ENP100 - Prosess og produksjon

Øving 4 - Løsningsforslag

A) Productivity index *J* is defined by equation (3.49) in the text book:*

$$J \equiv \frac{q_o}{P_e - P_{wf}}$$

*: (It is however used in equations prior to that, due to additions made for the 2nd Ed.)

Since all values of pwf in the table are above the boiling point pressure, there will be single-phase flow in the reservoir, leading to a linear IPR curve. => Any pair of (qo, pwf) will give approximately the same value for J:

$$J = \frac{4098}{6000 - 4030} = \underline{\underline{2.08}}$$

B) J is constant down to pwf = pb:

$$q_{ob} = J \cdot (P_e - P_b) = 2.08(6000 - 3500)$$

$$\underline{\underline{= 5200 \ Stb/d}}$$

C) Since there is single-phase flow of oil at least up to the perforations, any gas present at the surface must come from within the oil.

D) Compare the first inflow equation with the definition of *J*:

$$q_o = J \cdot (P_e - P_{wf})$$

$$q_o = \underbrace{\frac{kh}{141.2 \cdot \mu_o B_o} \cdot \frac{1}{\left[\ln\left(\frac{r_e}{r_w}\right) - 0.75 + s\right]}}_{J} \cdot (P_e - P_{wf})$$

J is already quantified, and with the available well- and fluid data the only unknown will be the skin factor *s*:

$$\frac{kh}{141.2 \cdot \mu_o B_o} \cdot \frac{1}{\left[\ln\left(\frac{r_e}{r_w}\right) - 0.75 + s\right]} = 2.08$$

(re in inches)

$$\Rightarrow s = \frac{150 \cdot 60}{141.2 \cdot 1.3 \cdot 1.5} \cdot \frac{1}{2.08} + 0.75 - \ln\left(\frac{1000 \cdot 12}{4.25}\right) = \underline{\underline{8.52}}$$

E) The complete IPR curve consists of a linear part down to (qob, pb), then a curved part which is to be described by Vogel's IPR model (which is really just an adaption of a 2nd degree polynomial to account for the curvature) (*This info is missing in the 2022 text*)

Vogel's IPR Model for partial two-phase reservoir:

$$q_o = q_{ob} + q_v\left[1 - 0.2\left(\frac{p_{wf}}{p_b}\right) - 0.8\left(\frac{p_{wf}}{p_b}\right)^2\right] \qquad (3.61)$$

q_{ob} → $q_o(p_{wf} = p_b)$; found in B)

$$q_v = \frac{J^* p_b}{1.8} \qquad (3.62)$$

→ J for linear part

For the plot calculation, make pwf the independent variable ("x") and qo the dependent ("y"), then flip the axis. The rest should be straight forward (see Figure 1).

F) Points on the TPR for given pwh:

pwf(TPR) = pwh + (pwf(qo) - pwh(qo))

The table below shows the points for pwh = 1500 (TPR 1) og for pwh = 500 (TPR 2)
For plot, see Figure 1.

	(IPR)	(WPR)		(TPR 1)	(TPR 2)
qo [stb/d]	pwf [psi a]	pwh [psi a]	Δpw	pwh = 1500	pwh = 500
0	6000	-	-	-	-
832	5600	2450	3150	4650	3650
2454	4820	1870	2950	4450	3450
4098	4030	790	3240	4740	3740
4555	3810	510	3300	4800	3800

G) The wellhead pressures may also be plotted in the diagram (they are pressures although not bottom hole pressures); see Figure 1.

With a grid and lines between the points as shown in the figure, the wellhead pressure can be read visually to pwh(2000) ≈ 2000 psi.

(Interpolation - though in this case a bit overkill - will give 2032 psi)

H) With both qo and pwh, Ros' formula can be "solved" w/ respect to nozzle size ("d_64"):

$$d_{64}^2 = \frac{17.4 \cdot \sqrt{GOR} \cdot q_o}{p_{wh}} = \frac{17.4 \cdot \sqrt{800} \cdot 2000}{2000}$$

$$= 492$$

Diameter in inches: $d = \frac{1}{64} \cdot \sqrt{492} = 0.347 \text{ in}$

I) As long as the reservoir pressure is above the boiling point (pb = 3500 psi a) the IPR curve should remain linear down to that pressure.

Assuming visual read-off is sufficiently accurate in the following: If the linear part of the IPR is shifted downwards (J = constant), it will intersect the TPR for pwh = 500 psi in the point (qo = 2000, pwh ≈ 3500). This is just at the boiling point.

But because of the linearity, the drop in reservoir pressure will be the same as the drop in bottom hole pressure over the same period. The bottom hole pressure at production start can be read off the original IPR curve to be appr. 5050 psi.

Pressure drop Dp = 5050 - 3500 = 1550 psi; divided by 200 psi/year = 7.75 years

J) E_F is a parameter used by Golan & Whitson, comparing a flow situation with a skin effect (i.e. real) to one without (i.e. ideal). **Skip this point.**

K) Skin effect is the result of the near-well deterioration of the permeability, often due to intrusion of drilling mud etc., during completion. Since this occurs where the flow velocity is the highest, the impact may be severe. The "damage" is quantified by the skin factor* s (calculated in D), which appears in the denominator of the inflow equations, thus high s = large skin factor/a lot of damage.

* *Mathematically this is a term, not a factor*

When changing the value of s from 8.52 (as calculated in D) to 5.0 the following will happen:

- Recalculating J (same procedure as in D, only now s is known, while J is unknown) gives new value J = 2.68. (J is actually the slope of the line when pwf is "x" and qo is "y", so in the current diagram the "new" IPR will have more "gentle" slope.
- The boiling point is the same, so the value of qob (calculated in B) will be shifted towards a higher value; from 5200 to qob = 6700 stb/d
- The value of qv (equation (3.62)) with the new J will be qv = 5211 stb/d

Otherwise the plot is constructed similarly, see Figure 2.

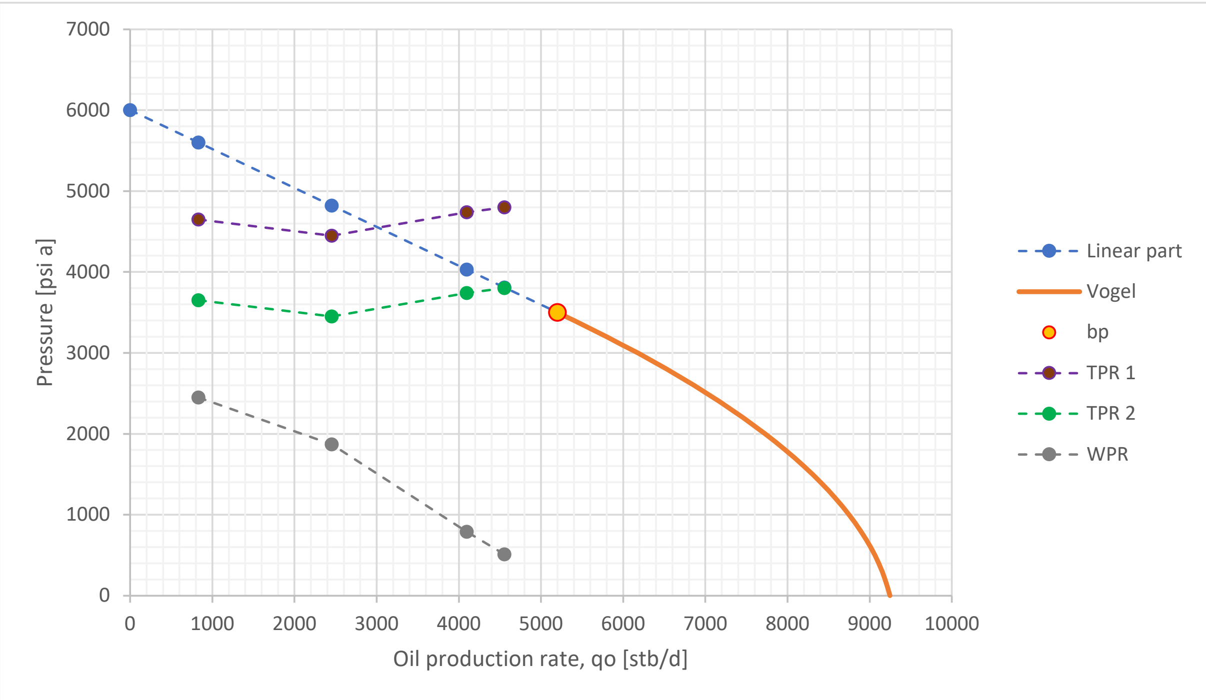

Figure 1: IPR, WPR and TPR curves

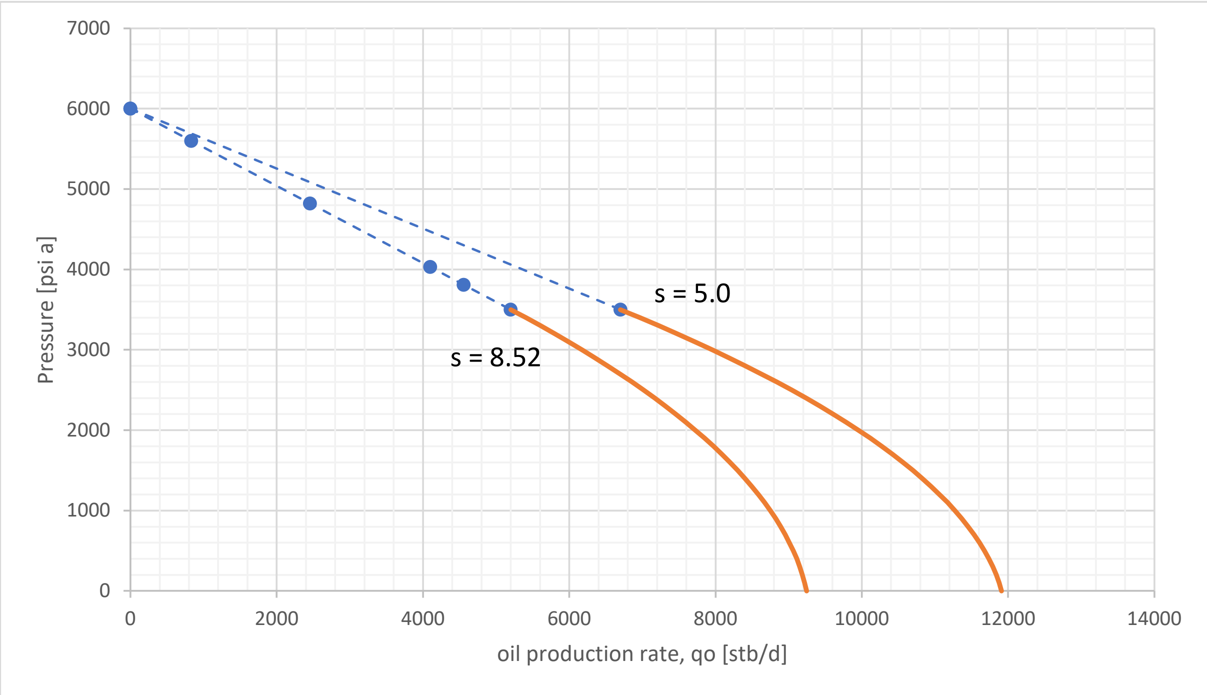

Figure 2: IPR curves for two different values of the skin factor