

**TENTAMEN : Production Technology I (mp3440)****April 29 1998****Answer all questions. Answer in either English or Dutch (or a mixture).****Question 1**

- a) Use the Duns/Ros gradient curves to calculate the flowing bottomhole pressure  $p_{wf}$  for the following well at the flowrates 400, 600, 800, 1000, 1500 and 2000 bbl/day
- |                             |              |
|-----------------------------|--------------|
| depth of producing interval | 12500 ft     |
| GOR                         | 2000 scf/bbl |
| Water cut                   | 0%           |
| Tubing size                 | 3½"          |
| Tubing head pressure        | 1000 psi     |
- b) The initial reservoir pressure is 4500 psi and the PI is 1 bbl/day/psi. What is the initial production rate and flowing bottomhole pressure ?
- c) If the PI of the well stays constant during production of the well, what is the lowest reservoir pressure at which the well can produce without artificial lift ? What is the final production rate in bbl/day ?
- d) The pressure downstream of the wellhead choke is 500 psi. Show that the flow through the choke is critical. Calculate the initial and final sizes of the choke in 1/64<sup>th</sup> of an inch (use the Gilbert correlation for a choke in critical flow)

**Question 2**

- a) A small diameter exploration well (4½" diameter) is being drilled. Casing has been set at 7000 ft. The well enters an oil reservoir with the following parameters :
- |                           |              |
|---------------------------|--------------|
| depth of top of reservoir | 10000 ft     |
| reservoir Pressure        | 4500 psi     |
| GOR                       | 2000 scf/bbl |
| water cut                 | 0%           |
- While the bit is out of the hole, pressure control is lost. Oil flows freely up the openhole section. The effective PI for flow into the well is 2bbl/day/psi. Use the Duns/Ros curves to calculate the flowing pressure at the depth of 7500 ft (i.e. 2500 ft above the top of the reservoir, and 500ft below the casing shoe), at the flowrates 200, 400, 600, 800, 1000, 1500 and 2000 bbl/day
- b) The well is shut-in at surface. At the level of 7500 ft there is a water-bearing sandstone, with water pressure 3200 psi. This sandstone has an Injectivity Index of 5 bbl/day/psi. Show that oil will be injected into this sandstone from the well and calculate the rate. (Note: since the well is shut-in at surface, any oil produced from the reservoir must be injected into the water layer).
- c) The flowing oil carries sand eroded from the walls of the openhole section. This sand impairs the water-bearing layer, and gradually the Injectivity Index reduces. What happens to the flowrate of oil ?

**Question 3**

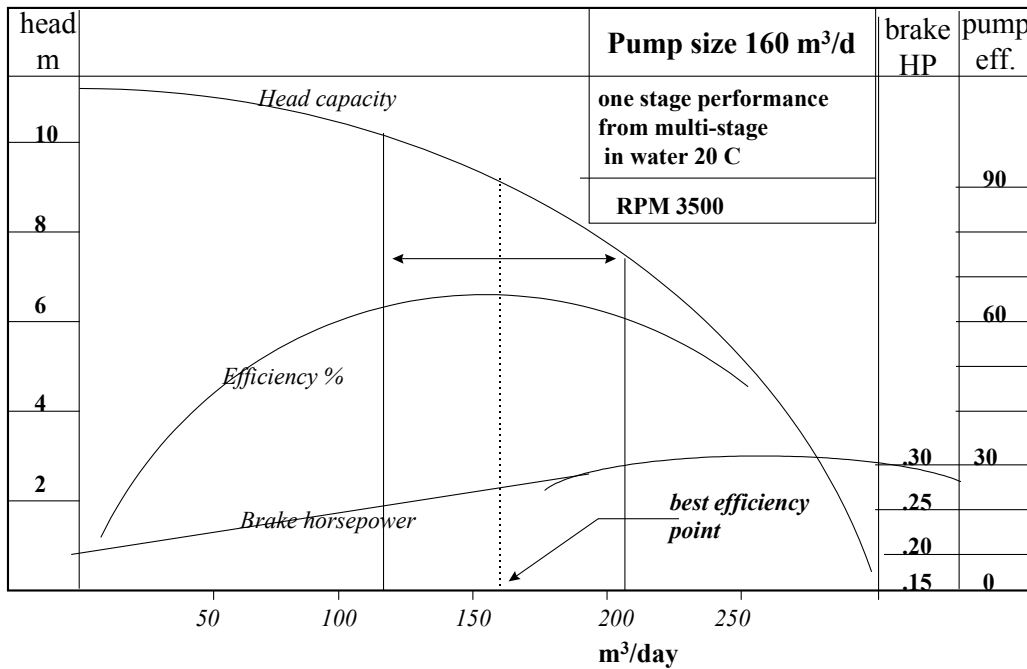
a) What are the advantages and disadvantages of an ESP compared with other forms of artificial lift ?

b) A well is producing under the following conditions

Depth	10000 ft
GLR	600 scf/bbl
Watercut	0%
Tubing size	4½"
Reservoir pressure	2000 psi
Productivity Index PI	4 bbl/day/psi

Calculate the flowing bottomhole pressure at a production rate of 1000 bbl/day.

c) This production rate of 1000 bbl/day (159 m<sup>3</sup>/day) is produced by an ESP installed at the depth of 7500 ft (NOT at the bottom of the hole). The tubing head pressure is 500 psi. The ESP performance curve is given here



Use this curve and the Duns/Ros gradient curves to calculate the number of stages required for the pump. (1 psi = 6.89 kPa).

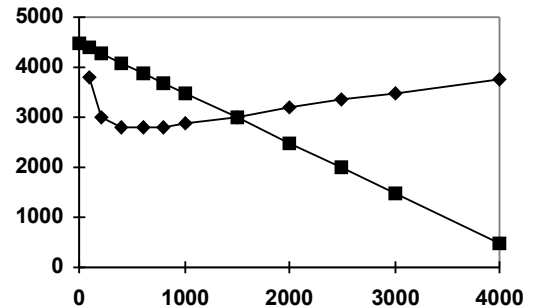
**Question 4**

- a) An oil well has stopped producing through 4½" tubing. The oil has a GOR (Gas/Oil Ratio) of 400 scf/bbl and zero watercut. It is planned to install gaslift, to restore production to 1000 bbl/day by injecting 600 thousand scf/day of gas. Determine the GOR of the produced oil.
- b) When the well is not flowing, the tubing head pressure is 100 psi and the pressure gradient in the oil is 0.4 psi/ft. The gas injection pressure on surface is 800 psi and the gas gradient is 0.04 psi/ft. Determine the deepest point at which gas can be injected without gaslift valves.
- c) When the well is flowing under gaslift, the tubing head pressure is maintained at 250 psi. Use the Duns/Ros curves to plot the gas lifted well gradient as a function of depth (take the depths 0, 2500, 5000, 7500 and 10000 ft). The gas injection pressure and gas gradient are the same as in (b). Estimate the deepest point at which gas can be injected with gaslift valves.
- d) The gaslift valves are adjusted to operate at a pressure 100 psi above the flowing well gradient. Estimate the deepest point at which gas can be injected.
- e) Estimate the setting depths and pressures of the first three valves.

Solution to Question 1

a)

q bbl/day	p <sub>wf</sub>	inflow
0		4500
100	3800	4400
200	3000	4300
400	2800	4100
600	2800	3900
800	2800	3700
1000	2900	3500
1500	3000	3000
2000	3200	2500
2500	3350	2000
3000	3500	1500
4000	3750	500



- b) Initial production rate is 1500 bbl/day. Flowing bottomhole pressure is 3000 psi.
- c) Lowest production rate is between 400 and 800 bbl/day, say 600 bbl/day, at bottomhole pressure 2800 psi. If PI stays as 1, reservoir pressure is  $2800 + 1 \cdot 600 = 3400$  psi
- d) The ratio of the pressures upstream and downstream of the choke is  $1000/500 = 2$ , which is greater than the value 1.7 required for critical flow. Hence the flow is critical.

The Gilbert formula gives  $p_1 = D + A q R^B/d^C$  where  $A = 10$ ,  $B=0.546$ ,  $C=1.89$ ,  $D=14.7$ . We want to calculate d, the choke diameter in 64<sup>th</sup> inch.

$$d^C = A q R^B / (p_1 - D) . \text{ Hence } d = [A q R^B / (p_1 - D)]^{1/C}$$

$$d = [10 \cdot q \cdot 2000^{0.546} / (1000 - 14.7)]^{1/1.89}$$

For the initial production rate  $q= 1500$  bbl/day,  
 $d = [10 \cdot 1500 \cdot 2000^{0.546} / (1000 - 14.7)]^{1/1.89} = 38$ . Hence initially install a 38/64" choke.

For the final production rate  $q= 600$  bbl/day,  
 $d = [10 \cdot 600 \cdot 2000^{0.546} / (1000 - 14.7)]^{1/1.89} = 23$ . Hence finally have a 23/64" choke.

prod rate	d					
1500	37.95809					
600	23.37513					

Question 2

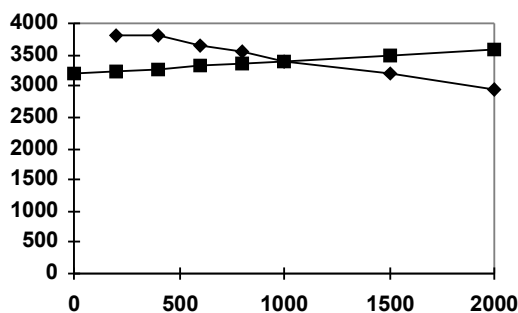
a)

q bbl/day	bottom hole pressure due to inflow from oil reservoir	pressure in well at 2500 ft higher, using Duns/Ros
0	4500	-
200	4400	3800
400	4300	3800
600	4200	3650
800	4100	3550
1000	4000	3400
1500	3750	3200
2000	3500	2950

b) The pressure/flowrate relationship for the injectivity is

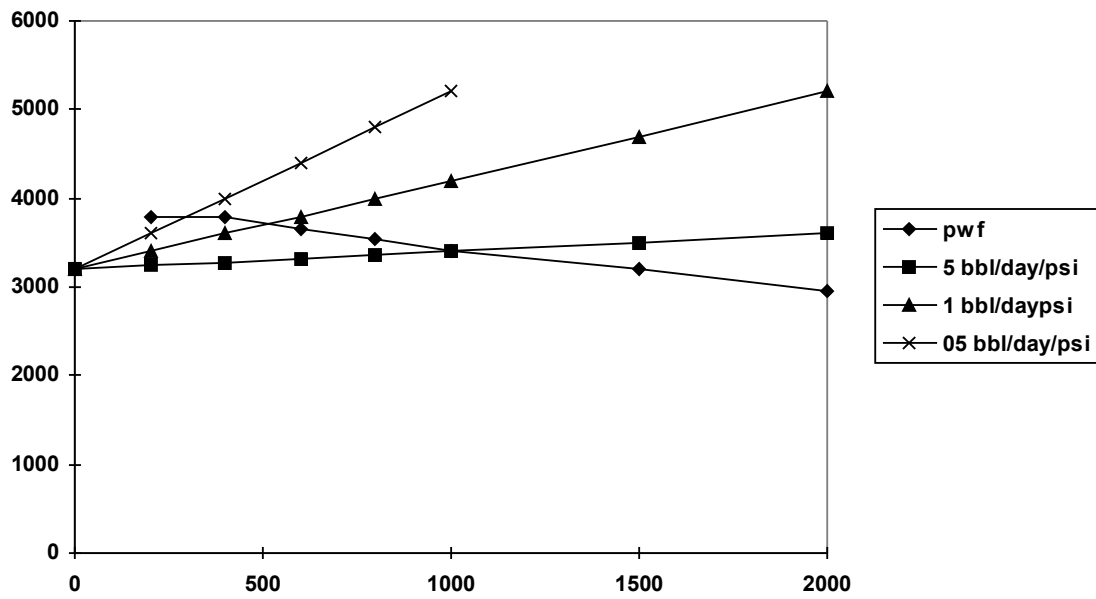
$$p_{\text{well}} = p_{\text{res}} + q/II, \text{ wher } II \text{ is the Injectivity Index.}$$

q bbl/day	bottom hole pressure due to inflow from oil reservoir	pressure in well at 2500 ft higher, using Duns/Ros	pressure in well using injectivity index 5 bbl/day/psi of water-bearing sandstone
0	4500	-	3200
200	4400	3800	3240
400	4300	3800	3280
600	4200	3650	3320
800	4100	3550	3360
1000	4000	3400	3400
1500	3750	3200	3500
2000	3500	2950	3600



Thus the rate at which oil is injected into the water-bearing sandstone is approximately 1000 bbl/day.

c) As the injectivity index decreases, the “Injectivity Line” becomes steeper. For example, for values of the Injectivity Index equal to 1 bbl/day/psi and 0.5 bbl/day/psi we have the following picture :



This the oil flow rate decreases steadily with time. According to the Duns/Ros curves, we expect it to stop completely when the II is about 0.5 bbl/day/psi, since then the flow is predicted to be unstable (slopes of equal sign). This prediction is not very certain, however.

**Question 3**

a) Advantages :

- does not require gas
- can handle deviated wells
- can be used offshore

Disadvantages :

- requires more careful handling and maintenance
- requires careful sizing
- cannot handle excessive sand
- cannot handle excessive gas

b) The flowing bottomhole pressure  $p_{wf}$  is given by  $(p_r - p_{wf}) * PI = q$ . Hence  $p_{wf} = 2000 - 1000/4 = 1750$  psi

c) From the Duns/Ros gradient curve, the flowing pressure at depth 7500 ft corresponding to tubing head pressure 500 psi is 2000 psi.

Also from the Duns/Ros gradient curve, the flowing pressure at height 2500 ft above the bottom of the well, corresponding to a bottom hole pressure of 1750 psi is 1100 psi.

The pump must provide the pressure difference of  $2000 - 1100 = 900$  psi.

1000 bbl/day = 159 m<sup>3</sup>/day. From the ESP Performance Curve, each stage produces 9.5 m head of water.

9.5 m water =  $9.5 * 1000 * 9.81$  Pa =  $9.5 * 9.81$  kPa =  $9.5 * 9.81 / 6.89$  psi = 13 psi

Need  $900/13 = 69.2$ , implying 70 stages

**Question 4**

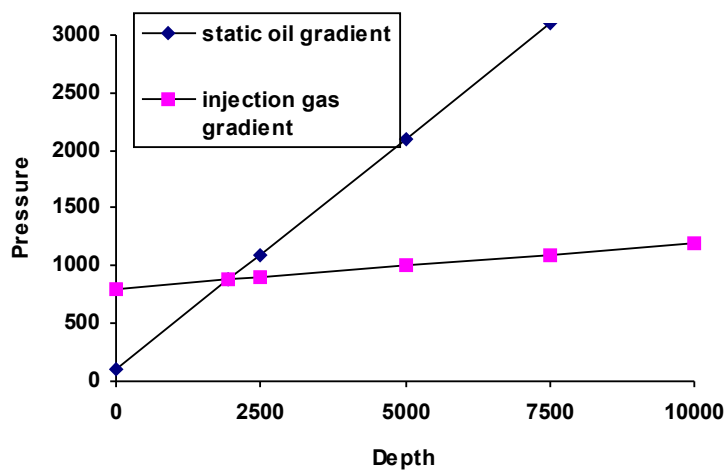
a) GOR of produced oil = GOR of reservoir oil +  $q_g/q = 400 + 600000/1000 = 1000$  scf/bbl

b) Depth  $d$  at which static oil gradient = gas gradient is given by

$$100 + 0.4 d = 800 + 0.04 d$$

$$d = 700/0.36 = 1944 \text{ ft} . \text{ Pressure} = 100 + 0.4 \cdot 700/0.36 = 878 \text{ psi}$$

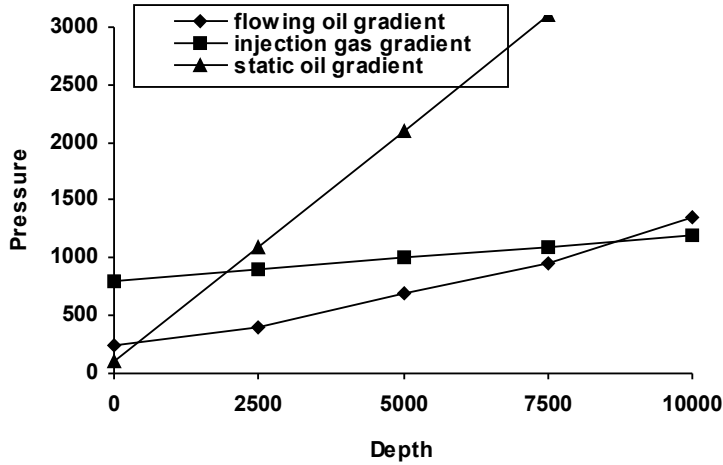
Depth	static oil gradient	injection gas gradient
0	100	800
1944	878	878
2500	1100	900
5000	2100	1000
7500	3100	1100
10000	4100	1200



c) From the Duns/Ros gradient curve (3½" tubing, GOR 1000, watercut 0%) for production rate 1000 bbl/day, get the following pressures, assuming 250 psi tubing head pressure

Depth	flowing well pressure	Gas injection pressure (from above)
0	250	
2500	400	900
5000	700	1000
7500	950	1100
10000	1350	1200

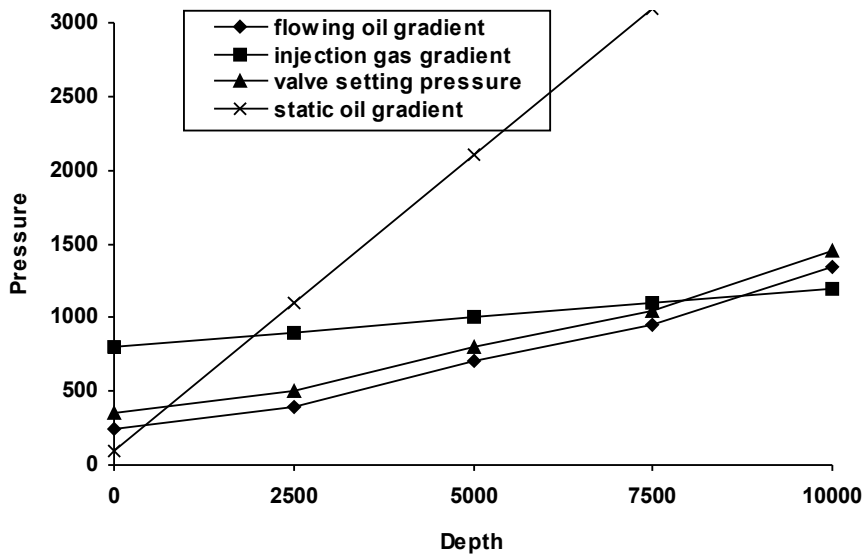




From graph estimate deepest injection point is about 8300 ft

d) The valve setting pressures are 100 psi above the flowing well gradient

Depth	flowing well pressure	valve setting pressure	Gas injection pressure (from above)
0	250	350	
2500	400	500	900
5000	700	800	1000
7500	950	1050	1100
10000	1350	1450	1200



Thus estimate maximum injection depth to be 7800 ft

- d) We can either calculate the valve depths and pressures graphically (see lecture notes ) or numerically. Graphically is far quicker, and advised in an examination. Numerically we proceed as follows :

*First valve.* The first valve is placed at 1944 ft. At this depth, the flowing well pressure is found by linear interpolation to be  $250 + (400-250)*(1944-0)/(2500-0) = 367$ . Thus the setting pressure is 467 psi.

Depth	flowing well pressure	interpolated well pressure	valve setting pressure
0	250		
1944		367	467
2500	400		
3086		470	570
4067		588	688
5000	700		
7500	950		
10000	1350		

*Second valve.* The fluid gradient line through 467 psi, 1944 ft has equation  $p = 467 + 0.4*(d - 1944)$

This meets the gas gradient line when

$$800 + 0.04*d = 467 + 0.4*(d - 1944) \text{ giving } d = 3086 \text{ ft}$$

The second valve is therefore placed at 3086 ft. At this depth, the flowing well pressure is found by linear interpolation to be  $400 + (700-400)*(3086-2500)/(5000-2500) = 470$ . Thus the setting pressure is 570 psi.

*Third valve.* The fluid gradient line through 570 psi, 3086 ft has equation  $p = 570 + 0.4*(d - 3086)$

This meets the gas gradient line when

$$800 + 0.04*d = 570 + 0.4*(d - 3086) \text{ giving } d = 4067 \text{ ft}$$

The third valve is therefore placed at 4067 ft. At this depth, the flowing well pressure is found by linear interpolation to be  $400 + (700-400)*(4067-2500)/(5000-2500) = 588$ . Thus the setting pressure is 688 psi.