Production Analysis Decline Type Curves

Library of Decline Type Curves

Library of Decline Type Curves:

- Fetkovich Type Curves — Radial Flow:
  - Original Fetkovich Decline Type Curve
  - "Rate Derivative" Decline Type Curve
- Fetkovich-McCray Type Curves — Radial Flow:
  - Fetkovich-McCray Type Curve
  - Fetkovich-Carter-McCray Type Curve (Gas)
  - Boundary Flux (do not use...)
- Fetkovich-McCray Curves — Fractured Wells:
  - Infinite Conductivity Vertical Fracture
  - Finite Conductivity Vertical Fracture
- Fetkovich-McCray Curves — Horizontal Wells
- Agarwal, et al. Methodology:
  - Radial Flow Case
  - Vertically Fractured Well Cases
- Crafton, et al. Methodology:
  - Rate normalization only...

SPE 4629

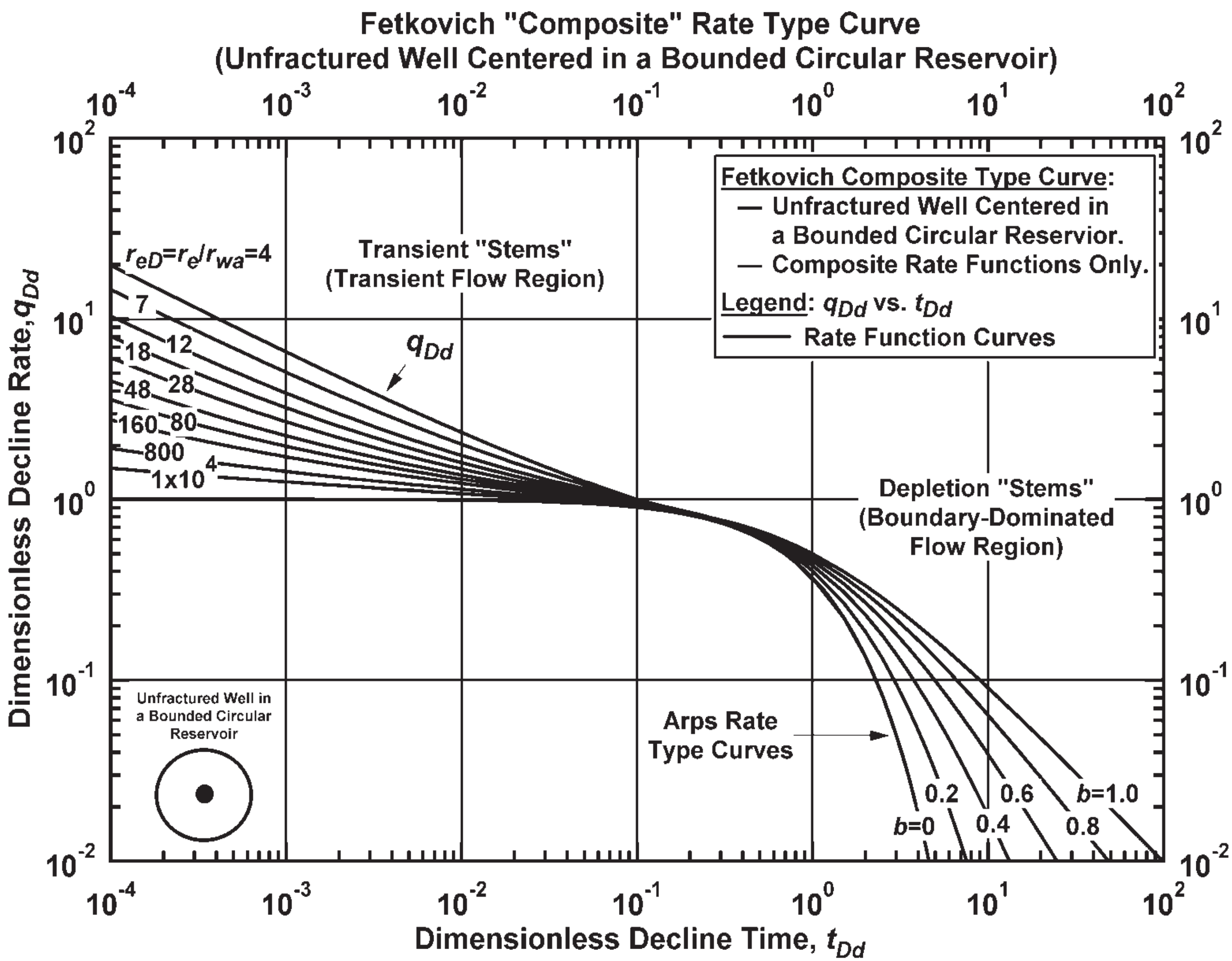
Decline Curve Analysis Using Type Curves

M.J. Fetkovich, SPE, Phillips Petroleum Co.

This paper demonstrates that decline curve analysis not only has a solid fundamental base but also provides a tool with more diagnostic power than has been suspected previously. The type curve approach provides unique solutions on which engineers can agree or shows when a unique solution is not possible with a type curve only.

JUNE 1980
1065

Fetkovich Decline Type Curve — Composite Curve

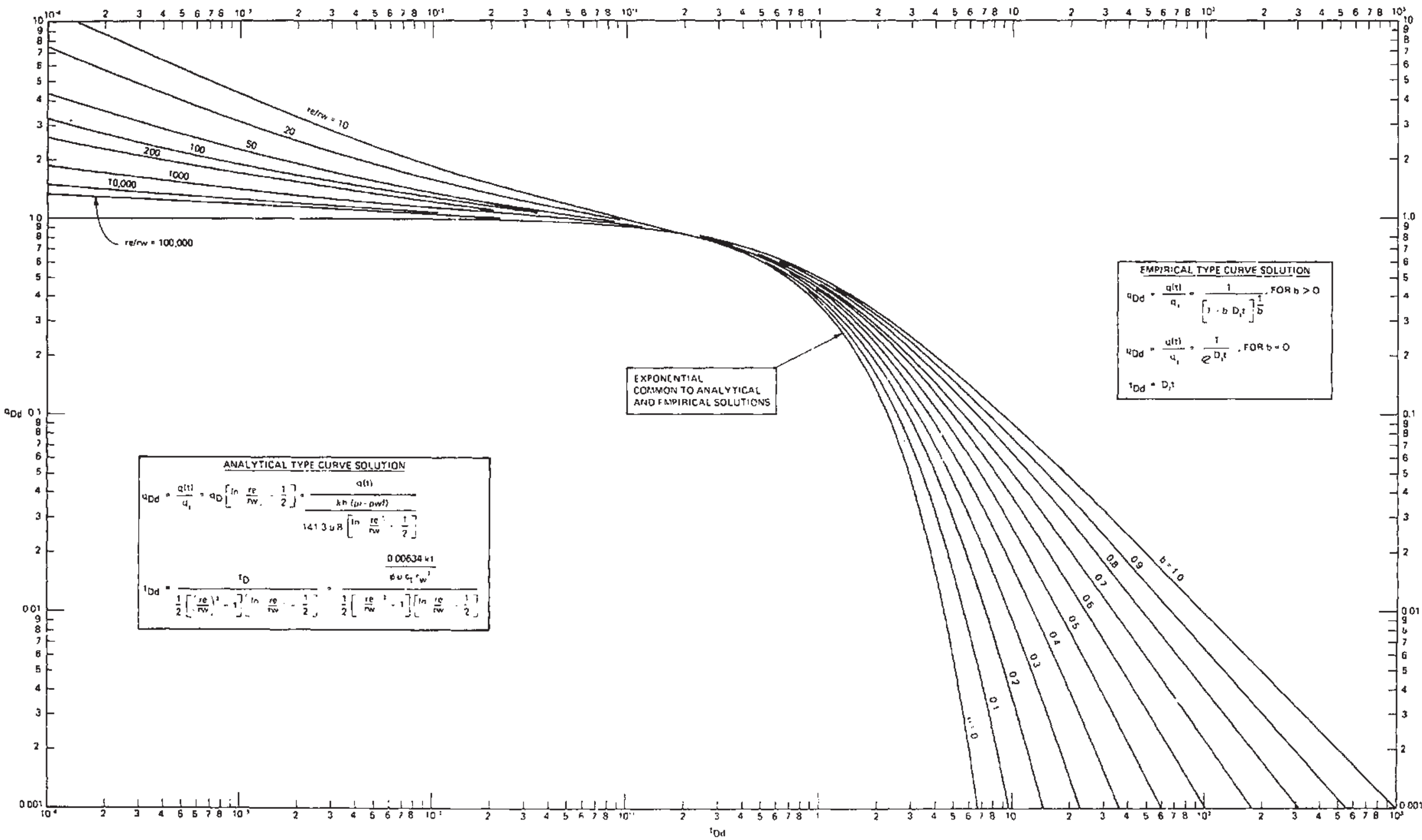


Fetkovich, M.J.: "Decline Curve Analysis Using Type Curves," JPT (June 1980) 1065-1077.

Discussion: ***Fetkovich "Composite" Decline Type Curve***
- **Assumes constant bottomhole pressure production.**
- **Radial flow in a finite radial reservoir system (single well).**

Fetkovich Decline Type Curve — Composite Curve (original curve)

Fetkovich, M.J.: "Decline Curve Analysis Using Type Curves," JPT (June 1980) 1065-1077.



Composite of analytical and empirical type curves.

<u>Discussion</u>: *Fetkovich "Composite" Decline Type Curve*

- **Reproduction of the original Fetkovich decline curve.**

Fetkovich Decline Type Curve — Example Data Case (Well 13 — SPE 004629)

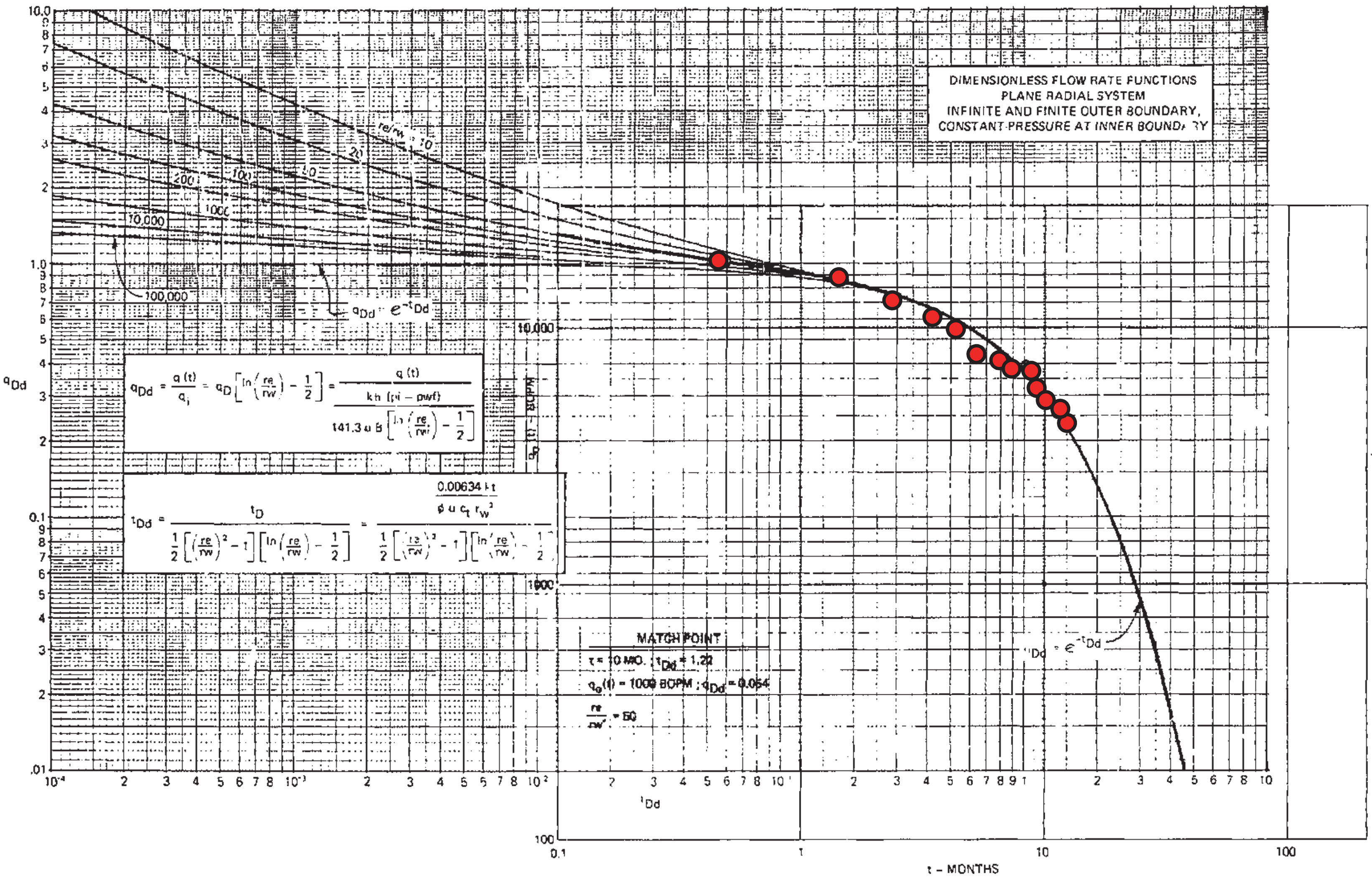
Fetkovich, M.J.: "Decline Curve Analysis Using Type Curves," JPT (June 1980) 1065-1077.

TABLE 3 – COMPARISONS OF kh DETERMINED FROM BUILDUP AND DECLINE CURVE ANALYSIS, FIELD A (SANDSTONE RESERVOIR); 160-ACRE SPACING, r_e = 1,490 ft, r_w = 0.25 ft

				Pressure Buildup Results			Decline Curve Analysis Results				
Well No.	h (ft)	ϕ (%)	S_{wc} (%)	Skin s	r_w' (ft)	kh (md-ft)	r_e/r_w' Matched	q_{Dd} (10,000 BOPM)	$\frac{p_i - p_{wf}}{(\mu_o B_o)}$	kh (md-ft)	k (md)
1	34	9.4	32.9	−0.23	0.3	120.5	*	0.52	6658	108	3.18
2	126	10.5	18.3	−2.65	3.5	56.7	*	0.68	7979	48	0.38
3	32	9.9	20.4	−3.71	10.3	63.0	*	0.43	8048	60	1.88
4	63	9.5	18.6	−3.41	7.6	28.5	40	0.58	8273	31	0.49
5	67	10.2	15.1	−4.29	18.3	44.4	20	0.57	6296	32	0.48
6	28	10.3	12.6	−2.07	2.0	57.9	*	0.60	7624	62	2.21
7	17	10.0	17.5	−3.41	7.6	16.8	10	1.30	7781	8.3	0.49
8	47	9.1	24.2	−3.74	10.6	16.6	10	1.14	7375	10	0.21
9	87	10.2	18.0	−4.19	16.5	104.7	*	0.435	5642	76	0.87
10	40	10.4	21.7	−5.80	82.9	363.2	*	0.36	1211	255	6.38
11	29	11.5	19.2	−1.00	2.0	59.9	*	0.56	7669	66	2.28
12	19	11.1	17.0	−3.97	13.3	8.9	50	3.30	5045	9.5	0.50
13	121	10.1	18.8	−3.85	11.8	47.5	50	0.54	7259	40.5	0.33
16	74	9.4	20.4	−4.10	15.0	224.8	*	0.32	5737	104	1.41
15	49	10.9	28.6	−3.59	9.1	101.9	*	0.43	4312	115	2.35
16	35	10.0	25.6	−4.57	24.2	14.3	20	0.96	5110	24	0.69
17	62	8.8	22.4	−3.12	5.7	27.2	*	0.82	8198	35	0.56
18	75	9.4	18.1	−1.50	1.2	65.1	*	0.52	6344	93	1.24
19	38	8.9	19.2	−2.11	2.1	40.5	20	0.54	6728	32	0.84
20	60	9.6	24.6	−5.48	60.1	88.1	*	0.345	5690	64	1.07
21	56	11.1	16.5	−2.19	2.2	39.1	20	0.72	5428	30	0.54
22	40	8.9	22.5	−3.79	11.1	116.0	100	0.46	8114	51	1.28

*r_w' used from buildup analysis with r_e of 1,490 ft.

Fetkovich Decline Type Curve — Example Data Case (Well 13 — SPE 004629)



$$q_{Dd} = \frac{q(t)}{q_i} = q_D\left[\ln\left(\frac{r_e}{r_w}\right) - \frac{1}{2}\right] = \frac{q(t)}{\dfrac{kh\,(p_i - p_{wf})}{141.3\,\mu B\left[\ln\left(\frac{r_e}{r_w}\right) - \frac{1}{2}\right]}}$$

$$t_{Dd} = \frac{t_D}{\frac{1}{2}\left[\left(\frac{r_e}{r_w}\right)^2 - 1\right]\left[\ln\left(\frac{r_e}{r_w}\right) - \frac{1}{2}\right]} = \frac{\dfrac{0.00634\,kt}{\phi \mu c_t r_w^2}}{\frac{1}{2}\left[\left(\frac{r_e}{r_w}\right)^2 - 1\right]\left[\ln\left(\frac{r_e}{r_w}\right) - \frac{1}{2}\right]}$$

Type-curve matching example for calculating Kh using decline curve data, Well 13, Field A.

Fetkovich, M.J.: "Decline Curve Analysis Using Type Curves," JPT (June 1980) 1065-1077.

Discussion: ***Fetkovich Example Match*** **(SPE 004629)**

- **Lack of early time data is an omen of things to come.**
- **Late time data follow an exponential trend (constant p_{wf}).**

Decline-Curve Analysis Using Type Curves—Case Histories

M.J. Fetkovich, SPE, Phillips Petroleum Co.
M.E. Vienot, SPE, Phillips Petroleum Co.
M.D. Bradley, SPE, Phillips Petroleum Co.
U.G. Kiesow, SPE, Phillips Petroleum Co.

SPE Formation Evaluation, December 1987 637

Fetkovich West Virginia Well A (SPE 013169)

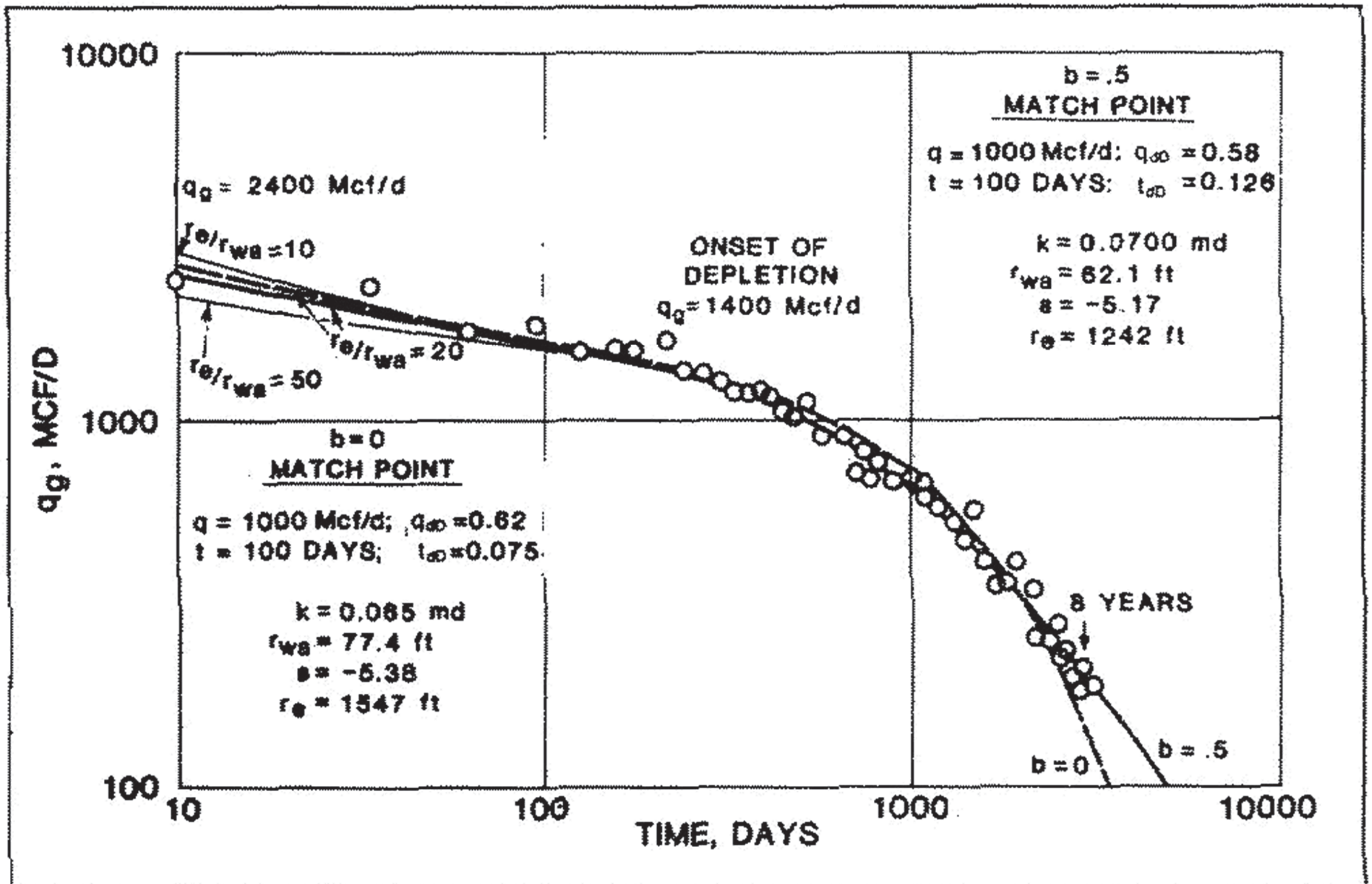


Fig. 17—West Virginia Gas Well A type-curve fit of 8 years of production data fit to a *b* = 0 and *b* = 0.5.

Fetkovich, M.J., Vienot, M.E., Bradley and M.D., Kiesow, U.G.: "Decline Curve Analysis Using Type Curves – Case Histories," SPEFE (Dec. 1987) 637-656.

Fetkovich West Virginia Well A (SPE 013169)

Fetkovich, M.J., Vienot, M.E., Bradley and M.D., Kiesow, U.G.: "Decline Curve Analysis Using Type Curves – Case Histories," SPEFE (Dec. 1987) 637-656.

TABLE 3—WEST VIRGINIA GAS WELL A

Reservoir and Fluid Properties	
Gas specific gravity	0.57 (air = 1.00)
Porosity	0.06
Water saturation	0.35
Original pressure, psia	4,175
Pressure at start of decline, psia	3,268
Viscosity at 3,268 psia, cp	0.0171
System compressibility at 3,268 psia, psi^{-1}	177×10^{-6}
Thickness, ft	70
Temperature, °F	160
Wellbore radius, ft	0.354
Rate before 106-day pressure buildup, Mscf/D	2,181
Δp_p, psi^2/cp	774×10^6
B_g at 3,268 psia, scf/ft^3	208.8
B_g at 4,175 psia, scf/ft^3	253.9

TABLE 5—WEST VIRGINIA GAS WELL A: SUMMARY OF RATE-TIME ANALYSIS RESULTS

Match Points

Composite Type Curve $b = 0$		Composite Type Curve $b = 0.5$		Carter Type Curve $\lambda = 0.55$ ($b = 0.5$)	
q_{dD}	0.62	q_{dD}	0.58	q_{DR}	0.24
t_{dD}	0.075	t_{dD}	0.126	t_{DR}	60
$q(t)$, Mscf/D	1,000	$q(t)$, Mscf/D	1,000	$q(t)$, Mscf/D	1,000
t, days	100	t, days	100	t, days	100

	$r_e/r_{wa} = 10$	$r_e/r_{wa} = 20$	$r_e/r_{wa} = 50$	Horner Analysis
$b = 0$ Evaluation				
kh, md-ft	3.292	4.558	6.231	
k, md	0.047	0.065	0.089	0.0805
r_{wa}, ft	154.7	77.4	30.9	
s	−6.08	−5.38	−4.47	−5.52
r_e, ft	1,547	1,547	1,547	
$b = 0.5$ Evaluation				
kh, md-ft	3.542	4.902	6.705	
k, md	0.0506	0.0700	0.0958	
r_{wa}, ft	124.2	62.1	24.8	
s	−5.86	−5.17	−4.25	
r_e, ft	1,242	1,242	1,242	
Carter's $\lambda = 0.55$ Evaluation				
kh, md-ft	3.451	4.746	6.699	
k, md	0.0493	0.0678	0.0957	
r_{wa}, ft	126.4	62.6	24.8	
s	−5.88	−5.17	−4.25	
r_e, ft	1,264	1,252	1,240	

Fetkovich Monterey Wells (SPE 013169)

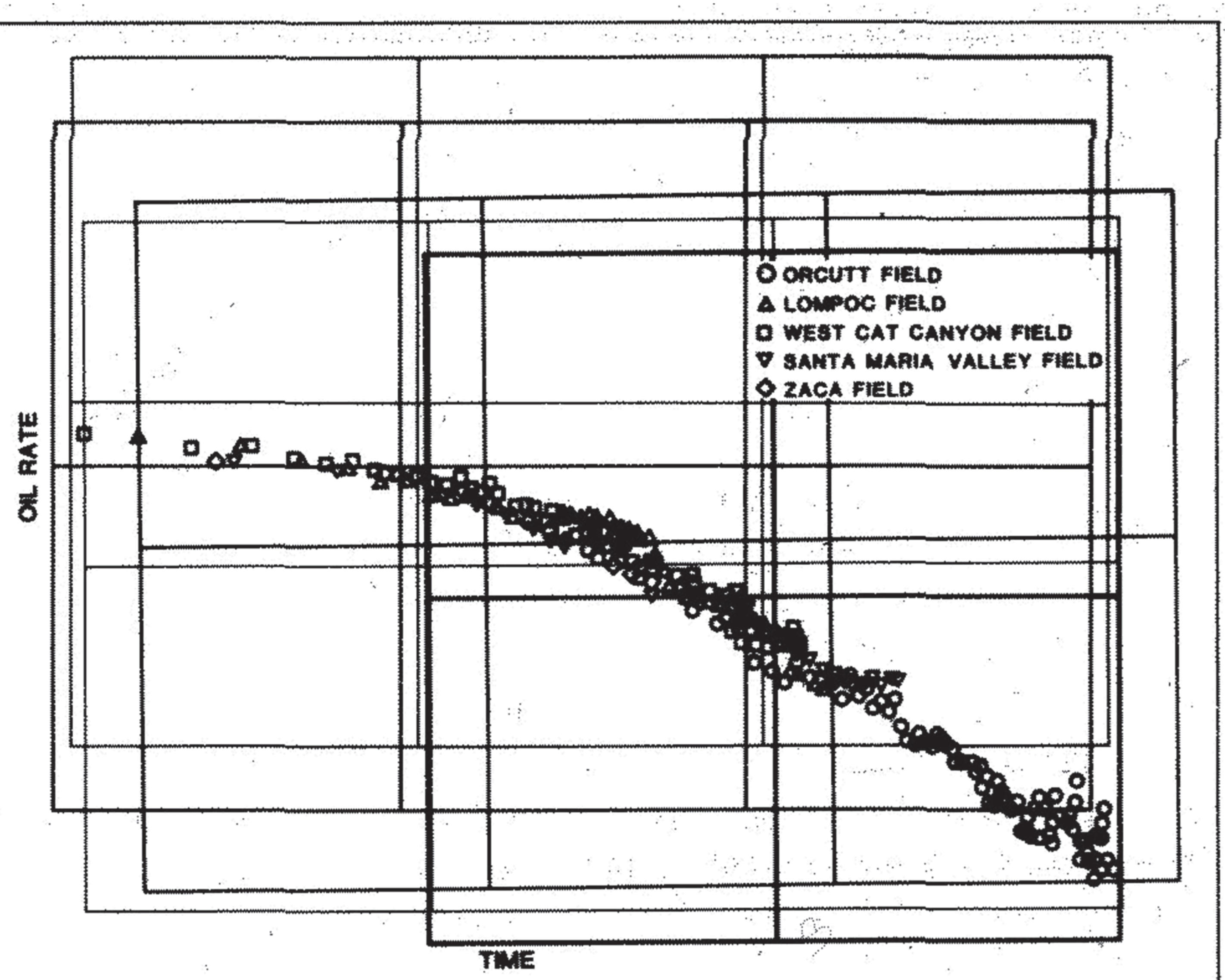


Fig. 42—Overlay of log-rate-vs.-log-time production data of five California Monterey producing fields.

Fetkovich, M.J., Vienot, M.E., Bradley and M.D., Kiesow, U.G.: "Decline Curve Analysis Using Type Curves – Case Histories," SPEFE (Dec. 1987) 637-656.

SPE
Society of Petroleum Engineers

SPE 21513

Decline Curve Analysis for Variable Pressure Drop/Variable Flowrate Systems

by T.A. Blasingame, T.L. McCray, and W.J. Lee, Texas A&M U.

SPE 25909

Decline-Curve Analysis Using Type Curves--Analysis of Gas Well Production Data

by J.C. Palacio, ECOPETROL(Colombia)/Texas A&M U. and T.A. Blasingame, Texas A&M U.

This is a preprint -- subject to correction.
19 October 1994

SPE
Society of Petroleum Engineers

SPE 28688

Decline Curve Analysis Using Type Curves--Analysis of Oil Well Production Data Using Material Balance Time: Application to Field Cases

by L.E. Doublet,* Texas A&M U., P.K. Pande,* Fina Oil and Chemical Company, T.J. McCollum,* UNOCAL-Coastal California, and T.A. Blasingame,* Texas A&M U.

* SPE Members

Auxiliary Plotting Functions (Theory)

Q. ***What are the "auxiliary" plotting functions for PA?***
A. ***Time (or material balance time)-averaged pressure drop and flowrate functions — "integral" and "integral-derivative" forms are used.***

Normalized Pressure Drop:

- **"Pressure Derivative"**

$$\left[\frac{\Delta p}{q_o}\right]_d = \bar{t}\,\frac{d}{d\bar{t}}\left[\frac{\Delta p}{q_o}\right]$$

- **"Pressure Integral"**

$$\left[\frac{\Delta p}{q_o}\right]_i = \frac{1}{\bar{t}}\int_0^{\bar{t}}\left[\frac{\Delta p}{q_o}\right]d\bar{t}$$

- **"Pressure Integral-Derivative"**

$$\left[\frac{\Delta p}{q_o}\right]_{id} = \bar{t}\,\frac{d}{d\bar{t}}\left[\left[\frac{\Delta p}{q_o}\right]_i\right]$$

Normalized Flowrate:

- **"Rate Derivative"**

$$\left[\frac{q_o}{\Delta p}\right]_d = \bar{t}\left|\frac{d}{d\bar{t}}\left[\frac{q_o}{\Delta p}\right]\right|$$

- **"Rate Integral"**

$$\left[\frac{q_o}{\Delta p}\right]_i = \frac{1}{\bar{t}}\int_0^{\bar{t}}\left[\frac{q_o}{\Delta p}\right]d\bar{t}$$

- **"Rate Integral-Derivative"**

$$\left[\frac{q_o}{\Delta p}\right]_{id} = \bar{t}\left|\frac{d}{d\bar{t}}\left[\left[\frac{q_o}{\Delta p}\right]_i\right]\right|$$

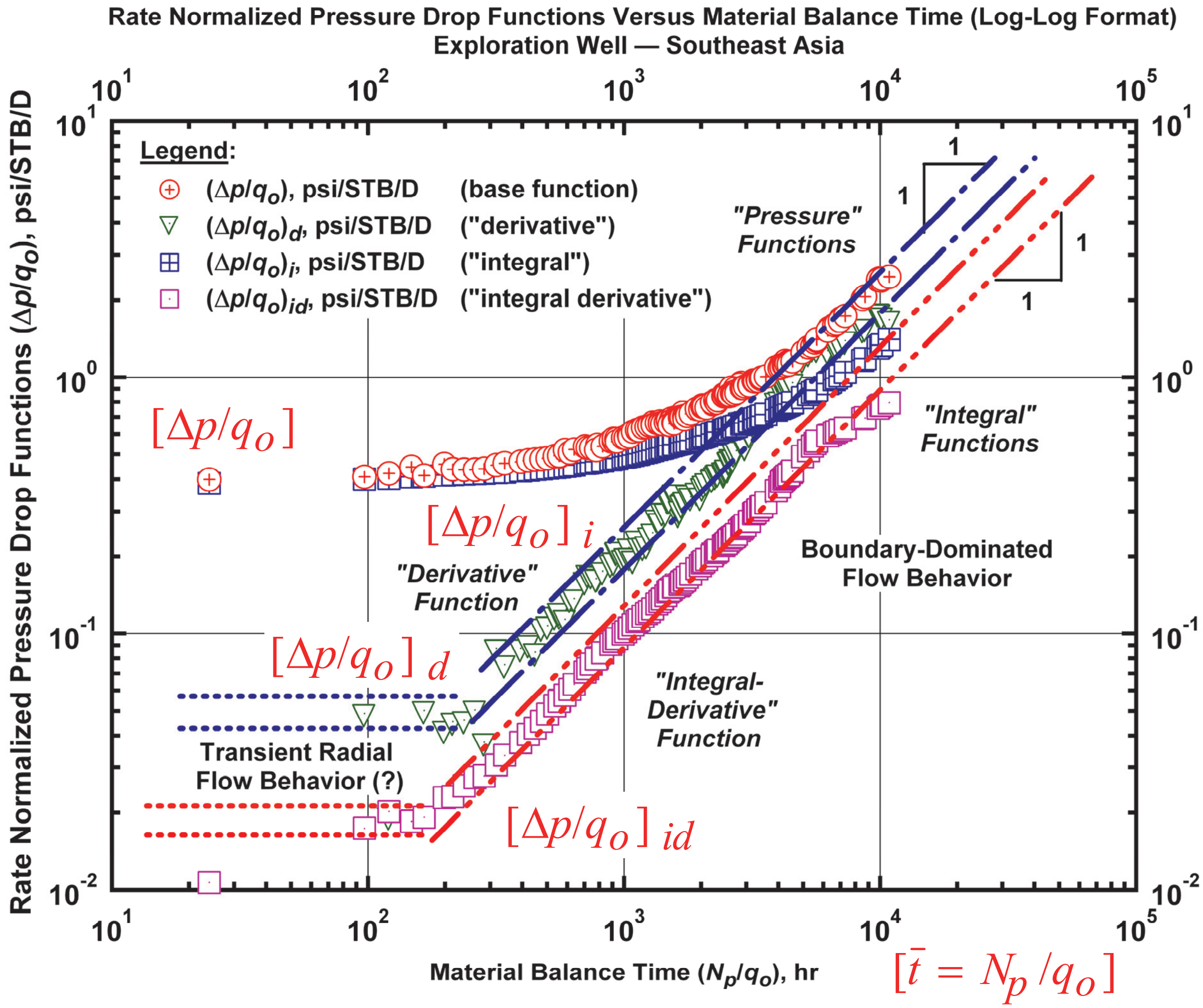
Theory:
The auxiliary functions (specifically the integral and integral derivative functions) are designed to provide "smooth" data functions – which should improve interpretation and analysis.

Application:
- ***"Pressure drop" functions → "Normalized PI" plot .***
- ***Flowrate" functions → "Blasingame" plot .***

Discussion: Modern *PA* — *Auxiliary Plotting Functions (Theory)*
- ***Theory for auxiliary plotting functions?*** **(just calculus ...)**
- ***Purpose of auxiliary plotting functions?*** **(more resolution for *PA* data)**
- ***Advice?*** **(use *BOTH* pressure drop and flowrate functions (separate plots))**

Auxiliary Plotting Functions (Application 1)

Q. *Application 1 — What is the "Normalized PI" plot?*
A. *Pressure drop auxiliary functions versus material balance time.*



Theory:
(Δp/qo) fcns versus N_p/q_o:

$$\bar{t} = \frac{N_p}{q_o}$$

$$\left[\frac{\Delta p}{q_o}\right]_d = \bar{t}\,\frac{d}{d\bar{t}}\left[\frac{\Delta p}{q_o}\right]$$

$$\left[\frac{\Delta p}{q_o}\right]_i = \frac{1}{\bar{t}}\int_0^{\bar{t}}\left[\frac{\Delta p}{q_o}\right]d\bar{t}$$

$$\left[\frac{\Delta p}{q_o}\right]_{id} = \bar{t}\,\frac{d}{d\bar{t}}\left[\left[\frac{\Delta p}{q_o}\right]_i\right]$$

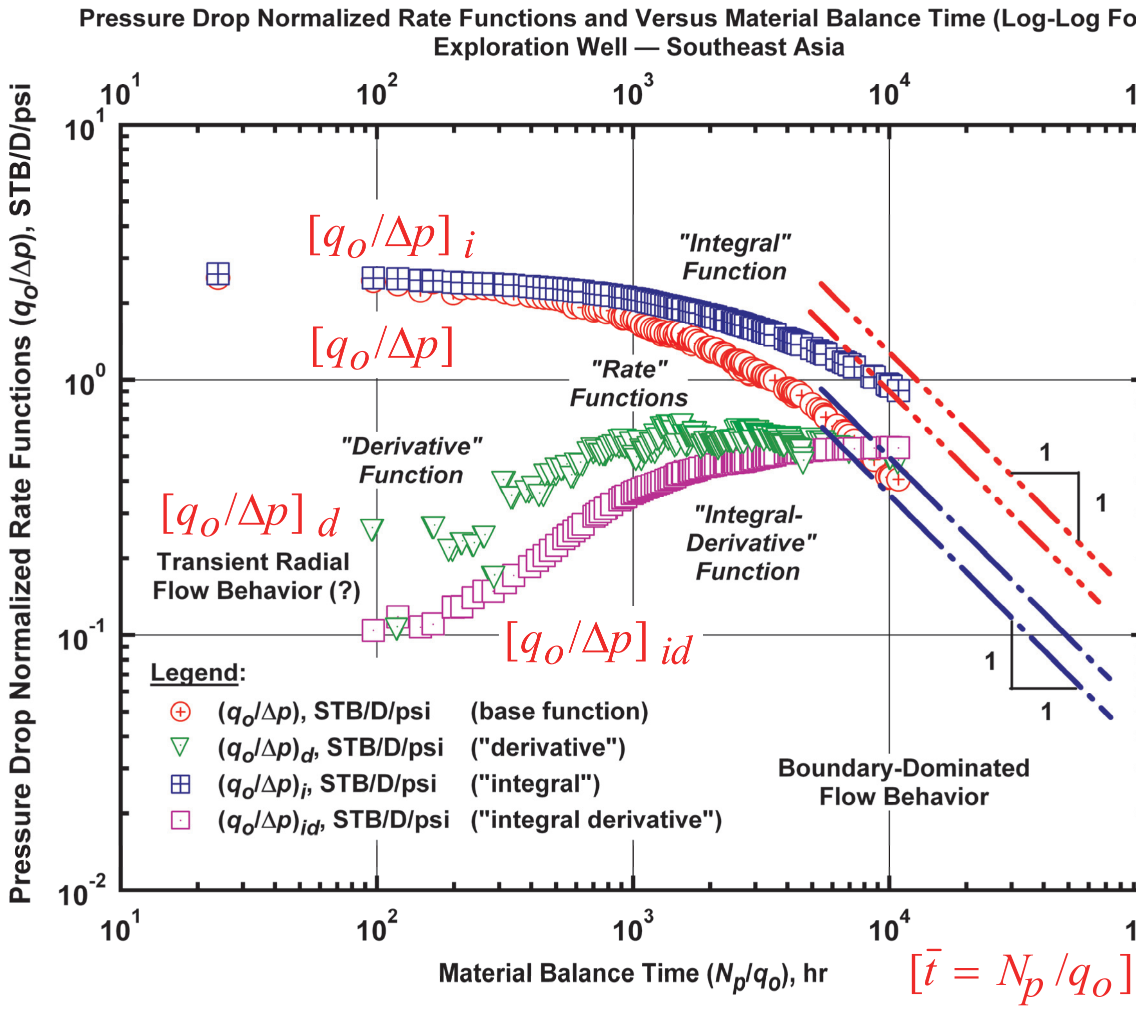
Application:
Analysis approach same as PTA — look for characteristic behavior.

Discussion: Modern *PA — Aux. Plotting Functions* ("*Normalized PI" plot*)

- ***$(\Delta p/q_o)$ functions versus N_p/q_o?*** (*PTA form*: transient flow — ?, *BDFB — yes!*)
- ***Validity of $(\Delta p/q_o)_d$ function?*** (exceptional case — downhole pressure data)
- ***$(\Delta p/q_o)_i$ and $(\Delta p/q_o)_{id}$ functions?*** (smooth and representative)

Auxiliary Plotting Functions (Application 2)

Q. *Application 2 — What is the "Blasingame" plot?*
A. *Rate auxiliary functions versus material balance time.*



Theory:
($q_o/\Delta p$) fcns versus N_p/q_o:

$$\bar{t} = \frac{N_p}{q_o}$$

$$\left[\frac{q_o}{\Delta p}\right]_d = \bar{t}\left|\frac{d}{d\bar{t}}\left[\frac{q_o}{\Delta p}\right]\right|$$

$$\left[\frac{q_o}{\Delta p}\right]_i = \frac{1}{\bar{t}}\int_0^{\bar{t}}\left[\frac{q_o}{\Delta p}\right]d\bar{t}$$

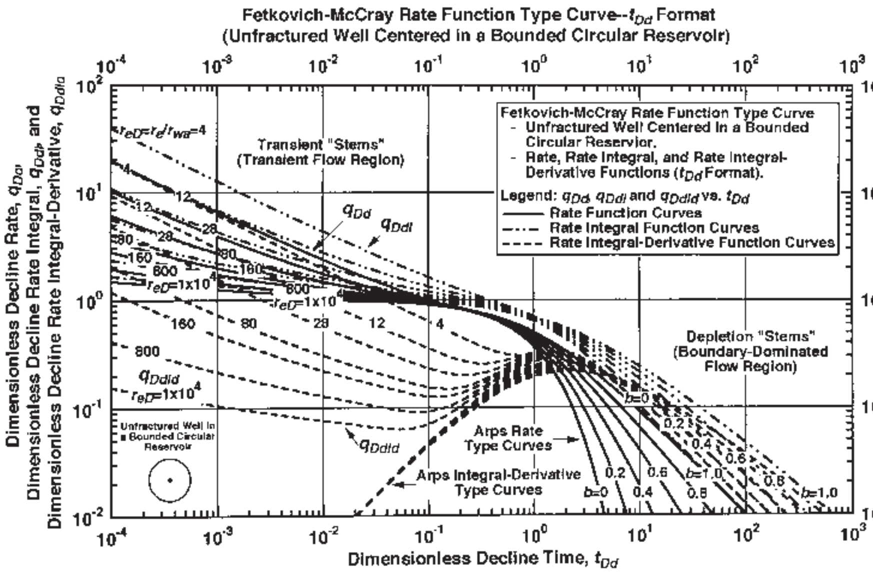
$$\left[\frac{q_o}{\Delta p}\right]_{id} = \bar{t}\left|\frac{d}{d\bar{t}}\left[\left[\frac{q_o}{\Delta p}\right]_i\right]\right|$$

Application:
Transient flow behavior is complex, but transition and BDFB unique.

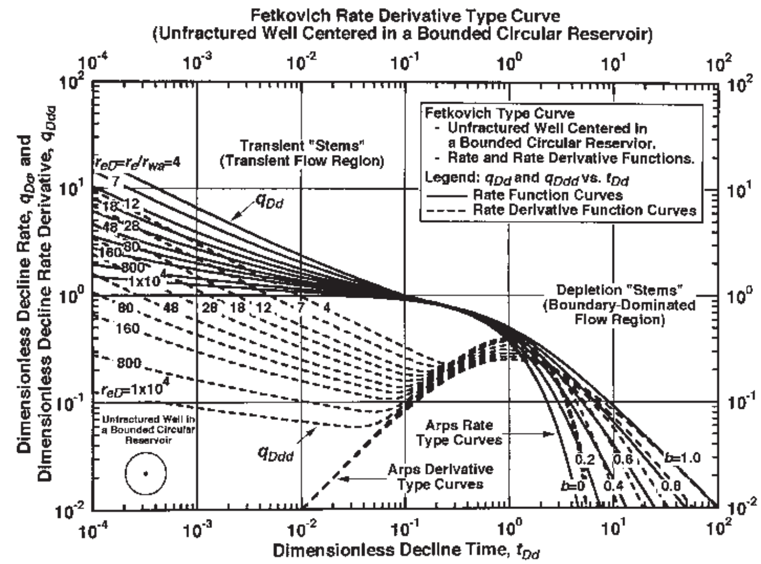
Discussion: Modern *PA* — *Auxiliary Plotting Functions* ("*Blasingame" plot*)

- ***($q_o/\Delta p$) versus N_p/q_o?*** (***rate decline form***: **transient flow — ?, *BDFB — yes!***)
- ***Validity of ($q_o/\Delta p$)$_d$ function?*** **((again) good — downhole pressure data)**
- ***($q_o/\Delta p$)$_i$ and ($q_o/\Delta p$)$_{id}$ functions?*** **(well-behaved and representative)**

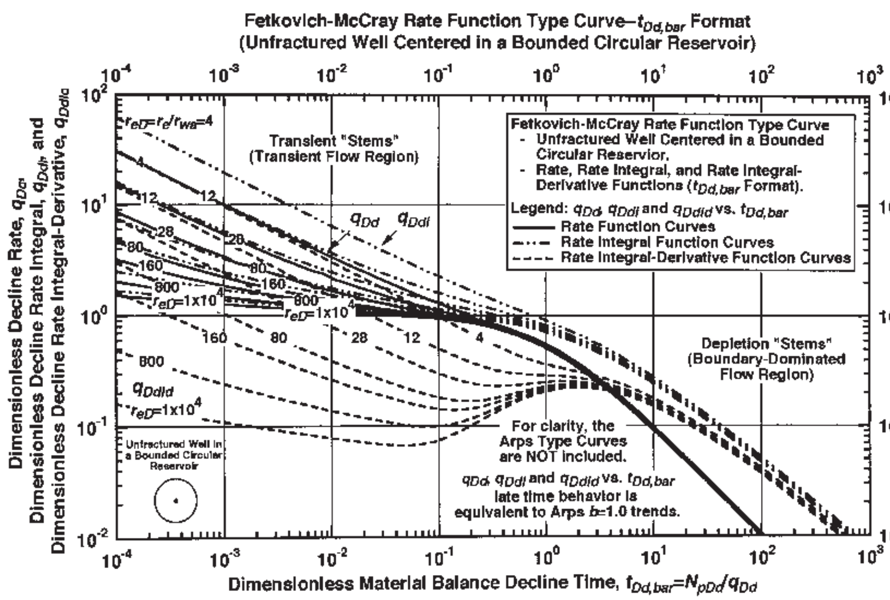
Fetkovich Radial Flow Type Curves



a. Palacio, et al (1993): "Fetkovich-McCray Original" (radial flow) — auxiliary functions. (t_{Dd} format)



b. Doublet, et al (1994): "Fetkovich Derivative" (radial flow) — not practical for analysis. (t_{Dd} format)



c. Doublet, et al (1994): "Fetkovich-McCray M.B. Time" (radial flow) — w/aux. functions. ($t_{Dd,bar}$)

Radial Flow Decline TC:

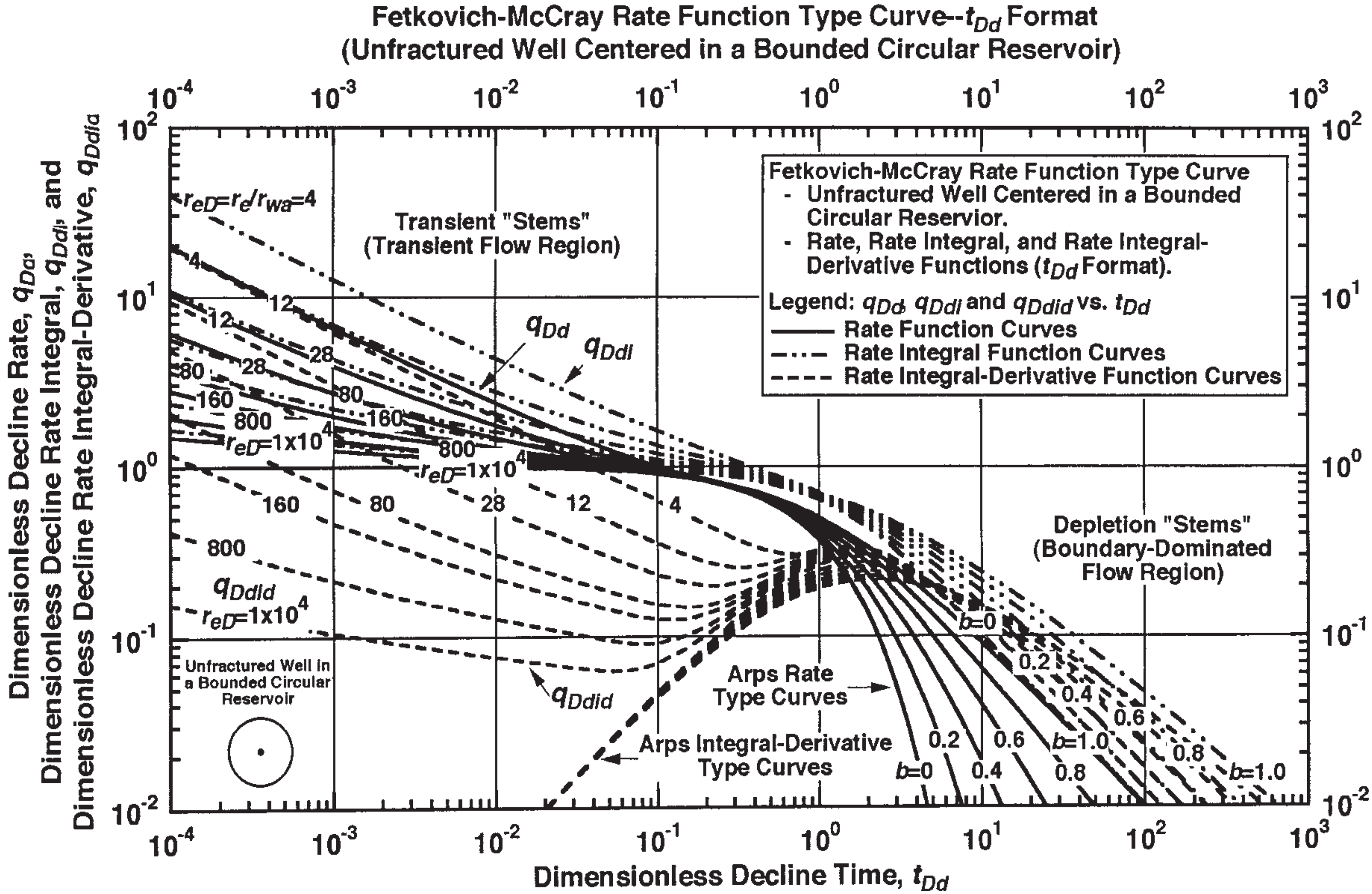
- "Fetkovich-McCray Original"
- "Fetkovich Derivative"
- "Fetkovich-McCray Material Balance Time" — Uses material balance to rigorously incorporate variations in rate and pressure over time. This technique substantially improves the analysis of variable-rate data.

Palacio, J.C. and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves — Analysis of Gas Well Production Data," paper SPE 25909 presented at the 1993 Joint Rocky Mountain Regional/Low Permeability Reservoirs Symposium, Denver, CO, 26-28 April 1993.

Doublet, L.E., Pande, P.K., McCollum, T.J., and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves — Analysis of Oil Well Production Data Using Material Balance Time: Application to Field Cases," paper SPE 28688 presented at the 1994 Petroleum Conference and Exhibition of Mexico held in Veracruz, MEXICO, 10-13 October 1994.

Palacio/Blasingame Type Curve

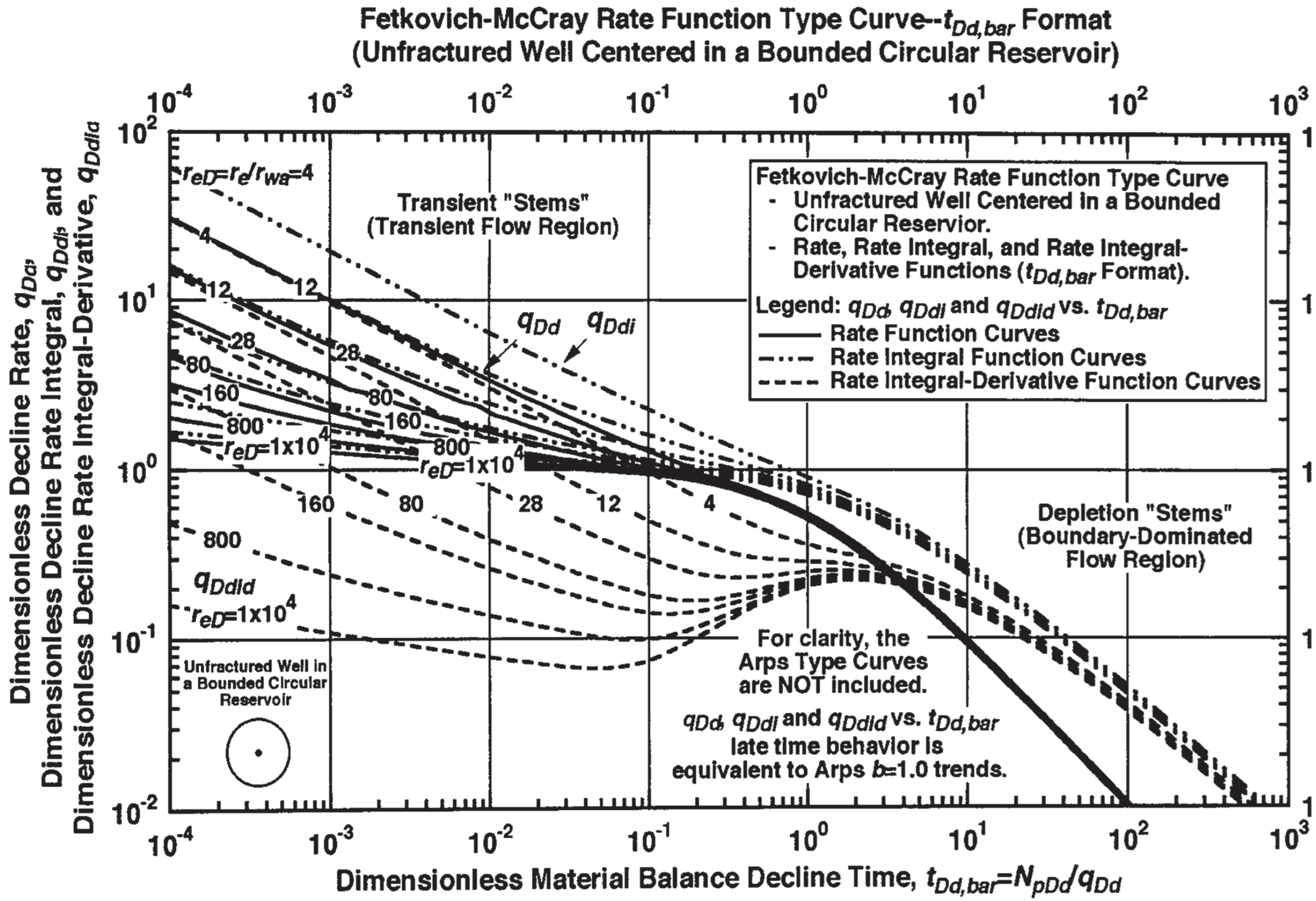
Palacio, J.C. and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves — Analysis of Gas Well Production Data," paper SPE 25909 presented at the 1993 Joint Rocky Mountain Regional/Low Permeability Reservoirs Symposium, Denver, CO, 26-28 April 1993.



<u>Discussion</u>: *Palacio/Blasingame Type Curve* (*constant p_{wf} case*)

- **Auxiliary functions (rate integral and integral derivative) enhance flow features.**
- **Need to use material balance time to account for variable rate.**
- **This plot includes the "Arps' relations," these are not included in general.**

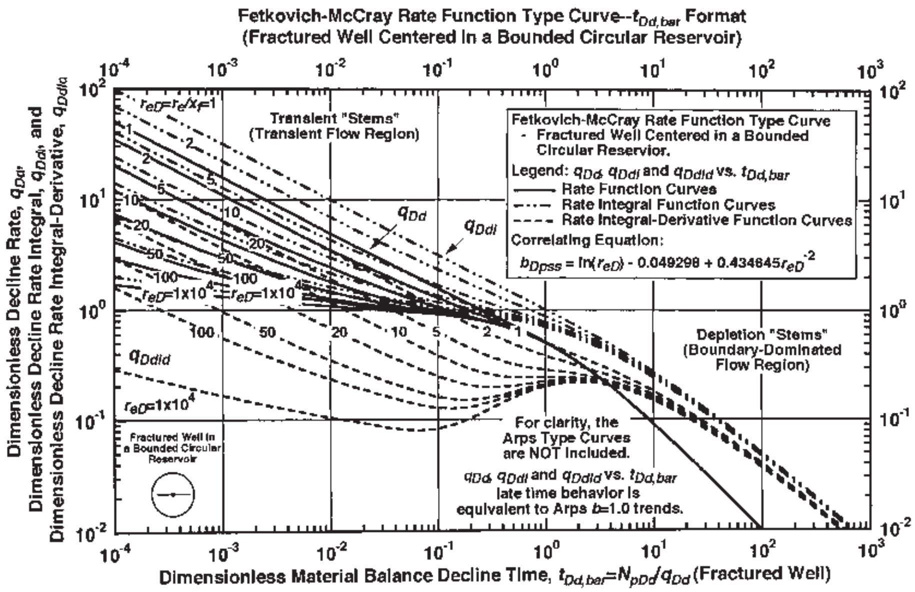
Doublet/Blasingame Type Curve



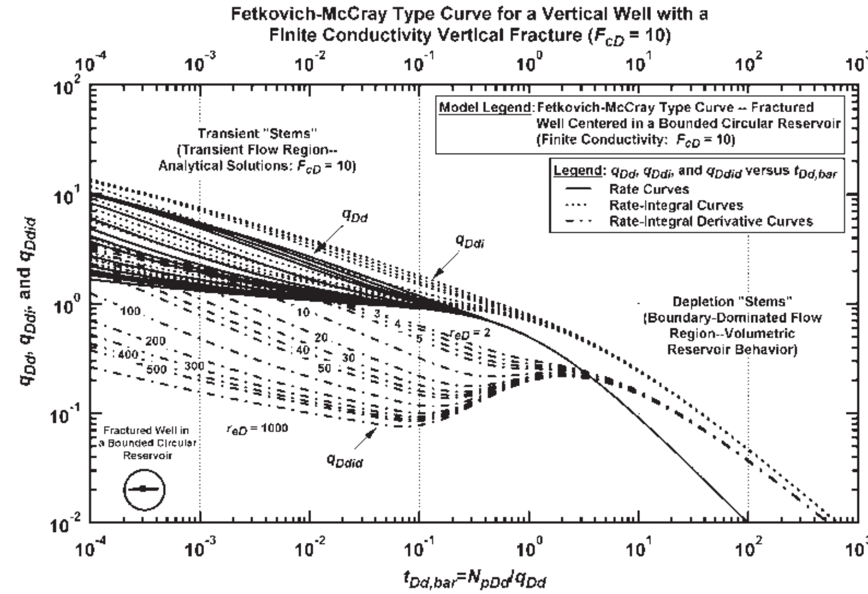
Doublet, L.E., Pande, P.K., McCollum, T.J., and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves — Analysis of Oil Well Production Data Using Material Balance Time: Application to Field Cases," paper SPE 28688 presented at the 1994 Petroleum Conference and Exhibition of Mexico held in Veracruz, MEXICO, 10-13 October 1994.

Discussion: *Doublet/Blasingame Type Curve* (*constant q_o equivalent*)
- **Note "convergence" of late stems to unique trends (material balance time).**
- **Type curve is valid for variable-rate/variable pressure drop cases.**
- **Original "RTA" plot — there is a companion plot for rate normalized pressure.**

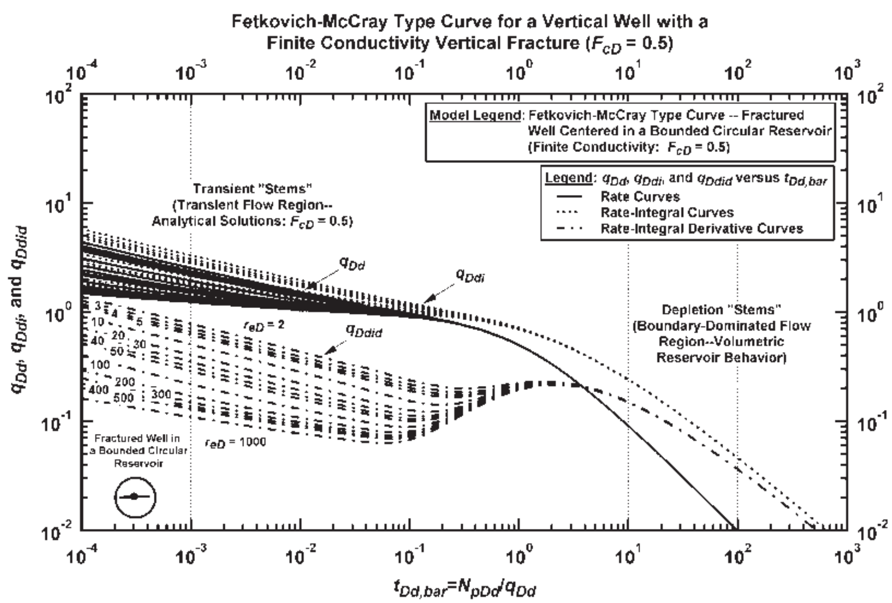
Doublet/Blasingame Type Curve — Vertically Fractured Wells



a. Doublet, et al (1996): "Fetkovich-McCray" format — INFINITE conductivity vertical fracture ($F_{cD}=\infty$).



b. Pratikno (2002): "Fetkovich-McCray" format — FINITE conductivity vertical fracture (F_{cD}=10).



c. Pratikno (2002): "Fetkovich-McCray" format — FINITE conductivity vertical fracture (F_{cD}=0.5).

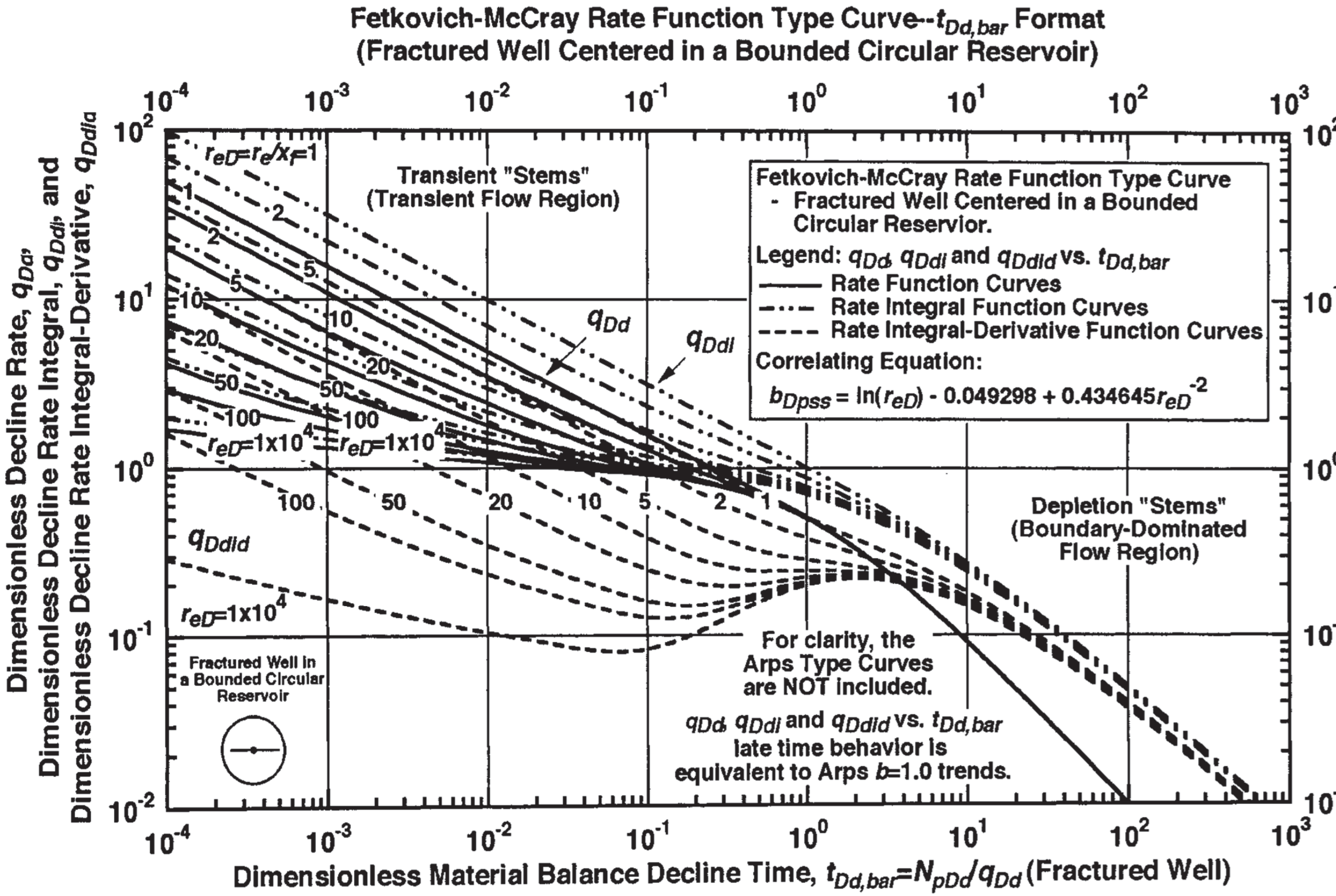
Decline Type Curves: Fractured Wells

- Infinite fracture conductivity:
  - Less complex solution, but somewhat ideal for use in practice.
- Finite fracture conductivity:
  - F_{cD}=10: Moderate to high fracture conductivity case.
  - F_{cD}=0.5: Low fracture conductivity case.

Doublet, L.E. and Blasingame, T.A.: "Evaluation of Injection Well Performance Using Decline Type Curves," paper SPE 35205 presented at the 1996 SPE Permian Basin Oil and Gas Recovery Conference, Midland, TX, 27-29 March, 1996.

Pratikno, H., Rushing, J.A., and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves: Fractured Wells," paper SPE 84287 presented at the 2003 Annual SPE Technical Conference and Exhibition, Denver, CO., 05-08 October 2003.

Doublet/Blasingame Type Curve Format — Vertically Fractured Wells



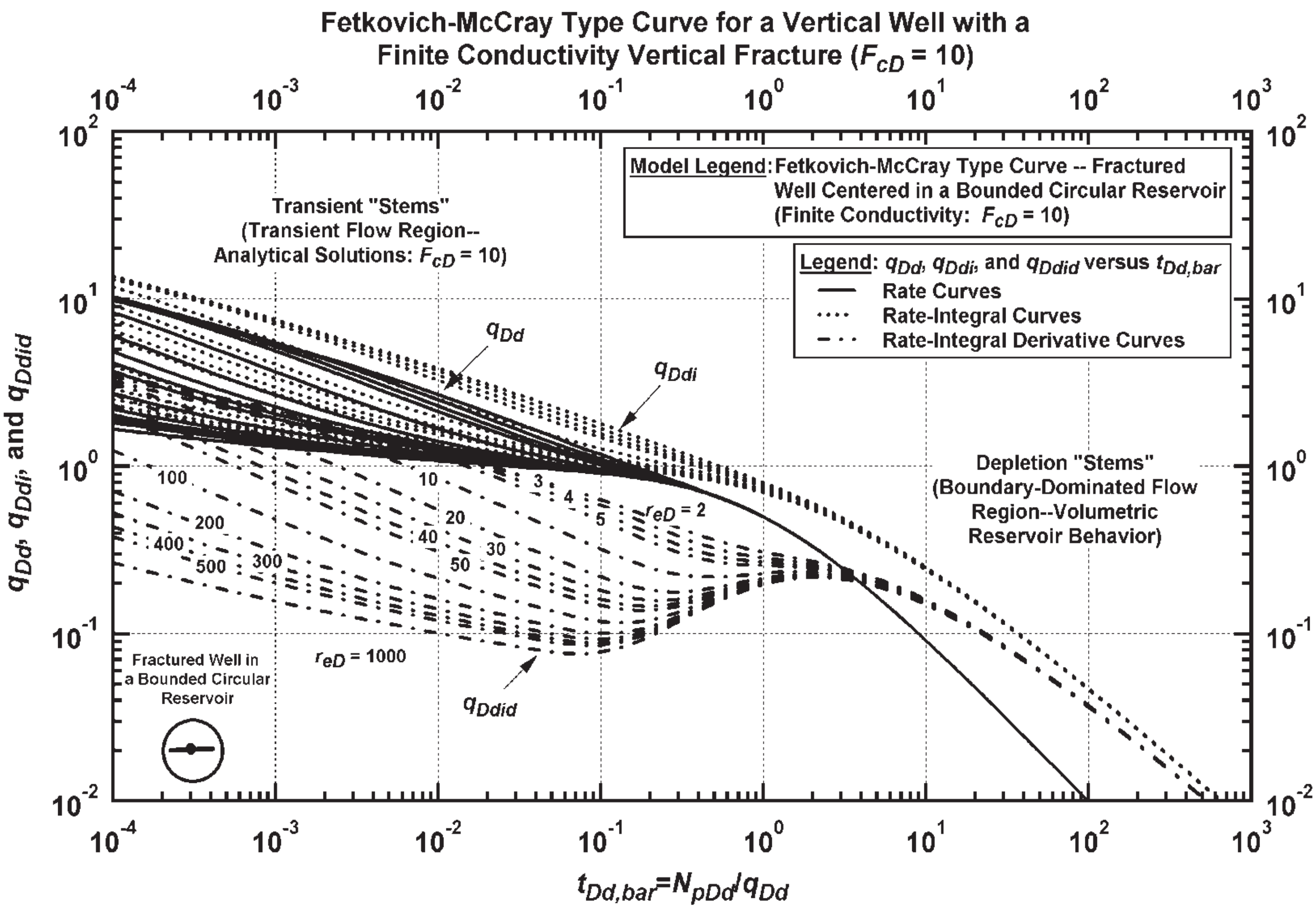
Doublet, L.E. and Blasingame, T.A.: "Evaluation of Injection Well Performance Using Decline Type Curves," paper SPE 35205 presented at the 1996 SPE Permian Basin Oil and Gas Recovery Conference, Midland, TX, 27-29 March, 1996.

Discussion: *Doublet/Blasingame Type Curve* (*infinite conductivity fracture*)

- **Note the transient flow behavior of the auxiliary functions (linear flow).**
- **Use of material balance time provides unique late time behavior.**
- **Can estimate fracture half-length, permeability, and reservoir volume.**

Doublet/Blasingame Type Curve Format — Vertically Fractured Wells

Pratikno, H., Rushing, J.A., and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves: Fractured Wells," paper SPE 84287 presented at the 2003 Annual SPE Technical Conference and Exhibition, Denver, CO., 05-08 October 2003.

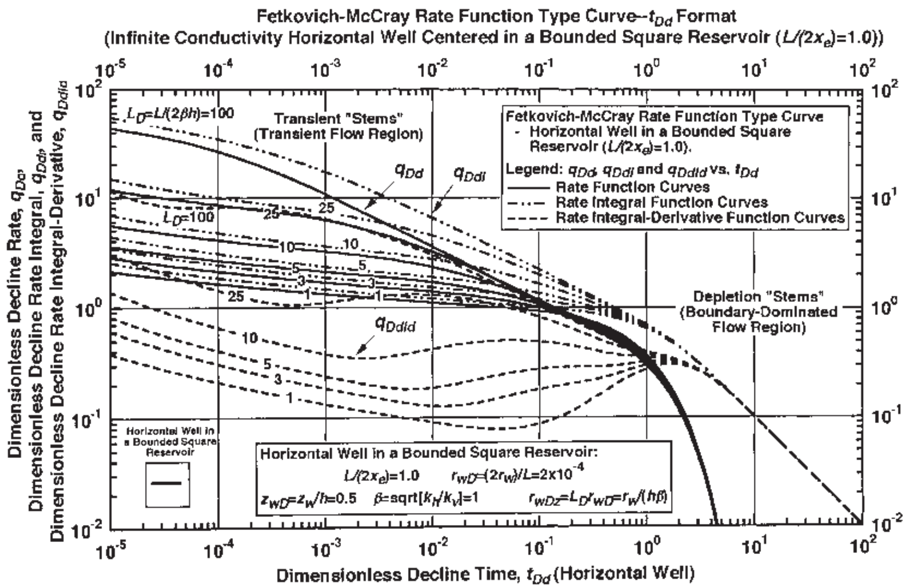


Discussion: ***Doublet/Blasingame Type Curve*** **(*****Finite conductivity fracture*****)**

- **Note the transient flow behavior of the auxiliary functions (bilinear flow).**
- **Individual type curves generated for each F_{cD}-value.**
- **Can estimate fracture half-length, permeability, and reservoir volume.**

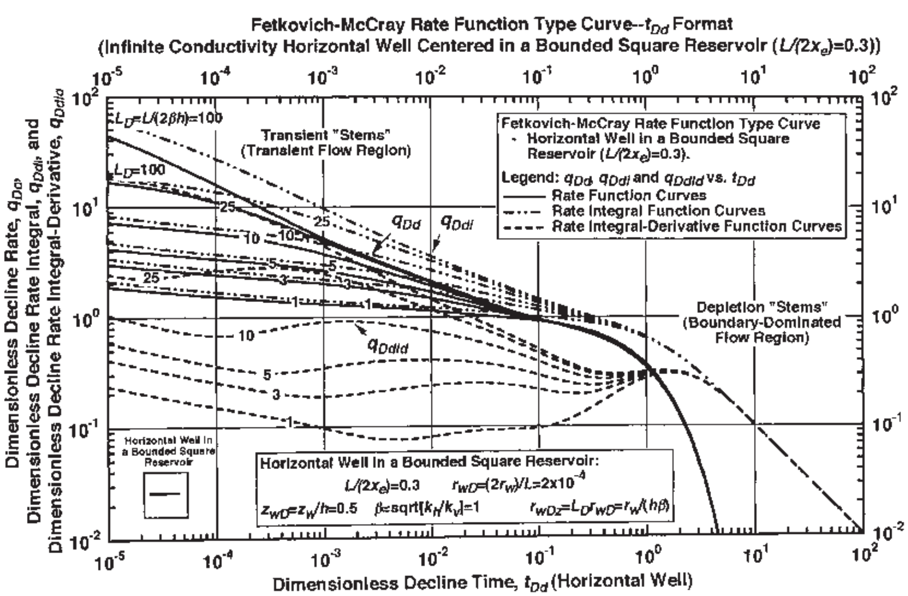
Doublet/Blasingame Type Curve Format — Horizontal Wells

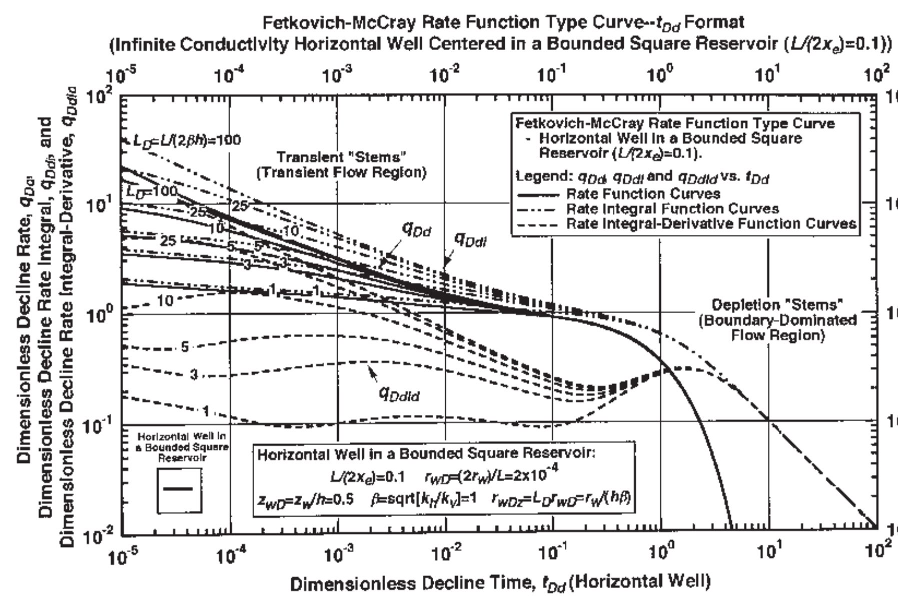
Shih, M.-Y. and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves: Horizontal Wells," paper SPE 29572 presented at the 1995 Joint Rocky Mountain Regional/Low Permeability Reservoirs Symposium, Denver, CO, 20-22 March, 1995.



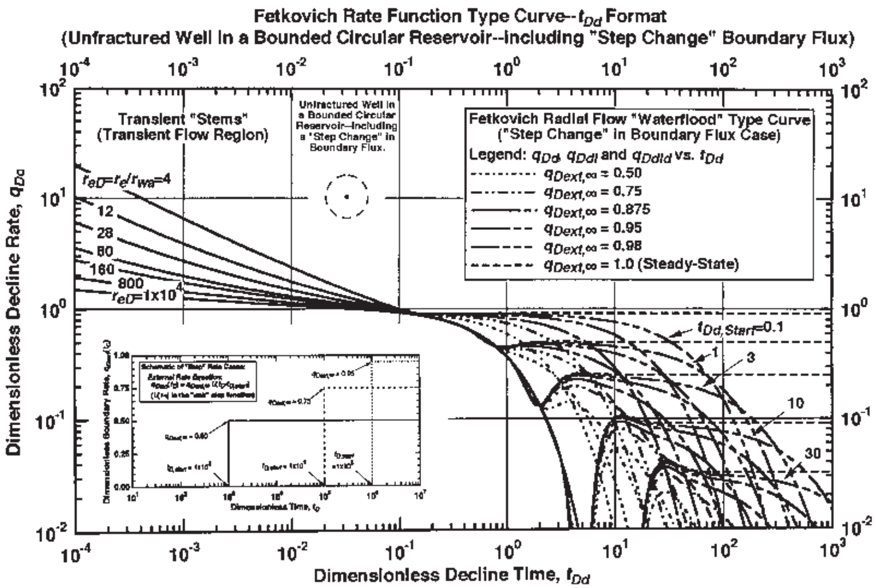
Horizontal Well Cases:

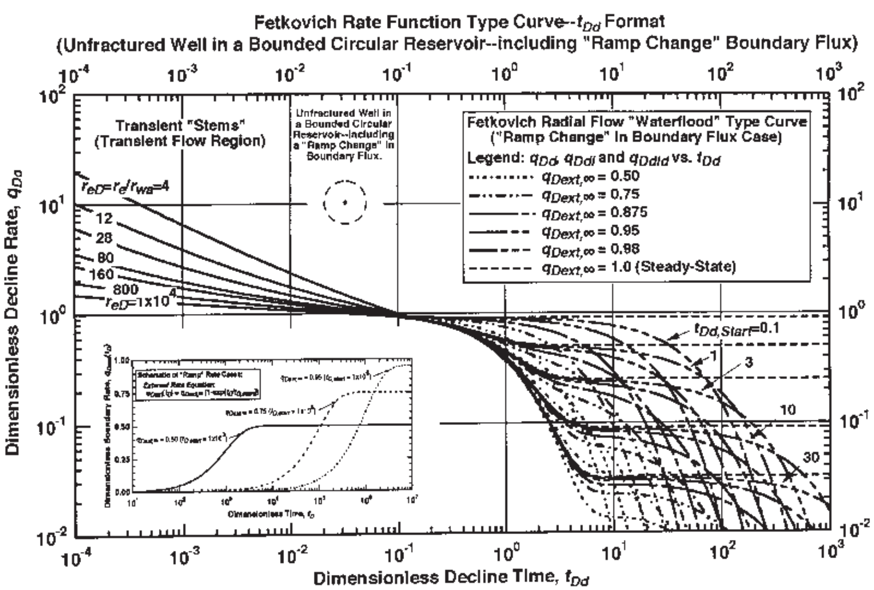
- "Infinite-conductivity" horizontal well case(s).
- Dimensionless reservoir model requires several parameters.





Decline Type Curves — Boundary Flux Cases

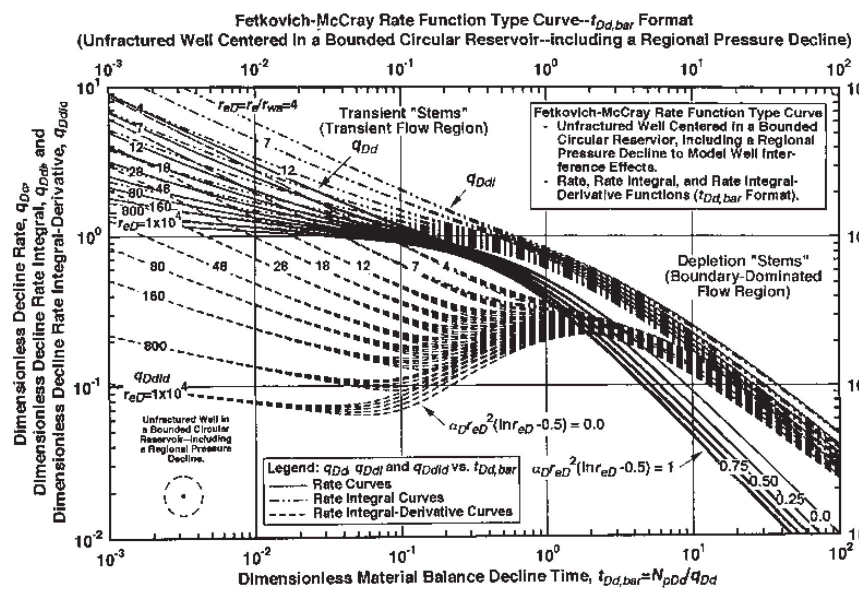




Decline Type Curve Analysis:

- "Break-glass-in-case-of-fire" cases
- Do not use (unless absolutely necessary) — and it should never be necessary.

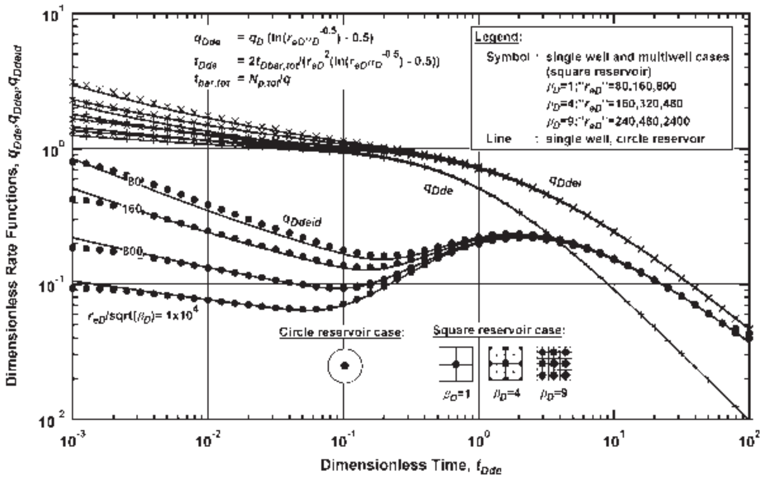
Unpublished — Marhaendrajana (2002)
(multiwell analysis — do not use)



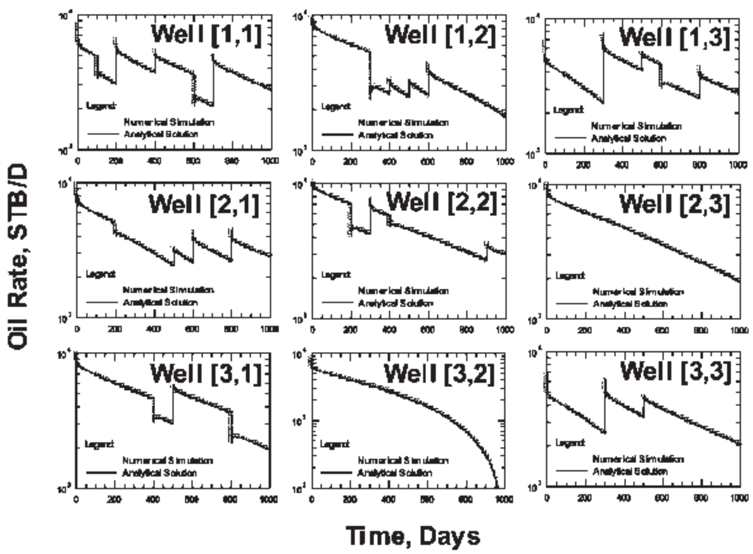
Doublet, L.E. and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves: Water Influx/Waterflood Cases," paper SPE 30774 presented at the 1995 Annual SPE Technical Conference and Exhibition, Dallas, TX, 22-25 Oct. 1995.

Decline Type Curves — Boundary Flux Cases

Marhaendrajana, T. and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves — Evaluation of Well Performance Behavior in a Multiwell Reservoir System," paper SPE 71514 presented at the 2001 Annual SPE Technical Conference and Exhibition, New Orleans, 30 Sept.-03 Oct. 2001.



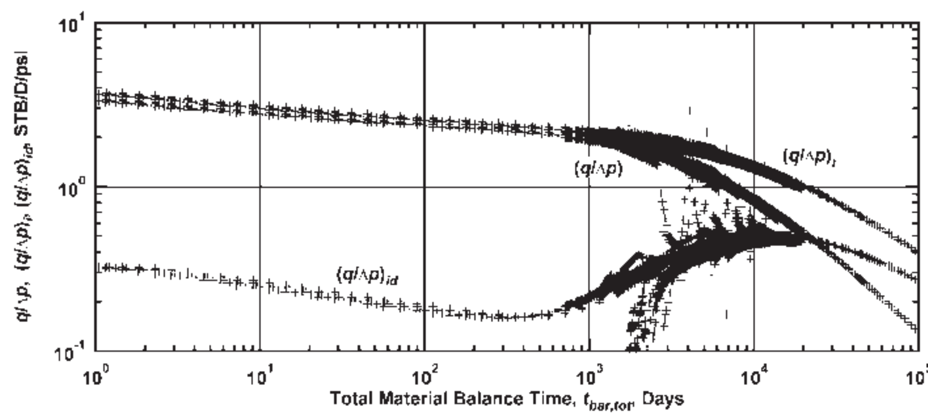
Dimensionless "decline variables" plot for the single well and multiwell performance cases — simulated performance used to validate the multiwell concept.



Oil rate versus time profiles (homogeneous reservoir example). (O Numerical Simulation, — Analytical Solution)

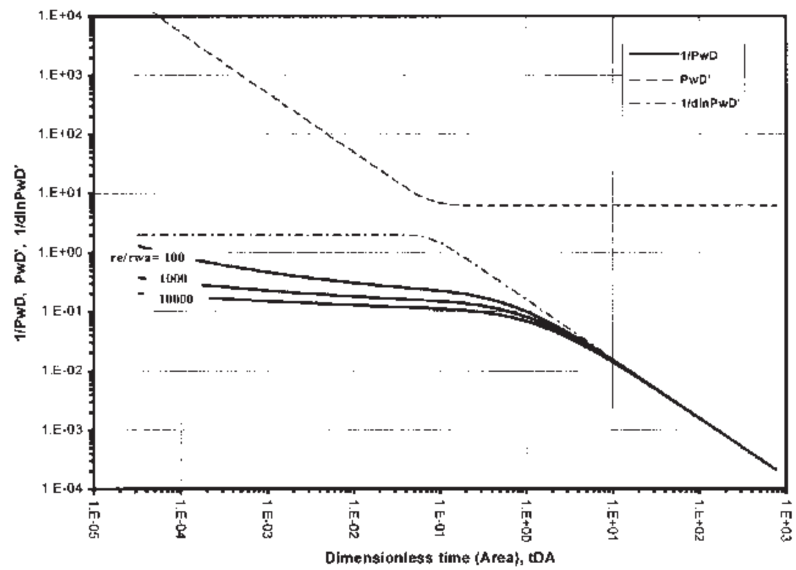
Multiwell Analysis: SPE 71514

- Multiwell case can be "recast" into single well case using cumulative production for entire field.
- Homogeneous reservoir example shows that all cases (9 wells) align — same behavior observed for heterogeneous reservoir cases.



Log-log plot of rate/pressure drop functions as a function of total material balance time (homogeneous reservoir example).

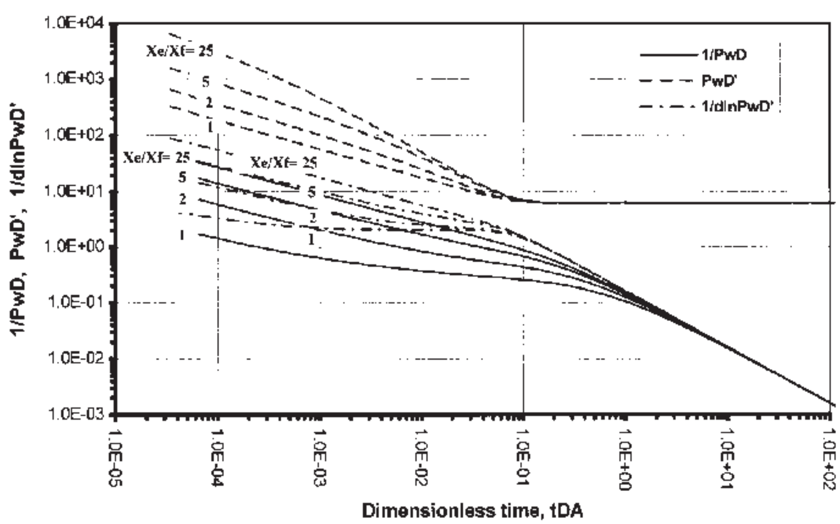
Decline Type Curves — Agarwal, et al Methodology



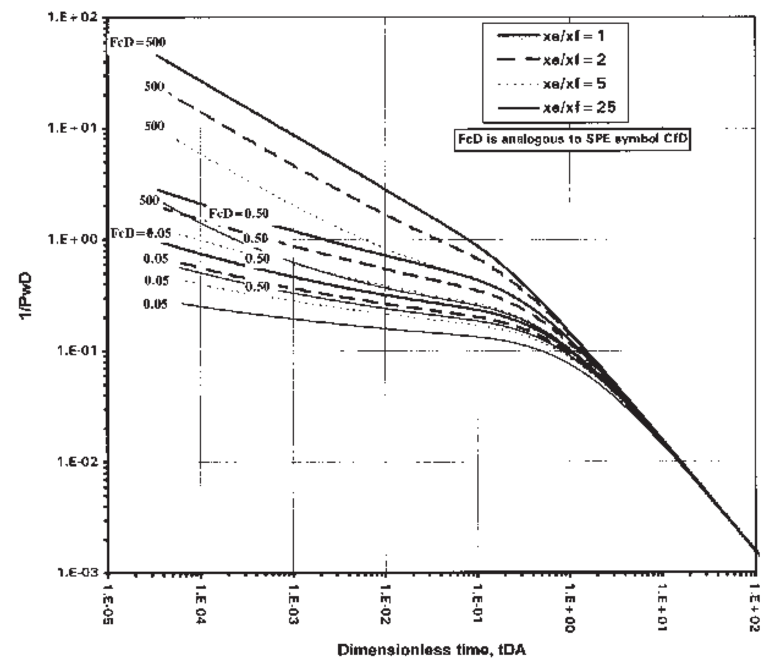
Rate-time production decline-type curves for radial systems using t_D based on area (r_e/r_{wa}=100, 1,000, 10,000).

<u>Agarwal, et al Methodology</u>: SPE 57916

- **Basically the same as Blasingame, et al work.**
- **More like pressure transient test analysis/interpretation.**

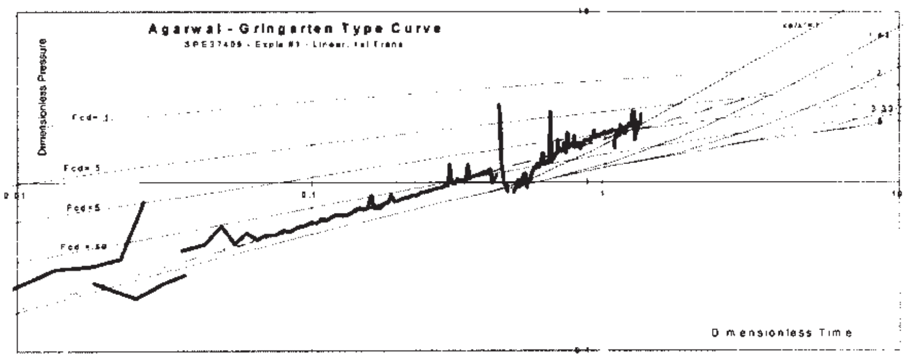


Rate-time production decline-type curves for infinite conductivity fracture using t_D based on area (x_e/x_f =1,2,5,25).



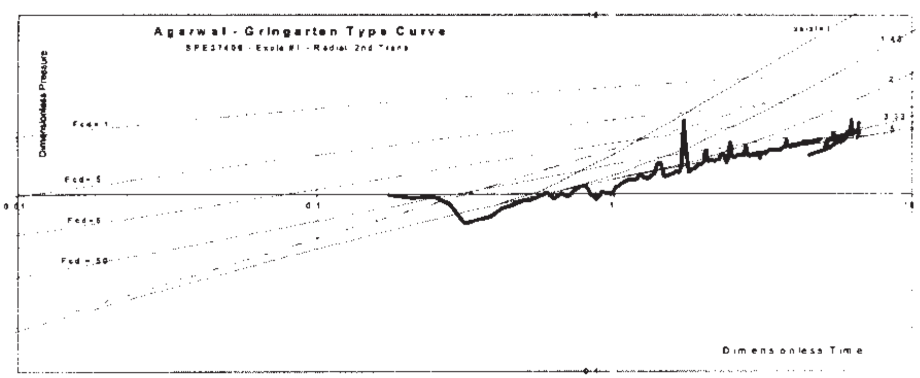
Rate-time production decline-type curves for finite conductivity fracture using t_D based on area (x_e/x_f=1, 2, 5, 25 and F_{cD}=0.05, 0.5, 500).

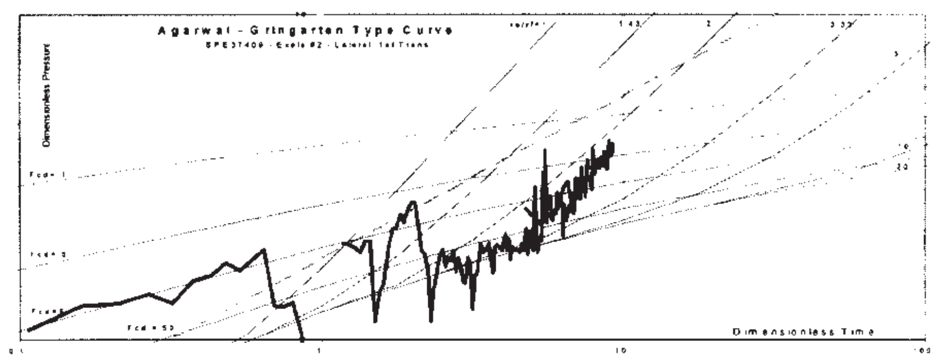
Crafton, et al Methodology



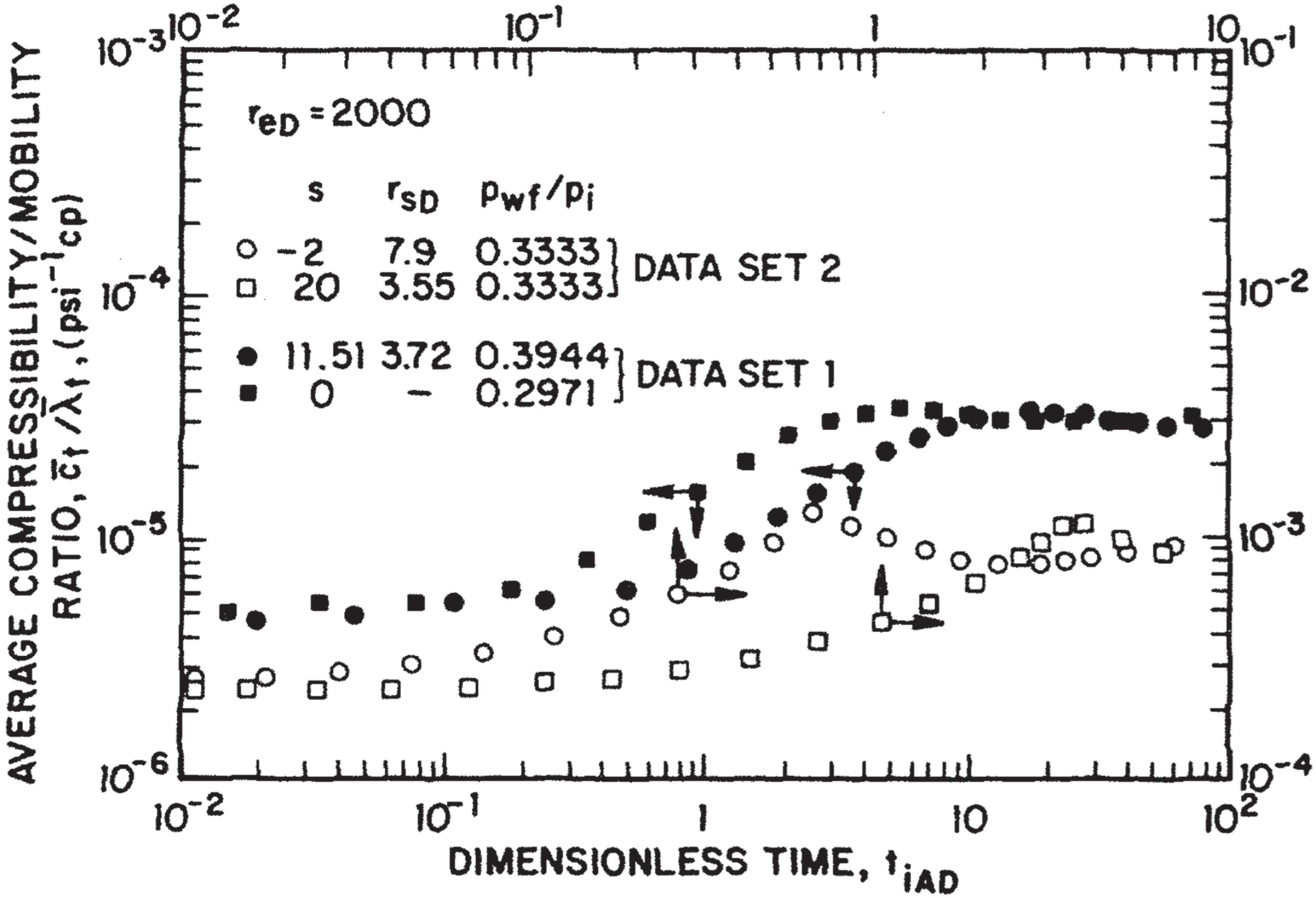
Crafton, et al Methodology: SPE 37409

- Rate normalized pressure drop versus production time ($\Delta p/q$ vs. t).
- Also analogous to pressure transient test analysis/interpretation.
- Very serious limitations — production time is not sufficient for general case of rate variation.





Single-Phase Liquid (Black Oil) — (c_t/λ_t) vs. Time



Variation of average compressibility/mobility ratio with time.

Camacho-V., R.G. and Raghavan, R.: "Boundary-Dominated Flow in Solution-Gas-Drive Reservoirs," SPERE (November 1989) 503-512.

Discussion: ***"Solution-Gas Drive" Behavior — ((c_t/λ_t) vs. time)***

- **Observation: (c_t/λ_t) ≅ constant for $p>p_b$ and later, for $p<p_b$.**
- **p_{wf} = constant — but probably valid for any production/pressure scenario.**

Multiwell Analysis — Governing Relation

$$\frac{q_k(t)}{(p_i - p_{wf})} = \frac{1}{\dfrac{1}{Nc_t}\dfrac{1}{q_k(t)}\displaystyle\int_0^t \sum_{i=1}^{n_{well}} q_i(t)dt + c(t)}$$

Production Data (Pressure & Rate)

Total Material Balance Time

||

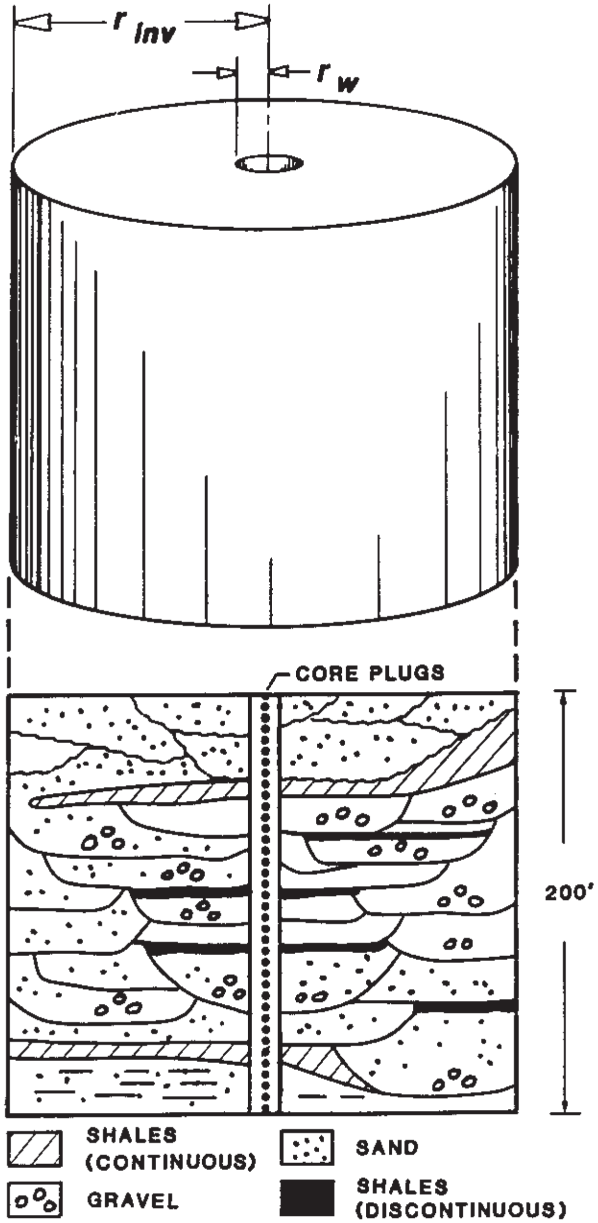
$$\bar{t}_{tot} = \frac{N_{p,field}}{q_{well}}$$

c(t) becomes constant at long times

Discussion: ***Multiwell Analysis — Governing Relation***

- **A general formulation of the "Arps' Exponential Decline" case.**
- **CONCLUSION**: ***A single well decline type curve can be used to analyze the performance of a single well in a multiwell system.***

Reality Check



From: Simulator Parameter Assignment and the Problem of Scaling in Reservoir Engineering — Halderson (1986).

Reservoir Volume-Averaging

- Pressure transient analysis.
- Production data analysis.
- Reservoir simulation.

Advanced Solutions

- Same view of the reservoir — just more "knobs" (*i.e.*, parameters).
- Time-pressure-rate data will always "see" a pressure/volume-averaged reservoir system.

Prediction of Future Work in PTA/PA

- Additional reservoir models.
- Full incorporation of PVT character.
- Reservoir scaling for PTA/PA.
- Handling poor quality data.
- Continuously measured p_{wf} data.
- Multiple well analysis/integration.
- Coupling of analysis/interpretation with numerical modeling (3D/3P).

References —— Production Data Analysis

Historical Methods — Production Data Analysis:

1. Arps, J.J: "Analysis of Decline Curves," Trans., AIME (1945) 160, 228-247.
2. Fetkovich, M.J.: "Decline Curve Analysis Using Type Curves," JPT (June 1980) 1065-1077.
3. Gringarten, A.C.: "Reservoir Limits Testing for Fractured Wells," paper SPE 7452 presented at the 1978 SPE Annual Technical Conference and Exhibition, Houston, TX., 1-3 October 1978.
4. Carter, R.D.: "Type Curves for Finite Radial and linear Gas Flow Systems: Constant Terminal Pressure Case," SPEJ (October 1985) 719-728.

Decline Type Curve Analysis:

1. Fraim, M.L., Lee, W.J., and Gatens, J.M., III: "Advanced Decline Curve Analysis Using Normalized-Time and Type Curves for Vertically Fractured Wells," paper SPE 15524 presented at the 1986 SPE Annual Technical Conference and Exhibition, New Orleans, LA, 5-8 October 1986.
2. McCray, T.L.: Reservoir Analysis Using Production Decline Data and Adjusted Time, M.S. Thesis, Texas A&M U., College Station, TX (1990).
3. Palacio, J.C. and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves — Analysis of Gas Well Production Data," paper SPE 25909 presented at the 1993 Joint Rocky Mountain Regional/Low Permeability Reservoirs Symposium, Denver, CO, 26-28 April 1993.
4. Doublet, L.E., Pande, P.K., McCollum, T.J., and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves — Analysis of Oil Well Production Data Using Material Balance Time: Application to Field Cases," paper SPE 28688 presented at the 1994 Petroleum Conference and Exhibition of Mexico held in Veracruz, Mexico, 10-13 October 1994.
5. Shih, M.-Y. and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves: Horizontal Wells," paper SPE 29572 presented at the 1995 Joint Rocky Mountain Regional/Low Permeability Reservoirs Symposium, Denver, CO, 20-22 March, 1995.
6. Doublet, L.E. and Blasingame, T.A.: "Evaluation of Injection Well Performance Using Decline Type Curves," paper SPE 35205 presented at the 1996 SPE Permian Basin Oil and Gas Recovery Conference, Midland, TX, 27-29 March 1996.
7. Crafton, J. W.: "Oil and Gas Well Evaluation Using the Reciprocal Productivity Index Method," paper SPE 37409 presented at the 1997 SPE Production Operations Symposium, held in Oklahoma City, Oklahoma, 9-11 March 1997.
8. Agarwal, R.G., Gardner, D.C., Kleinsteiber, S.W., and Fussell, D.D.: "Analyzing Well Production Data Using Combined Type Curve and Decline Curve Analysis Concepts," paper SPE 49222 prepared for presentation at the 1998 SPE ATCE, New Orleans, LA, 27-30 September 1998.
9. Marhaendrajana, T. and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves — Evaluation of Well Performance Behavior in a Multiwell Reservoir System," paper SPE 71514 presented at the 2001 Annual SPE Technical Conference and Exhibition, New Orleans, 30 September-03 October 2001.
10. Pratikno, H., Rushing, J.A., and Blasingame, T.A.: "Decline Curve Analysis Using Type Curves: Fractured Wells," paper SPE 84287 presented at the 2003 Annual SPE Technical Conference and Exhibition, Denver, CO., 05-08 October 2003.