

Pulse Test

The term pulse test refers to a multiwell interference test in which the active well is repeatedly pulsed, with each drawdown / buildup sequences lasting only a few hours. Although the frequency of the pulses makes the response more easily identified in the observation wells, superposition effects may make the interpretation of the data somewhat more complex. Otherwise, the test configurations objectives, and sensor requirements are like those of the conventional interference test.

Remark 5.5a In the case of reservoir with a low diffusivity (K_{ppc}) and a large distance between the wells, the time needed to produce three oscillations in the observation well can be so long that pulse testing is not possible, only the interference procedure can be envisaged in such conditions.

b- Pulse test are recommended in a reservoir where mobility ($\frac{K}{\mu}$) and hydraulic diffusivity (K_{ppc}) are high (e.g. a very permeable gas reservoir). In this type of reservoir the pressure variation is small, but is felt very quickly in the observation well.

c- In a pulse test each constant flow period is short compared to an interference test. Because of this, the pressure variations measured at the observation well are small; often approximately 0.1 to 0.01 psi. To measure them correctly, the observation well must be shut in and the pressure gauges must be highly sensitive.

d- Pulse tests have the same objectives as an conventional interference tests, which include:

- 1- Estimation of permeability
- 2- Estimation of porosity
- 3- Whether communication exists between wells

Figure 1. Schematically illustrates pulse testing for two-well system.
The figure ~~is~~ is for a producing well that is pulsed by shutting in, continuing production, shutting in, continuing production, etc. The upper portion of the figure shows the constant production rate before the test and the rate pulses. The lower portion of the figure illustrates the pressure behavior at the observation well and ~~the~~ correlates the pressure pulses with the rate pulses. Although the flow time and shut-in time are equal in Figure 1, pulse testing can be done with unequal flow and shut-in times. However all flow times must be the same and all shut-in times must be the same.

Two characteristics of the pressure response @ the observation well are used for pulse-test analysis. One is the time lag, the time between the end of a pulse and the pressure peak caused by the pulse (Fig 2). Time lags for the first and fourth pulses are shown in Fig. 2.

The second variable used in pulse-test analysis is the amplitude of the pressure response, $\Delta P_1, \Delta P_2, \dots$ etc. shown in Fig 2. We determine pulse response amplitude by first constructing the tangent between the two peaks (~~or valleys~~) on either side of the pulse to be measured. Then we draw a line parallel to that tangent at the peak of the subject response. The pressure amplitude is the vertical distance between the two lines. The same approach applies to both peaks and valleys.

Strictly speaking, the ΔP value for the first peak is negative as it is for all other odd peaks; ΔP is positive for even responses. In the analysis methods presented here, the sign convention is eliminated. Kamal and Brigham (1975) proposed a pulse test analysis technique that uses the following four dimensionless groups

Kamal and Brigham (1975) proposed a pulse test analysis

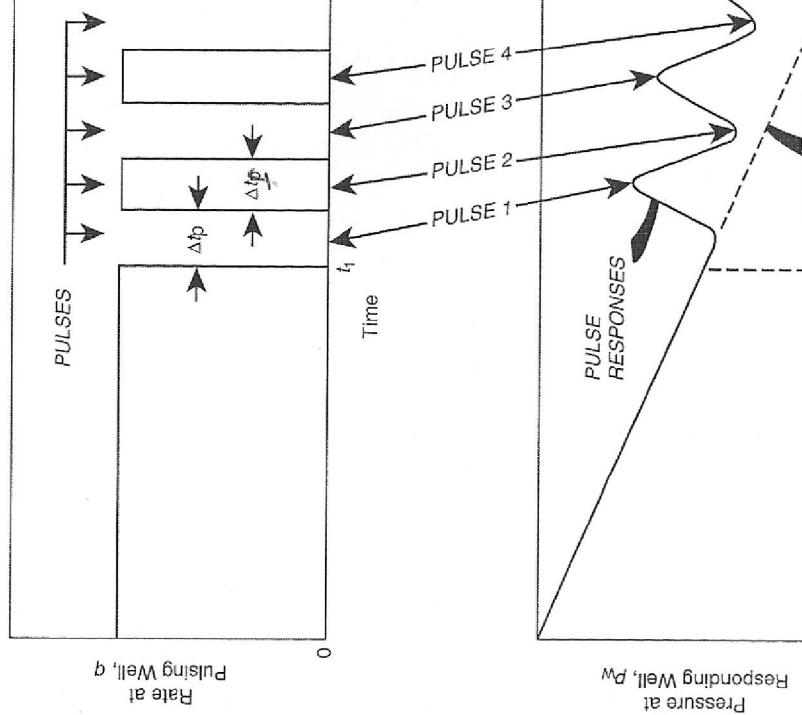


Figure 1. Schematic illustration of rate (pulse) history and pressure response for a pulse test (After Earougher, R. Advances in Well Test Analysis) (Permission to publish by the SPE, copyright SPE, 1977).

t_L : Time lag, represent the elapsed time between the end of pulse and the pressure peak caused by the pulse.

Δt_c : The cycle period, represent the total time length of a cycle

$$\Delta t_c = \Delta t_p + \Delta t_f$$

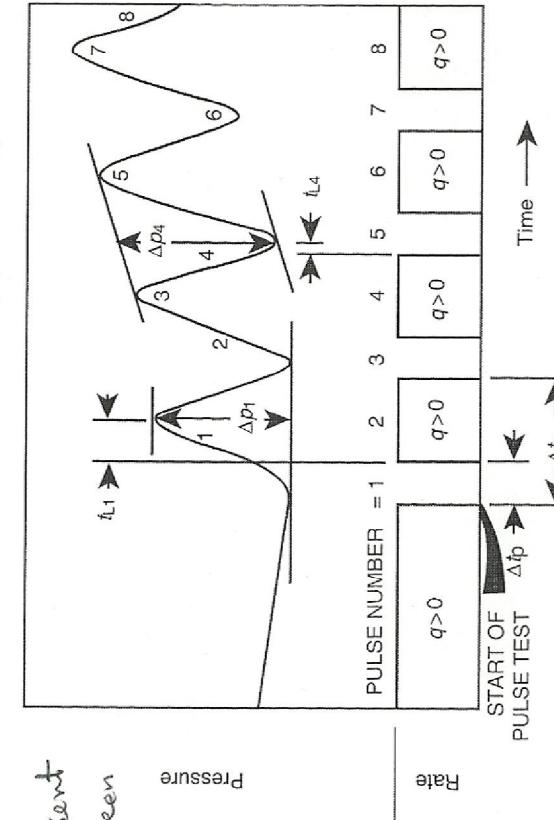


Figure 2. Schematic pulse test rate and pressure history showing definition of time lag (t_L) and pulse response amplitude (Δp) curves. (After Earougher, R. Advances in Well Test Analysis) (Permission to publish by the SPE, copyright SPE, 1977).

The first odd pulse and pulse 2 (first even pulse) have characteristics that differ from all subsequent pulses beyond these initial pulses; all odd pulses have similar characteristics and all even pulses exhibit similar behavior.

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$$\text{III} \quad \text{Pulse ratio } F' = \frac{\text{Pulse Period}}{\text{Cycle Period}} \Rightarrow F' = \frac{\Delta t_P}{\Delta t_P + \Delta t_f}$$

or

$$F' = \frac{\Delta t_P}{\Delta t_C}$$

where the time is expressed in hours.

[2] Dimensionless time lage (t_L) ; $(t_L)_D = \frac{t_L}{\Delta t_C} = \frac{0.002637 k_L}{\sigma \eta C \rho_w r^2}$

[3] Dimension distance r_D between the active and observation wells

$r_D = \frac{r}{r_w}$, where: r = Distance between the active well and the observation well.

[4] - Dimensionless pressure response amplitude ΔP_D

$$\Delta P_D = \frac{K h \Delta P}{i 41.2 \eta_0 M_0 B_0} \quad [\frac{\Delta P}{q} \text{ is always positive}]$$

K = Average permeability, md., q = is the rate of the active well

Kamel and Brigham developed a family of curves as shown in figures 3 through 10

- One set of two charts for the first odd pulse (figs. 3 and 4)
- a second set for the first even pulse (figs 5 and 6)
- a third set for the other odd pulses (figs 7 and 8)
- a fourth set for other even pulses (figs 9 and 10)

Analysis Technique

The figures appropriate for a given pulse number are used to obtain values of:

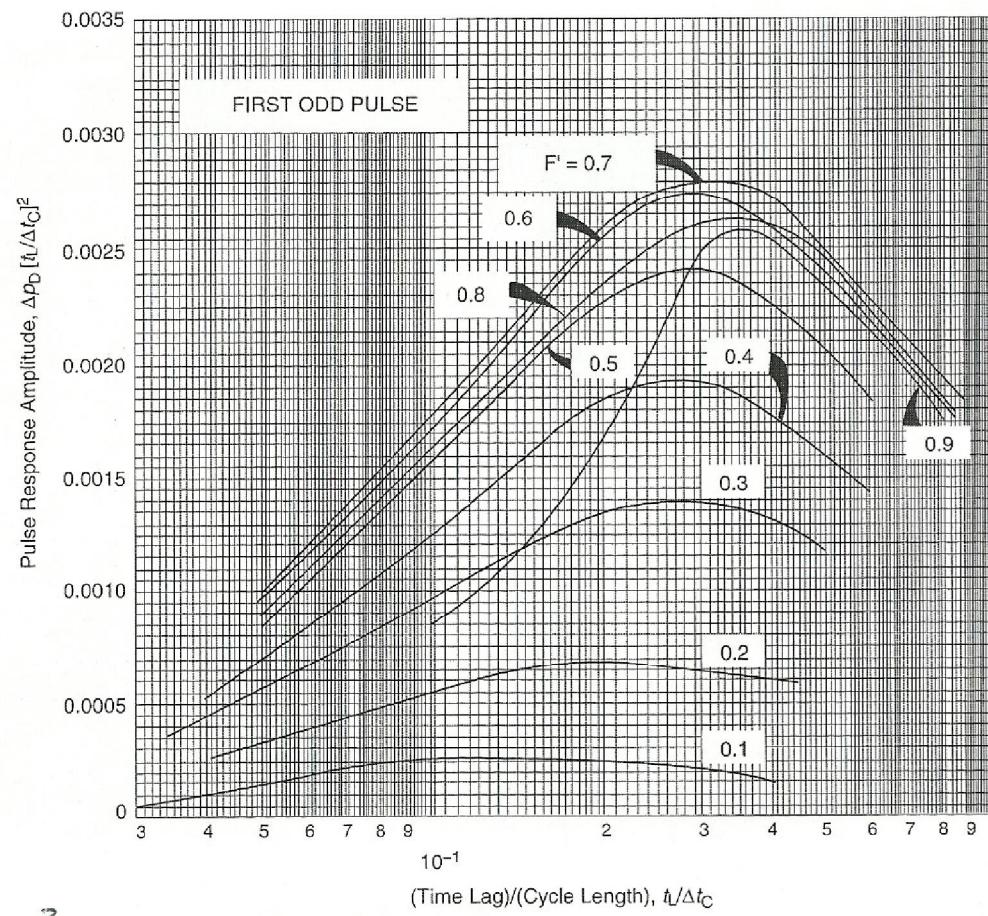


Figure . . . Pulse testing: relation between time lag and response amplitude for first odd pulse. (After Kamal and Brigham, 1976).

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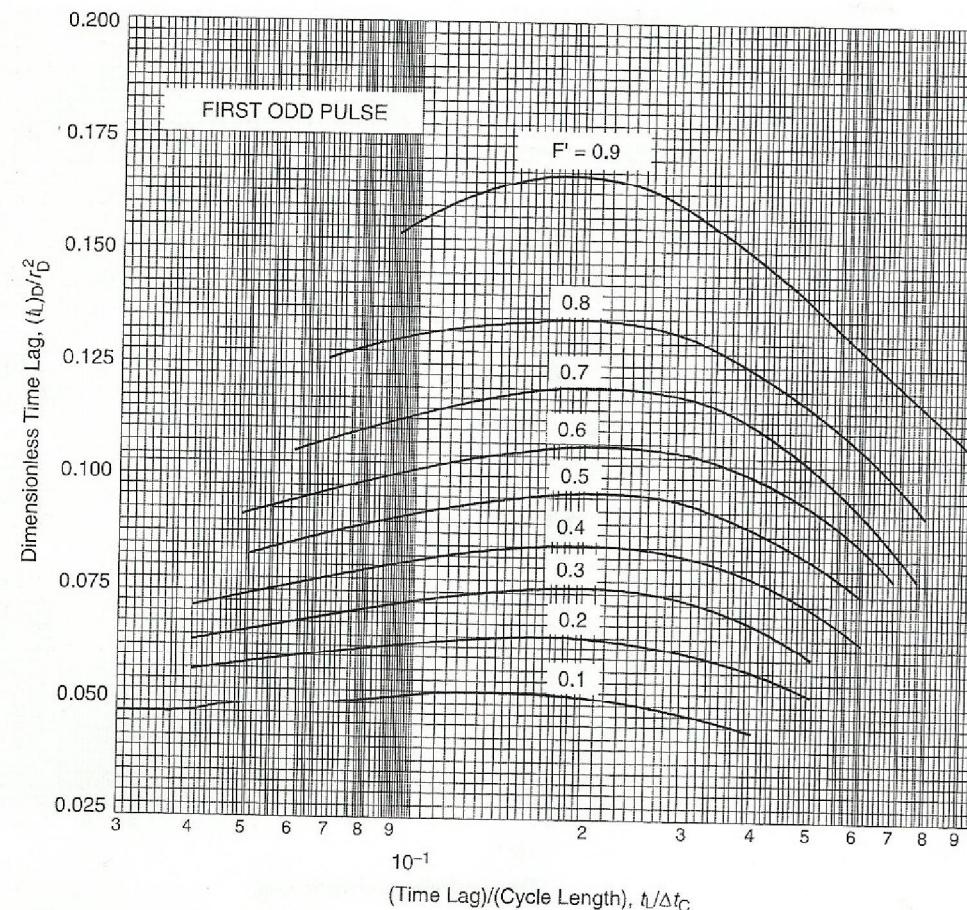


Figure 4 Pulse testing: relation between time lag and cycle length for first odd pulse. (After Kamal and Brigham, 1976).

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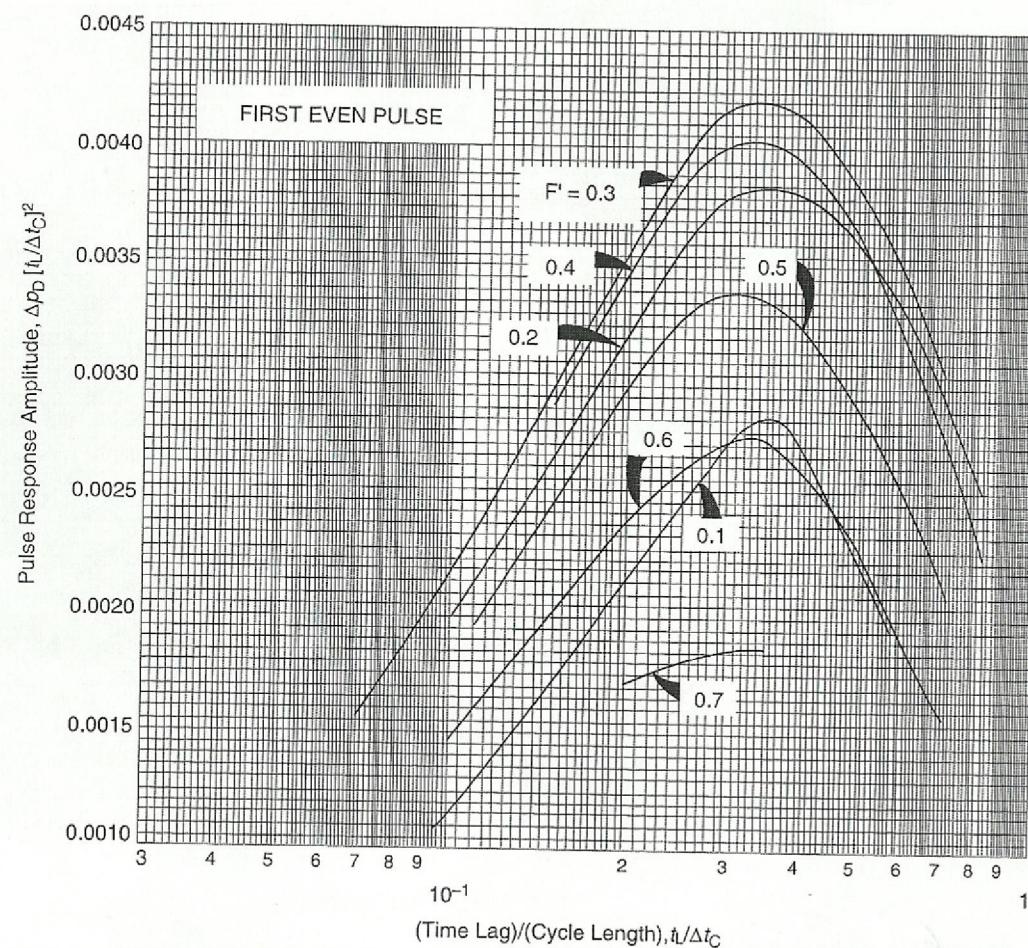


Figure 5. Pulse testing: relation between time lag and response amplitude for first even pulse. (After Kamal and Brigham, 1976).

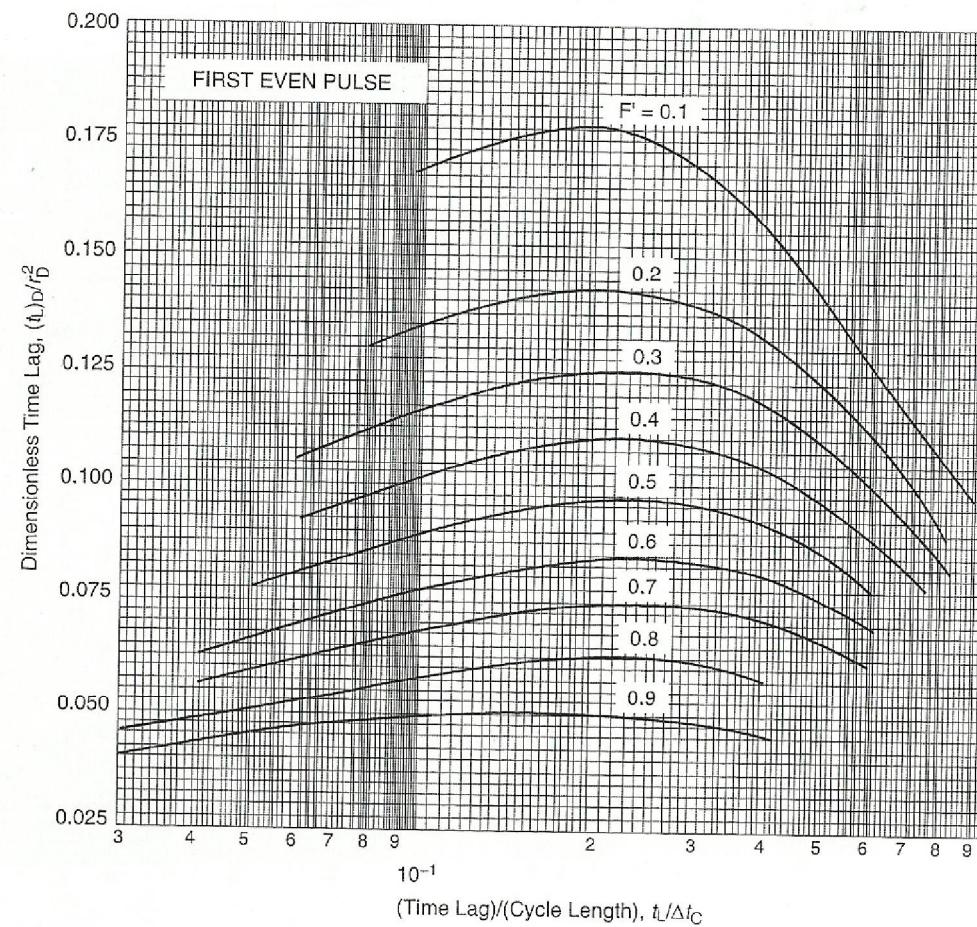


Figure 6 Pulse testing: relation between time lag and cycle length for first even pulse. (After Kamal and Brigham, 1976).

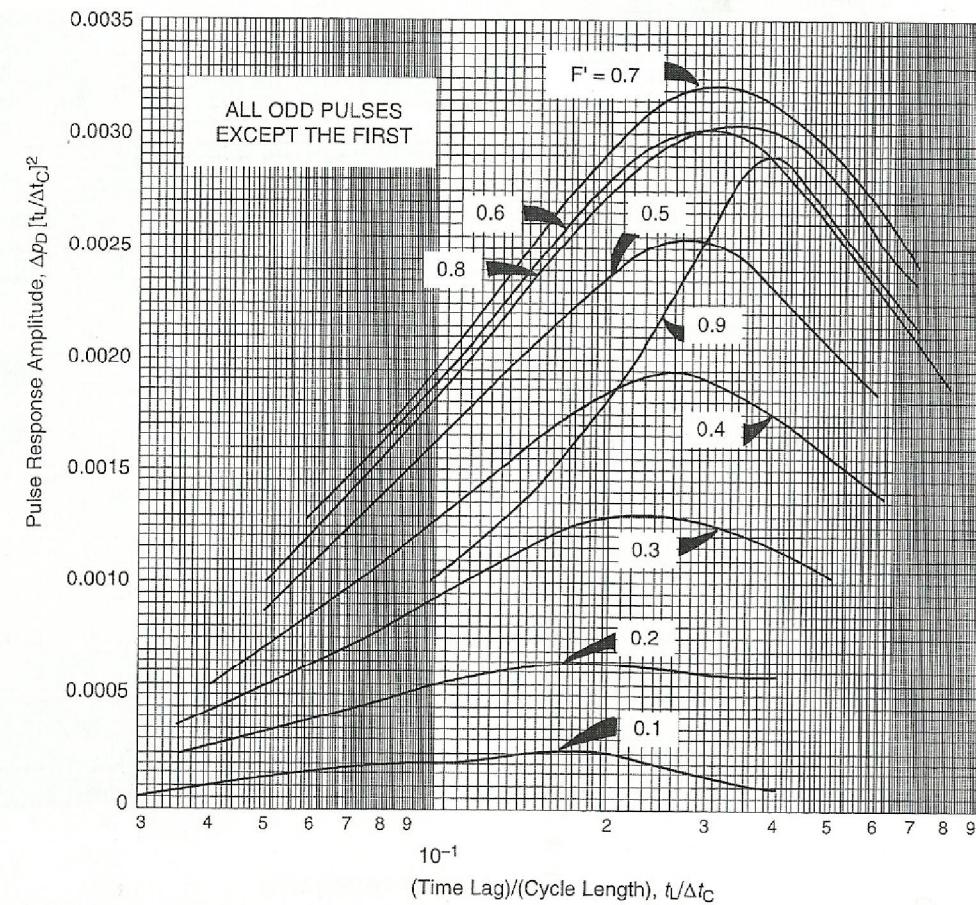


Figure 7.11. Pulse testing: relation between time lag and response amplitude for all odd pulses after the first. (After Kamal and Brigham, 1976).

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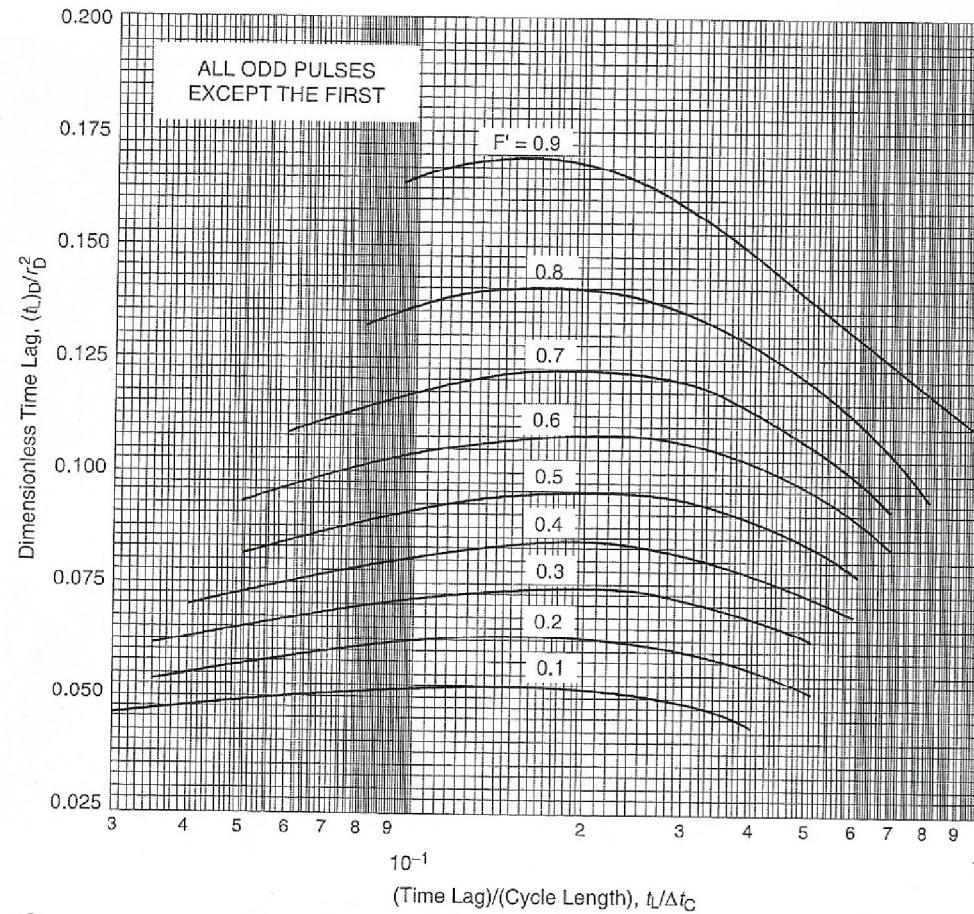


Figure 8 Pulse testing: relation between time lag and cycle length for all odd pulses after the first. (After Kamal and Brigham, 1976).

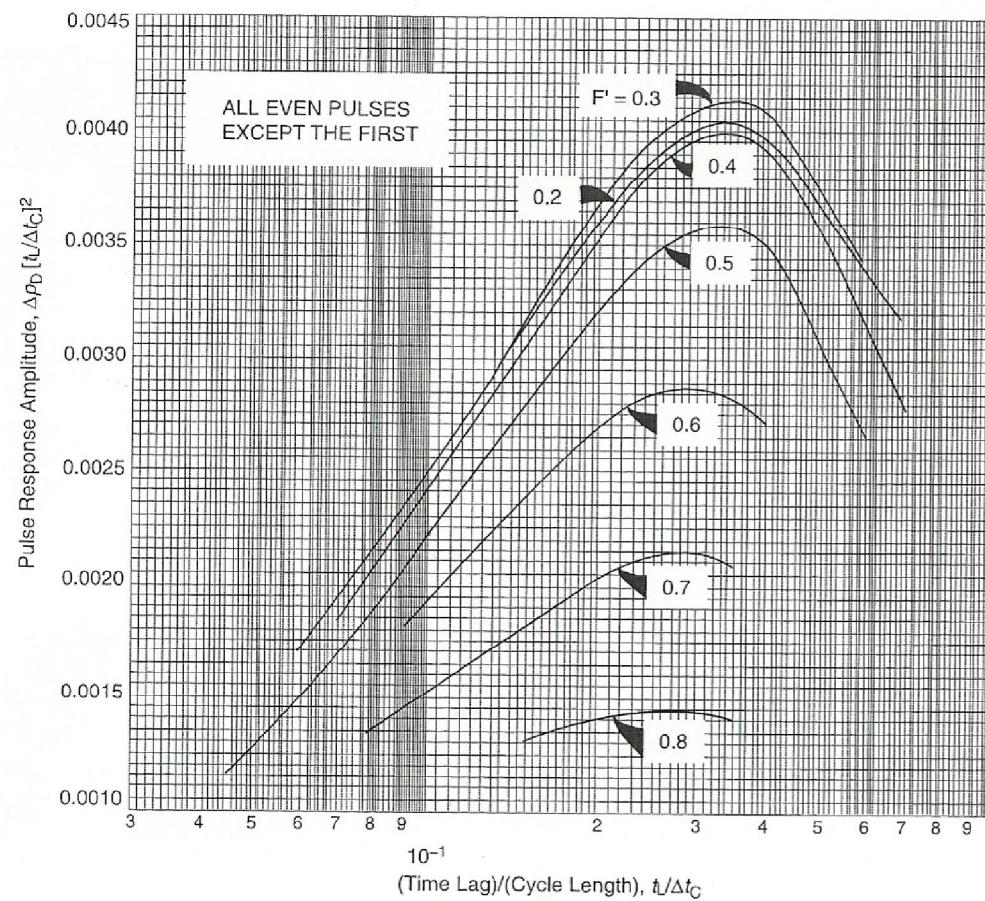


Figure 9.11 Pulse testing: relation between time lag and response amplitude for all even pulses after the first. (After Kamal and Brigham, 1976).

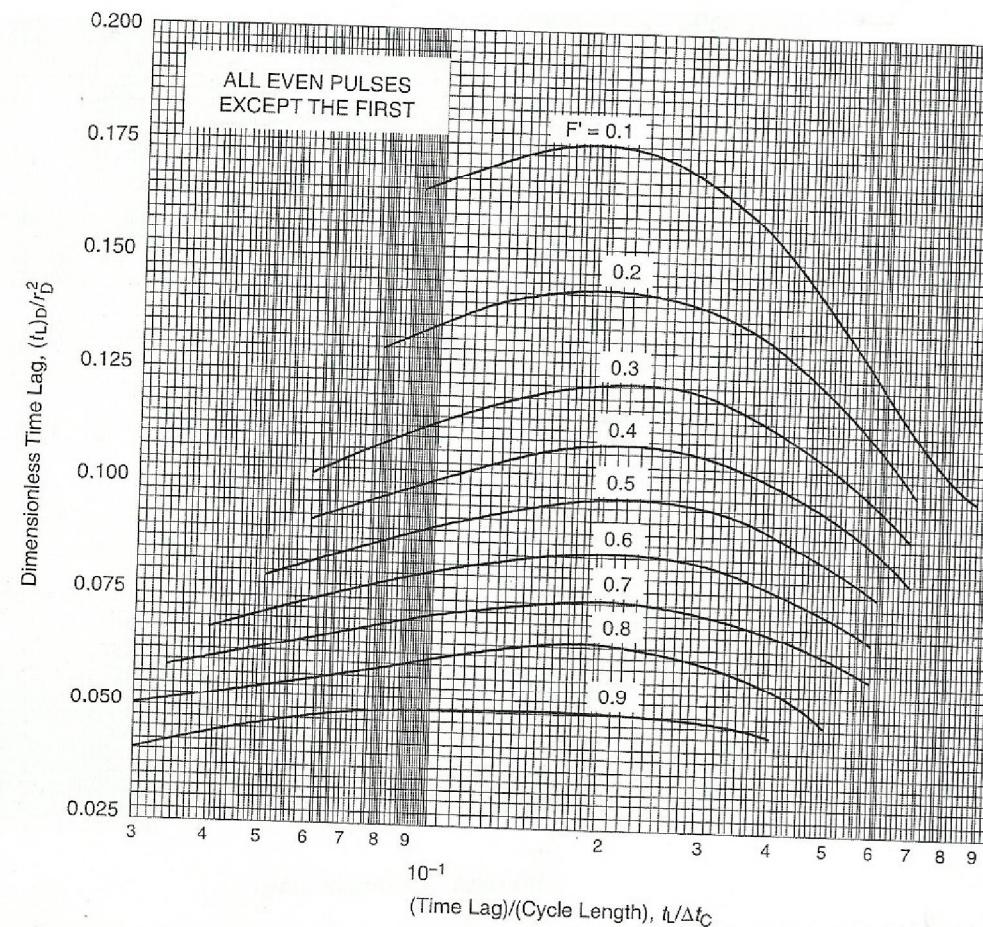


Figure 10 Pulse testing: relation between time lag and cycle length for all even pulses after the first. (After Kamal and Brigham, 1976).

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$$\textcircled{1} \quad \Delta P_D \left(\frac{t_L}{\Delta t_c} \right)^2 \quad \text{and}$$

$$\textcircled{2} \quad \left(\frac{(t_U)_D}{V_{D2}} \right)$$

which are then used to provide estimate of \bar{K} and ϕc_t as follows:

$$\bar{K} = 141.2 \quad \eta_0 \mu_0 B_0 \quad \Delta P_D \left(\frac{t_L}{\Delta t_c} \right)^2$$

$$h \Delta P \left(t_L / \Delta t_c \right)^2$$

$$\phi c_t = 0.00263 \neq K t_L$$

$$\mu \phi^2 \left((t_U)_D / V_D^2 \right)$$

Ex. In a pulse test following rate stabilization, the active well was shut in for 2 hours, then produced for 2 hours, and the sequence was repeated several times. An observation well at 933 from the active well recorded an amplitude pressure response of 0.639 psi during the fourth pulse and a time lag of 0.4 hours. The following additional data is also available.

$$Q = 425 \text{ STB/D}, B_0 = 1.26 \text{ RBSIB}, \quad h = 933 \text{ ft}, \quad h = 26 \text{ ft}$$

$$\mu = 0.8 \text{ cp}, \quad \phi = 0.08 \quad \text{Estimate } \bar{K} \text{ and } \phi c_t$$

Solution:

Step 1: Calculate the pulse ratio F'

$$F' = \frac{\Delta t_P}{\Delta t_P + \Delta t_f} \Rightarrow F' = \frac{2}{2+2} = 0.5 \quad [\Delta t_c = 4 \text{ hours}]$$

Step 2: Calculate the dimensionless time-lag

$$(t_U)_D = \frac{t_L}{\Delta t_c} = \frac{0.4}{4} = 0.1$$

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Step 3: Using the values of $(t_L)_D = 0.1$, $F' = 0.5$ use

figures to get

$$\left[\Delta P_D \left(\frac{t_L}{\delta t_c} \right)^2 \right]_{\text{Fig}} = 0.00221 \quad [\text{Fig. 9}]$$

Step 4: Estimate, the average permeability.

$$K = \left[\frac{141.2 \rho_0 \mu_0 B_0}{h \Delta P (t_L D)^2} \right] \left[\Delta P_D \left(\frac{t_L}{\delta t_c} \right)^2 \right]_{\text{Fig.}}$$

$$K = \frac{\left[141.2 (425) (1.26) (0.8) \right] (0.00221)}{(26) (0.269) (0.1)^2} = 0.00221$$

$$= 817 \text{ md.}$$

Step 5: Using $(t_L)_D = 0.1$ $F' = 0.5$ use figure 10

to get

$$\left[\frac{(t_L)_D / r_D^2}{\nu_D} \right]_{\text{Fig.}} = 0.091$$

Step 6:

$$\phi c_t = \left[\frac{0.0002637 K(t_L)}{H r^2} \right] \frac{1}{(0.091)}_{\text{Fig.}}$$

$$\phi c_t = \left[\frac{(0.0002637) (817) (0.4)}{(0.8) (933)^2} \right] \frac{1}{(0.091)}$$

$$= 1.36 \times 10^{-6}$$

Step 7: Estimate c_t as

$$c_t = \frac{1.36 \times 10^{-6}}{0.08} = 17 \times 10^{-6} \text{ psi}^{-1}$$

H.W: A pulse test was conducted using an injection well in a five-spot pattern with the four offsetting production wells as the responding wells. The reservoir was at its static pressure condition when the first injection pulse was initiated at 9:40 am. with an injection rate of 700 bbl/day.

The injection rate was maintained for 3 hours followed by a shut-in period of 3 hours. The injection shut-in period were repeated several times and the results of pressure observation are given in Table 1. The following additional data is available : $\mu = 0.87 \text{ cp}$, $C_t = 9.6 \times 10^{-6} \text{ psi}^{-1}$, $d = 16\%$, $V = 330 \text{ ft}$. Calculate the permeability and average thickness.

Pulse Test Design Procedure

Prior knowledge of the expected pressure response is important so that the range and sensitivity of the pressure gauges and length of time needed for the test can be predetermined. To design a pulse test Kamal and Brigham (1975) recommended the following procedure.

Step 1: The first step in designing a pulse test is to select the appropriate pulse ratio (F') $\left[F' = \frac{\text{step}}{\text{stc}} \right]$. A pulse ratio near 0.7 is recommended if analyzing the odd pulses; and near 0.3 if analyzing the even pulses. It should be noted the (F') should not exceed 0.8 or drop below 0.2

Step 2: Calculate the dimensionless time lag from one of the following approximation :

$$\text{For odd pulses } (t_{L_D})_D = 0.09 + 0.3 F'$$

$$\text{For even pulses } (t_{L_D})_D = 0.027 - 0.027 F'$$

Step 3: Using the values of (F') and $(t_{L_D})_D$ from step 1 and step 2 respectively, determine the dimensionless parameter $\left[\frac{(t_{L_D})_D}{V_D} \right]$

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Table 1: Pressure behaviour of producing Well. After Slider, H. C., Worldwide Practical Petroleum Reservoir Engineering Methods, copyright ©1983, Penn Well Publishing

Time	Pressure (psig)	Time	Pressure (psig)	Time	Pressure (psig)
9:40 a.m.	390.1	2:23 p.m.	411.6	11:22 p.m.	425.1
10:10 a.m.	390.6	2:30 p.m.	411.6	12:13 a.m.	429.3
10:30 a.m.	392.0	2:45 p.m.	411.4	12:40 a.m.	431.3
10:40 a.m.	393.0	3:02 p.m.	411.3	1:21 a.m.	433.9
10:48 a.m.	393.8	3:30 p.m.	411.0	1:53 a.m.	433.6
11:05 a.m.	395.8	4:05 p.m.	410.8	2:35 a.m.	432.0
11:15 a.m.	396.8	4:30 p.m.	412.0	3:15 a.m.	430.2
11:30 a.m.	398.6	5:00 p.m.	413.2	3:55 a.m.	428.5
11:45 a.m.	400.7	5:35 p.m.	416.4	4:32 a.m.	428.8
12:15 p.m.	403.8	6:00 p.m.	418.9	5:08 a.m.	430.6
12:30 p.m.	405.8	6:35 p.m.	422.3	5:53 a.m.	434.5
12:47 p.m.	407.8	7:05 p.m.	424.6	6:30 a.m.	437.4
1:00 p.m.	409.1	7:33 p.m.	425.3	6:58 a.m.	440.3
1:20 p.m.	410.7	7:59 p.m.	425.1	7:30 a.m.	440.9
1:32 p.m.	411.3	8:31 p.m.	423.9	7:58 a.m.	440.7
1:45 p.m.	411.7	9:01 p.m.	423.1	8:28 a.m.	439.6
2:00 p.m.	411.9	9:38 p.m.	421.8	8:57 a.m.	438.6
2:15 p.m.	411.9	10:26 p.m.	421.4	9:45 a.m.	437.0

From Figure(4) (first odd pulse) or figure(6) (first even pulse)

Step 4 : Using the value of (F') and $(t_L)_D$ determine the dimensionless response amplitude $\left[\Delta P_D (t_L/t_c)^2 \right]_{Fig.}$ from the appropriate curve in figure (3) [first odd pulse] or figure (5) [first even pulse]

Step 5 : Using the following parameters :

a - Estimates K, h, ϕ, μ and C_f

b - Values of $\left[(t_L)_D / r_0^2 \right]_{Fig.}$ and $\left[\Delta P_D (t_L/t_c)^2 \right]_{Fig.}$ from step 3 and 4

c - Calculate the time lag t_L

$$t_L = \left[(t_L)_D / r_0^2 \right]_{Fig} \left[\frac{\phi M_C r^2}{0.002637 K} \right]$$

d - Calculate the cycle time Δt_c

$$\Delta t_c = \frac{t_L}{(t_L)_D} \equiv \frac{t_L}{\left[t_L / \Delta t_c \right]}$$

e - Calculate the pulse length Δt_p

$$\Delta t_p = F' \Delta t_c$$

f - Estimate the pressure response

$$\Delta P = \left[\frac{141.2 g_o B_o H_0}{K h (t_L)^2} \right] \left[\Delta P_D (t_L/t_c)^2 \right]_{Fig.}$$

g - Calculate the flow period

$$\Delta t_f = \Delta t_c - \Delta t_p$$

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H.W. Design a pulse test using the following approximated properties

$$M = 3 \text{ cp}, q = 0.18, H = 200 \text{ rad}, h = 25 \text{ ft.}, V = 600 \text{ ft.},$$

$$C_t = 10 \times 10^{-6} \text{ psi}^{-1}, B = 1. bbl/psi^3, Q = 100 \text{ BPD}, F' = 0.6,$$

Ref. Kamal M and Brigham W.C " Pulse - Testing Response for unequal pulse and shut in Period " SPEJ Oct 1975
pp. : 399 - 410 , Trans. AIME 255 g .

Well Test Analysis by use of Type Curves

The type curve analysis approach was introduced in the petroleum industry by Agarwal et.al (1970) as a valuable tool when used with conjunction with conventional Semilog plot.

A type curve is a graphical representation of the theoretical solution to flow equations. The type curve analysis consists of finding the theoretical type curve that "matches" the actual response from a test well and the reservoir when subjected to changes in production rates or pressures. The match can be found graphically by physically superposing a graph of actual test data with similar graph of type curves, and searching for the type curve that provides the best match.

Since type curves are plots of theoretical solution to transient and pseudosteady-state of flow equations, they are usually presented in terms of dimensionless variables (e.g. P_D , t_D , k_D and C_D) rather than real variables (e.g. ΔP , t , v , and c). The reservoir and well parameters such as permeability and skin, can then be calculated from the dimensionless parameters defining the type curve.

Consider the line-source or E_i function solution for slightly compressible liquids

$$P_i - P = \frac{70.69 q_o B_o \gamma_o}{kh} E_i \left(\frac{-948 \phi \gamma_o C_o v^2}{k t} \right) \quad [2]$$

The solution can be made more compact if the equation is rearranged and some dimensionless variable are defined. Rearrangement of eq. 1 as

$$\frac{k h (P_i - P)}{141.2 q_o B_o \gamma_o} = -\frac{1}{2} E_i \left(\frac{-(v/v_w)^2}{4 C_o \phi \gamma_o k t / \gamma_o C_o v_w^2} \right) \quad [2]$$

suggests the following dimensionless pressure, radius and time variable respectively:

$$P_D = \frac{kh(P_i - P)}{141.2 \sigma_0 \beta_0 r_0^4} \quad \boxed{3}$$

$$r_D = \frac{r}{r_0} \quad \boxed{4}$$

and

$$t_D = \frac{0.0002637 k t}{\phi r_0 c + r_0^2} \quad \boxed{5}$$

Combining equation $\boxed{2}$ through $\boxed{5}$ yields the E_i -function solution in dimensionless form

$$P_D = -\frac{1}{2} E_i \left(-\frac{r_D^2}{4 t_D} \right) \quad \boxed{6}$$

At the well where $r_D = 1$, the solution simplifies to

$$P_D = P_D = -\frac{1}{2} E_i \left(-\frac{1}{4 t_D} \right) \quad \boxed{7}$$

where the dimensionless pressure evaluated at the wellbore is

$$P_D = \frac{kh(P_i - Pwf)}{141.2 \sigma_0 \beta_0 r_0^4} \quad \boxed{8}$$

Equation $\boxed{7}$ implies that we can develop a type curve from a plot of P_D as a function of the single variable t_D . Generating a single graph in terms of P_{wf} is much simpler than attempting to plot bottomhole flowing pressure Pwf , as a function of time t , for all reasonable values of the variable that appear in the dimensional form of the line source solution. Thus, with this type curve, we can analyze any pressure transient test conducted under conditions that satisfy the assumptions made in deriving the E_i -function solution. For more general complex reservoir than that modeled by the line source solution, the solution to the flow equations can be

expressed in general functional forms as:

$$P_D = f(t_D, \nu_{D,1}, \nu_2) \quad \boxed{9}$$

Remarks

As shown by eq. [7], the solution to the diffusivity equation can be expressed in terms of the dimensionless pressure drop as

$$P_D = -\frac{1}{2} E_i \left(-\frac{\nu_D^2}{t_D} \right)$$

when $t_D/\nu_D^2 > 25$, P_D can be approximated by

$$P_D = \frac{1}{2} \left[\ln \left(\frac{t_D}{\nu_D^2} \right) + 0.80907 \right] \quad \boxed{10}$$

Notice that

$$\frac{t_D}{\nu_D^2} = \left(\frac{0.0002637 K}{\phi \rho c_t \nu^2} \right) t \quad \boxed{11}$$

Taking the logarithm of both sides of eq. [11] gives

$$\log \left(\frac{t_D}{\nu_D^2} \right) = \log \left(\frac{0.0002637 K}{\phi \rho c_t \nu^2} \right) + \log(t) \quad \boxed{12}$$

also

$$P_D = \left(\frac{K h}{141.2 \phi \nu_D^2 \rho_0 \mu_0} \right) \Delta P$$

Taking the logarithm of both sides of the equation gives

$$\log(P_D) = \log(\Delta P) + \log \left(\frac{K h}{141.2 \phi \nu_D^2 \rho_0 \mu_0} \right) \quad \boxed{13}$$

For a constant flow rate equation [13] indicates that the logarithm of the dimensionless pressure drop, $\log(P_D)$ will differ from the logarithm of the actual pressure drop, $\log(\Delta P)$ by a constant amount of

$$\log \left(\frac{K h}{141.2 \phi \nu_D^2 \rho_0 \mu_0} \right)$$

Similarly the dimensionless time

$$t_D = \frac{0.0002637 K t}{\phi \rho c_t \nu^2} \quad , \text{Taking the logarithm of both}$$

sides

$$\log(t_D) = \log(t) + \log \left[\frac{0.0002637K}{\phi_{10} C_t K_w^2} \right] \quad \boxed{14}$$

then:

[a] : Equations $\boxed{13}$ and $\boxed{18}$

$$\log(P_D) = \log(\Delta P) + \log \left(\frac{K_h}{141.2 \phi_{10} K_w} \right) \quad \boxed{13}$$

$$\log \left(\frac{t_D}{V_D^2} \right) = \log \left(\frac{0.0002637K}{\phi_{10} C_t V^2} \right) + \log(t) \quad \boxed{12}$$

indicates that a graph of $\log(\Delta P)$ vs $\log(t)$ will have an identical shape (i.e parallel) to a graph of $\log(P_D)$ vs. $\log\left(\frac{t_D}{V_D^2}\right)$, although the curve will appear shifted by $\log\left(\frac{K_h}{141.2 \phi_{10} K_w}\right)$ vertically in pressure and $\log\left(\frac{0.0002637K}{\phi_{10} C_t V^2}\right)$ horizontally in time. When these two curves are moved relative to each other until they coincide or "match", the vertical and horizontal movements, in mathematical terms, are given by

$$\left(\frac{P_D}{\Delta P} \right) = \frac{K_h}{141.2 \phi_{10} K_w}$$

$$\text{and } \left(\frac{t_D/V_D^2}{t^{mp}} \right) = \frac{0.0002637K}{\phi_{10} C_t V^2}$$

[b]

Consider Eqs. $\boxed{13}$ and $\boxed{14}$

$$\log(P_D) = \log(\Delta P) + \log \left(\frac{K_h}{141.2 \phi_{10} K_w t_w} \right) \quad \boxed{13}$$

$$\log(t_D) = \log(t) + \log \left[\frac{0.0002637K}{\phi_{10} C_t K_w^2} \right] \quad \boxed{15}$$

Hence, a graph of $\log(\Delta P)$ vs. $\log(t)$ will have an identical shape (i.e parallel) to a graph of $\log(P_D)$ vs. $\log(t_D)$, although the curve,

will be shifted by $\log (Kh / 141.2 \cdot \rho_0 \cdot B \cdot r_0)$ vertically in pressure and
 $\log (0.0002637K) \cdot \text{horizontally in time}$. This concept is illustrated
 $\Phi P_0^2 C_t V_w^2$
in figure 11.

Types: Several kinds of Type curves are used to interpret
test in a vertical well with an infinite homogeneous reservoir

- Agarwal et al type curves. [Fig. 12 ((Fig. c.6))]
- McKinley type curves. [Fig. 13 ((Fig. c.8))]
- Earlougher and Kerach type curves [Fig. 14 ((Fig. c.9))]
- Guringarten et al type curves [Fig. 15]

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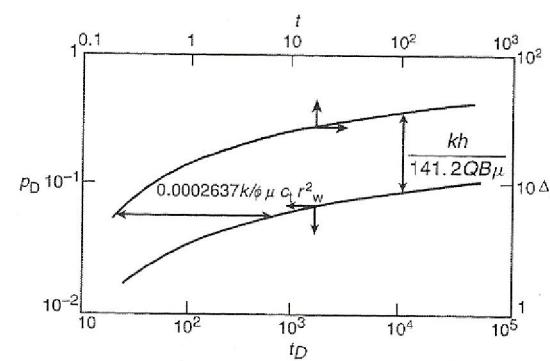


Figure 11 / Concept of type curves.

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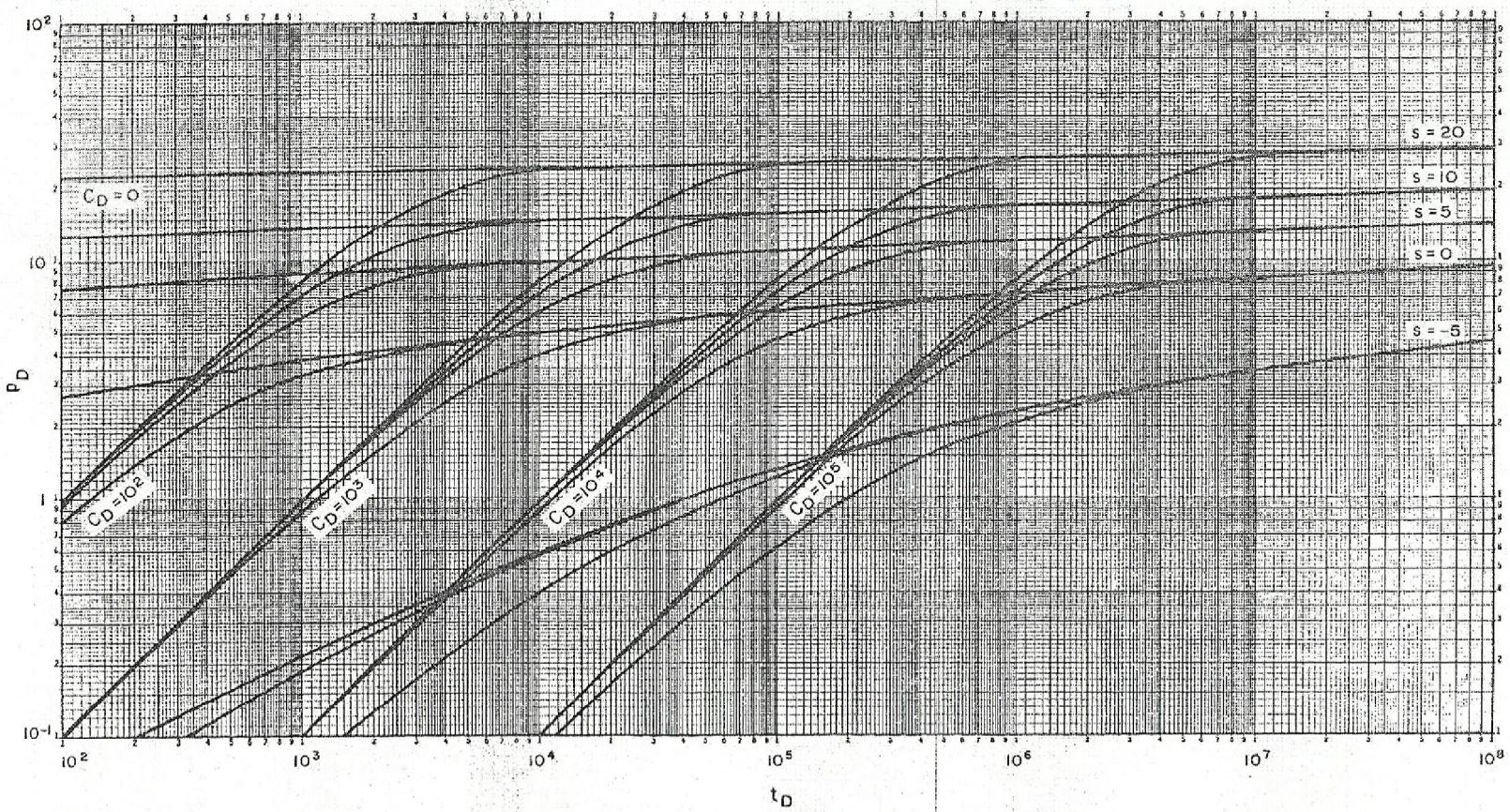


Fig. 12 Dimensionless pressure for a single well in an infinite system, wellbore storage and skin included. After Agarwal, Al-Hussainy, and Ramey.¹⁰ Graph courtesy H. J. Ramey, Jr.

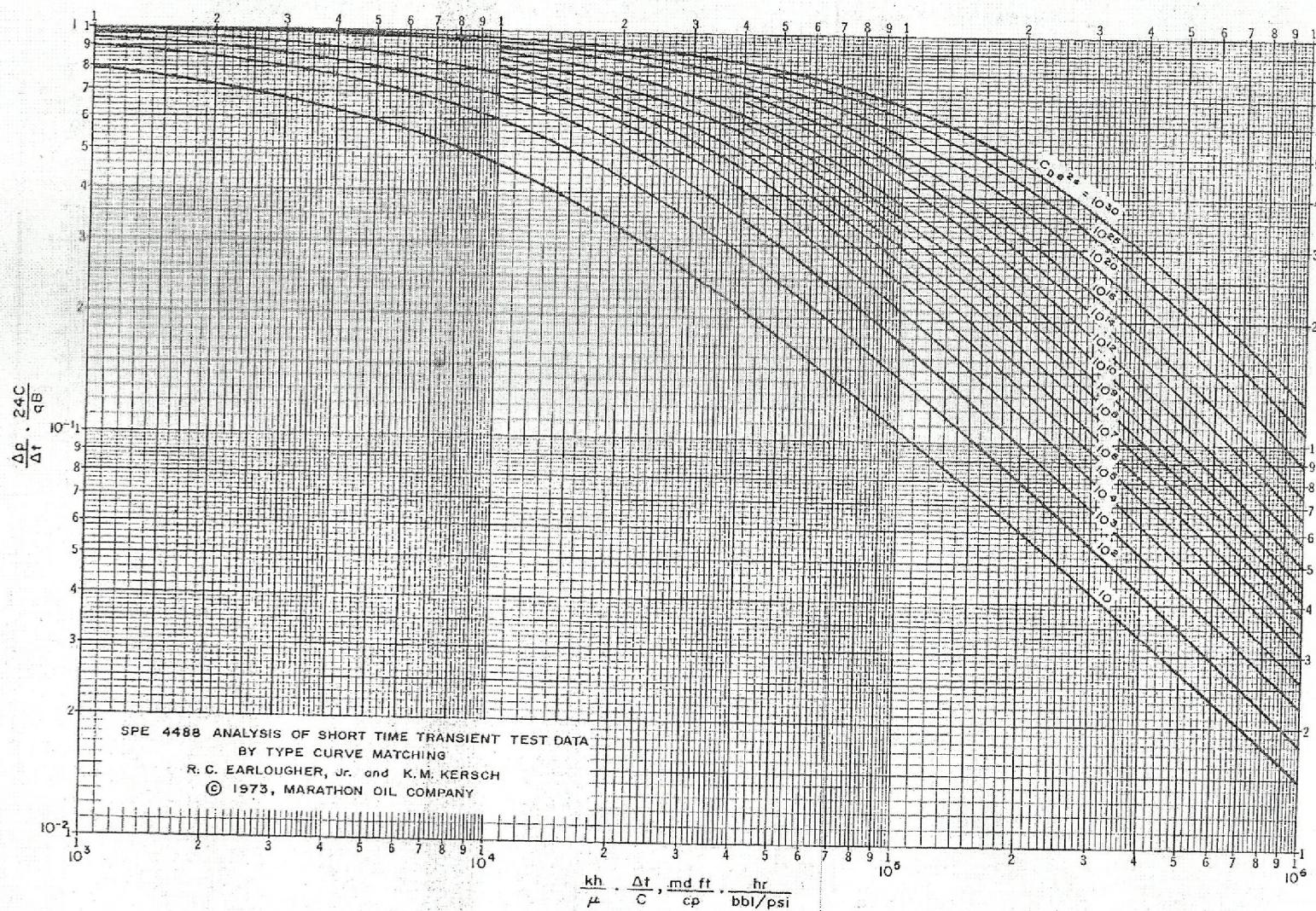


Fig. 13 Type curve for a single well in an infinite system, wellbore storage and skin effects included. After Earlougher and Kersch.¹²
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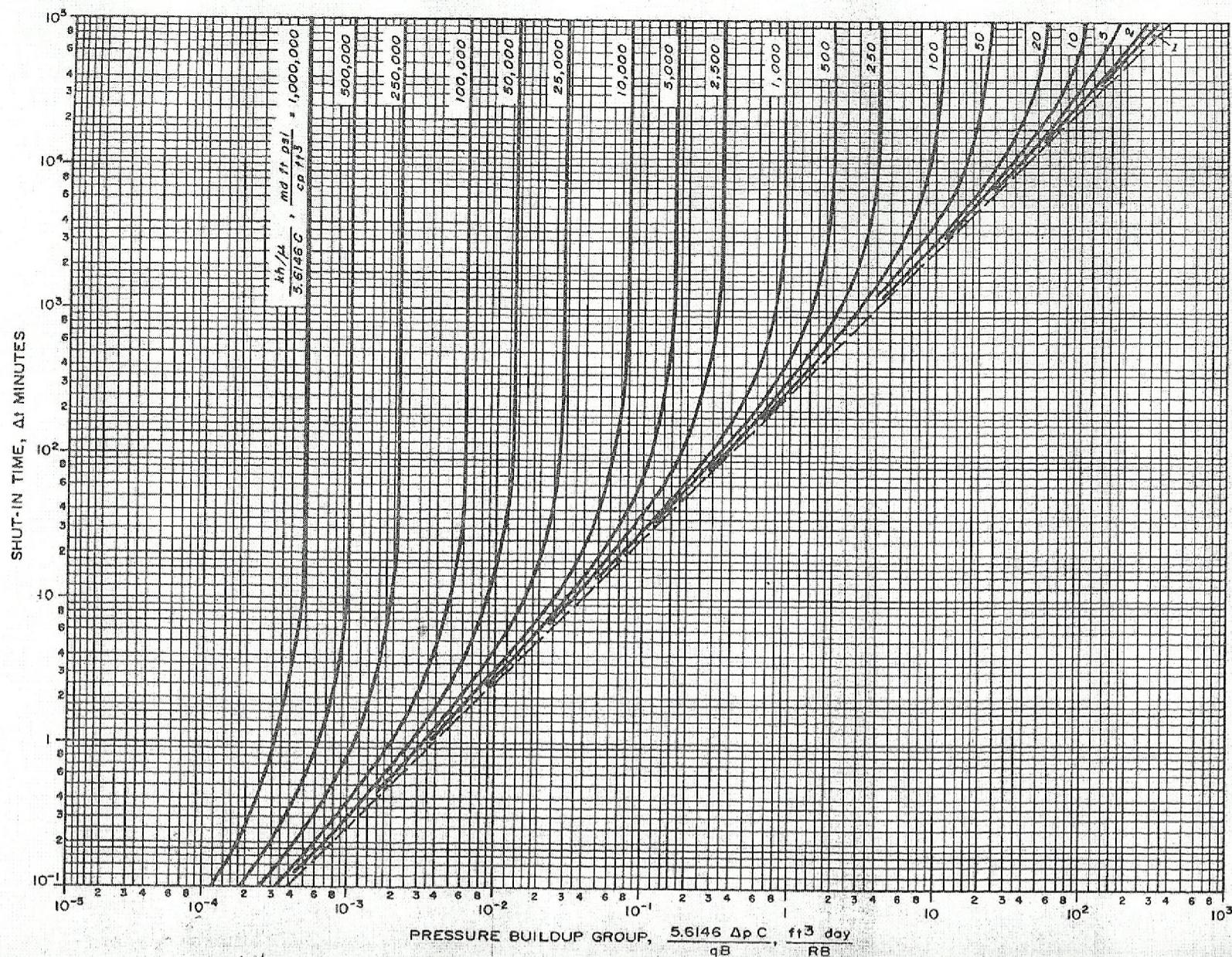


Fig. 14 Type curve for a single well in an infinite system, wellbore storage included, no skin. After McKinley.¹⁹

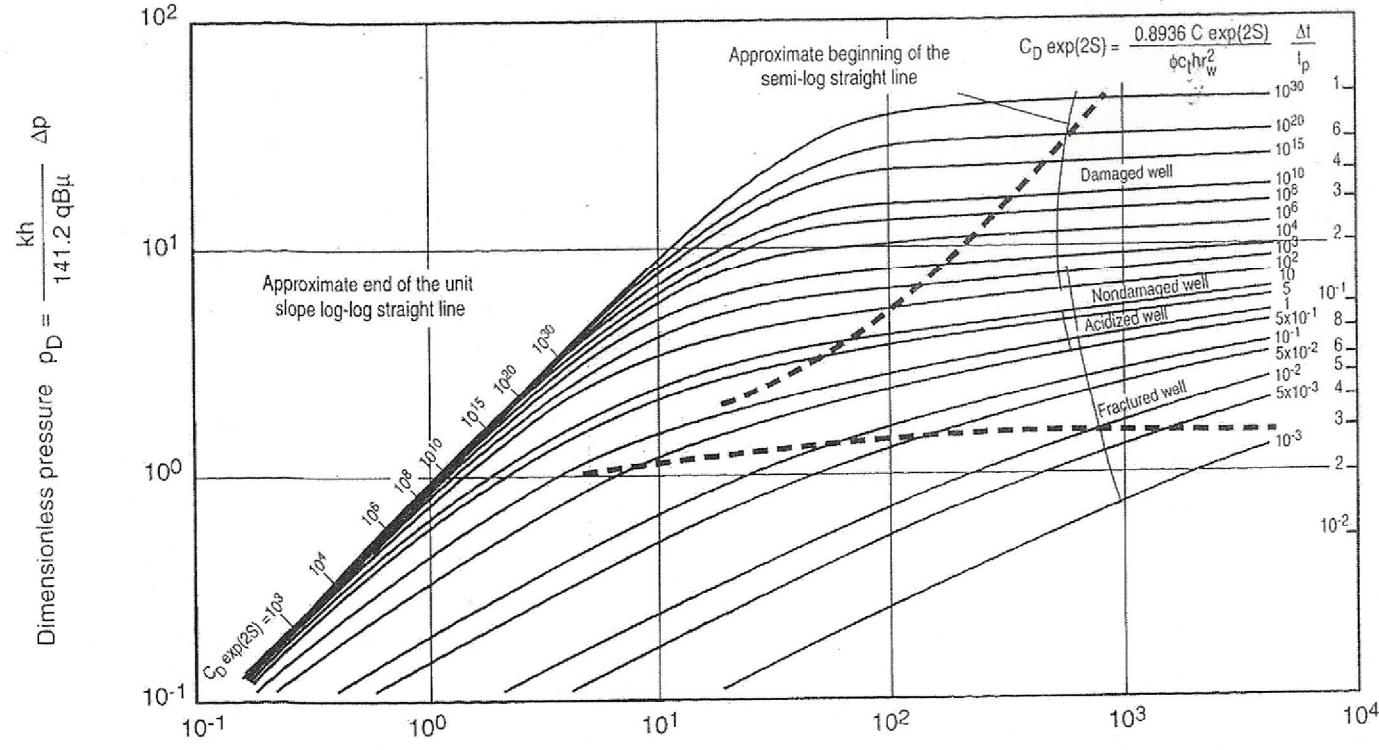


Fig.15 Type curves for a well with wellbore storage and skin (infinite homogeneous reservoir)

Craigartan type Curve

During the early time period where the flow is dominated by the wellbore storage, the wellbore pressure is described by eq.

$$P_D = \frac{t_0}{C_D} \quad [16]$$

or

$$\log(P_D) = \log(t_0) - \log(C_D) \quad [17]$$

This relationship gives the characteristic signature of well bore storage effect on well testing data which indicates that a plot of P_D vs. t_0 on a log-log scale will yield a straight line of unit slope. At the end of the storage effect, which signifies the beginning of the infinite acting period, the resulting pressure behavior produces the usual straight line on a semilog plot as described by

$$P_D = \frac{1}{2} [\ln(t_0) + 0.80901 + 2s'] \quad [18]$$

It is convenient when using the type curve approach in well testing to include the dimensionless wellbore storage coefficient in eq. [18]. Adding and subtracting $\ln(C_D)$ inside the brackets of the above equation gives

$$P_D = \frac{1}{2} [\ln(t_0) + 2s' + 0.80901 + \ln(C_D) - \ln(C_D)]$$

or

$$P_D = \frac{1}{2} \left[\ln\left(\frac{t_0}{C_D}\right) + 0.80901 + \ln(Ce^{2s'}) \right] \quad [19]$$

P_D = Dimensional pressure

C_D = Dimensional wellbore storage coefficient

t_0 = Dimensional time

s' = skin factor

Equation [19] describes the pressure behavior of a well with a wellbore storage and a skin in a homogeneous reservoir during the transient * LSL : unit stop line

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or infinite - acting flow period.

Griegart et al. (1979) expressed eq. [19] in the graphical type curve format shown in fig. 15. In this figure, the dimensionless pressure P_D is plotted on a log-log scale versus dimensionless time group $t_{D,0}/C_D h$. The resulting curves, characterized by the dimensionless group $C_D e^{2\delta'}$, represent different well conditions ranging from damaged wells to stimulated wells. Figure 15 shows that all the curves merge in early time into a unit - slope straight line corresponding to pure wellbore storage flow. At a later time with the end of the wellbore storage-dominated period, curves correspond to infinite - acting radial flow. There are three dimensionless groups that Griegart et al used when developing the type curve

1- Dimensionless pressure P_D .

2- Dimensionless ratio $t_{D,0}/C_D$

3- Dimensionless characterization group $C_D e^{2\delta'}$

The above three dimensionless are defined mathematically for both the draw down and buildup test as follows

For Draw-Down

$$P_D = \frac{kh \Delta P_j}{141.2 \eta_0 B_0 t_0} = 0.00768 \frac{kh}{\eta_0 B_0 t_0} \Delta P_j$$

and

$$\Delta P = P_{wf}(t=0) - P_{wf,j}$$

where

K = Permeability md. h : Thickness ft. ΔP_j = Pressure difference

η_0 = oil flow rate STP, $B_0 = \sigma_{FVF} RB/STP$

η_0 = oil viscosity c.P.

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For build up

$$P_D = 0.00708 \frac{Kh}{\alpha_0 B_0 / \gamma} \Delta P_j$$

and

$$\Delta P_j = P_{wsj} - P_{ws} (\Delta t = 0)$$

Dimensionless wellbore storage C_D

$$C_D = 0.8936 \frac{C}{\varphi c_t h r_w^2} \quad \boxed{20}$$

and

$$C = \frac{\alpha_0 B_0}{24} \left(\frac{\Delta t}{\Delta P} \right)^l \quad \boxed{21}$$

where :

C : wellbore storage bbl/psi

t : time hr

Dimension less time

$$t_D = \frac{0.0002637 K t}{\varphi f' c_t r_w^2}$$

where

φ : porosity c_t : Total Compressibility psi^{-1}

r_w : wellbore radius , ft

$$\frac{t_D}{C_D} = \left(\frac{0.000295 K h}{\mu C} \right) t \quad \boxed{22}$$

from eq. $\boxed{20}$

$$C_D t_D = 0.8936 \left(\frac{C}{\varphi c_t h r_w^2} \right) e^{2 \mu t}$$

then

$$N^l = 0.5 \ln \left(\frac{C_D e^{2 \mu t}}{C_D} \right) \quad \boxed{23}$$

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also

$$C_D = 0.63723 \frac{\rho_0 B_0}{\phi C_t R r_w^2} \left(\frac{\delta t}{\Delta P} \right)_{VSL} \boxed{2w}$$