TENTAMEN : Production Technology I (mp3440)
June 23 1999

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 6000 psi and the PI is 0.5 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 200 psi. Show that the flow through the choke is critical. Calculate the initial and final sizes of the choke in $1/64^{th}$ of an inch (use the Gilbert correlation for a choke in critical flow)

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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 2500 psi. This sandstone has an Injectivity Index of 2 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? At which value of the injectivity index do you expect the flow to stop?

Question 3

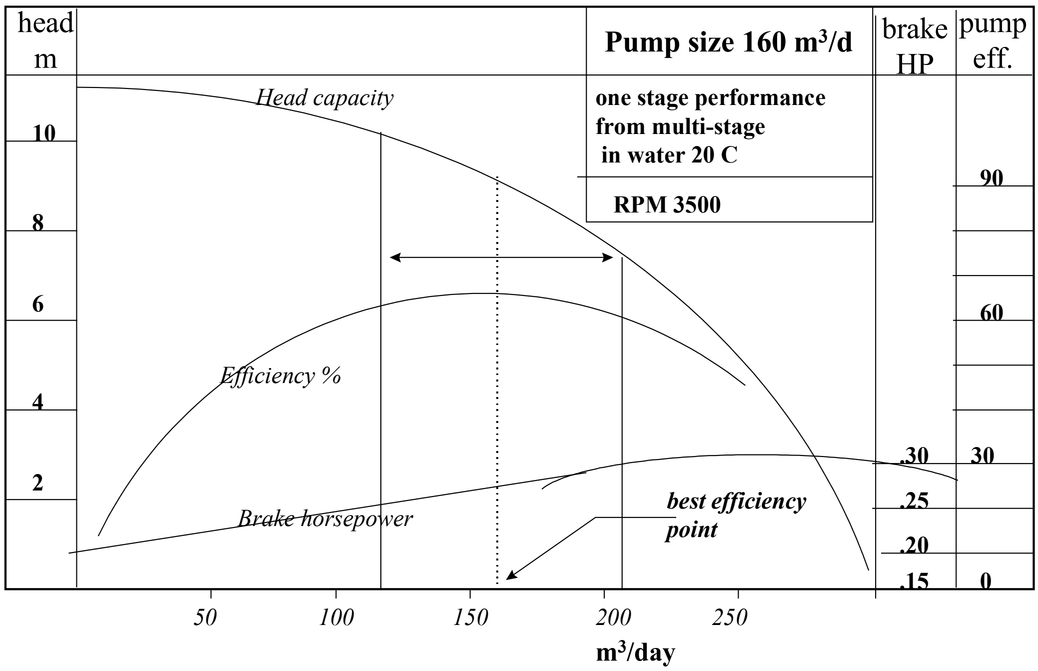
a) What are the advantages and disadvantages of an ESP compared with other forms of artificial lift? How can sand and gas (in moderation) be handled?

b) A well is producing under the following conditions

Depth	10000 ft
GLR	600 scf/bbl
Watercut	0%
Tubing size	4½"
Reservoir pressure	2750 psi
Productivity Index PI	1 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^3/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 200 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 1000 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.

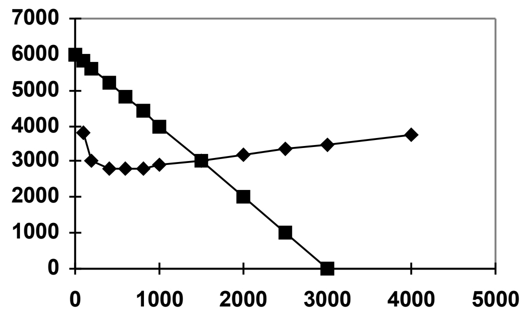
d) The gaslift valves are adjusted to operate at a pressure 100 psi above the flowing well gradient. Estimate the deepest point at which gas can be injected.

e) Estimate the setting depths and pressures of the first three valves.

Solution to Question 1

a)

q bbl/day	p_{wf}	inflow
0		6000
100	3800	5800
200	3000	5600
400	2800	5200
600	2800	4800
800	2800	4400
1000	2900	4000
1500	3000	3000
2000	3200	2000
2500	3350	1000
3000	3500	0
4000	3750	



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 0.5, reservoir pressure is 2800 + 0.5*600 = 3100 psi

d) The ratio of the pressures upstream and downstream of the choke is 1000/200 = 5, 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 64th inch.

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

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

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

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

prod rate	d					
1500	37.95809					
600	23.37513					

Question 2

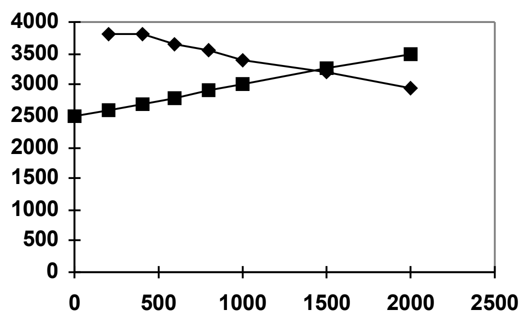
a)

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

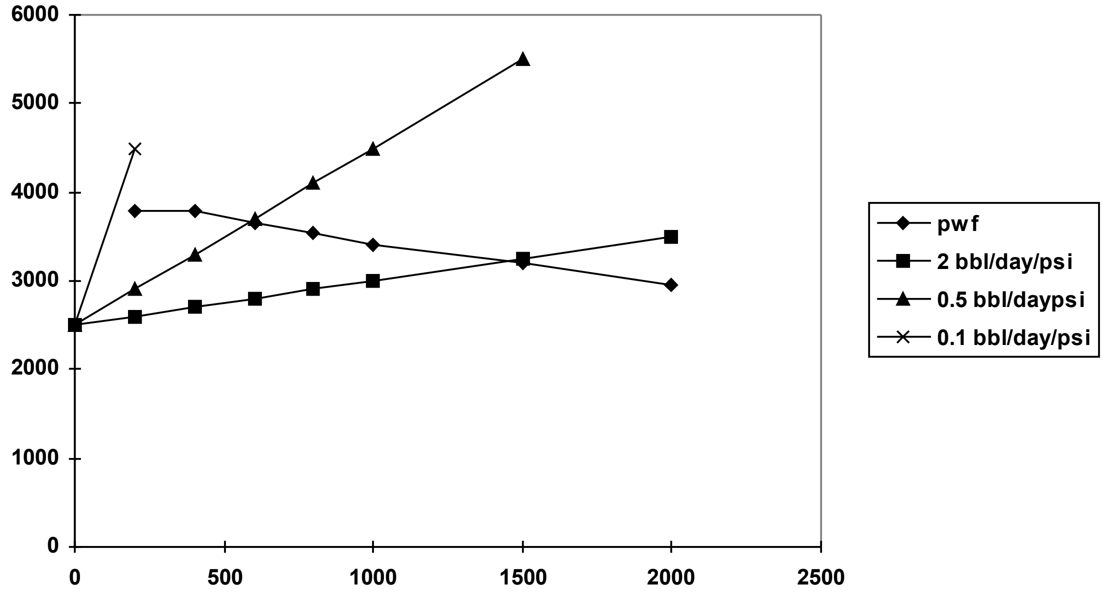
$p_{well} = p_{res} + q/II$, where II is the Injectivity Index.

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 2 bbl/day/psi of water-bearing sandstone
0	4500	-	2500
200	4400	3800	2600
400	4300	3800	2700
600	4200	3650	2800
800	4100	3550	2900
1000	4000	3400	3000
1500	3750	3200	3250
2000	3500	2950	3500



Thus the rate at which oil is injected into the water-bearing sandstone is just less than 1500 bbl/day, say 1450 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 :



Thus the oil flow rate decreases steadily with time. According to the Duns/Ros curves, we expect it to stop completely when the flow rate is about 400 bbl/day and p_{well} = 3800 psi, i.e. when II is about 400/(3800-2500) = 0.3 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} = 2750 - 1000/1 = 1750 psi

c) From the Duns/Ros gradient curve, the flowing pressure at depth 7500 ft corresponding to tubing head pressure 200 psi is 1700 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 1700 - 1100 = 600 psi.

1000 bbl/day = 159 m^3/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 600/13 = 46.1, implying 50 stages

Question 4

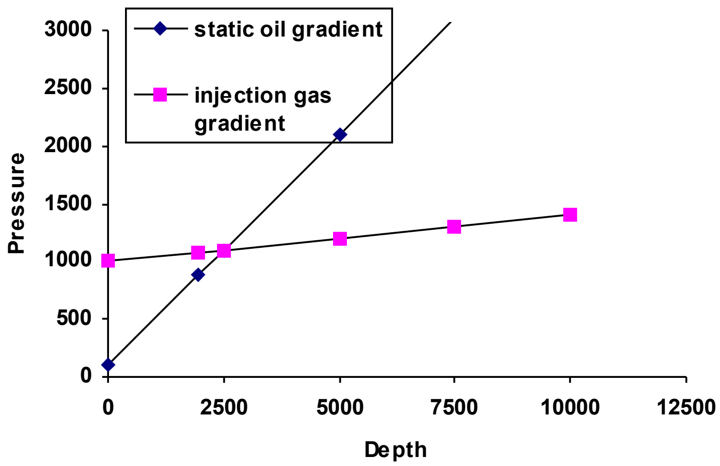
a) GOR of produced oil = GOR of reservoir oil + q_g/q = 400 + 600000/1000 = 1000 scf/bbl

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

100 +0.4 d = 1000 + 0.04 d

d = 900/0.36 = 2500 ft . Pressure = 100 + 0.4*900/0.36 = 1100 psi

Depth	static oil gradient	injection gas gradient
0	100	1000
1944	878	1078
2500	1100	1100
5000	2100	1200
7500	3100	1300
10000	4100	1400



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	1000
2500	400	1100
5000	700	1200
7500	950	1300
10000	1350	1400

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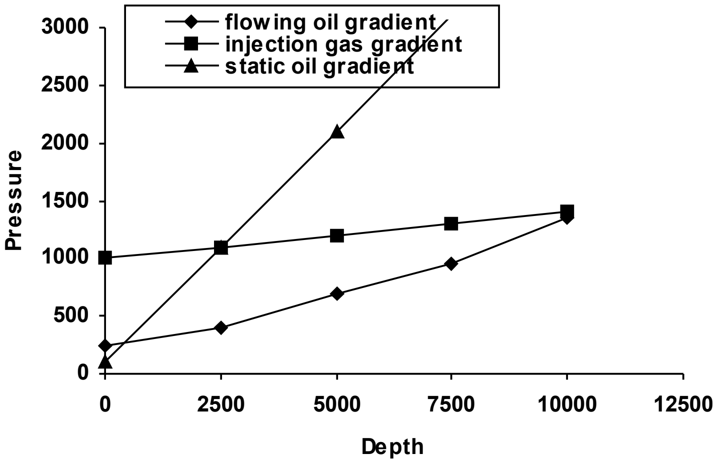

From graph estimate deepest injection point is between 10000 and 11000 ft

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	1000
2500	400	500	1100
5000	700	800	1200
7500	950	1050	1300
10000	1350	1450	1400

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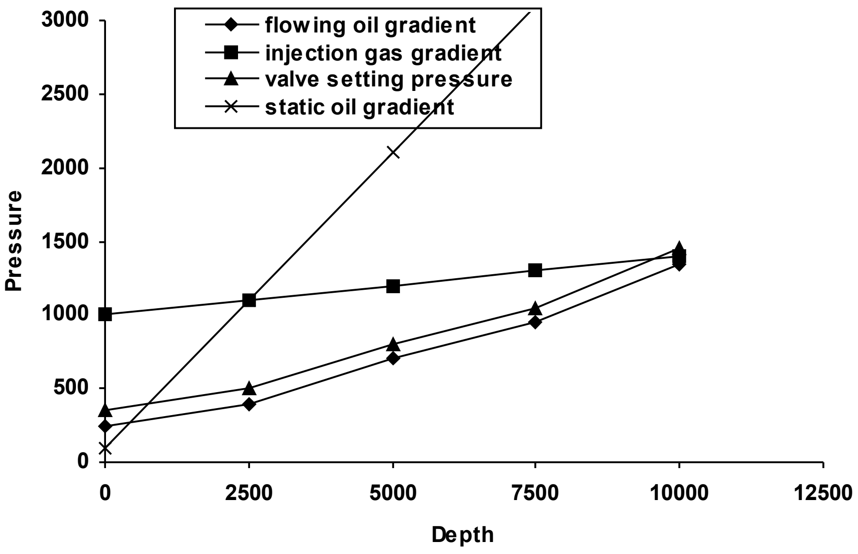

Thus estimate maximum injection depth is estimated to be 9000 ft

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 2500 ft. At this depth, the flowing well pressure is 400 psi. Thus the setting pressure is 500 psi.

Depth	flowing well pressure	interpolated well pres	valve setting pressur
0	250		
2500	400	400	500
3611		533	633
4475		637	737
5000	700		
7500	950		
10000	1350		

Second valve. The fluid gradient line through 500 psi, 2500 ft has equation

$$p = 500 + 0.4*(d - 2500)$$

This meets the gas gradient line when

$$1000 + 0.04*d = 500 + 0.4*(d - 2500) \quad \text{giving } d = 3611 \text{ ft}$$

The second valve is therefore placed at 3611 ft. At this depth, the flowing well pressure is found by linear interpolation to be 400 + (700-400)*(3611-2500)/(5000-2500) = 533. Thus the setting pressure is 633 psi.

Third valve. The fluid gradient line through 633 psi, 3611 ft has equation

$$p = 633 + 0.4*(d - 3611)$$

This meets the gas gradient line when

$$1000 + 0.04*d = 633 + 0.4*(d - 3611) \quad \text{giving } d = 4475 \text{ ft}$$

The third valve is therefore placed at 4475 ft. At this depth, the flowing well pressure is found by linear interpolation to be 400 + (700-400)*(4475-2500)/(5000-2500) = 637. Thus the setting pressure is 737 psi.