Well Test Interpretation

SKM4323

RESERVOIR BOUNDARIES

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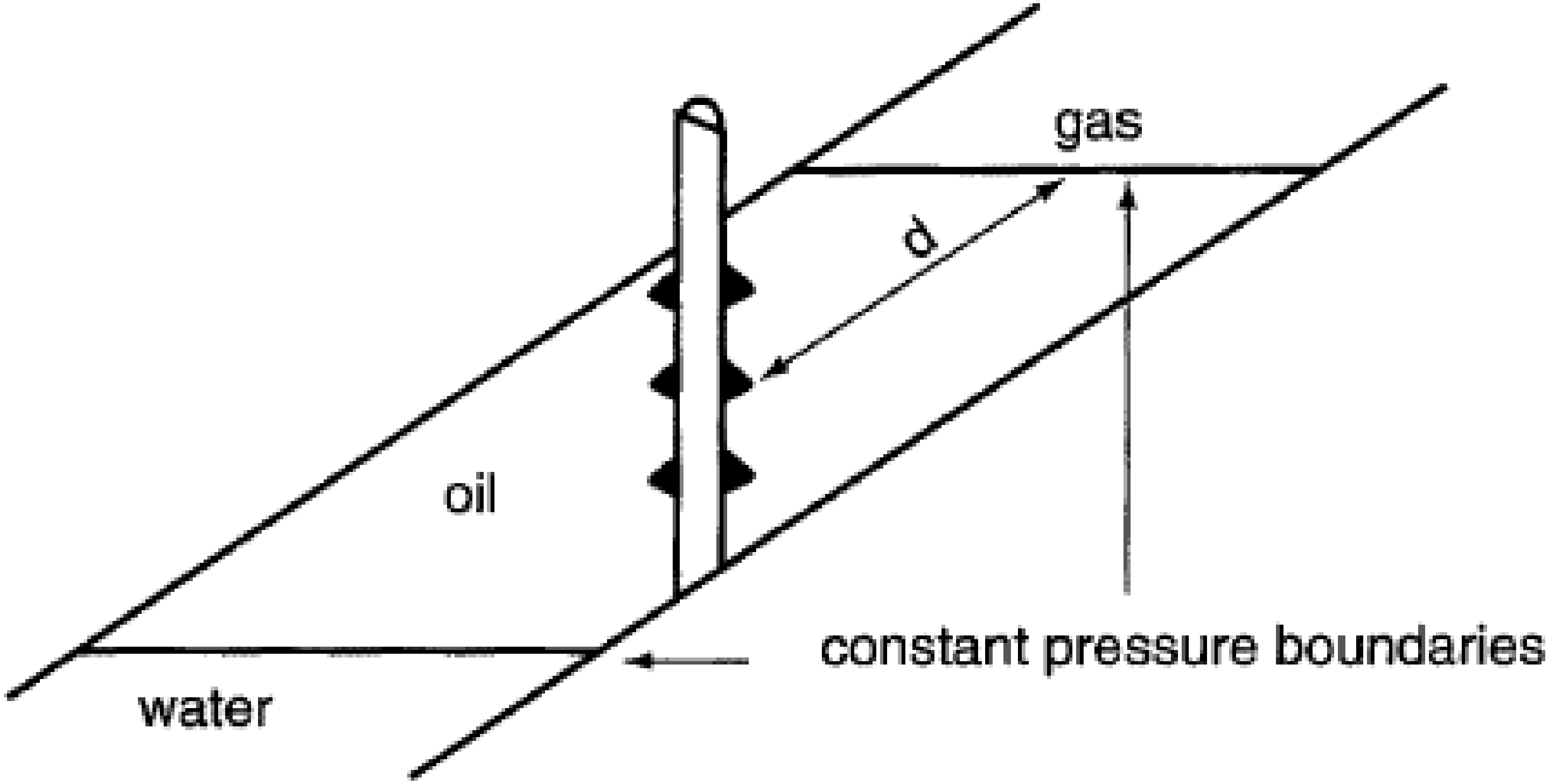
WEEK 09

CONSTANT PRESSURE BOUNDARY

Description

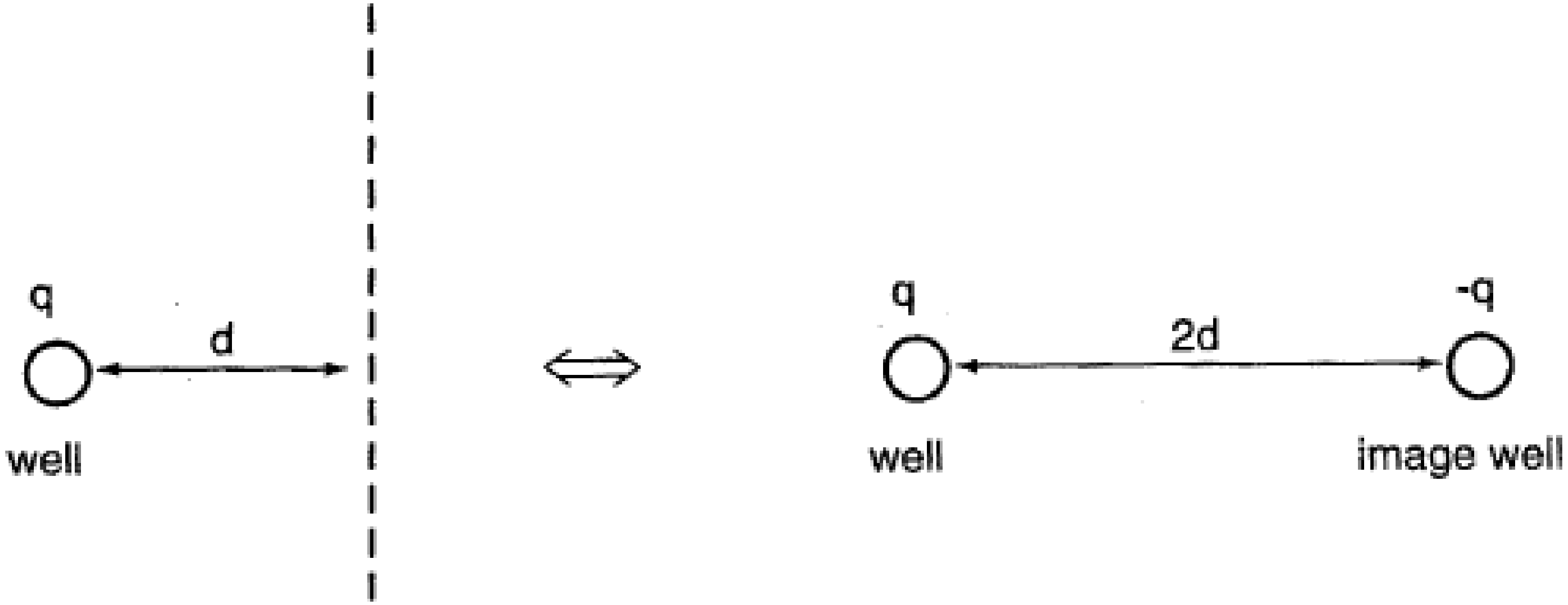
- A constant pressure boundary effect can be seen during a well test in several cases:
  - When the compressible zone reaches a gas cap laterally;
  - When the compressible zone reaches an aquifer with the mobility of the water much greater than that of the oil


gas
d
oil
water
constant pressure boundaries

The Method of Images

- A constant pressure boundary is obtained analytically using the method of images.
- The image well is symmetrical to the tested well in relation to the boundary.
    - It has a flow rate opposite that of the tested well.

The Method of Images…/2



The Method of Images…/3

- Applying the image method, the pressure at the well is written:

$$p_D = p_D(t_D, r_D = 1, S) - p_D(t_D, 2r_D) \qquad \textbf{(10.1)}$$

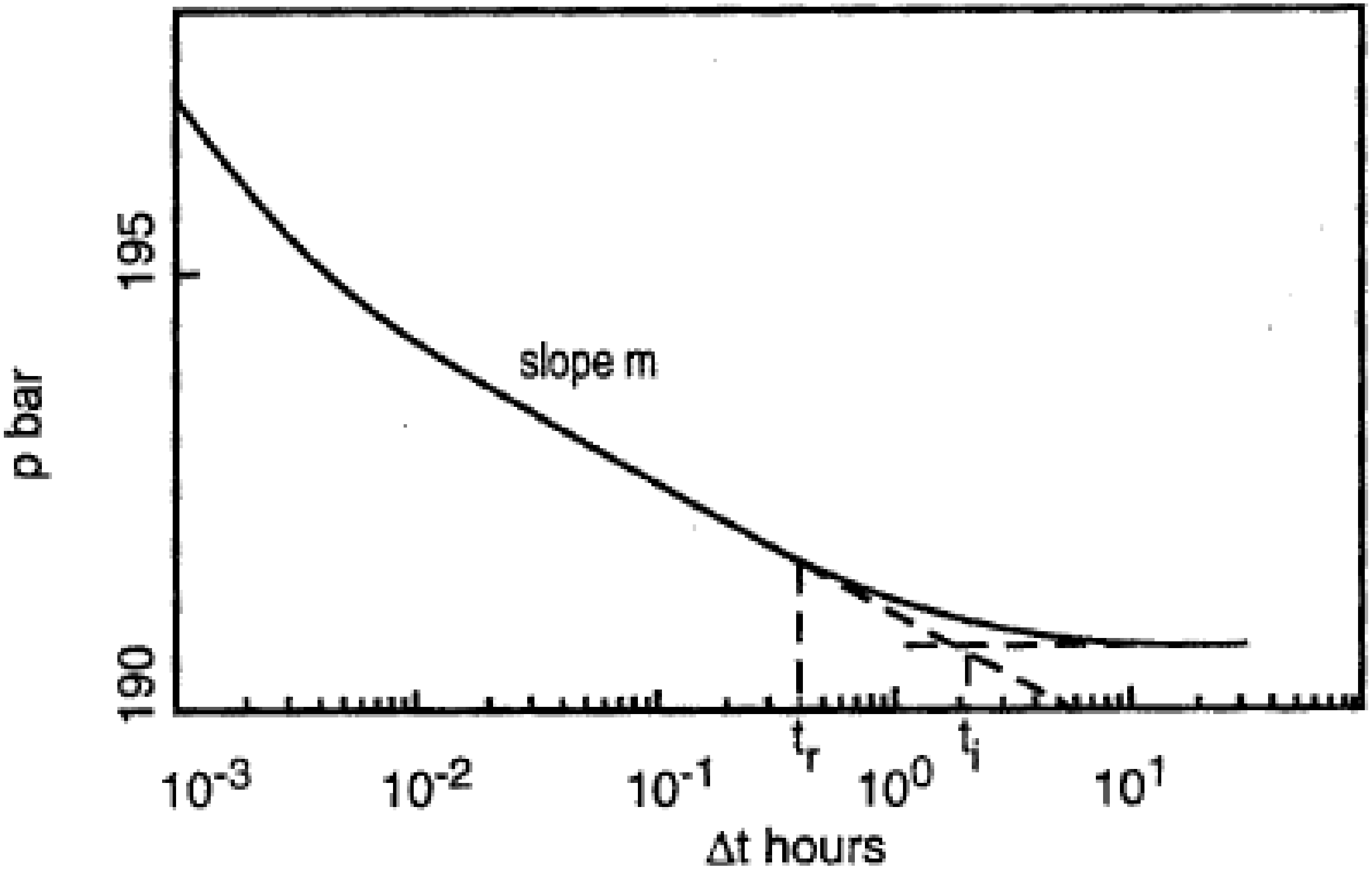
Pressure variation due to the well

Pressure variation due to the image well

Distance to The Boundary

- Two methods can be used to determine the distance to the boundary:
  - The intersection of the semi-log straight line and the constant pressure straight line that was reach at the end of the test.
  - The radius of investigation at the time when the compressive zone reaches the boundary.

Distance to The Boundary…/2



Distance to The Boundary…/3

- Intersection of the two straight line:
  - The expression of the distance is identical to that obtained for a fault:

$$d=0.012\sqrt{\frac{kt_i}{\phi\mu c_t}} \quad \text{(in practical US units)} \quad \textbf{(10.7)}$$

Distance to The Boundary…/4

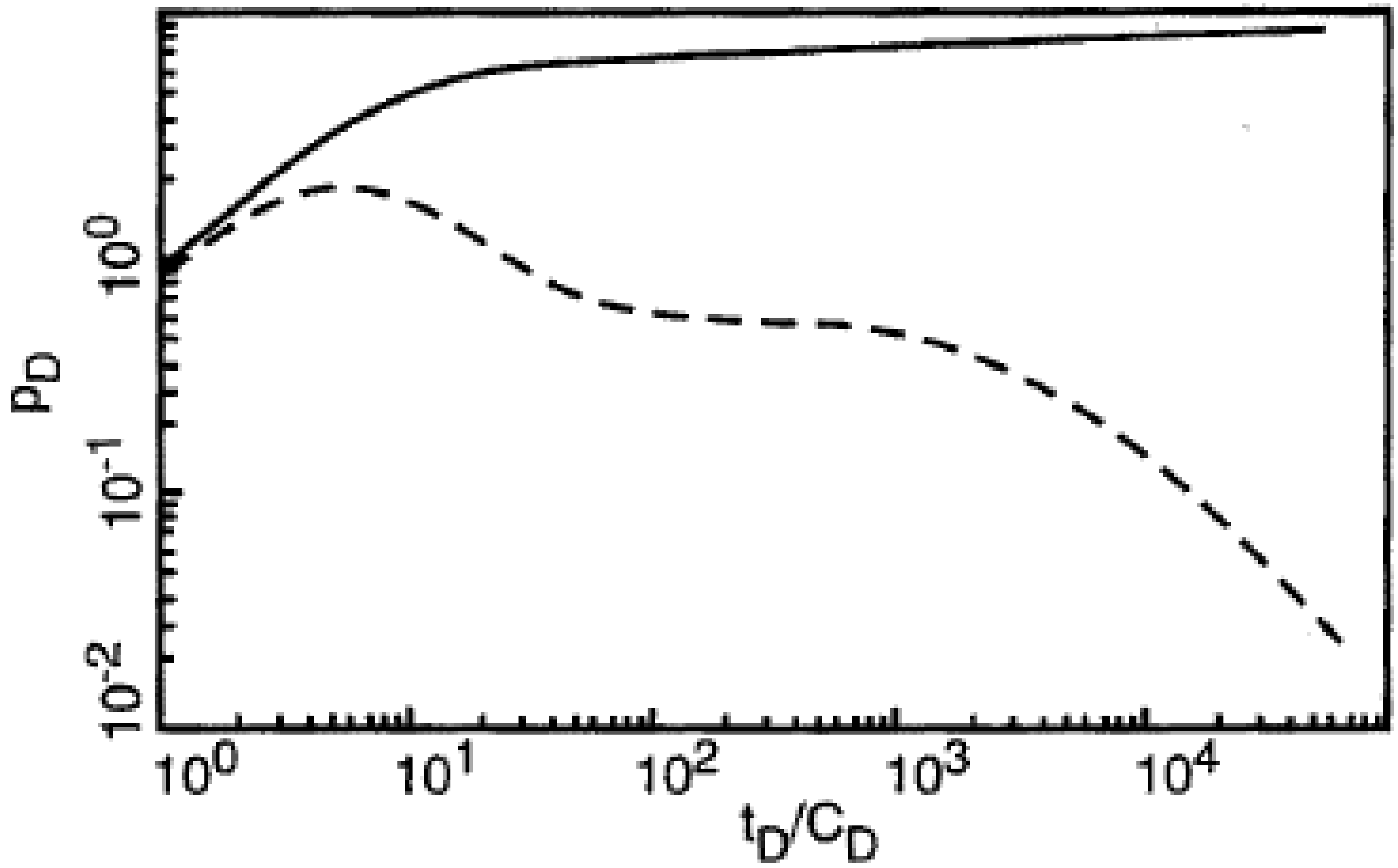
- Radius of investigation:
  - The distance from the well to the boundary can be determined by the time t_r when the measurement points leave the semi-log straight line:

$$d = 0.032\sqrt{\frac{kt_r}{\phi \mu c_t}}$$ (in practical US units) **(10.8)**

Type Curves: The Derivative

- The presence of a constant pressure boundary is characterized by a pressure stabilization.
- A pressure derivative going to zero and appearing as a sharp decrease of the log-log representative corresponds to this pressure stabilization .

Type Curves: The Derivative…/2



Example 13

(In-class workshop)

- Constant pressure boundary-

CLOSED RESERVOIR

Description

- If the reservoir is limited by no-flow boundaries, two cases can be distinguished when the compressible zones reaches the limits:
  - **The well is producing**: when the no-flow boundaries are reached, the flow regimes becomes **pseudosteady-state**.
  - **The well is shut-in**: when the no-flow boundaries are reached, the pressure stabilizes at a value called average pressure in the whole area defined by the no-flow boundaries.

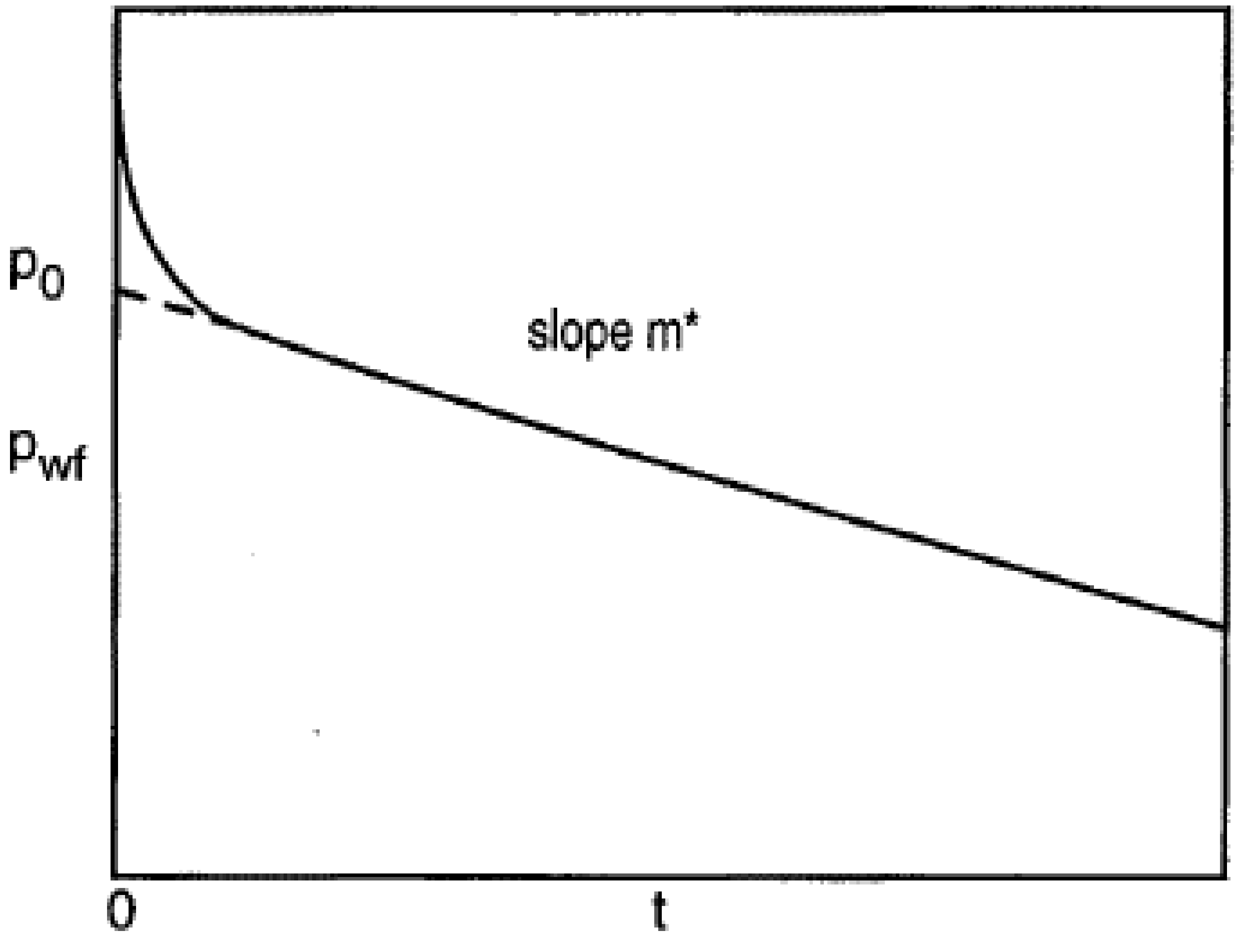
Pseudosteady-State Regime

- When all the no-flow boundaries have been reached, the flow regime becomes pseudosteady-state regime.
- The no-flow boundaries define **the drainage area** of the well.

$$A = \frac{0.234qB}{\phi c_t h \underset{\uparrow}{m}^*} \tag{11.6}$$

Positive
value

Pseudosteady-State Regime…/2



Pseudosteady-State Regime…/3

- The value of P_0 is used to determine the shape factor, C_A.

From drawdown

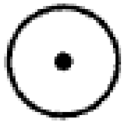
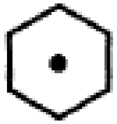
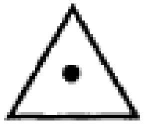
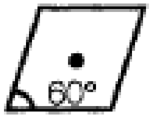
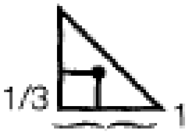
$$C_A = 5.456\frac{m}{m^*}10^{-\left[\frac{P_{1h}-P_0}{m}\right]} \qquad \textbf{(11.8)}$$

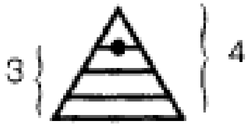
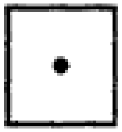
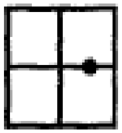
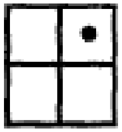
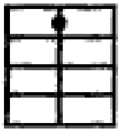
From drawdown or buildup, positive value

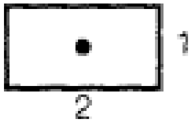
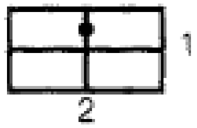
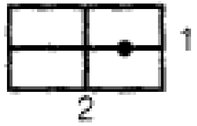
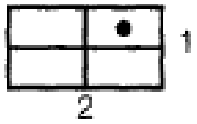
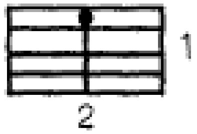
Pseudosteady-State Regime…/4

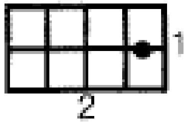
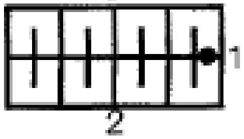
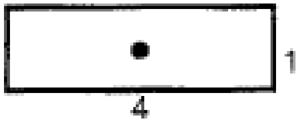
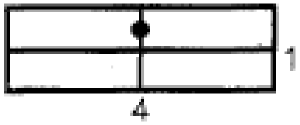
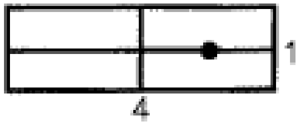
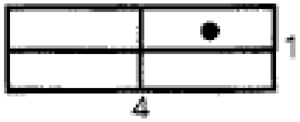
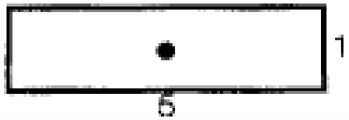
- Table 11.1 can be used to determine the t_{DA} corresponding to the end of the transient flow and to the beginning of pseudosteady-state flow for a given reservoir-well configuration:
  - The fourth column of the table indicates the exact beginning of the pseudosteady-state flow;
  - The fifth column shows the beginning of the pseudosteady-state with less than 1% error;
  - The sixth column gives the end of the transient flow with less than 1% error.

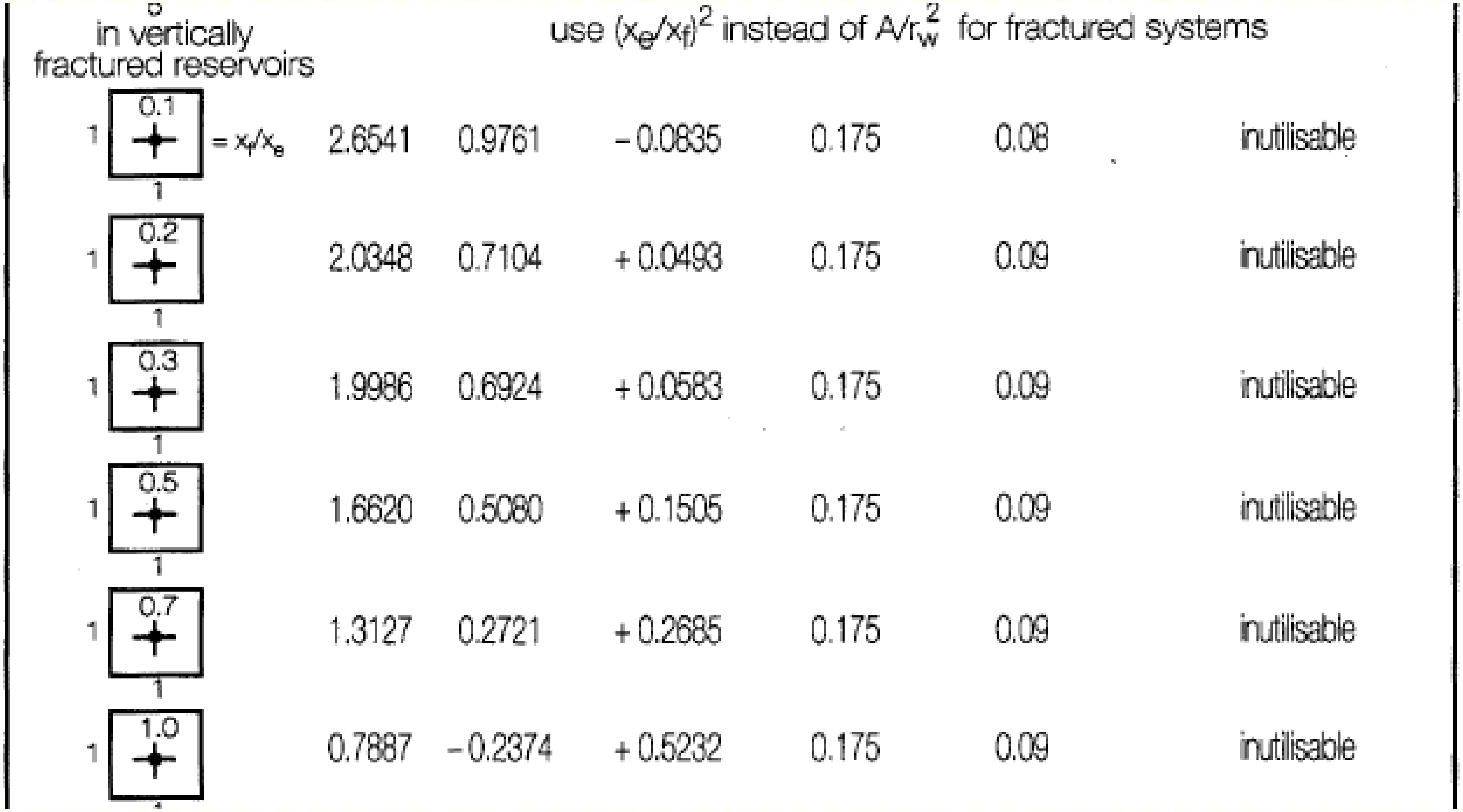
Table 11.1

In bounded reservoirs	C_A	ln C_A	$\frac{1}{2}\ln\left(\frac{2.2458}{C_A}\right)$	Exact for $t_{DA}>$	Less than 1% error for $t_{DA}>$	Use infinite system solution with less than 1% error for $t_{DA}<$
	31.62	3.4538	−1.3224	0.1	0.06	0.10
	31.6	3.4532	−1.3220	0.1	0.06	0.10
	27.6	3.378	−1.2544	0.2	0.07	0.09
	27.1	3.2995	−1.2452	0.2	0.07	0.09
	21.9	3.0865	−1.1387	0.4	0.12	0.08

	0.098	−2.3227	+1.5659	0.9	0.60	0.015
	30.8828	3.4302	−1.3106	0.1	0.05	0.09
	12.9851	2.5638	−0.8774	0.7	0.25	0.03
	4.5132	1.5070	−0.3490	0.6	0.30	0.025
	3.3351	1.2045	−0.1977	0.7	0.25	0.01

	21.8369	3.0836	− 1.1373	0.3	0.15	0.025
	10.8374	2.3830	− 0.7870	0.4	0.15	0.025
	4.5141	1.5072	− 0.3491	1.5	0.50	0.06
	2.0769	0.7309	+ 0.0391	1.7	0.50	0.02
	3.1573	1.1497	− 0.1703	0.4	0.15	0.005

	0.5813	−0.5425	+0.6758	2.0	0.60	0.02
	0.1109	−2.1991	+1.5041	3.0	0.60	0.005
	5.3790	1.6825	−0.4367	0.8	0.30	0.01
	2.6896	0.9894	−0.0902	0.8	0.30	0.01
	0.2318	−1.4619	+1.1355	4.0	2.00	0.03
	0.1155	−2.1585	+1.4838	7.0	2.00	0.01
	2.3606	0.8589	−0.0249	1.0	0.40	0.025



in vertically fractured reservoirs

use $(x_e/x_f)^2$ instead of A/r_w^2 for fractured systems

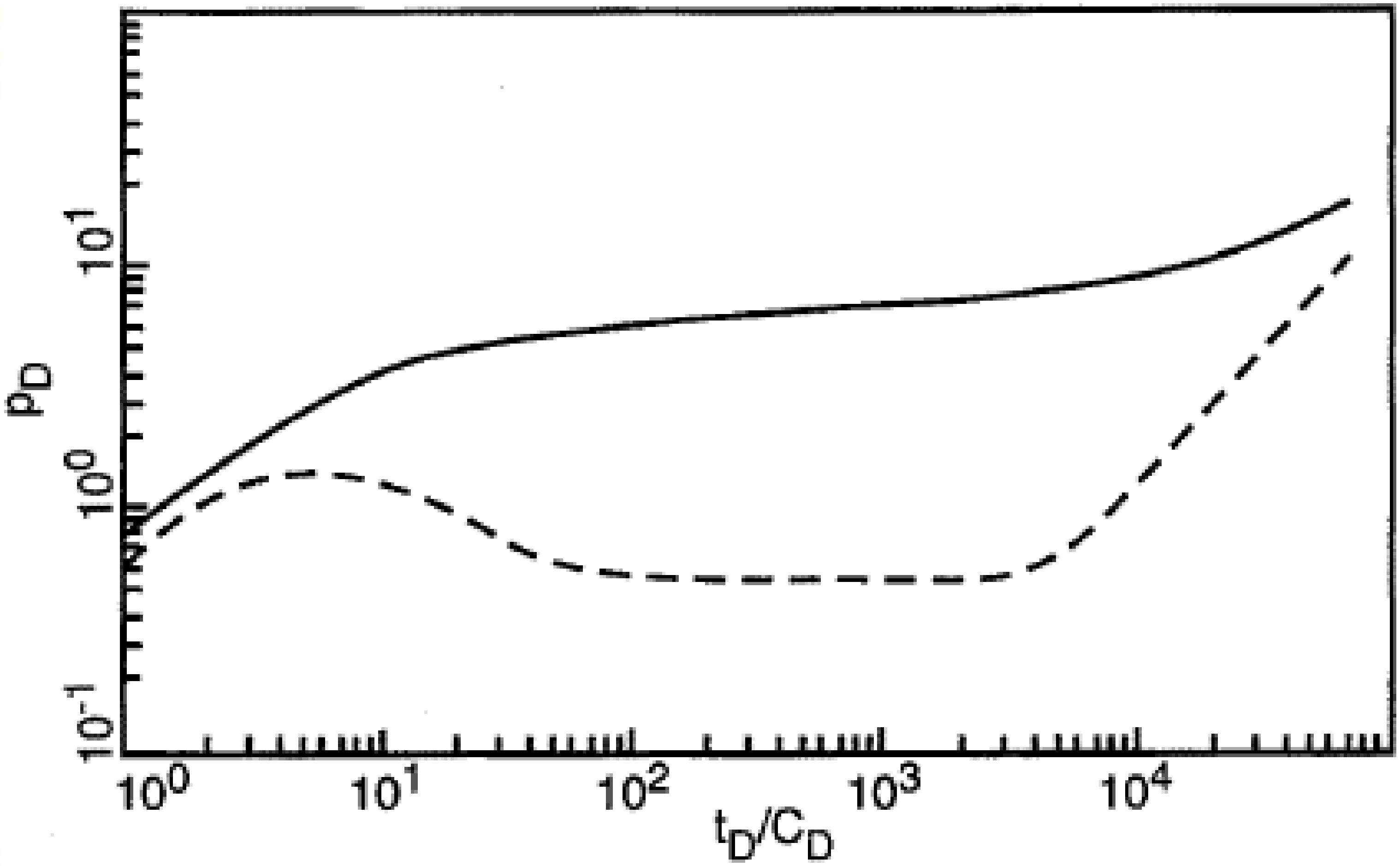
0.1 = x_f/x_e	2.6541	0.9761	−0.0835	0.175	0.08	inutilisable
0.2	2.0348	0.7104	+0.0493	0.175	0.09	inutilisable
0.3	1.9986	0.6924	+0.0583	0.175	0.09	inutilisable
0.5	1.6620	0.5080	+0.1505	0.175	0.09	inutilisable
0.7	1.3127	0.2721	+0.2685	0.175	0.09	inutilisable
1.0	0.7887	−0.2374	+0.5232	0.175	0.09	inutilisable

in reservoirs with water drive						
⊙	19.1	2.95	- 1.07	–	–	–
in reservoirs of unknown production character						
⊙	25.0	3.22	- 1.20	–	–	–

Pseudosteady-State Regime…/11

- Since pressure varies linearly versus time during the pseudosteady-state flow, this flow is characterized on the pressure derivative by a straight line with a **slope of 1** on a log-log plot.
- The shape of the transition between the transient regime and the pseudosteady-state regime depends on the shape of the drainage area on the position of the well in the area.
  - The shape of the transition is used to characterize the reservoir well configuration.

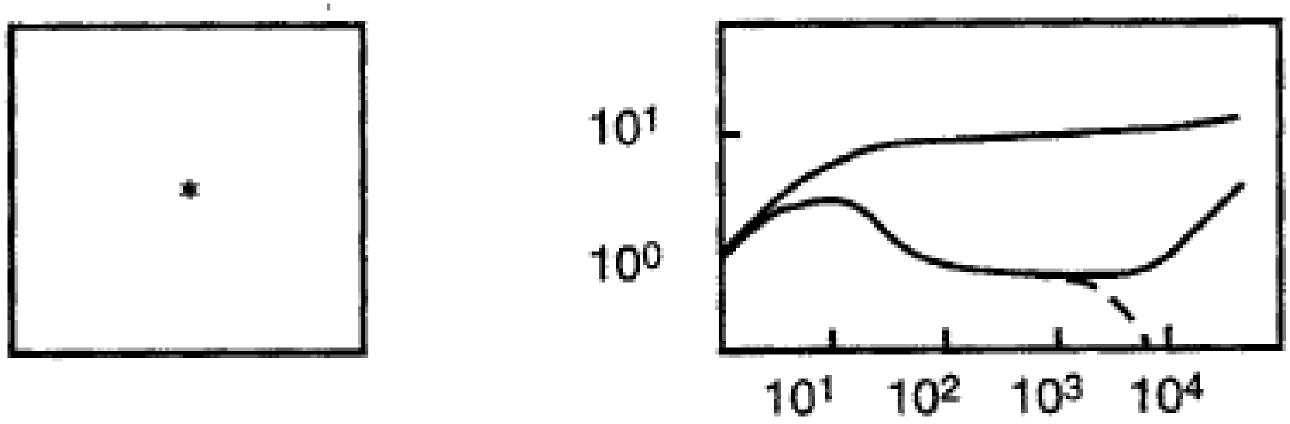
Pseudosteady-State Regime…/12



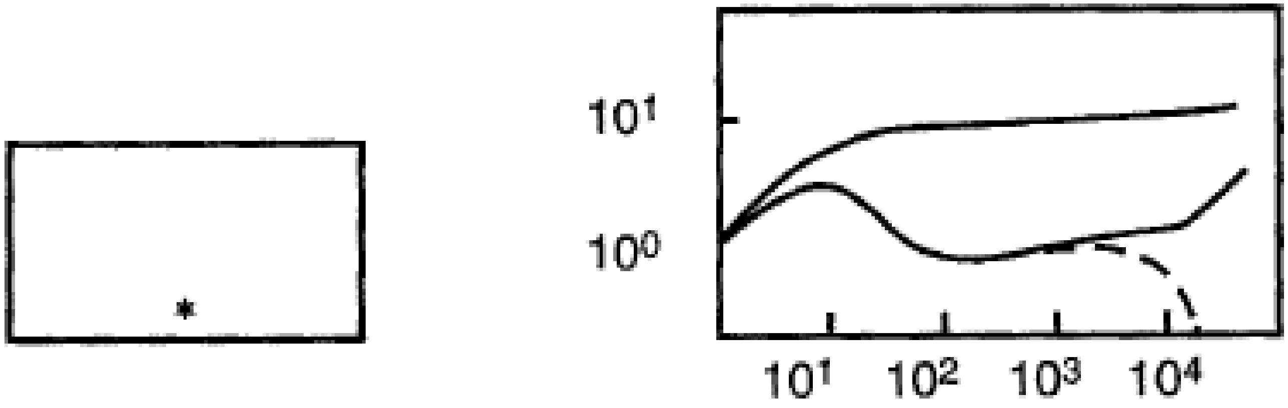
Pseudosteady-State Regime…/13

- Figures below shows a number of typical configurations and how they are characterized on the pressure derivative plot.
- It shows the boundary during a drawdown, but also during buildup (broken line).

Pseudosteady-State Regime…/14

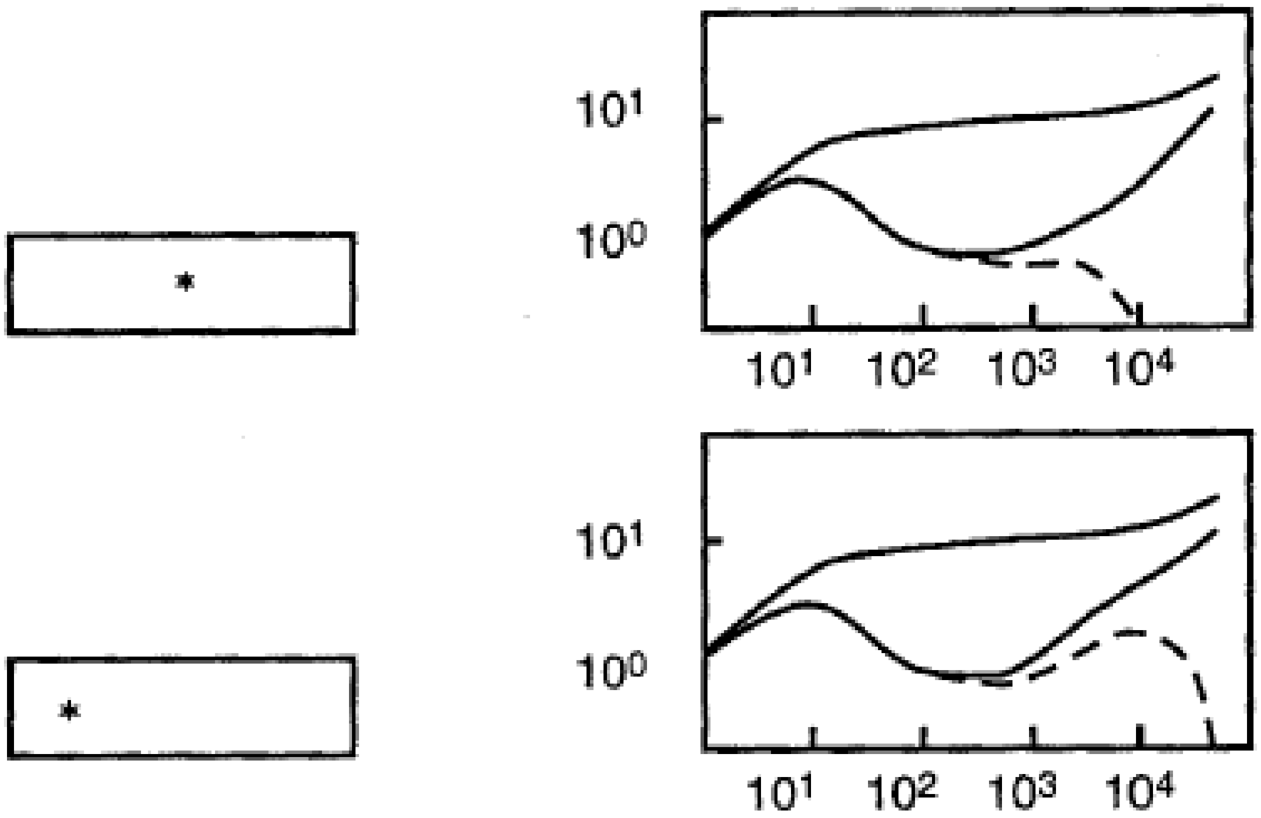


slope of 1, pseudosteady-state flow



fault

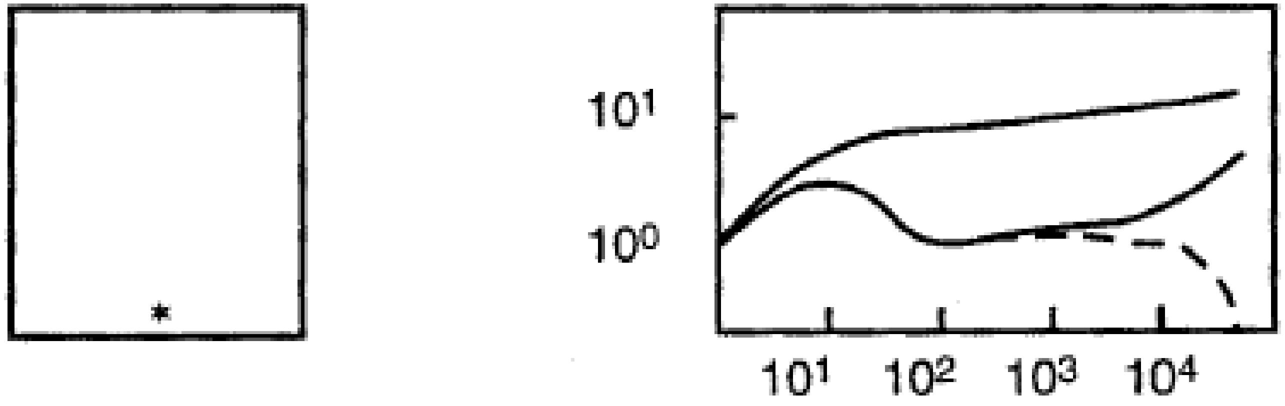
Pseudosteady-State Regime…/15



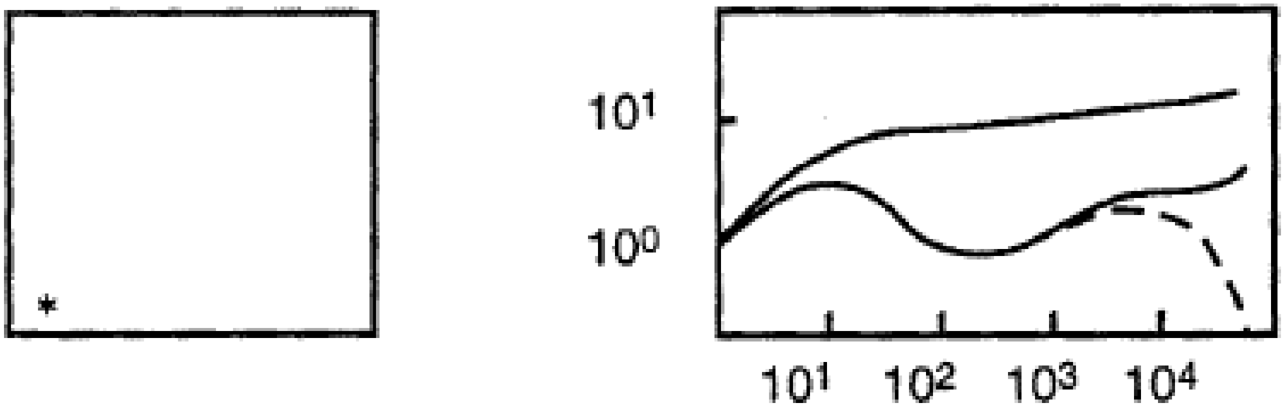
slope of 0.5 ;
channel

slope of 0.5 ;
bounded channel

Pseudosteady-State Regime…/16



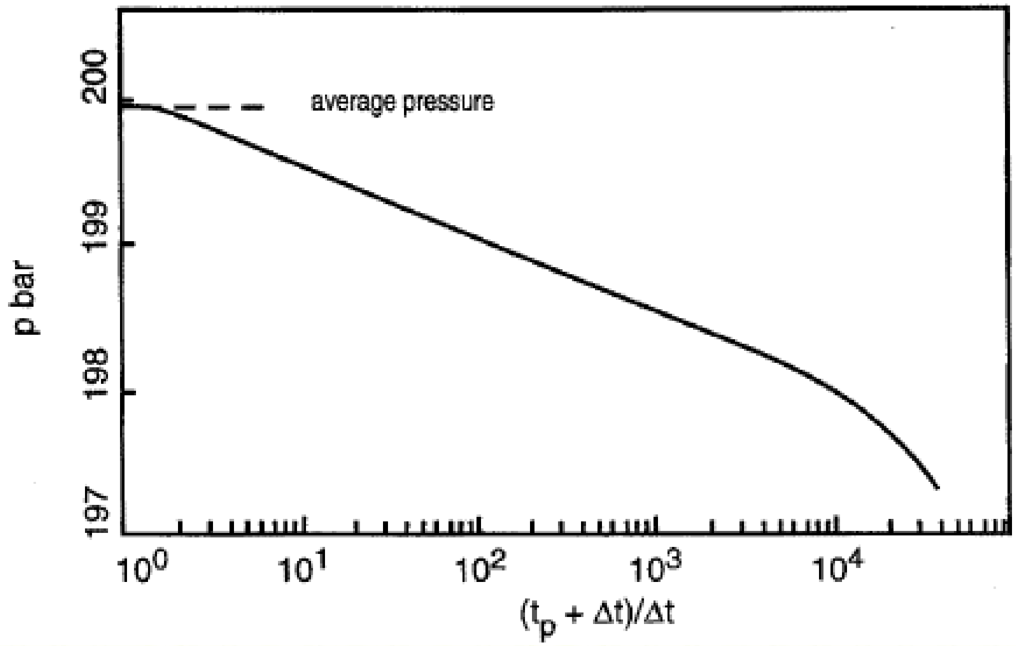
fault ; channel



two intersecting faults (90° angle)

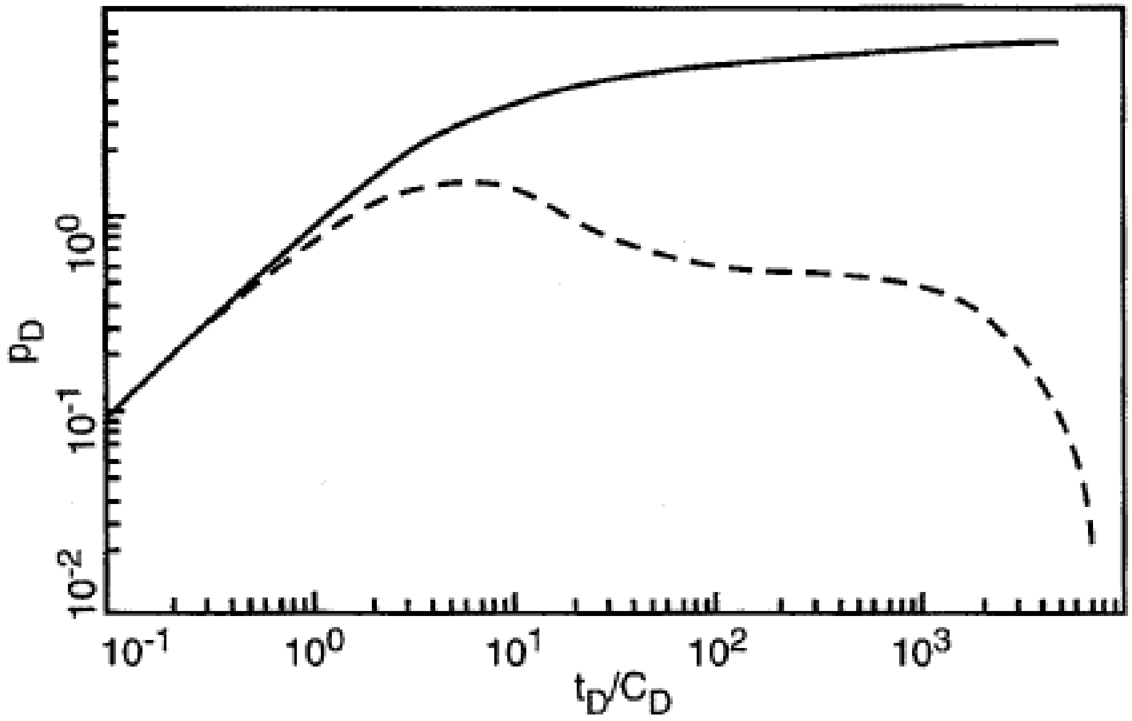
Shut-in Well, Average Pressure

- When the compressible zone reaches real no-flow physical boundaries during buildup, the pressure in the drainage area becomes uniform and constant – average pressure of the drainage area.



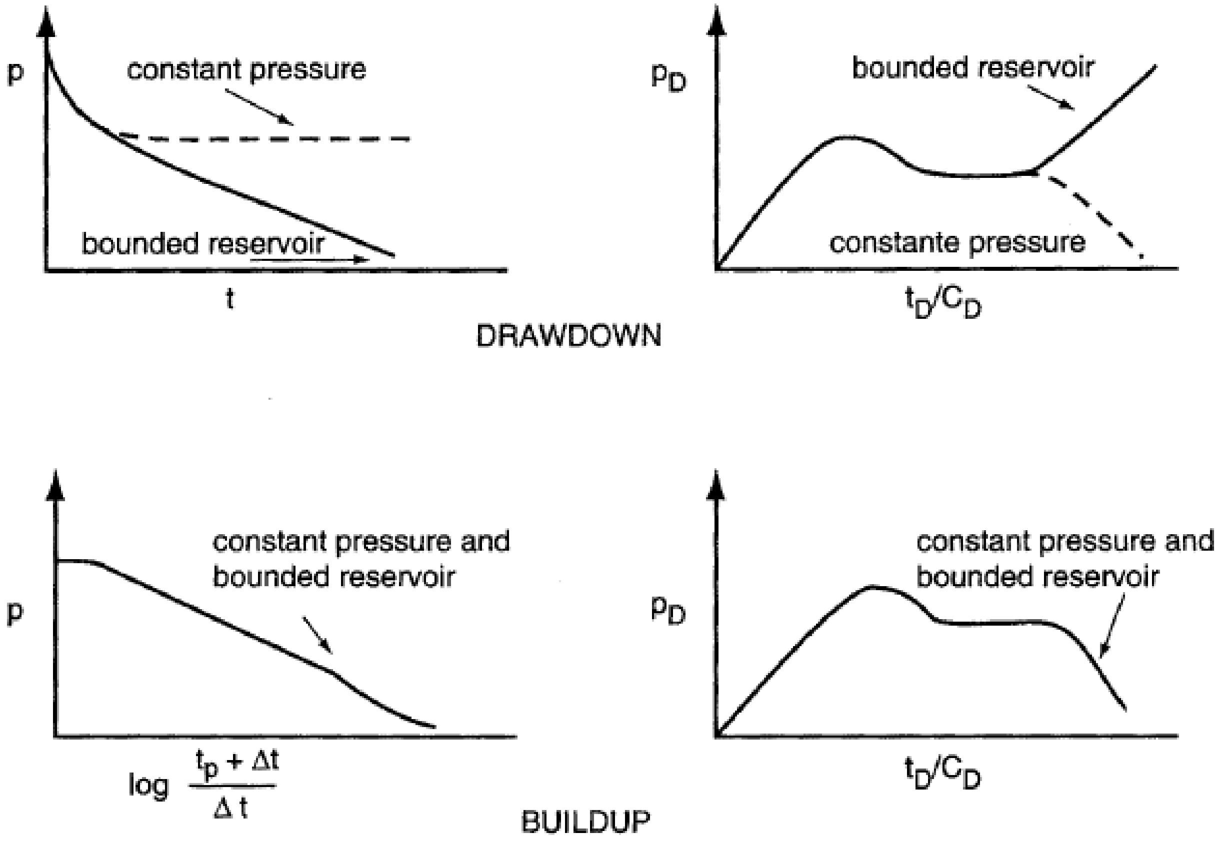
Shut-in Well, Average Pressure…/2

- A derivative going to zero corresponds to reaching the average pressure. It corresponds to a steep decrease of the derivative on a log-log plot.



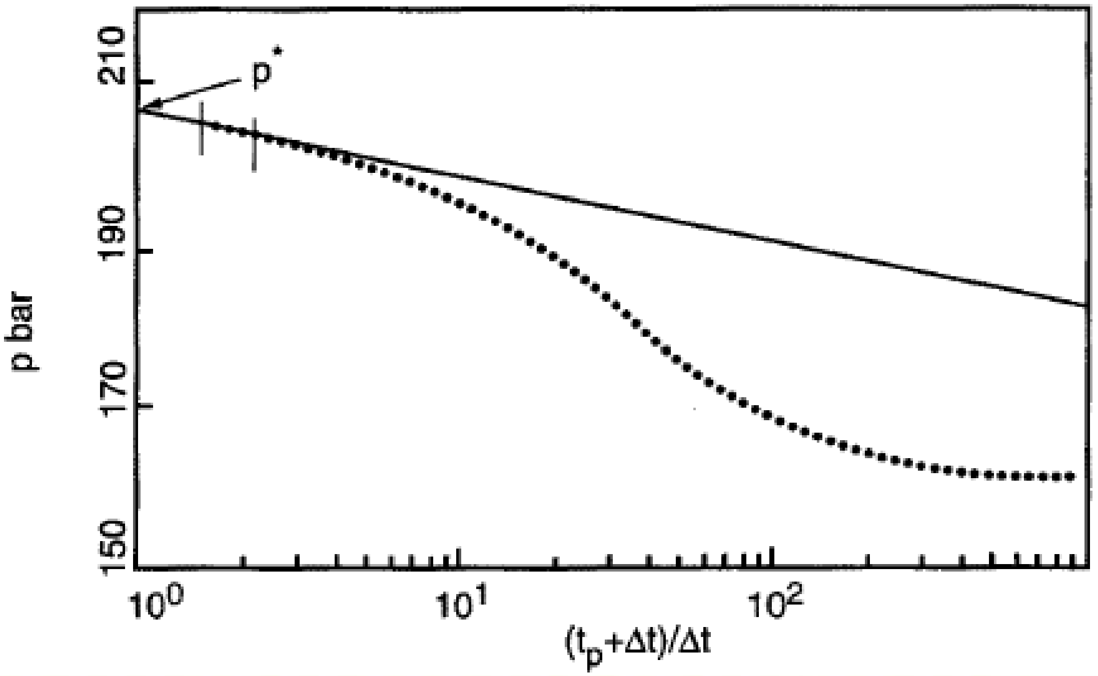
Shut-in Well, Average Pressure…/3

- Comparison with a constant pressure boundary.



Shut-in Well, Average Pressure…/4

- Calculating the average pressure using MBH (Mathews, Brons, Hazebroek) method:



Note: P* must be determined on the first semi-log straight line that corresponds to the infinite acting period

Shut-in Well, Average Pressure…/5

1. Calculate t_{pDA} :

$$t_{pDA} = \frac{0.000264\, k t_p}{\phi \mu c_t A}$$

2. Choose the curve corresponding to the reservoir-well configuration of the test (Figure 11.8 - 1.11).

3. Use the chart to determine:

$$P_{DMBH} = \frac{2.303\left(p^* - \overline{p}\right)}{m}$$

4. Calculate the average pressure.

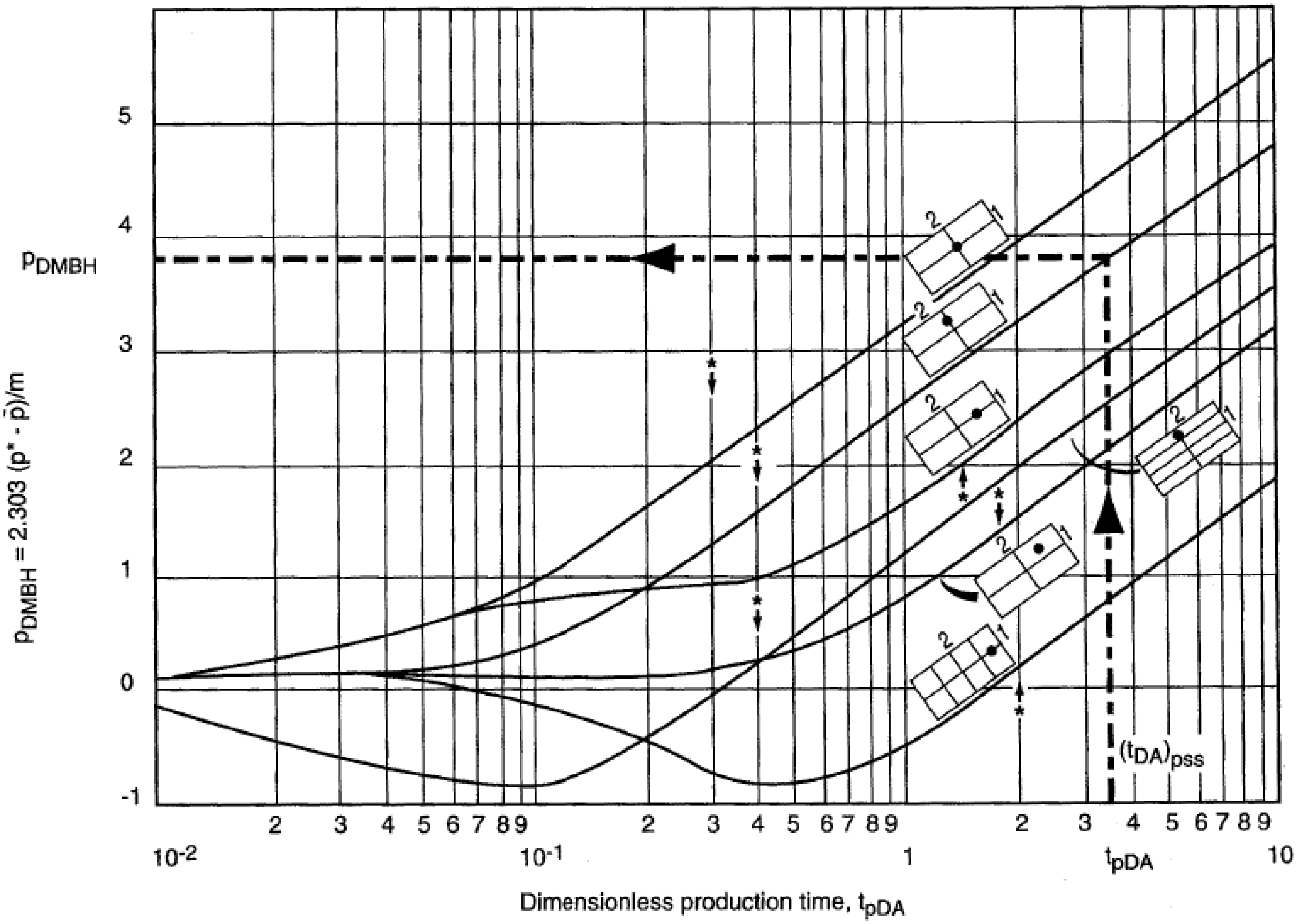

p_{DMBH}
$p_{DMBH} = 2.303\,(p^* - \bar{p})/m$
5
4
3
2
1
0
-1
10^{-2}
2 3 4 5 6 7 8 9
10^{-1}
2 3 4 5 6 7 8 9
1
2 3 4 5 6 7 8 9
10
t_{pDA}
$(t_{DA})_{pss}$
2
1
*
Dimensionless production time, t_{pDA}

Fig. 11.8

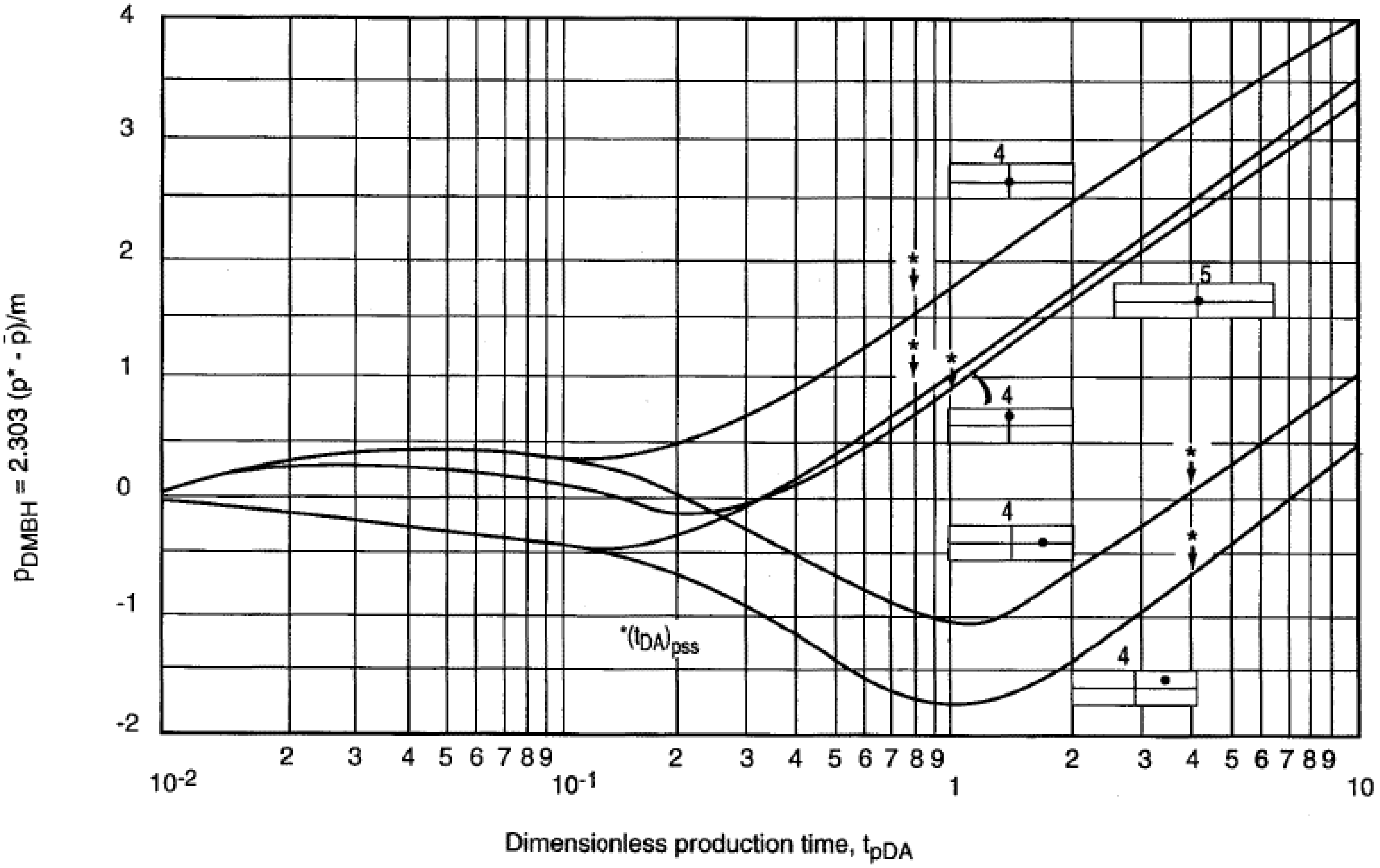

4
3
2
1
0
-1
-2
$p_{DMBH} = 2.303 (p^* - \bar{p})/m$
10^{-2}
2
3
4
5
6
7
8
9
10^{-1}
1
10
Dimensionless production time, t_{pDA}
$^*(t_{DA})_{pss}$
4
5
4
4
4

Fig. 11.9

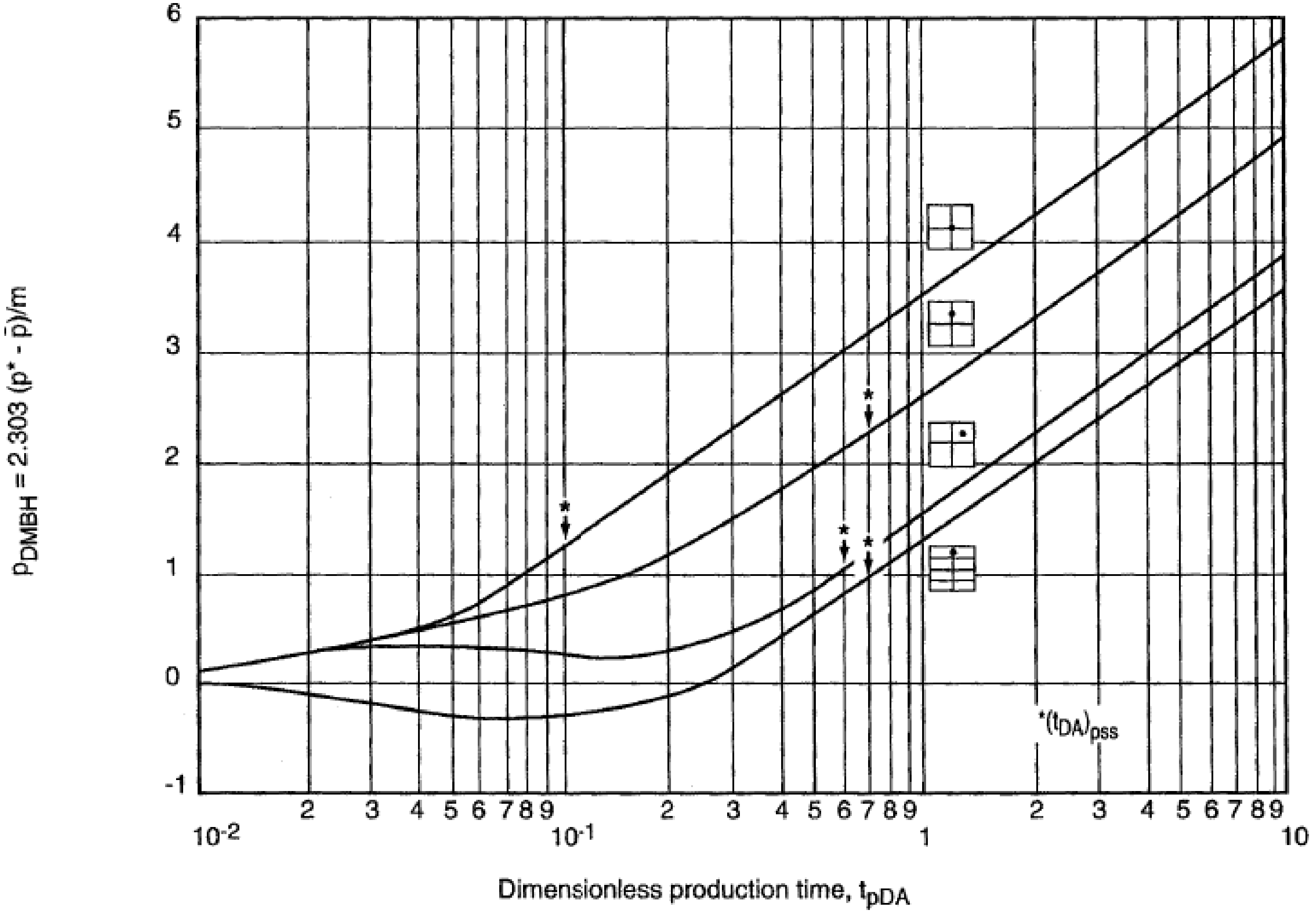

$p_{DMBH} = 2.303\,(p^* - \bar{p})/m$
6
5
4
3
2
1
0
-1
10^{-2}
2
3
4
5
6
7
8
9
10^{-1}
1
10
*
$^*(t_{DA})_{pss}$
Dimensionless production time, t_{pDA}

Fig. 11.10

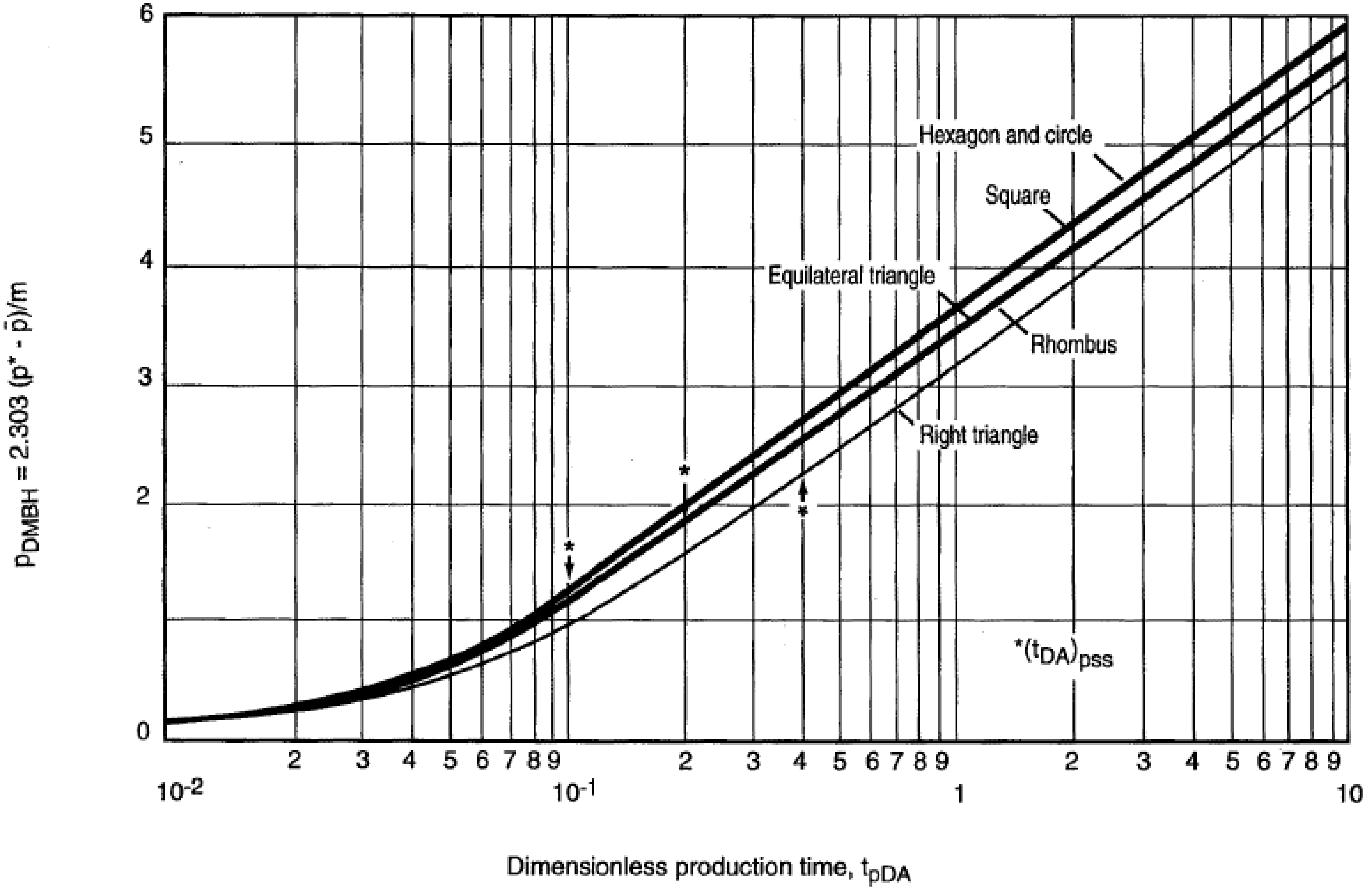

6
5
4
3
2
0
p_{DMBH} = 2.303 (p* - p̄)/m
Hexagon and circle
Square
Equilateral triangle
Rhombus
Right triangle
*
*
*
$^*(t_{DA})_{pss}$
2
3
4
5
6
7
8
9
10^{-2}
10^{-1}
1
10
Dimensionless production time, t_{pDA}

Fig. 11.11

Productivity Index

- The productivity index of a well is the ratio between:
  - The well flow rate;
  - The difference between the average pressure of the drainage area and the bottomhole pressure:

$$\mathrm{PI} = \frac{q}{\bar{p} - p_{wf}} \tag{12.1}$$

Productivity Index…/2

- Productivity index during the infinite-acting period can be calculated by:

$$\mathrm{PI} = \frac{kh}{162.6B\mu\left(\log t + \log\frac{k}{\phi\mu c_t r_w^2} - 3.23 + 0.87S\right)} \qquad \textbf{(12.2)}$$

Productivity Index…/3

- Productivity index during the pseudosteady-state flow can be calculated by:

$$\mathrm{PI} = \frac{kh}{162.6B\mu\left(\log\frac{A}{r_w^2} + \log\frac{2.2458}{C_A} + 0.87S\right)} \tag{12.6}$$

Example 14

(In-class workshop)

- Closed reservoir

References

1. Bourdarot, Gilles : Well Testing: Interpretation Methods, Éditions Technip, 1998.
2. Internet.