VOL. 9, NO. 7, JULY 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

APPROXIMATION OF THE STARTING TIME OF RADIAL FLOW REGIME UNDER VARIABLE WELLBORE STORAGE CONDITIONS IN VERTICAL WELLS

Freddy Humberto Escobar[1], David Alexander Olaya[2] and María Victoria Medina[3]
[1]Universidad Surcolombiana/CENIGAA, Avenida Pastrana, Neiva, Huila, Colombia
[2]Oil Field Services and Supplies, Bogotá, Colombia
[3]Tano Supply Services S.A.S., Bogotá, Colombia
E-Mail: fescobar@usco.edu.co

ABSTRACT

It has been observed that wellbore storage changes either increasingly or decreasingly when a well test is run in a producing hydrocarbon well. It causes alterations of the time at which radial flow initiates which normally takes longer time than in wells with constant wellbore storage. This also leads to difficulties in establishing the actual radial flow regime and therefore the interpretation may not be accurate. So far, only for cases of constant wellbore storage the starting time of the radial flow regime can be predicted. In this work, the available mathematical modeling was used to simulate pressure tests with variable wellbore storage to study their behavior so empirical expressions were developed to estimate the starting time of the radial flow regime when wellbore storage is no longer constant. The expressions were validated using synthetic examples.

Keywords: radial flow, changing wellbore storage, pressure buildup, pressure drawdown.

1. INTRODUCTION

The expression for the determination of the starting of the semilog straight line (or radial flow regime) in a flow test was introduced by Earlogher (1977). Usually, this time takes place at about 1.5 log cycles after the initiation of the deviation from the early unit-slope line caused by wellbore storage. An analog expression was introduced Chen and Brigham (1974) for pressure buildup and fall-off tests.

Variable wellbore storage observed in hydrocarbon-well pressure tests has been reported in the oil literature for more than three decades. Such circumstances as phase redistribution, high gas-oil ratios and lowering the level of water injection wells cause changes of wellbore storage coefficient.

Ramey and Agarwal (1972) present an analytical solution to respond for the changes in wellbore storage coefficient. Also, Fair (1981) introduced a solution for exponential increase of wellbore storage which used the phase redistribution modeling. He found that phase redistribution can lead to a reduction of the wellbore storage coefficient which could be negative indicating a reversing of flow direction.

According to Hegeman, Hallford, and Joseph. (1993), who presented another model for pressure behavior under variable wellbore storage, the decreasing storage - usually caused by wellbore fluid compressibility reduction- is often found in pressure buildup tests. It is important to remark that the simultaneous recording of well-flowing pressure and flow rate can reduce the severe effect of variable wellbore storage. However, such procedure does not eliminate the problem when the rate recording tool is affected by the fluid volume beneath it. When a well test is designed with enough time for the development of reservoir radial flow regime, the visual impact at early time pressure points can lead to an inappropriate interpretation of the test. Moreover, sometimes the recorded pressure data are considered to be uninterpretable due to the combination of variable wellbore storage and insufficient pressure-time points (short test, equipment failure, etc.)

In this work, the model proposed by Hegeman *et al.* (1993) was employed to generate dimensionless pressure and pressure derivative versus time data under several conditions of changing wellbore storage coefficient in both drawdown and buildup tests with the purpose of generating expressions for the determination of the start time of the radial flow regime, Medina and Olaya (2012).

2. FORMULATION

2.1. Pressure drawdown tests

Using the data reported in the second column of Table-1, several synthetic pressure tests were generated with the model proposed Hegeman *et al.* (1993). Case-1 considers variations of skin factor ($-4 \leq s \leq 150$), wellbore storage coefficient ($25 \leq C \leq 295$ bbl/psi), storage amplitude ($20 \leq SA \leq 100$ psi) and storage time constant ($1 \leq STC \leq 30$ hr). Figures-1 to 4 present pressure and pressure derivative behaviors or different conditions.

From the above mentioned plots, radial flow is assumed to start when the dimensionless pressure derivative takes the value of 0.5009. For case-1, skin factor is the variable most affecting the dimensionless time of the starting value $(t_{SSL})_D$ of the radial flow regime, then, it is followed by wellbore storage coefficient. Such variables as amplitude of the “hump” and the storage time constant played a much less notorious role effect.

The following statistical expression is found from the observed behaviors:

$$(t_{SSL})_D = 1334183656s + 453661982.4C + 35241389.43(t*\Delta P')_i \quad (1)$$
$$+172072259.3t_i - 3323068248$$

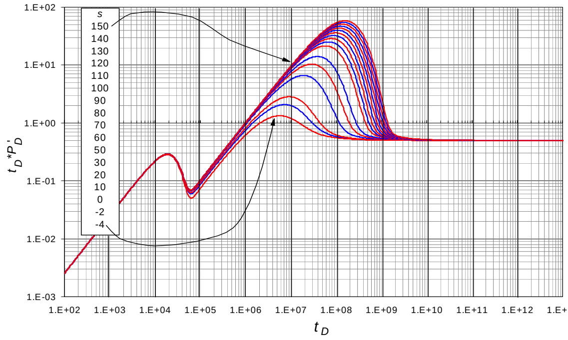

Figure-1. Dimensionless pressure derivative vs. time for drawdown tests with variable skin factor. $C = 25$ bbl/psi, $SA = 20$ psi, and $STC = 1$ hr.

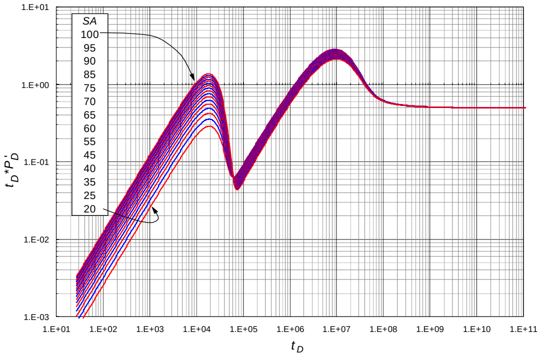

Figure-2. Dimensionless pressure derivative vs. time for drawdown tests with variable storage amplitude, $s = 0$, $C = 25$ bbl/psi, and $STC = 1$ hr.

Table-1. Information used examples and for simulation runs.

	Simulation runs	Field case example	Synthetic example for declination	Synthetic example for buildup
Parameter	**Value**			
r_w, ft	0.5	0.43	0.5	0.5
q, STB/D	500	224	500	500
h, ft	115	43	115	115
φ, %	20	30	20	20
c_t, psi^{-1}	4x10^{-6}	7.19x10^{-4}	4x10^{-6}	4x10^{-6}
P_i, psi	3000		3000	3000
k, md	50		50	50
B, bbl/STB	1.15	1.02149	1.15	1.15
μ, cp	2.15	295	2.15	2.15

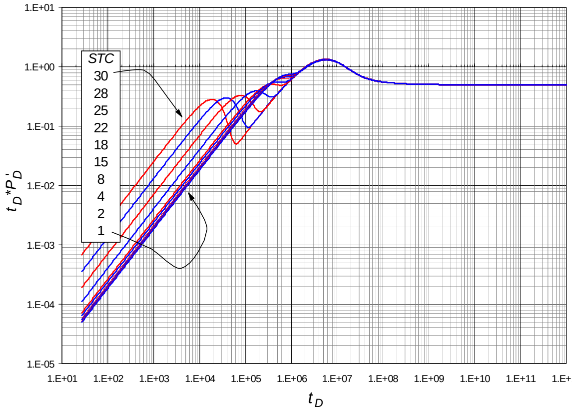

Figure-3. Dimensionless pressure derivative vs. time for drawdown tests with variable storage time constant, $s = -4$, $C = 25$ bbl/psi, and $SA = 20$ psi.

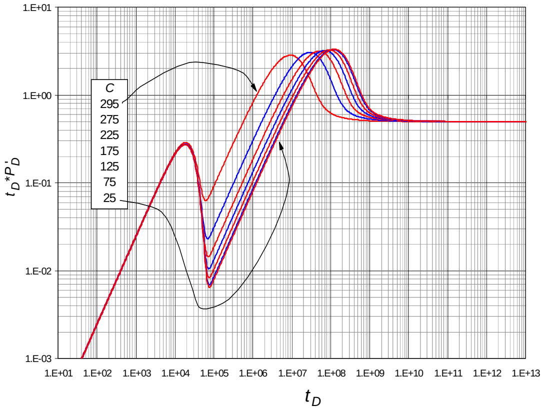

Figure-4. Dimensionless pressure derivative vs. time for drawdown tests with variable wellbore storage coefficient, $s = 0$, $SA = 20$ psi and $STC = 1$ hr.

Case-2 takes into account variations of skin factor ($-3 \le s \le 200$), wellbore storage coefficient ($0.008 \le C \le 0.021$) bbl/psi, storage amplitude ($-7 \le \mathrm{SA} \le -21$ psi) and storage time constant ($0.0045 \le STC \le 0.013$ hr). Figures 5 through 7 show the behaviors for different scenarios of case-2. For these new ranges, the obtained governing correlation is:

$$(t_{SSL})_D = 337923.0117s + 265693003.5C + 48157.75664(t*\Delta P')_i - 18233438.96*t_i + 227596.7084 \tag{2}$$

2.2. Pressure buildup tests

Again, synthetic pressure and pressure derivative versus time data were generated with the model proposed Hegeman *et al*. (1993) using input data from Table-1. For this situation, case-1 considers variations of skin factor ($-4 \le s \le 150$), wellbore storage coefficient ($25 \le C \le 295$) bbl/psi, storage amplitude ($20 \le SA \le 100$ psi) and storage time constant ($1 \le STC \le 30$ hr). For this case also the most affecting variable is skin factor and, then, wellbore storage coefficient. Once the initiation of the radial flow is defined and tabulated, the following expression is obtained:

$$(t_{SSL})_D = 1420789056s + 238769131.4(t*\Delta P')_i + 454775214.8C - 204756789.5t_i - 8251018399 \tag{3}$$

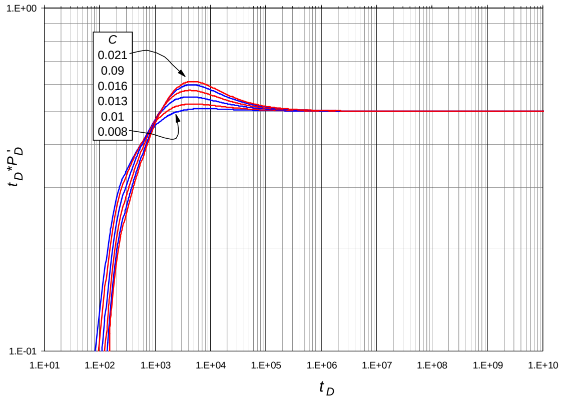

Figure-5. Dimensionless pressure derivative vs. time for drawdown tests with variable wellbore storage coefficient, $s = -3$, $SA = -7$ psi and $STC = 0.0045$ hr.

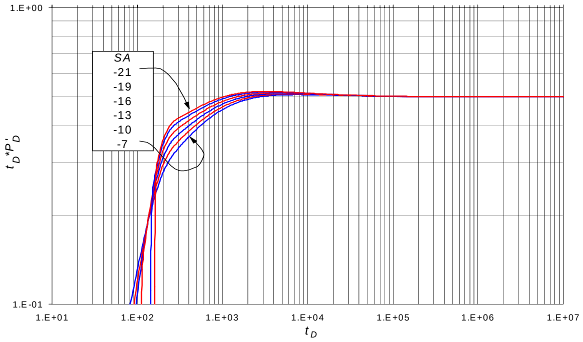

Figure-6. Dimensionless pressure derivative vs. time for drawdown tests with variable storage amplitude, $s = -3$ and $STC = 0.0045$ hr.

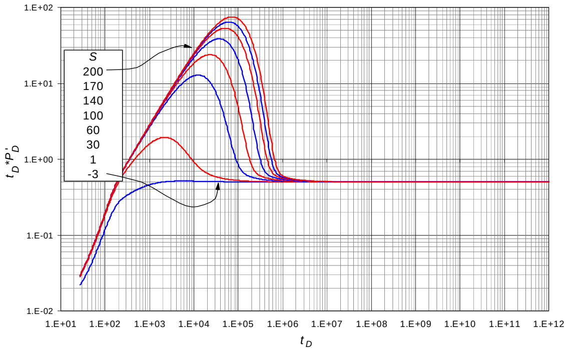

Figure-7. Dimensionless pressure derivative vs. time for drawdown tests with variable skin factor, $C = 0.09$ bbl/psi, $SA = -7$ psi and $STC = 0.0045$ hr.

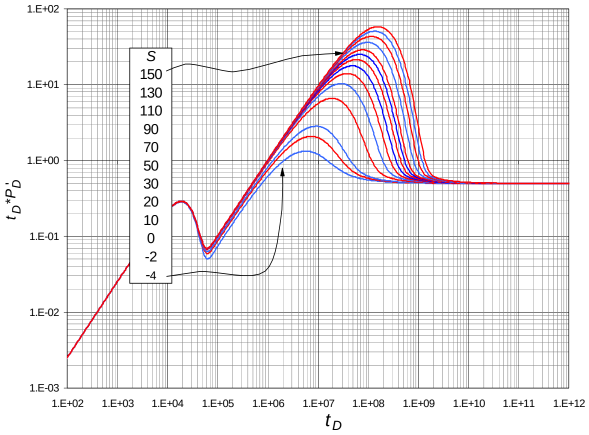

Figure-8. Dimensionless pressure derivative vs. Time for drawdown tests with variable skin factor, $C = 25$ bbl/psi, $SA = 20$ psi and $STC = 1$ hr.

Case-2 considers variations of skin factor ($-3 \le s \le 200$), wellbore storage coefficient ($0.008 \le C \le 0.021$) bbl/psi, storage amplitude ($-7 \le SA \le -21$ psi) and storage time constant ($0.0045 \le STC \le 0.013$ hr). The different pressure and pressure derivative behaviors are shown in Figures 8 through 13. Again, skin factor is the most impacting variable followed by the wellbore storage coefficient. The obtained governing correlation is:

$$(t_{SSL})_D = 347751.4072s + 917482083.1C - 3976962300(t*\Delta P')_i - 1555180.704t_i \tag{4}$$

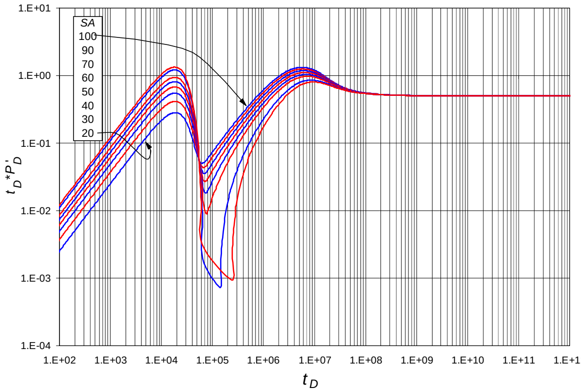

Figure-9. Dimensionless pressure derivative vs. Time for buildup tests with variable storage amplitude, s = -4, C = 25 bbl/psi and STC = 1 hr.

2.3. Other calculations

Such other parameters as wellbore storage coefficient, skin factor and permeability are needed for the determination of the time at which radial flow regime starts. For that purpose, Equations 5 to 7, presented by Tiab (1993) are given below:

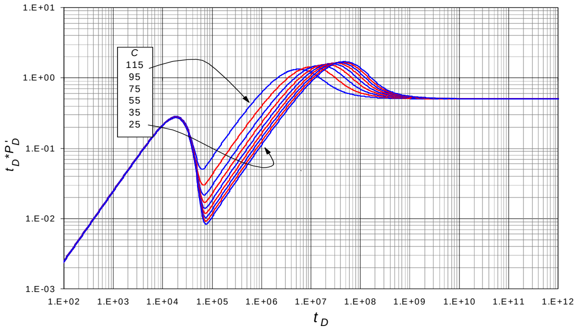

Figure-10. Dimensionless pressure derivative vs. Time for buildup tests with variable wellbore storage coefficient, s = -4, C = 20 bbl/psi and STC = 1 hr.

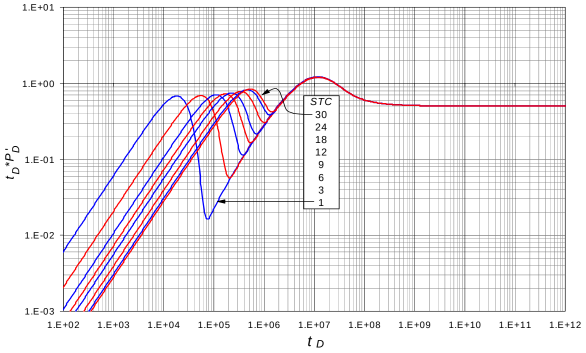

Figure-11. Dimensionless pressure derivative vs. Time for buildup tests with variable storage time constant, s = -4, C = 45 bbl/psi and SA = 50 psi.

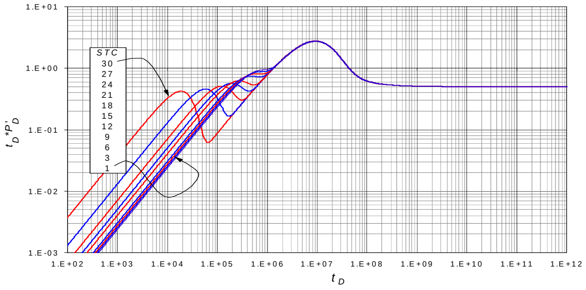

Figure-12. Dimensionless pressure derivative vs. Time for buildup tests with variable storage time constant, s = 0, C = 25 bbl/psi and SA = 30 psi.

$$C = \left(\frac{qB}{24}\right)\frac{t}{(t*\Delta P')} = \left(\frac{qB}{24}\right)\frac{t}{\Delta P} \tag{5}$$

$$s = 0.5\left[\frac{(\Delta P)_r}{(t*\Delta P)_r} - \ln\left(\frac{kt_r}{\phi\mu c_t r_w^2}\right) + 7.43\right] \tag{6}$$

$$k = \frac{70.6q\mu B}{h\left(t*\Delta P'\right)_r} \tag{7}$$

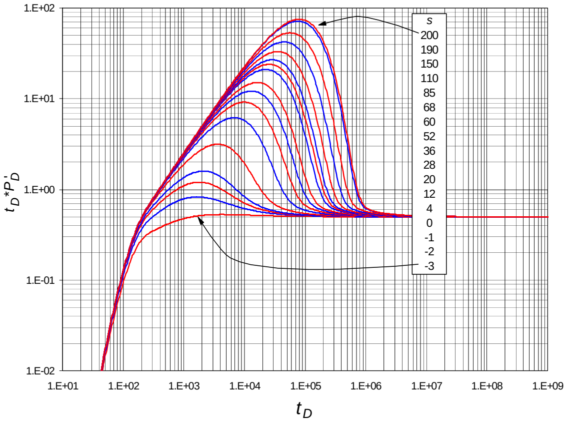

Figure-13. Dimensionless pressure derivative vs. time for buildup tests with variable skin factor, $C = 0.01$ bbl/psi, $SA = -10$ psi and $STC = 0.0045$ hr.

The dimensionless time is defined by:

$$t_D = \frac{0.0002637kt}{\phi \mu c_t r_w^2} \tag{8}$$

3. EXAMPLES

3.1. Field example

The presence of variable wellbore storage was observed in a pressure test run in an oil well in Colombia. Pressure and pressure derivative for this case are reported in Figure-14 and relevant information for this test is given in the third column of Table-1. As notice in Figure-14, the high influence of the bottom aquifer does not allow the development of radial flow regime. Then, this example was only presented for demonstrating typical cases of wellbore storage variation. However, a simulation was performed to find the variables affecting the variable wellbore storage. See Table-2.

Table-2. Output data for field example.

Parameter	Value
C, bbl/psi	0.11
SA, psi	160
STC, hr	0.3305
s	-2

3.2. Synthetic drawdown example

Relevant data for this test are given in the fourth column of Table-1 and pressure and pressure derivative data are plotted in Figure-15 from which we read:

$t_{min} = 2.5$ hr $(t*\Delta P')_{min} = 1.4$ psi $t_r = 1\text{x}10^5$ hr
$(t*\Delta P')_r = 15$ psi $\Delta P_r = 230$ psi $t_i = 0.7$ hr
$(t*\Delta P')_i = 15$ psi

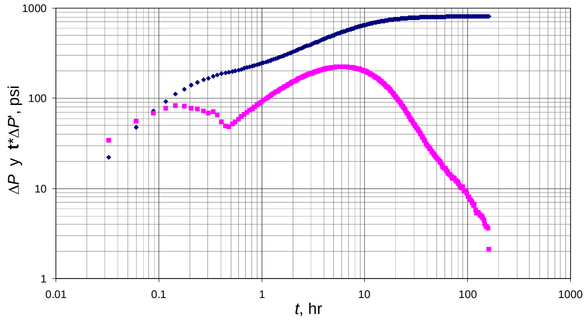

Figure-14. Pressure derivative vs. time log-log plot for a pressure test run in a Colombian well - field example.

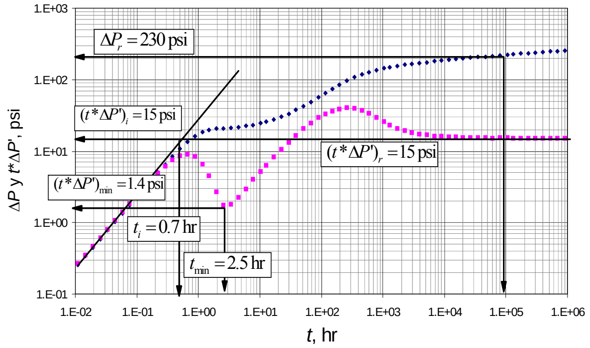

Figure-15. Pressure derivative vs. Time log-log plot for for synthetic drawdown example.

Equations-5 and 6 allow to find a wellbore storage coefficient of 42 bbl/psi and a skin factor of -3.66, respectively. Equation 1 was used to estimate a start o radial flow dimensionless time, $(t_{SSL})_D$, of 11496694255 which translates into 311000 hr by means of Equation 8 which according to Figure-15 matches with the expected value.

3.3. Synthetic buildup example

Figure-16 presents an example for validation of Equation 4 for a pressure buildup tests with variable wellbore storage. This test was generated with input data from the fifth column of Table-1. From Figure-16, the following information was read.

$t_{min} = 2.3$ hr $(t*\Delta P')_{min} = 1.3$ psi $t_r = 1\text{x}10^5$ hr
$(t*\Delta P')_r = 16$ psi $\Delta P_r = 220$ psi $t_i = 0.75$ hr
$(t*\Delta P')_i = 16$ psi

Again, Equations-5 and 6 were used to find values of wellbore storage of 42 bbl/psi and a skin factor of -4.45. As mentioned above, Equation 3 allowed the estimation of $(t_{SSL})_D$ of 8193767834 which also results in 311000 hr by using Equation 8. The obtained result is close to the expected one as observed in Figure-16.

As a final remark, the time of start of the radial flow regime in both exercised were estimated with an error less than 15 %.

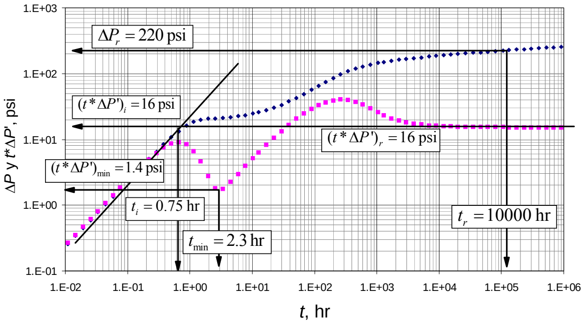

Figure-16. Pressure derivative vs. Time log-log plot for for synthetic buildup example.

4. CONCLUSIONS

Correlations for the estimation of the start of radial flow regime (start of semilog straight line) for cases of variable wellbore storage coefficient in both pressure drawdown and buildup tests are introduced and successfully tested with synthetic examples.

ACKNOWLEDGEMENTS

The authors gratefully thank the Most Holy Trinity and the Virgin Mary mother of God for all the blessing received during their lives.

The authors also thank Universidad Surcolombiana for providing financial support for the complement of this study.

Nomenclature

B	Oil volume factor, rb/STB
c_t	Compressibility, 1/psi
h	Formation thickness, ft
k	Formation compressibility, md
P	Pressure, psi
P_{wf}	Well-flowing pressure, psi
P_{ws}	Shit-in well pressure, psi
q	Flow rate, STB/D
r_w	Wellbore radius, ft
s	Skin factor
t	Test time, hr
$(t*\Delta P')$	Pressure derivative, psi
(t_D*P_D')	Dimensionless pressure derivative
SA	Maximum storage amplitude, psi
STC	storage time constant, hr

Greek

Δ	Change
ϕ	Porosity, fraction
μ	Viscosity, cp

Suffixes

D	Dimensionless
i	Intercept of radial and early unit-slope lines
min	Minimum
r	Radial
w	well

REFERENCES

Chen H. and Brigham W.E. 1974. Pressure Buildup for a Well with Storage and Skin in a closed Square. Paper SPE 4890, 44th Annual California Regional Meeting. San Francisco.

Earlougher R. C. Jr. 1977. Advances in Well Test Analysis. SPE monograph. February. (5): 264.

Fair W.B. Jr. 1981. Pressure Buildup Analysis with Wellbore Phase Redistribution. SPEJ (April) 259. Trans. AIME 271.

Hegeman P. S., Hallford D.K. and Joseph J.A. 1993. Well-test Analysis with Changing Wellbore Storage. SPE Formation Evaluation. September. pp. 201-207.

Medina M.V. and Olaya D.A. 2012. Determinación del Tiempo de Inicio del Flujo Radial en Pruebas de Presión con Almacenamiento Variable. B.Sc. thesis. Universidad Surcolombiana.

Ramey H.J. Jr. and Agarwal R.G. 1972. Annulus Unloading Rates as Influenced by Wellbore Storage and Skin Effects. SPEJ (October) 453. Trans. AIME 253.

Tiab D. 1993. Analysis of Pressure and Pressure Derivative without Type-Curve Matching: 1- Skin and Wellbore Storage. Journal of Petroleum Science and Engineering. 12: 171-181.