A New Approach to Interference Test Analysis

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Summary. The line-source solution of the diffusivity equation is differentiated and rearranged so that a linear relation between the variables is obtained. A plot of log tp' vs. $1/t$ yields a straight line whose intercept and slope are used to estimate the transmissivity, kh/μ, and the storativity, $h\phi c_t$, respectively. The method is extended to handle two-rate tests, including buildup tests, and can be used for the analysis of the combined data of the two periods.

Introduction

In interference test analysis, the semilog plotting techniques are inadequate because of the invalidity of the logarithmic approximation of the exponential integral function at large times. Usually type-curve matching is used. Recently, analysis methods based on the pressure derivative, p', were introduced.[1-3] Tiab and Kumar[1] used the maximum value of p' and the time at that point to estimate the transmissivity and storativity of the reservoir. Bourdet *et al.*[2] introduced type-curve matching methods that involve both pressure-drop and pressure-derivative matching. Clark and van Golf-Racht[3] extended the pressure-derivative methods to variable-rate testing using a superposition time function. In this work, a derivative method that yields a straight-line plot is introduced. More details can be found in Ref. 4.

Method

The derivative of the pressure, with respect to time at a radial distance Δr from an active well as obtained from the line-source solution, is[4]

$$p'(\Delta r,t)=-A\frac{\exp(-b/t)}{t}. \quad (1)$$

Multiplying Eq. 1 by $-t$ and taking logarithms of both sides, we get

$$\ln(-tp')=\ln A-b/t. \quad (2)$$

The constants A and b are related to the transmissivity, T, and storativity, S, by the following equations:

$$T=\frac{kh}{\mu}=\frac{70.6qB}{A} \quad (3)$$

and

$$S=h\phi c_t=\frac{Tb}{948(\Delta r)^2}. \quad (4)$$

It is clear from Eq. 2 that a plot of $|tp'|$ vs. $1/t$ on a semilog graph gives a straight line. The intercept and slope can be used to estimate the transmissivity and storativity of the reservoir. The intercept, A, is read directly on the logarithmic scale as the value of $|tp'|$ at $1/t=0$. The slope in cycles/hr^{-1} would be $-b/2.303$.

Extension to Two-Rate Tests

If the rate at the active well is changed from q_1 to q_2 at time t, it can be shown that[4]

$$\ln|\Delta t(p'+C)q_1/(q_1-q_2)|=\ln A-b/\Delta t, \quad (5)$$

where

$$C=A\frac{\exp[-b/(t+\Delta t)]}{(t+\Delta t)}. \quad (6)$$

Eq. 5 is similar to Eq. 2 and yields a straight line if $|\Delta t(p'+C)q_1/(q_1-q_2)|$ is plotted vs. $1/\Delta t$ on a semilog plot. In this format, the slope and intercept of the straight line are the same as those of Eq. 2. This means that data points from the first rate region ($q=q_1$) calculated according to Eq. 2 can be combined with data points from the second rate region ($q=q_2$) calculated according to Eq. 5 and analyzed together to obtain the values of T and S that fit the data points in the two regions.

In pressure-buildup testing, $q_2=0$ and a semilog plot of $|\Delta t(p'+C)|$ vs. $1/\Delta t$ would give a straight line with the same slope and intercept as those of Eqs. 2 and 5.

Because C is not known in advance and depends on A and b in addition to Δt, an iterative procedure must be used in the analysis. An initial value of $C=0$ may be used, and the constants A and b are estimated either graphically or by linear regression. The values of A and b obtained are used to update C according to Eq. 6. The iteration is continued until successive values of A and b become constant within a prescribed limit. The final values of A and b are then used to estimate the transmissivity and storativity from Eqs. 3 and 4, respectively.

Illustrative Example

The developed method is applied to the interference test data of a gas well reported by Ramey *et al.*[5] Table 1 shows the test data, calculations, and final results. The term tp' is approximated by $\Delta p/\Delta \ln t$ at the geometric average time $\sqrt{t_1 t_2}$. The method of least squares was used to find the constants A and b. A graphic presentation of the data is shown in Fig. 1. Type-curve matching results reported by Ramey *et al.* are also shown in Table 1. Comparison with results obtained by this method indicates a difference of about 3% in the transmissivity and 0.6% in the storativity, indicating the accuracy of the proposed method.

Conclusions

A new approach for interference test analysis is introduced. A semilog plot of tp' vs. $1/t$ gives a straight line from its intercept, and slope reservoir parameters can be estimated. The method can also be applied to two-rate interference tests for which an iterative procedure is used. Data points from the two regions may be analyzed separately or combined.

Nomenclature

- A = constant defined in Eq. 3, psi [kPa]
- b = constant defined in Eq. 4, hours
- B = FVF, RB/STB [res m^3/stock-tank m^3]
- B_g = gas FVF, ft^3/STB [m^3/stock-tank m^3]

TABLE 1—TEST DATA AND CALCULATIONS FOR EXAMPLE

t (hours)	p_w (psig)	$-\Delta p$ (psi)	$\ln t$ (hours)	$\Delta \ln t$ (hours)	$\frac{-\Delta p}{\Delta \ln t}$ (psi)	$\bar{t}$ (hours)	$1/\bar{t}$ (hours^{-1})
0	2,715	0	—	—	—	—	—
48	2,712	3	3.8712	—	—	—	—
72	2,706	6	4.2767	0.4055	14.80	58.79	0.0170
96	2,700	6	4.5643	0.2876	20.87	83.14	0.0120
120	2,693	7	4.7875	0.2232	31.37	107.33	0.0093
144	2,687	6	4.9698	0.1923	32.91	131.45	0.0076
168	2,680	7	5.1240	0.1542	45.40	155.54	0.0064
336	2,640	40	5.8171	0.6931	57.71	237.59	0.0042
504	2,615	25	6.2266	0.4055	61.66	411.51	0.0024

Reservoir Data	
Δr, ft	495
q, scf/D	1.25×10^6
c_t, psi^{-1}	23.45×10^{-5}
B_g, reservoir volume/ stock-tank volume	5.63×10^{-3}
h, ft	12
μ_g, cp	0.0203
ϕ	0.17

Final Results	Proposed Method	Type-Curve Matching
A, psi	82.22	84.57
$-b$, hours	105.05	107.36
T, md-ft/cp	1,076.18	1,046.30
S, ft-psi^{-1}	4.87×10^{-4}	4.84×10^{-4}

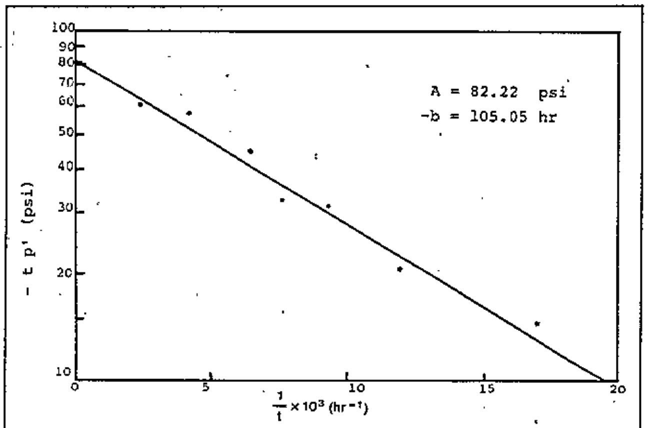

Fig. 1—Analysis of interference test data.

c_t = total compressibility, psi^{-1} [kPa^{-1}]
C = parameter defined by Eq. 6, psi/hr [kPa/s]
h = formation thickness, ft [m]
k = permeability, md
p = pressure, psi [kPa]
p_w = wellbore pressure, psi [kPa]
p' = time derivative of pressure, psi/hr [Pa/s]
q = flow rate, STB/D [stock-tank m^3/d]
Δr = radial distance, ft [m]
S = storativity$=h\phi c_t$, ft-psi^{-1} [m·kPa^{-1}]
t = time, hours
$\bar{t}$ = average time, hours
T = transmissivity$=kh/\mu$, md-ft/cp [md·m/kPa·s]
μ = viscosity, cp [kPa·s]
μ_g = gas viscosity, cp [kPa·s]
ϕ = porosity, fraction

References

1. Tiab, D. and Kumar, A.: "Application of the p_D' Function to Interference Analysis," *JPT* (Aug. 1980) 1465-70.
2. Bourdet, D. *et al.*: "A New Set of Type Curves Simplified Well Test Analysis," *World Oil* (May 1983) 95-106.
3. Clark, D.G. and van Golf-Racht, T.D.: "Pressure-Derivative Approach to Transient Test Analysis: A High-Permeability North Sea Reservoir Example," *JPT* (Nov. 1985) 2023-29.
4. El-Khatib, N.A.F.: "A New Approach to Interference Test Analysis," paper SPE 13733 presented at the 1985 SPE Middle East Oil Technical Conference, Bahrain, March 11-14.
5. Ramey, H.J. Jr., Kumar, A., and Gulati, M.S.: *Gas Well Test Analysis Under Water Drive Conditions*, AGA, Arlington, VA (1973) 14-20.

SI Metric Conversion Factors

cp	× 1.0*	E+00	= mPa·s
ft	× 3.048*	E−01	= m
ft^3	× 2.831 685	E−02	= m^3
psi	× 6.894 757	E+00	= kPa
psi^{-1}	× 1.450 377	E−01	= kPa^{-1}

*Conversion factor is exact.

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