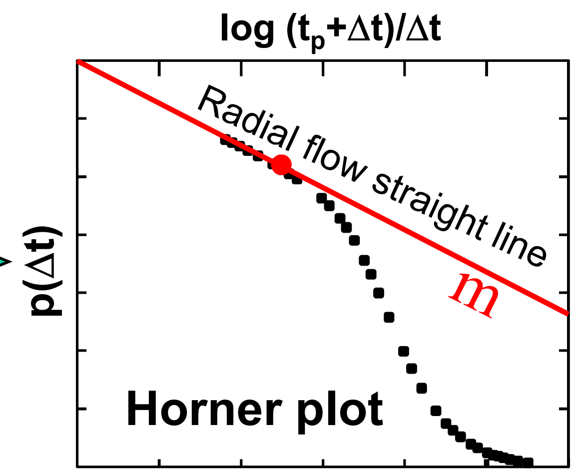
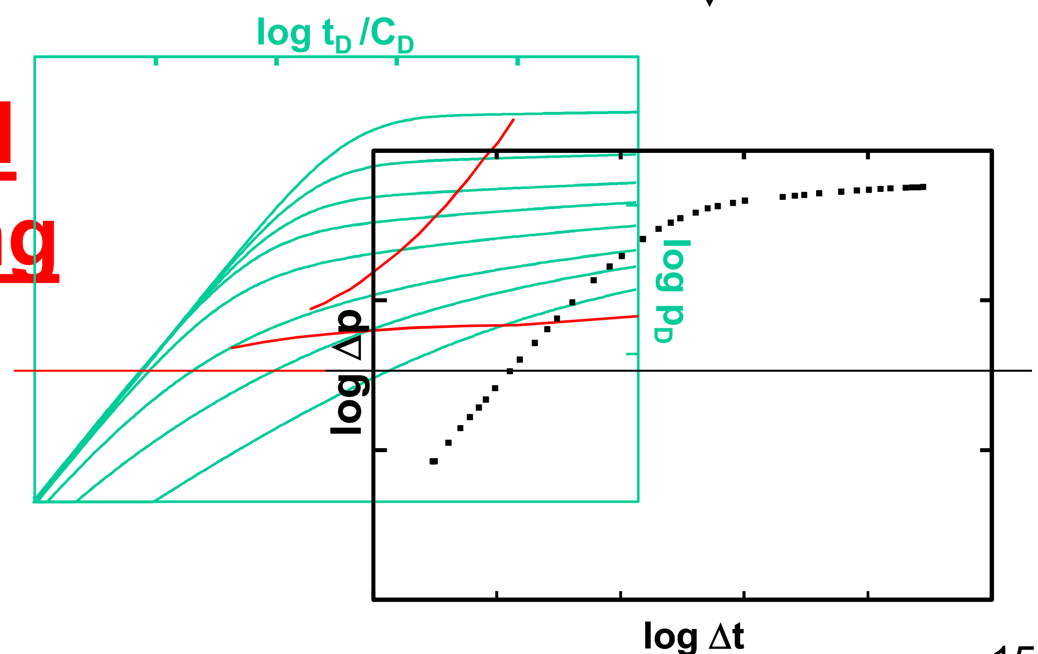


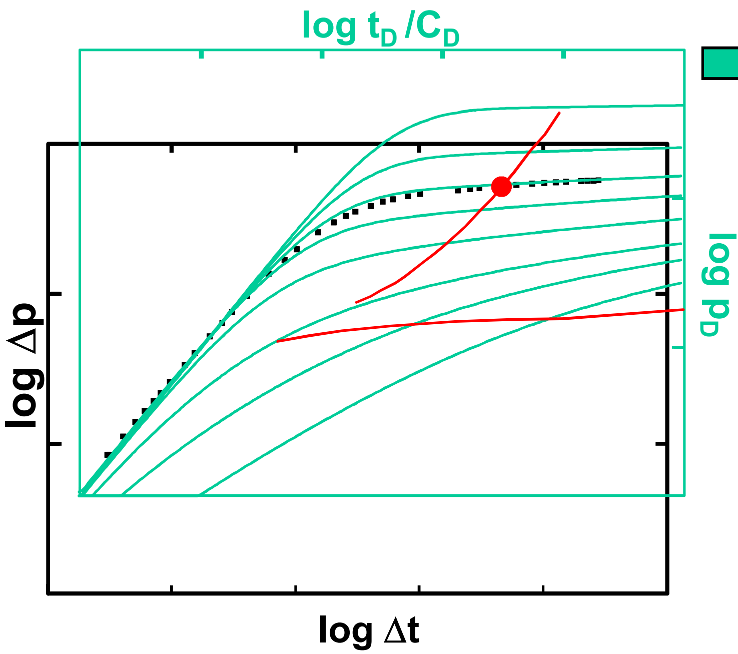
4. Calculate pressure match PM = 1.151/m

Iteration on manual type curve matching

5. **Final** log-log match
- Select Δp
- Calculate $p_D = \Delta p \times PM$
- Match Δp with p_D

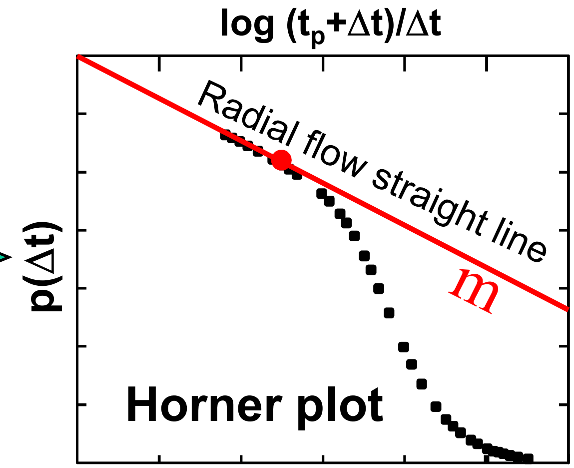


1. **Preliminary** log-log match



2. Find start of semi-log straight line

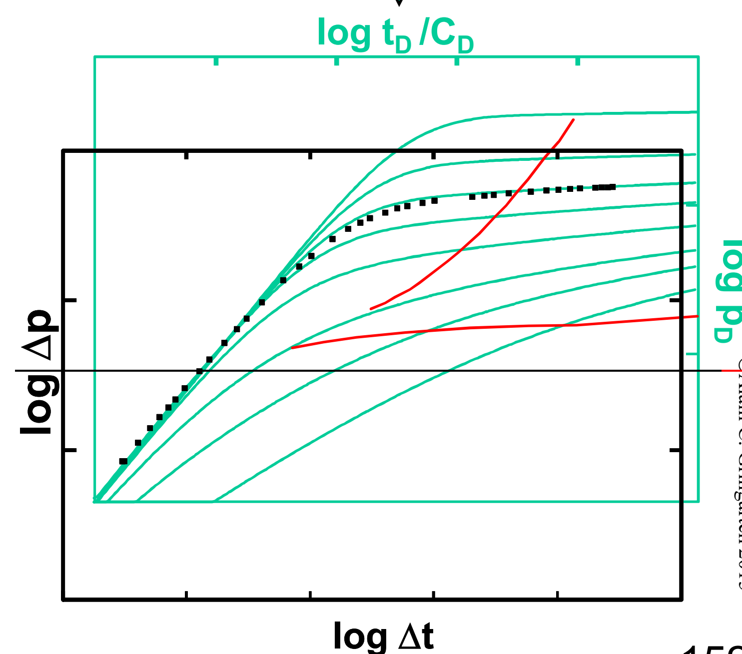
3. Draw semi-log straight line and find slope m



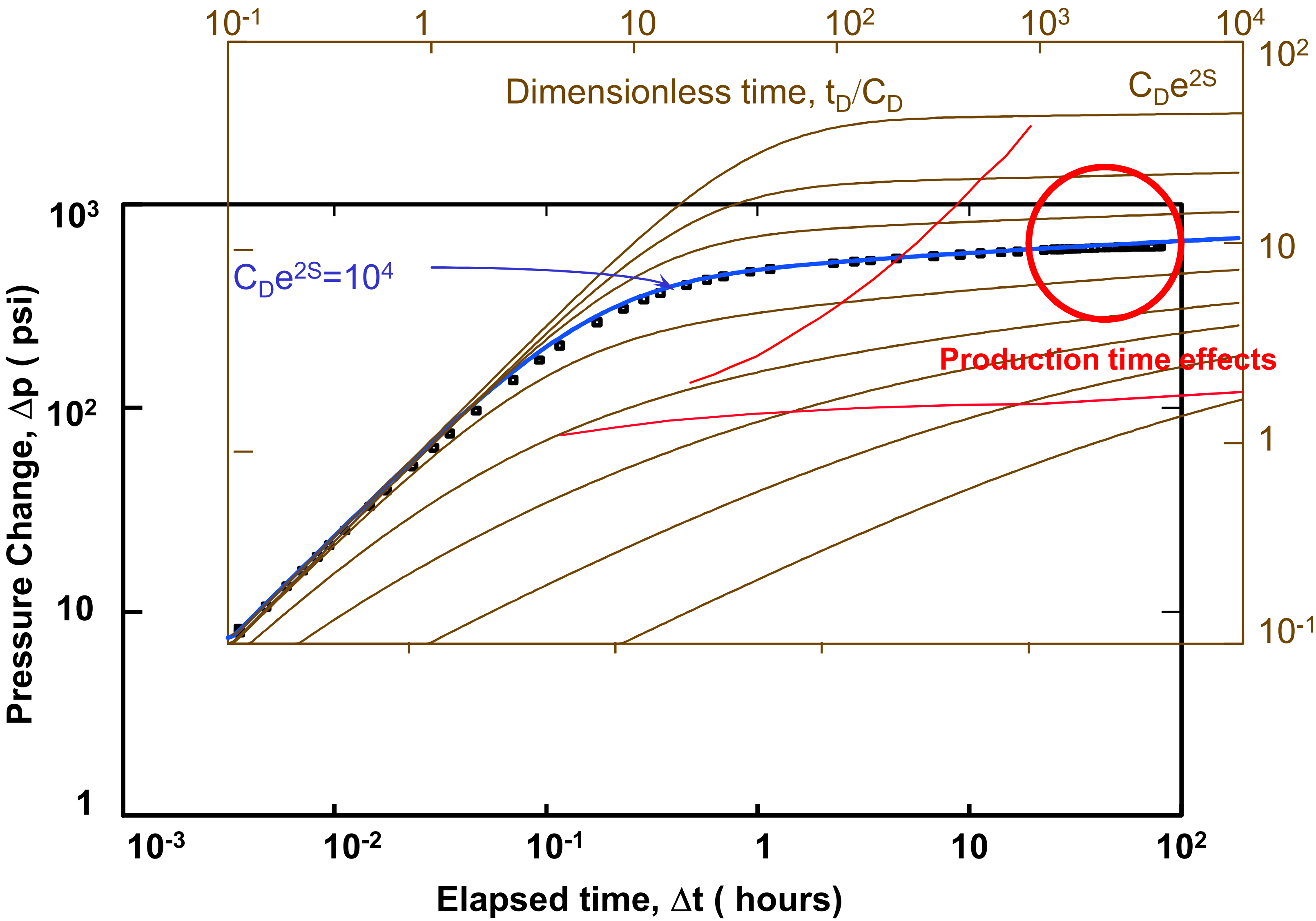
4. Calculate pressure match PM = 1.151/m

Iteration on manual type curve matching

5. **Final** log-log match
- Select Δp
- Calculate $p_D = \Delta p \times PM$
- Match Δp with p_D
- Adjust time match



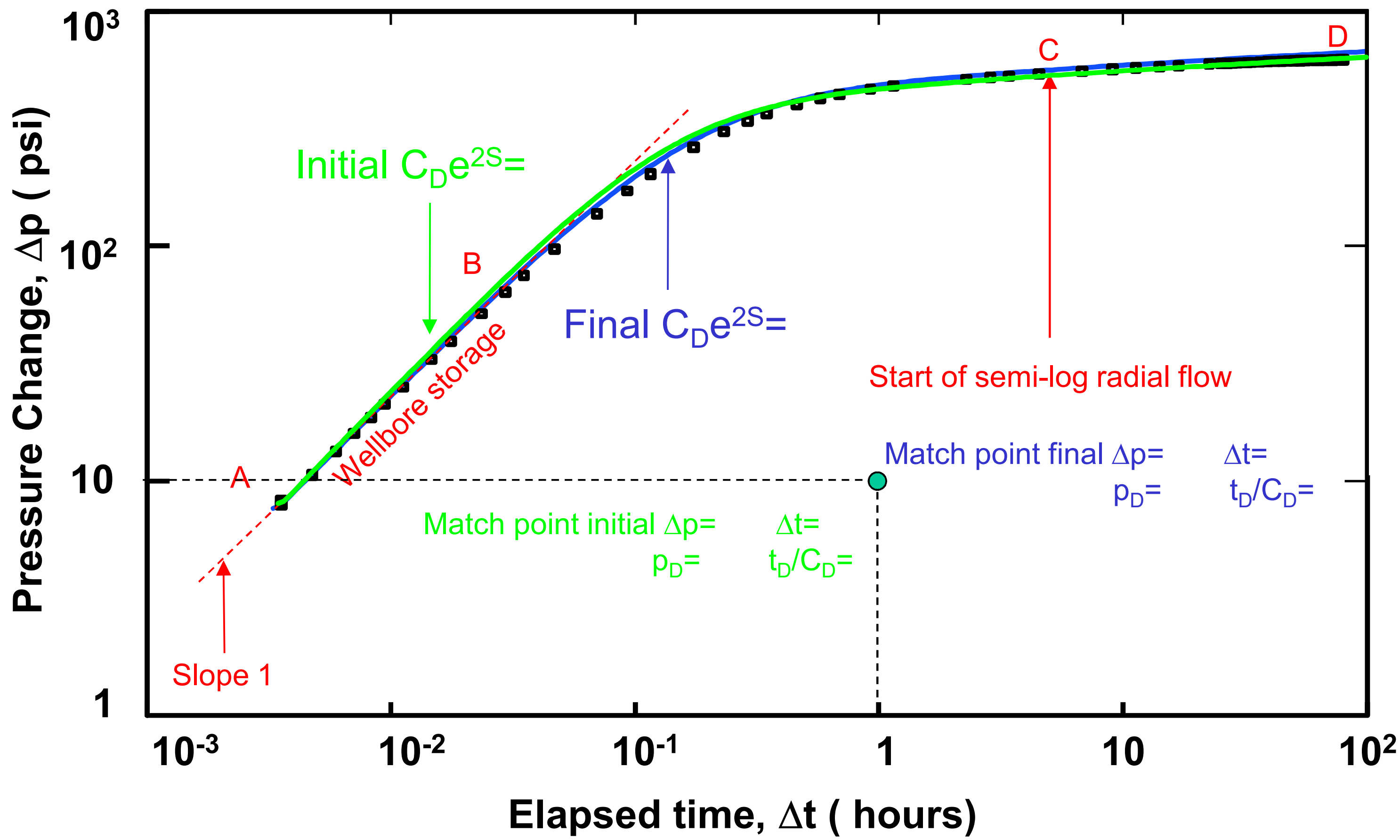
STEP 2: Final Type Curve Match for a Well with Wellbore Storage and Skin in a Reservoir of Infinite Extent with Homogeneous Behaviour



Presentation of analysis results

Indicate all relevant information on the graphs (log-log, specialised and Horner)

Example: log-log



Verification of the interpretation model

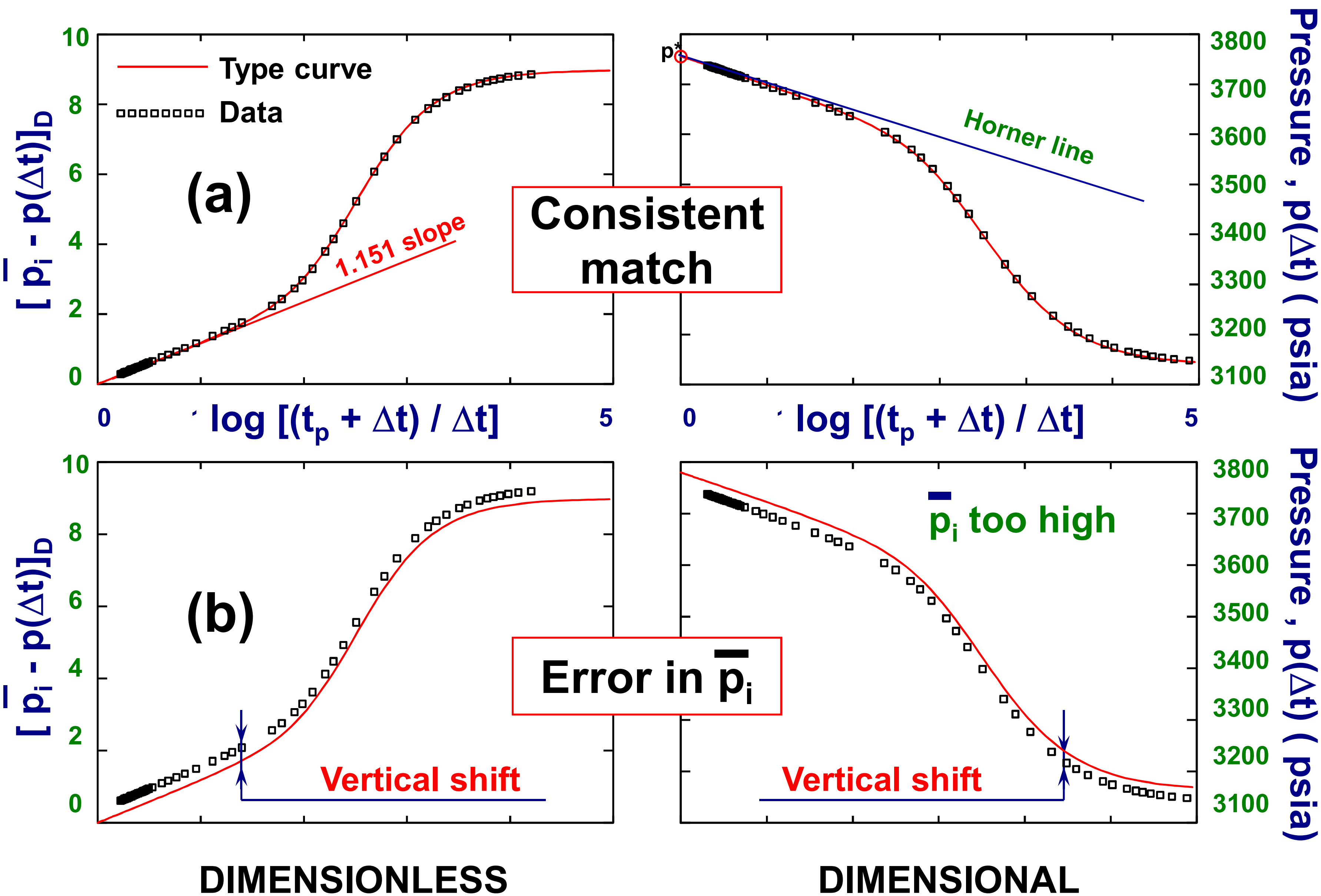
- Consistency
  - Start and end of flow regimes on log-log and straight-line plots
  - Parameter values from log-log and straight-line analyses:

kh	± 10%
C	± 10%
S	± 0.5

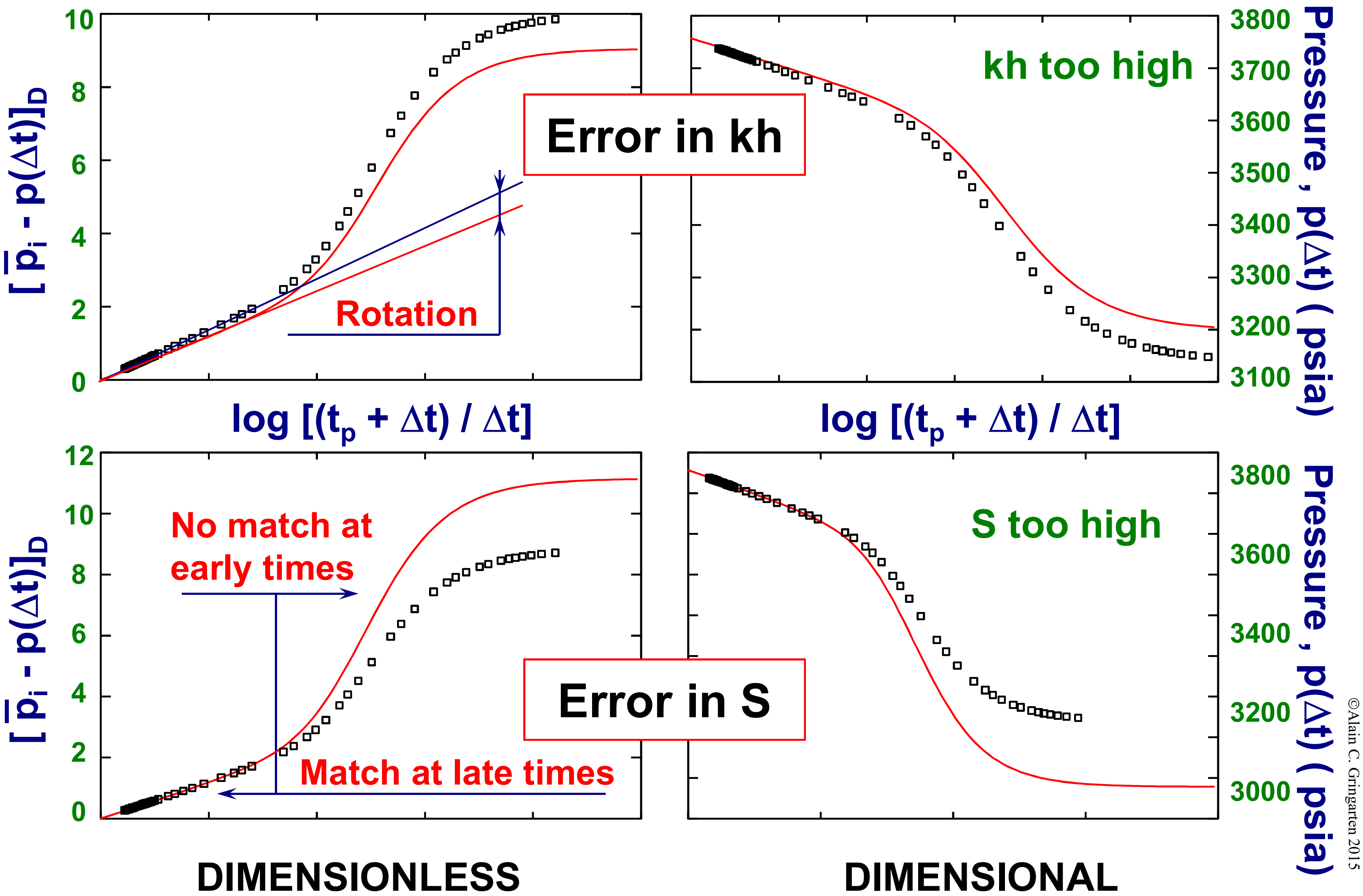
- Log-log match

- Horner match
  - **Dimensionless:** $PM[\bar{p}_i - p(\Delta t)] \equiv p_D\left[\mathrm{TM}\left(t_p + \Delta t\right)\right] - p_D\left(\mathrm{TM}\Delta t\right)$
  - **Dimensional:** $p(\Delta t) \equiv \bar{p}_i - \frac{1}{\mathrm{PM}} p_D\left[\mathrm{TM}\left(t_p + \Delta t\right)\right] + \frac{1}{\mathrm{PM}} p_D\left(\mathrm{TM}\Delta t\right)$

Horner Match: Verification of the interpretation model

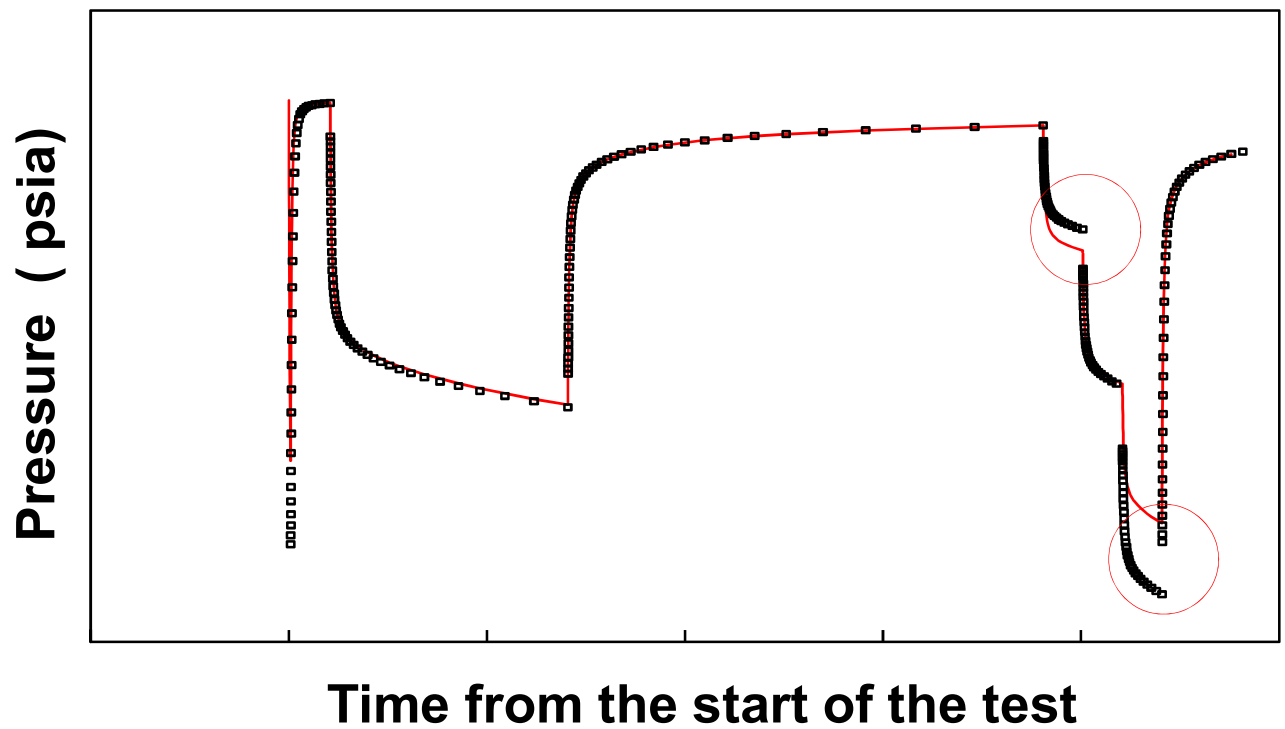


Horner Match: Verification of the interpretation model (cont'd)



Verification of the interpretation model

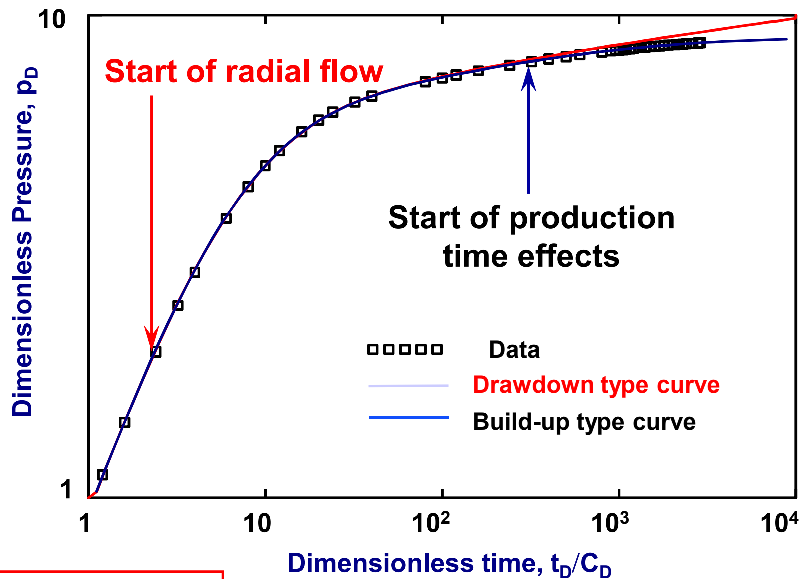
❑ **Simulation of the entire test**

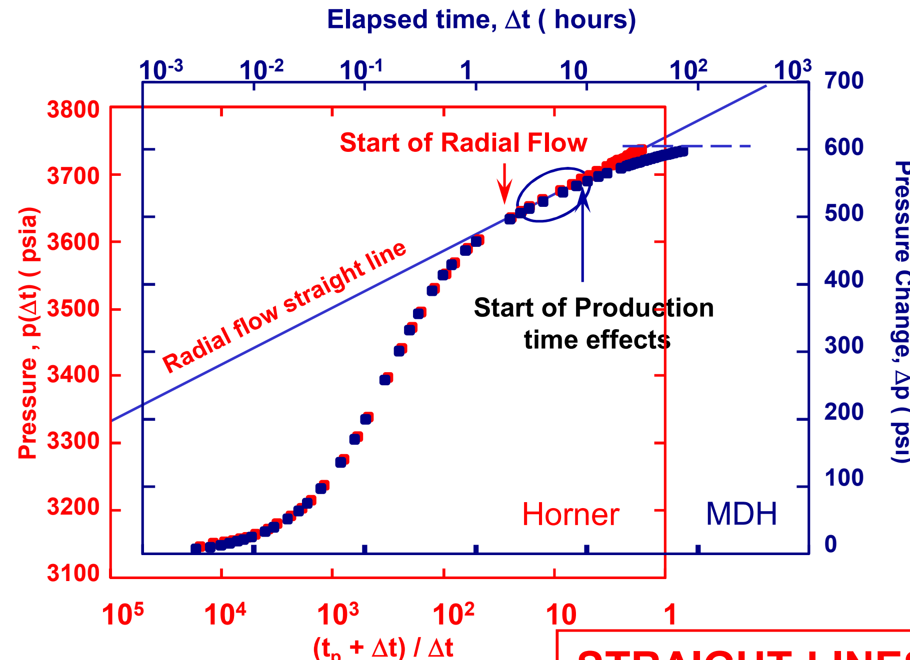


Lack of match due to:

- **Errors in rates (± 10% vs. pressure ± 0.1 psi)**
- **Changes in characteristics: skin (gas, 2-phase, stimulation)**
  fluid bank
- **Wrong interpretation model**

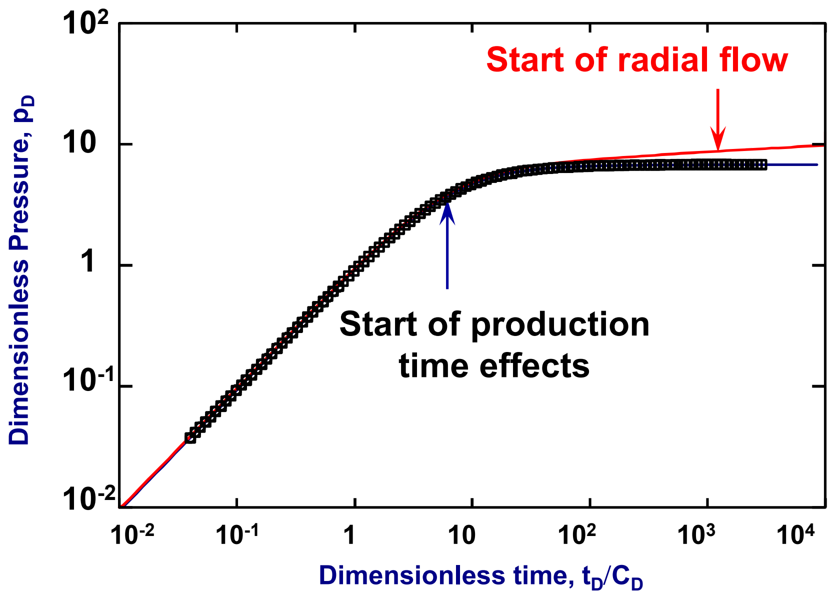
PRODUCTION TIME EFFECTS

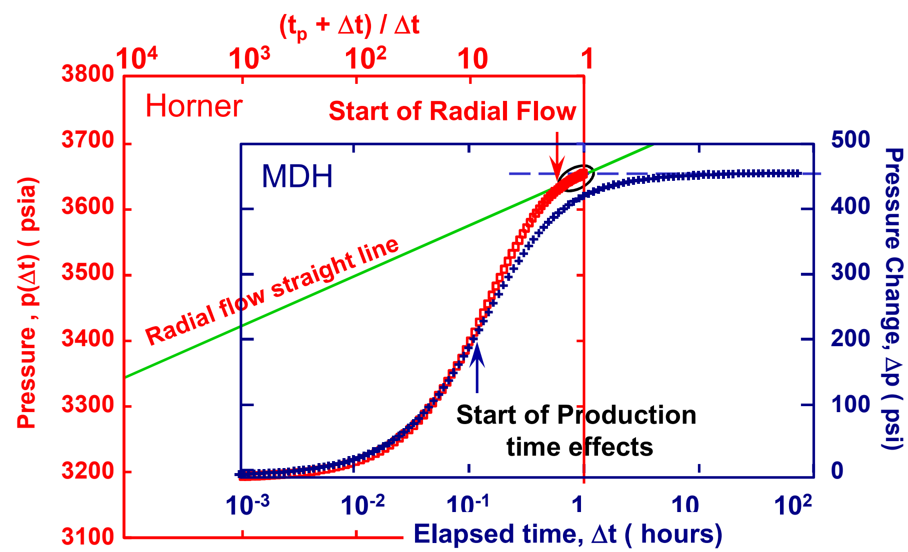




LOG-LOG

STRAIGHT LINES





Approximate start of semi-log radial flow

Ramey, H.J.,Jr. : "Practical Use of Modern Well Test Analysis", paper SPE 5878, presented at the SPE-AIME 46th Annual California Regional Meeting, Long Beach, April 7-9, 1976.

the dimensionless pressure drawdown, $\bar{p}_D(t_D)$ with wellbore storage and skin eventually coincide with the $p_D(t_D)$ for constant rate production at large enough values of dimensionless time. If the time of coincidence is plotted against the dimensionless wellbore storage constant C, **the start of the correct semi-log straight line for a damaged well** is $t_D = C_D\ (60 + 3.5S)$

An alternate approach is available the top of the unit slope straight line on a log-log graph is about 1-1/2 log cycles prior to the start of the correct semi-log straight line. This is termed the "one and one-half log cycle rule."

Chen, H.K. and Brigham, W.E. : "Pressure Build-up for a Well With Storage and Skin in a Closed Square", J. Pet. Tech. (Jan. 1978) 141.

It is important to predict the buildup time required before a useful semilog straight line can be found on a Horner plot. The times needed to begin the approximately correct lines can be expressed in equation form:

$$\Delta t_D \geqslant 50\ C_D\ e^{0.14s} \quad \text{(9)}$$

For a skin of +10, Eq. 9 specifies $t_D \geqslant 200\ C_D$, while Agarwal *et al*. indicate a time about one-half as long. In short, when there is wellbore storage, the buildup curve is somewhat more sensitive to skin damage than is the drawdown curve. This result is quite the opposite of the no-storage case. When there is no storage, skin has *no* effect on the buildup curve.

The Nuts and Bolts of Falloff Testing — Ken Johnson, Susie Lopez

Time to Radial Flow Calculation

- **Calculate the time to reach radial flow for an injectivity test:**

$$t_{radial\ flow} > \frac{(200000 + 12000\,s)\cdot C}{\frac{k \cdot h}{\mu}}\ hours$$

Ramey (Drawdown)

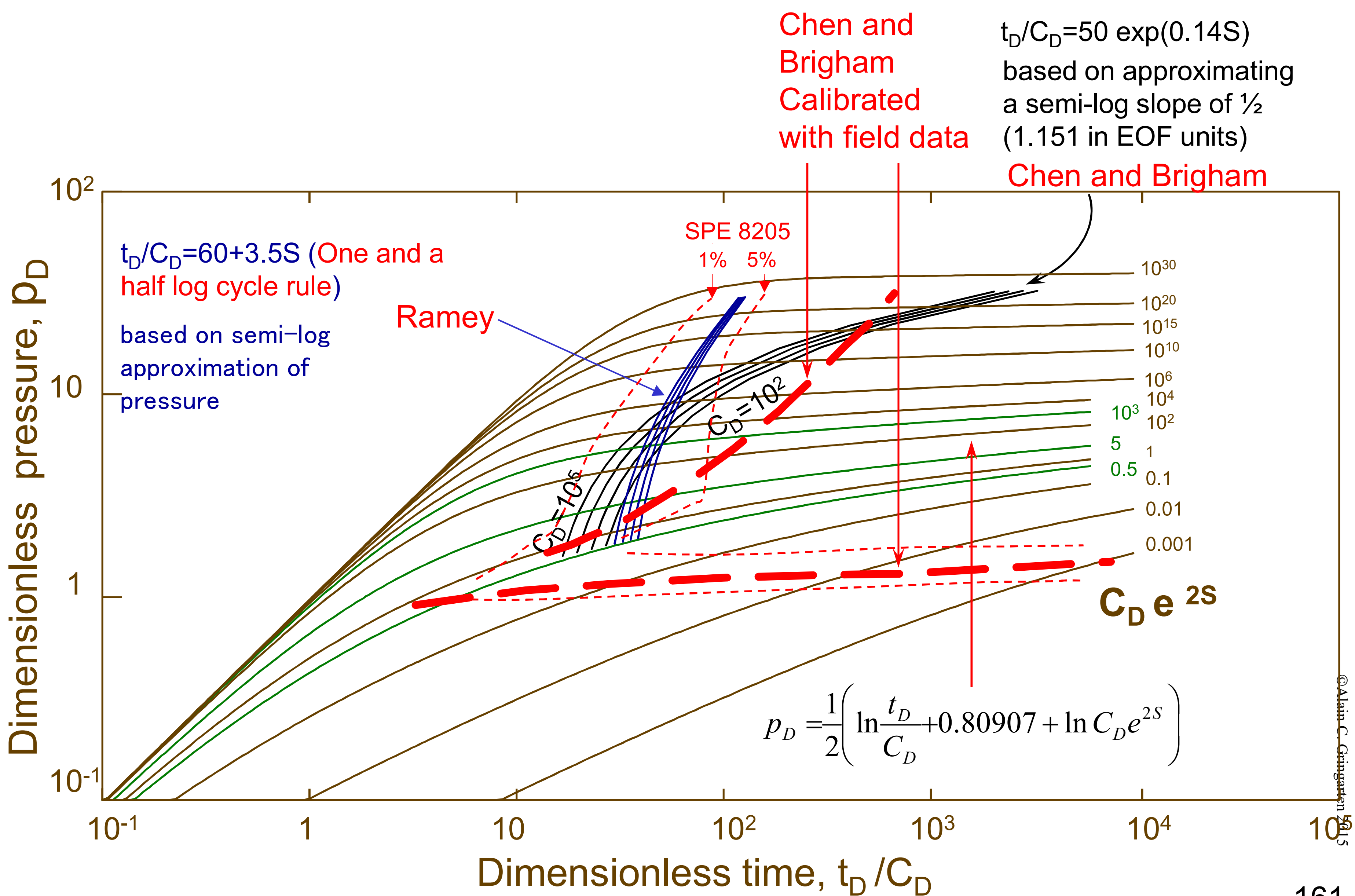
- **Calculate the time to reach radial flow during the falloff test:**

$$t_{radial\ flow} > \frac{170000 \cdot C \cdot e^{0.14\cdot s}}{\frac{k \cdot h}{\mu}}\ hours$$

Chen & Brigham (Build up)

- **Note the skin factor,s, influences the falloff more than the injection period**

Approximate start of semi-log radial flow



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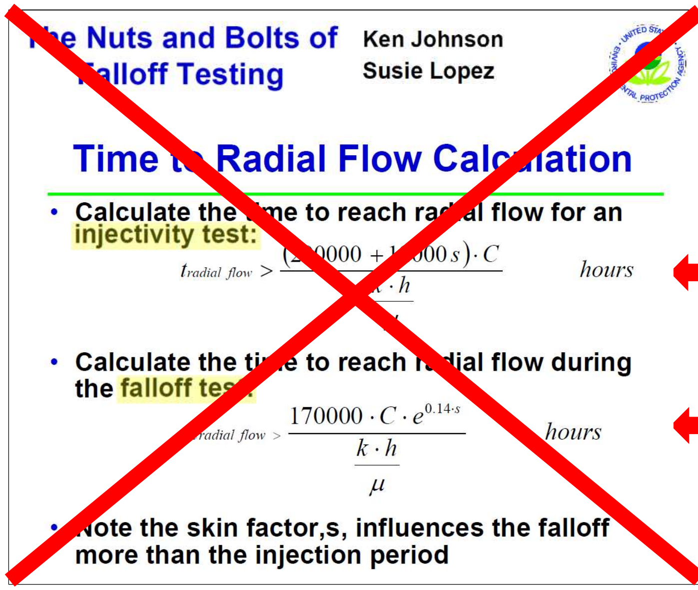

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This time is far longer than the time needed to reach the correct straight line on a drawdown;[6] however, if we relax our requirements for a "correct" slope, the time can be reduced considerably.

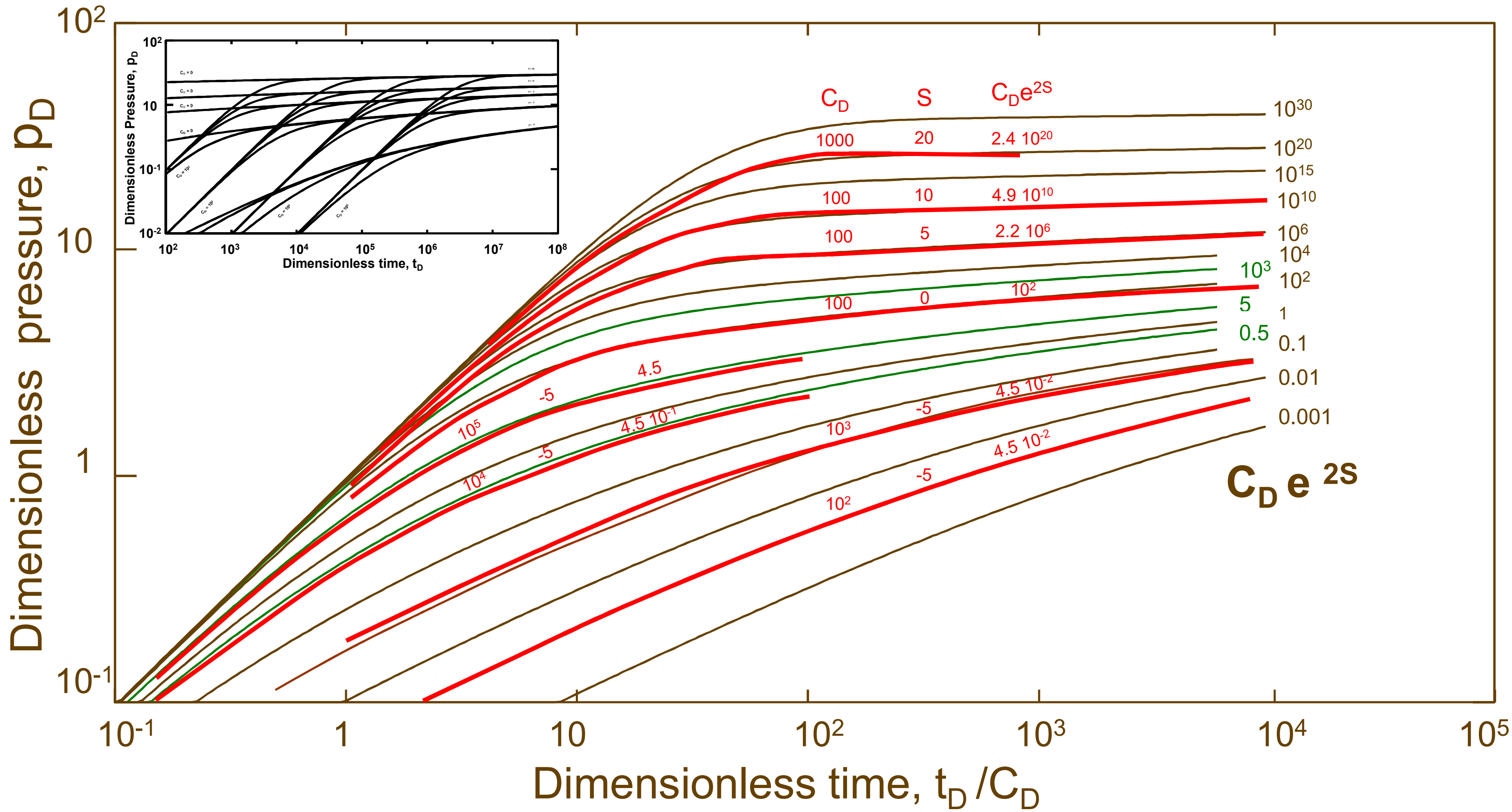
The errors in the slopes of the lines starting at these times are about 5 to 10 percent. The *kh* calculated from these lines will be low by this amount.

EARLY MISCONCEPTIONS ON LOG-LOG PRESSURE ANALYSIS

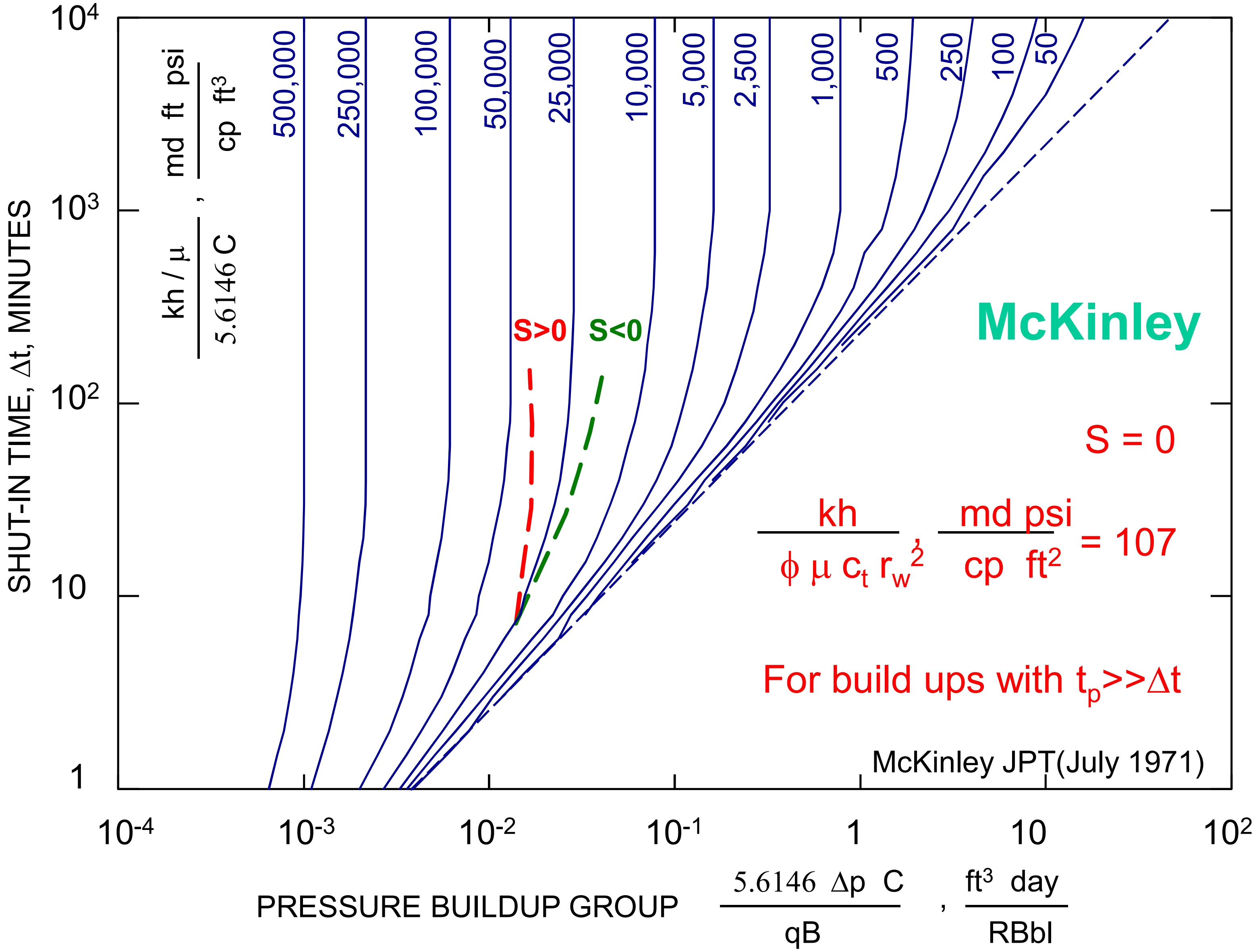
Henry J. Ramey, Jr. (Stanford U.) SPE 5878 46th Annual California Regional Meeting Long Beach, Ca. (Apr. 1975)
In regard to wellbore storage cases, several distinctly different appearing type curves are in the literature. First was the wellbore storage and skin type curve from Agarwal, Al-Husseiny and Ramey, second was the afterflow type curve of McKinley, and third was the type curve from Earlougher and Kersch.
There appear to be essential differences between these three type curves. Results obtained from them can be sufficiently different to indicate substantial differences.

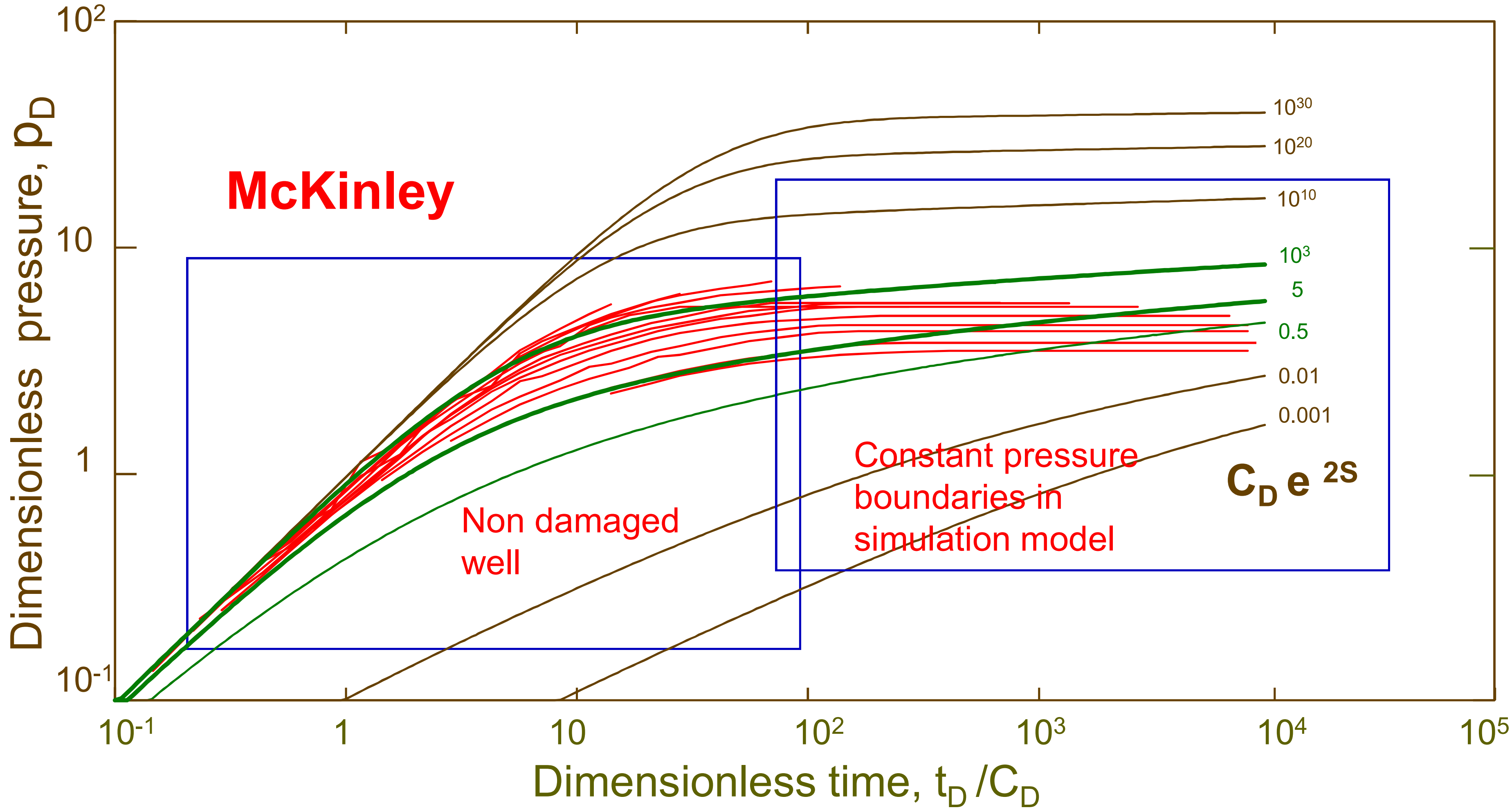
Henry J. Ramey, Jr. (Stanford U.) SPE 20592 46th Distinguished Author Series JPT(June 1992)
A new type curve of the log of dimensionless pressure vs. the log of t_D/C_D with C_De^{2S} as a parameter ended the controversy in 1978 over the best form of the wellbore-storage and skin-effect type curve. The type curve combined radial flow and fracture flow results and indicated the effect of producing time on buildups. The type curve was a remarkable improvement that was accepted immediately and became the industry standard. So one problem identified earlier was solved.

Agarwal, Al-Hussainy and Ramey type curve

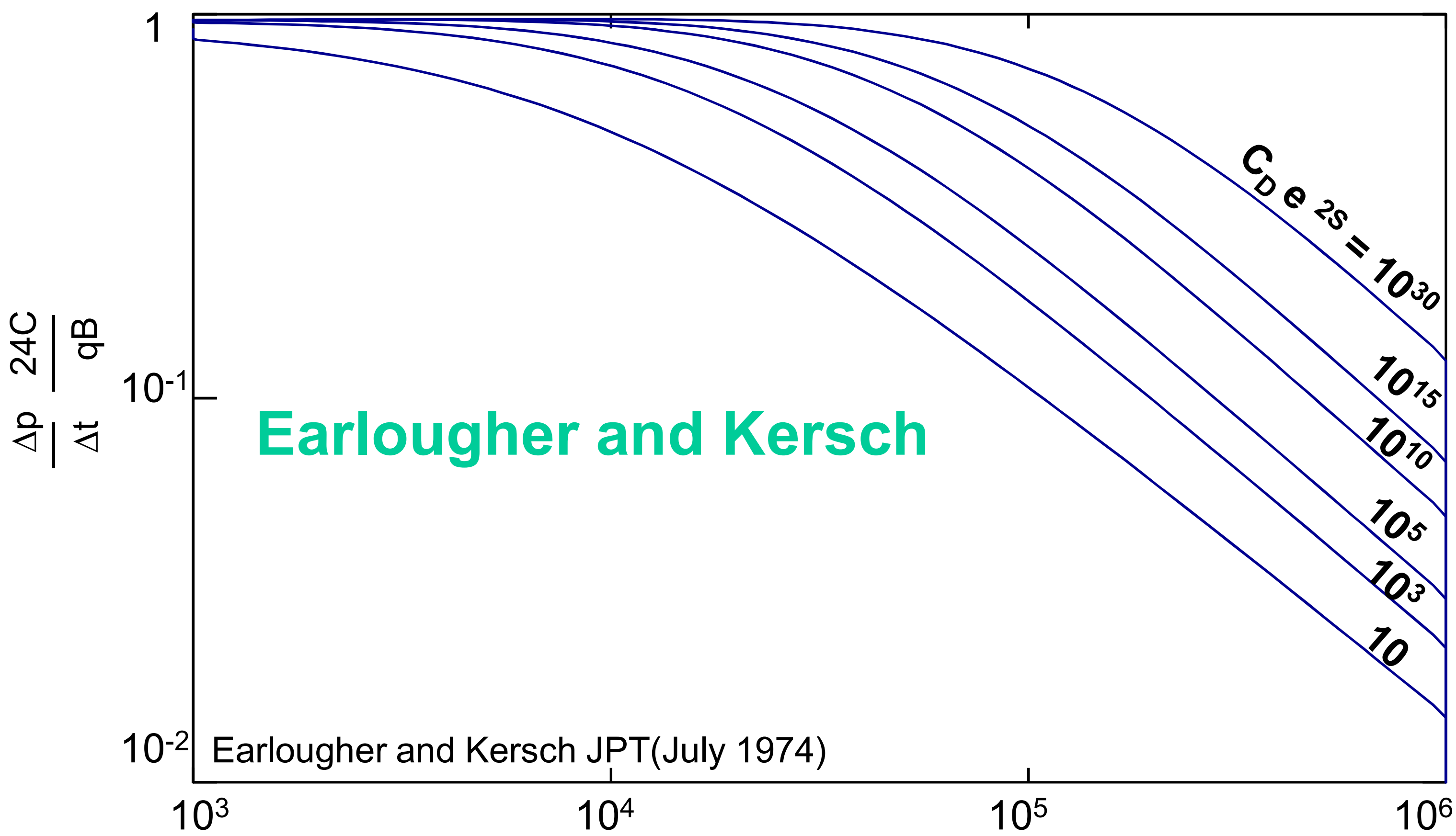


OTHER WELLBORE STORAGE AND SKIN TYPE CURVES



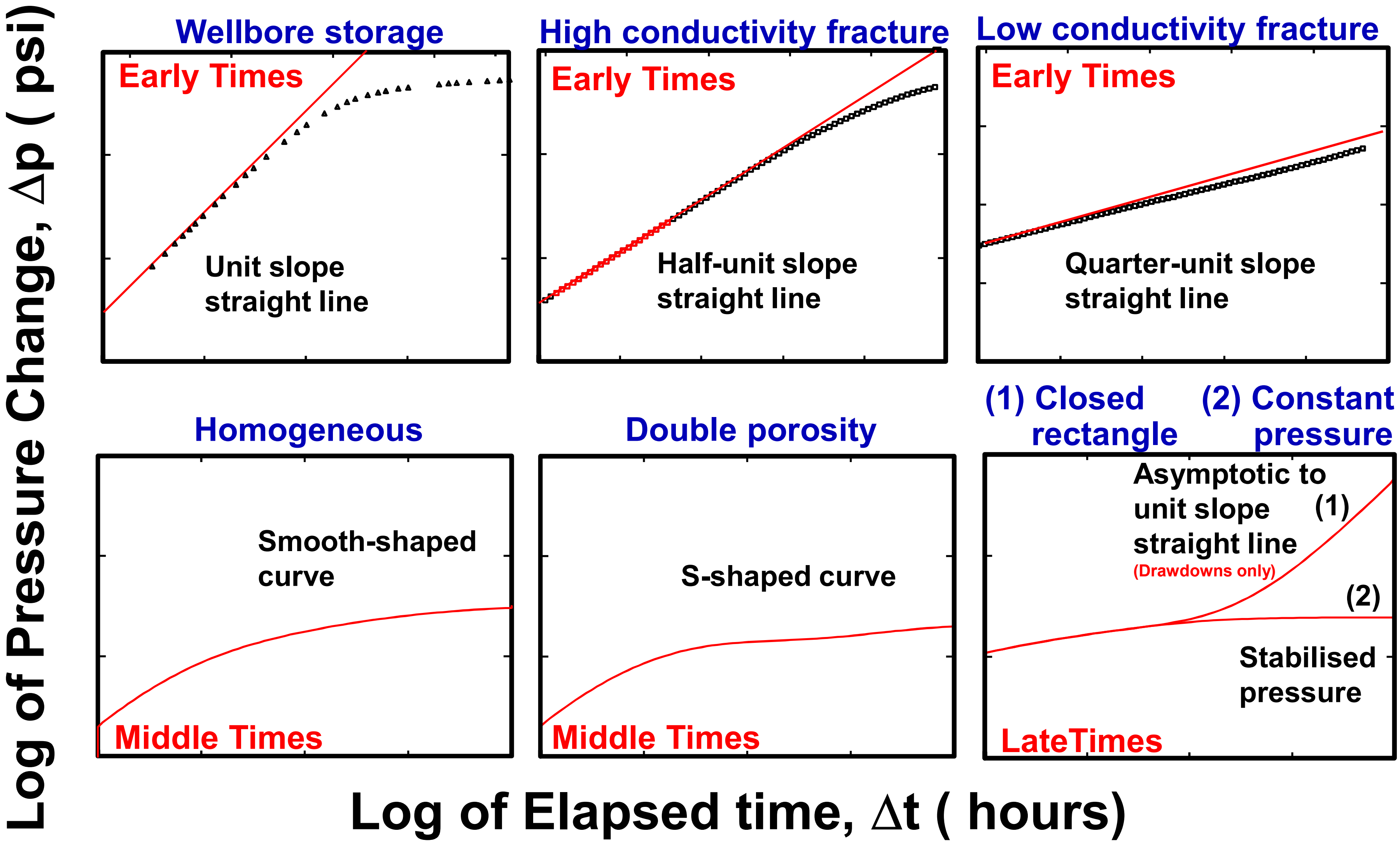

McKinley
Dimensionless pressure, p_D
Dimensionless time, t_D/C_D
10^{-1}
1
10
10^2
10^3
10^4
10^5
10^{30}
10^{20}
10^{10}
10^3
5
0.5
0.01
0.001
$C_D e^{2S}$
Non damaged well
Constant pressure boundaries in simulation model

OTHER WELLBORE STORAGE AND SKIN TYPE CURVES



$$\frac{1}{0.000295} \frac{t_D}{C_D} = \frac{kh}{\mu} \frac{\Delta t}{C} \quad , \quad \frac{md.ft}{cp} \cdot \frac{hr}{bbl/psi}$$

Summary: LOG-LOG PRESSURE ANALYSIS



Summary: PRESSURE TYPE CURVE ANALYSIS

ADVANTAGES:

- Better identification than with straight lines
- Validation with straight lines

LIMITATIONS:

- Lack of resolution at late times
- Shape function of production time
- Not applicable to short tests
- Published type curves valid for drawdown only
- Limited number of published type curves (models)
- Early type curves not efficient (parameters not independent)