TENTAMEN : Production Technology I (mp3440)
January 21 1999

Answer all questions. Answer in either English or Dutch (or a mixture).

Question 1

a) Explain the phase behaviour of a hydrocarbon as it is produced from the reservoir, through the tubing and into the surface facilities.

b) Oil is produced from a reservoir at depth 10000 feet. The reservoir pressure is 3500 psi and the reservoir temperature is 195 F. The oil has API gravity 35, gas specific gravity 0.65, and producing gas/ oil ratio 600 scf/bbl. Use Standing's black oil correlation to calculate the bubble point pressure for the oil at the reservoir temperature.

c) This oil is produced by a vertical well with 4½" tubing. The watercut is zero and the PI of the well is 10 bbl/day/psi. The production rate is 1000 bbl/day. Calculate the flowing bottom hole pressure and the tubing head pressure, using the Duns/Ros gradient curves.

d) Estimate from the Duns/Ros curve the depth in the tubing at which gas comes out of solution (accuracy to within 500 ft). Ignore temperature effects - assume oil stays at reservoir temperature.

e) At a later time, the reservoir pressure has dropped to 2950 psi. Calculate the minimum production rate for which the gas stays in solution while in the formation. What are the consequences if gas comes out of solution before entering the well?

Question 2

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	15000 ft
GOR	2000 scf/bbl
Water cut	0%
Tubing size	2 7/8"
Tubing head pressure	500 psi

b) The initial reservoir pressure is 3500 psi and the PI is 2 bbl/day/psi. What is the initial production rate and flowing bottomhole pressure ?

c) It is planned to produce the reservoir at a plateau rate of 20000 bbl/day. It is believed that there is a strong aquifer to maintain reservoir pressure. How many wells would you drill?

d) After some years, it becomes clear that aquifer is not strong enough to maintain reservoir pressure, and the reservoir pressure drops to 3200 psi. What is the production rate at this reservoir pressure, assuming the PI has not changed. It is decided to stimulate the wells, to improve the PI and restore production. Calculate the new PI if the production is to be restored to the desired plateau level.

e) If the reservoir pressure continues to fall, and the PI stays constant at this new value, what is the lowest stable rate of production from an individual well?

Question 3

a) Describe the advantages and disadvantages of gas-lift compared with other forms of artificial lift.

b) It is planned to install gaslift in a well that has stopped flowing. The tubing head pressure is 200 psi and the pressure gradient in the oil is 0.4 psi/ft. If 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. What is the pressure at that depth?

c) When the well is flowing under gaslift, the tubing head pressure is maintained at 200 psi. From a wellflow simulator, it is found that the flowing well gradient is given approximately by the straight line through 200 psi with gradient 0.1 psi/ft. Determine the deepest point at which gas can be injected with gaslift valves. What is the pressure at that depth?

d) The gaslift valves are adjusted to operate at a pressure 100 psi above the flowing well gradient. Calculate the setting depths of the valves. Valves are not placed below 5000 ft.

e) What is the opening pressure of the bottom valve? The temperature at the depth of the valve is 60 C. Calculate the pressure in the nitrogen chamber, measured at surface temperature (15 C) before the valve is installed. The area ratio of the valve (A_b/A_p) is 5.

Question 4

a) A well is producing under the following conditions

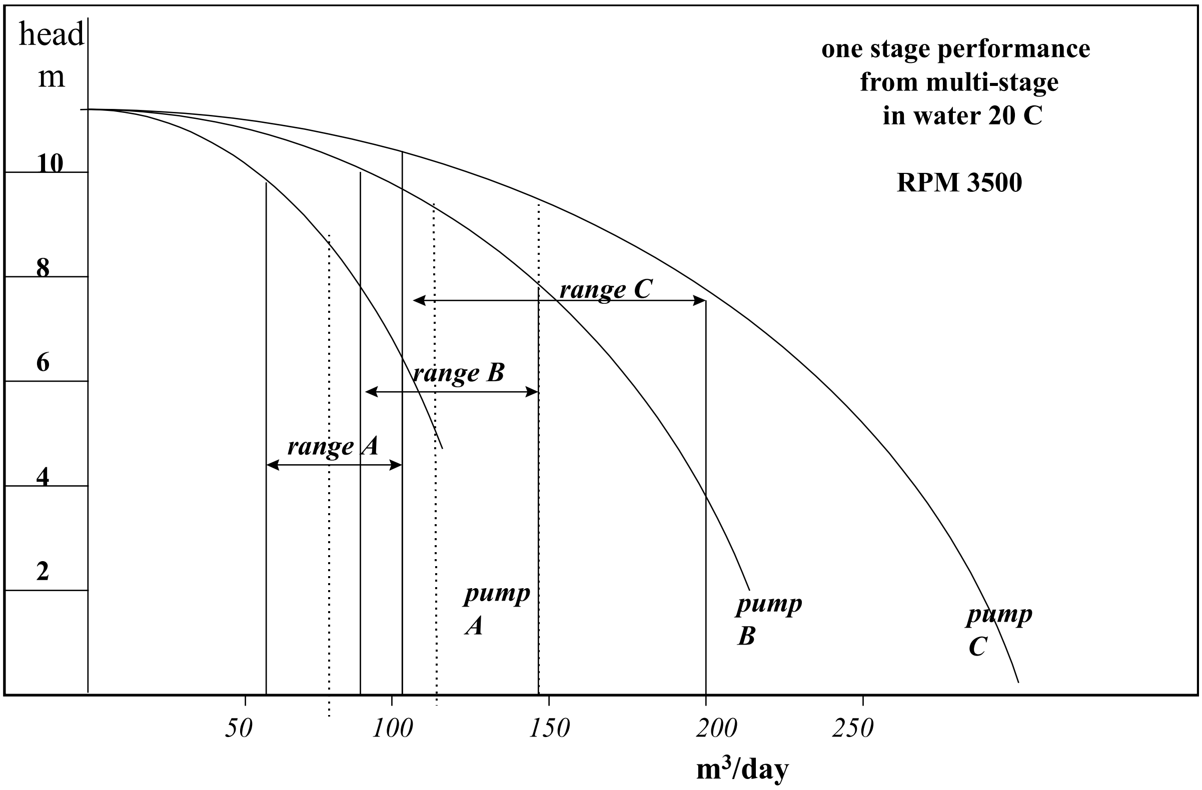
Depth	10000 ft
GLR	1000 scf/bbl
Watercut	0%
Tubing size	4½“
Reservoir pressure	1700 psi
Productivity Index PI	4 bbl/day/psi

Calculate the flowing bottomhole pressure at a production rate of 800 bbl/day.

b) This production rate of 800 bbl/day (120 m^3/day) is produced by an ESP installed at depth 5000 ft (not at the bottom of the hole). The tubing head pressure is 500 psi. For the given tubing size, the ESP manufacturer offers a series of three pumps with different operating ranges. The performance curves of the three pumps are given below. The dashed lines indicate the best efficiency point. Calculate the number of stages for each type of pump which can be used. (note : 1 kPa = 6.89 psi)

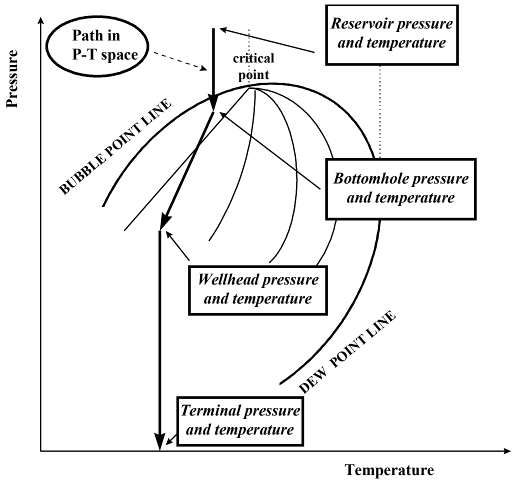
c) Which of the two possible pumps would you choose, considering their efficiency. Explain how you can optimise the efficiency using a variable speed drive.

d) The pump performance curves are given for frequency 50 Hz. What happens to the best efficiency point of pump C if the frequency is increased to 60 Hz. Estimate the head produced by one stage of Pump C at its best efficiency point for frequency 60Hz.



Solution to Question 1

a) As a hydrocarbon flows from the reservoir through the production system, it follows a path in P-T space.



Critical points in this path are those when the bubble-point line or the dew-point-line are crossed. At these points the flow becomes multiphase; either gas comes out of solution (for an oil reservoir) or liquid condenses (for a gas reservoir.

In an oil reservoir, the gas is generally in solution, and stays there until the oil enters the tubing. As the oil rises in the tubing, the pressure and temperature increase. At a given point gas comes out of solution, and more comes out of solution as the oil rises further in the tubing. As the oil passes through the choke at the wellhead, even more gas comes out of solution.

b) Standing's correlation in field units gives :

$$p_b = 18.2 \{ (R / \gamma_g)^{0.83} \, 10^{[0.00091 T - 0.0125 \gamma API]} - 1.4 \}$$

Hence,

$$p_b = 18.2 \{ (600 / 0.65)^{0.83} \, 10^{[0.00091*195 - 0.0125*35]} - 1.4 \}$$
$$= 2870 \text{ psi } (=19.8 \text{ MPa})$$

c) Reservoir pressure is 3500 psi and PI is 10 bbl/day/psi. Production rate is 1000 bbl/day. Hence flowing bottom hole pressure is given by :

$$p_{wf} = p_r - q/PI = 3500 - 1000/10 = 3400 \text{ psi}$$

Using Duns/Ros curve (4½" tubing, GOR 600 scf/bbl, 1000 bbl/day) the pressure at the tubing head (10000 ft higher) is 700 psi.

d) The gas comes out of solution when the pressure is 2870 psi. from the Duns/Ros curve, this occurs at a height 1500 above bottomhole (difficult to estimate from Duns/Ros curve), i.e. at depth 8500 ft.

e) If reservoir pressure has dropped to 2950 psi, then production rate at which the bottomhole pressure is equal to the bubble point pressure is given by

$$q = (2950-2870)*PI = 80*10 = 800 \text{ bbl/day}.$$

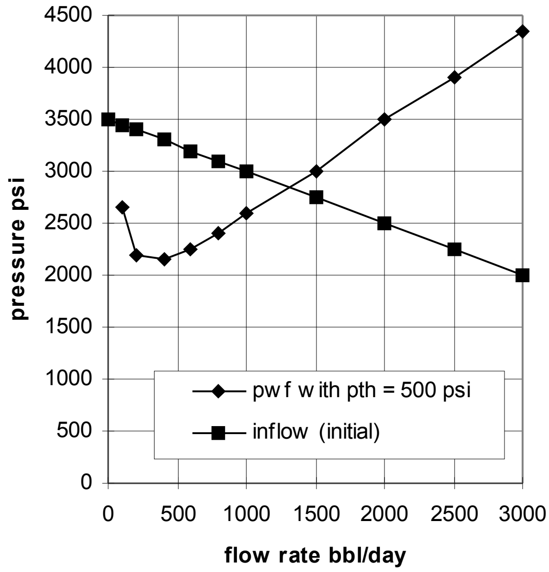
This is the maximum production rate for which gas will stay in solution in the formation.

If gas comes out of solution in the formation, then the flow in the formation becomes multiphase, resulting in larger pressure losses. The straight line PI formula will no longer be valid. Because of these higher losses, it my not be possible to produce at this higher rate.

Solution to Question 2

a) From Duns/Ros curves and inflow performance

q bbl/day	pwf with pth = 500 psi	inflow (initial)
0		3500
100	2650	3450
200	2200	3400
400	2150	3300
600	2250	3200
800	2400	3100
1000	2600	3000
1500	3000	2750
2000	3500	2500
2500	3900	2250
3000	4350	2000



b) Initial production rate is 1300 bbl/day. Flowing bottomhole pressure is 2850 psi.

c) To achieve plateau production of 20000 bbl/day from the wells, need 20000/1300 = 15 - 16 wells.

d) If reservoir pressure is 3200 psi, then above curve changes to

q bbl/day	pwf with pth = 500 psi	inflow (later)
0		3200
100	2650	3150
200	2200	3100
400	2150	3000
600	2250	2900
800	2400	2800
1000	2600	2700
1500	3000	2450
2000	3500	2200
2500	3900	1950
3000	4350	1700

The production rate is 1100 bbl/day

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If the production rate is to be increased back to 1300 bbl/day, with p_{wf} = 2850 psi, then the PI must be increased from 2 to 1300/(3200-2850) = 3.7 bbl/day/psi.
With this new PI, the above curves become

q bbl/day	pwf with pth = 500 psi	inflow (initial)
0		3200
100	2650	3172.97
200	2200	3145.95
400	2150	3091.89
600	2250	3037.84
800	2400	2983.78
1000	2600	2929.73
1500	3000	2794.59
2000	3500	2659.46
2500	3900	2524.32
3000	4350	2389.19

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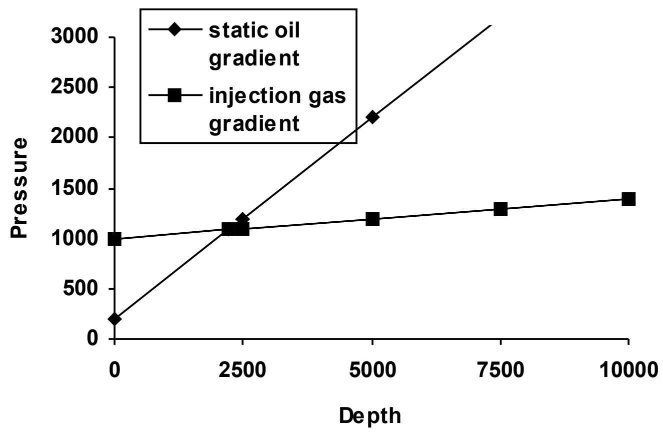
e) The lowest stable rate of production with this new PI is when inflow performance curve passes through the lowest point of the Duns/Ros curve, say through 400 bbl/day, with p_{wf}= 2150 psi. Then the reservoir pressure is p_{wf} + q/PI = 2150 + 400/3.7 = 2260 psi.

Solution to Question 3

a) **Advantages of gaslift**
robust, produces oil even if poorly operated
can be used for all types of oil
not sensitive to sand
can handle deviated holes
centrally-located energy source (gas supply)
can be used offshore
Disadvantages of gaslift
requires supply of gas
requires gas-tight casing

b) Depth d at which static oil gradient = gas gradient is given by
200 +0.4 d = 1000 + 0.04 d . So d = 800/0.36 = 2222 ft .
Pressure = 200 + 0.4*800/0.36 = 1089 psi

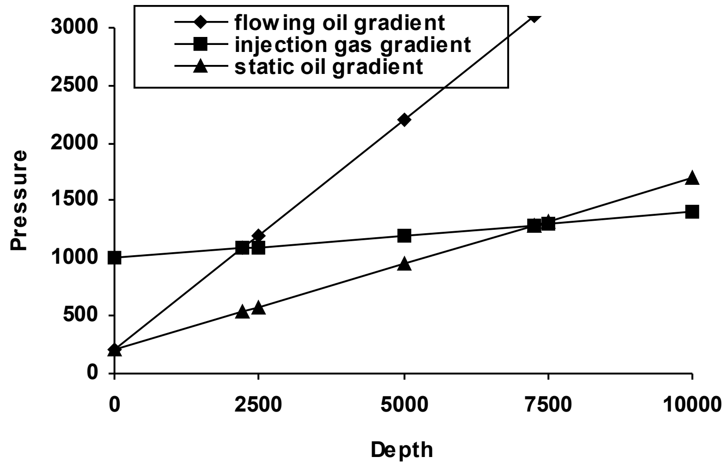
Depth	static oil gradient	injection gas gradient
0	200	1000
2222	1088.8	1088.88
2500	1200	1100
5000	2200	1200
7500	3200	1300
10000	4200	1400



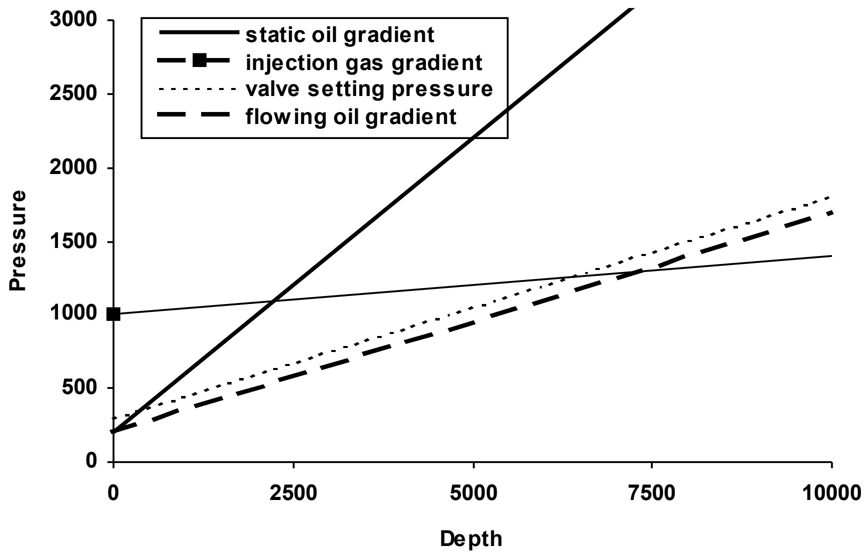
c) If the flowing well gradient is 0.15 psi/ft, then get , deepest injection point is given by d, where 200 +0.15 d = 1000 + 0.04 d . So d = 800/0.11 = 7273 ft . Pressure = 100 + 0.4*800/0.11 = 3009 psi

Depth	static oil gradient	injection gas gradient	flowing well gradient
0	200	1000	200
2222	1088.8	1088.88	533.3
2500	1200	1100	575

5000	2200	1200	950
7273	3109.2	1290.92	1290.95
7500	3200	1300	1325
10000	4200	1400	1700



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



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. General formula is :

$d_n = d_{n-1} + (\text{gaspressure}_{n-1} - \text{valvepressure}_{n-1})/(\text{staticgradient} - \text{gasgradient})$

$\text{gaspressure}_n = \text{injection pressure} + \text{gasgradient} * d_n$

$\text{valvepressure}_n = \text{flowing tophole pressure} + \text{valve margin} + \text{flowinggradient} * d_n$

This gives :

			valve depth	valve setting pressure	gas pressure
			0	200	1000

static gradient	*0.4*		2222	633	1089
flowing gradient	*0.15*		3488	823	1140
gas gradient	*0.04*		4366	955	1175
static pth	*200*		4977	1047	1199
flowing pth	*200*		5400	1110	1216
gas injection pressure	*1000*		5695	1154	1228
valve pressure margin	*100*		5899	1185	1236

Thus the valves are set at depths 2222, 3488, 4366 and 4977 ft.

e) The setting pressure of the bottom valve is 1199 psi. i.e it must close when the tubing head pressure is 1047 psi. The gas pressure is 1199 psi. The pressure in the nitrogen chamber p_d then satisfies

$p_i (A_b/A_p-1) + p_f = p_d A_b/A_p$ and $A_b/A_p = 5$, $p_i = 1199$, $p_f = 1047$

Hence p_d = (1199 *4 +1047)/ 5 = 1167 psi.

But at surface, temperature is different. Using the gas law p/T = constant we get

pressure at surface in chamber
= (pressure at 60 C in chamber) *(abs.temp at 15 C/abs.temp at 60 C)
= 1167*(273+15)/(273+60) = 1011 psi

Solution to Question 4

a) The flowing bottomhole pressure at the production rate q is p_r - q/PI = 1700 - 800/4 = 1500 psi.

b) If tubing head pressure is 500 psi, then from Duns/Ros curve, the flowing pressure at the depth 5000 ft, above the ESP, is 1050 psi
If the flowing bottomhole pressure is 1500 psi, then from Duns/Ros curve the flowing pressure at the depth 5000 ft, just below the ESP, is 750 psi
The pressure difference to be supplied by the pump is 300 psi.

Pump A cannot be used, because the rate is outside its range. Pumps B and C can be used.

For pump B, the head delivered at rate 120 m^3/day is 9m water
For pump B, the head delivered at rate 120 m^3/day is 10m water

Hence pressure difference supplied by one stage of pump A is 9*1000*9.81 Pa = 9*9.81 kPa = 9*9.81/6.89 psi = 12.8 psi. Hence number of stages required is 300/12.8 = 23.4 stages. For pump C require 300/(10*9.81/6.89) = 21.1 stages

Hence require 24 stages for pump B and 22 stages for pump C.

c) Pump B is close to its best efficiency flow rate, so this is chosen.

The operating speed of the pump is governed by the electrical characteristics and the frequency of the motor. For a properly-loaded motor, the speed is a direct function of the driving frequency, and the flow rate is proportional to the speed. If the pump has a variable speed drive, then the frequency can be varied to optimise the total system.

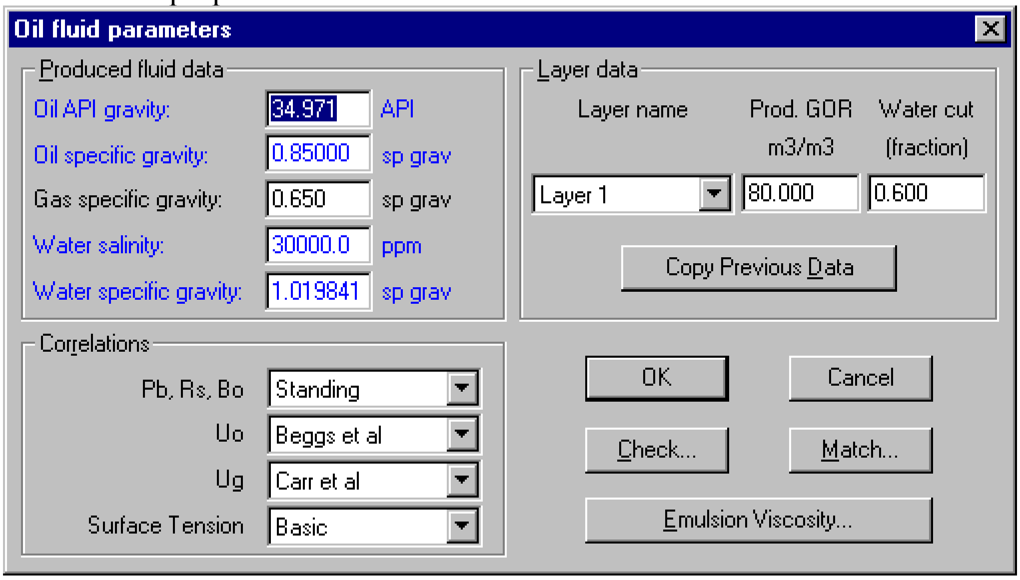
The best efficiency point of Pump C is 160 m3/day. Flow rate is proportional to speed and hence to frequency, so if the frequency is increased from 50 to 60 Hz the best efficiency flow rate increases to 160*(60/50) = 192 m3/day. The head is proportional to the square of the speed, hence the square of the frequency. Hence the head increases from 9 m to $9*(60/50)^2$ = 13m

Additional Question using the WELLFLOW program

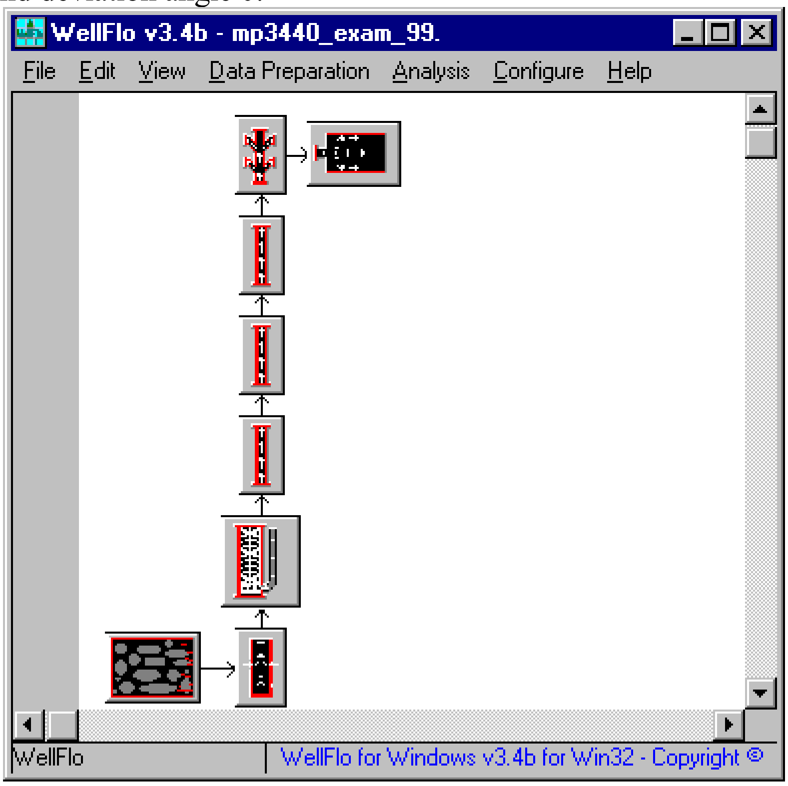
This question is not to be answered during the written examination on January 21. Grades (cijfers) based on the written examination can be improved by submitting answers to this question before February 12, with WELLFLOW file saved on a floppy.

Aim : ESP selection for an oil well

An oil well has fluid properties as shown on this screen.

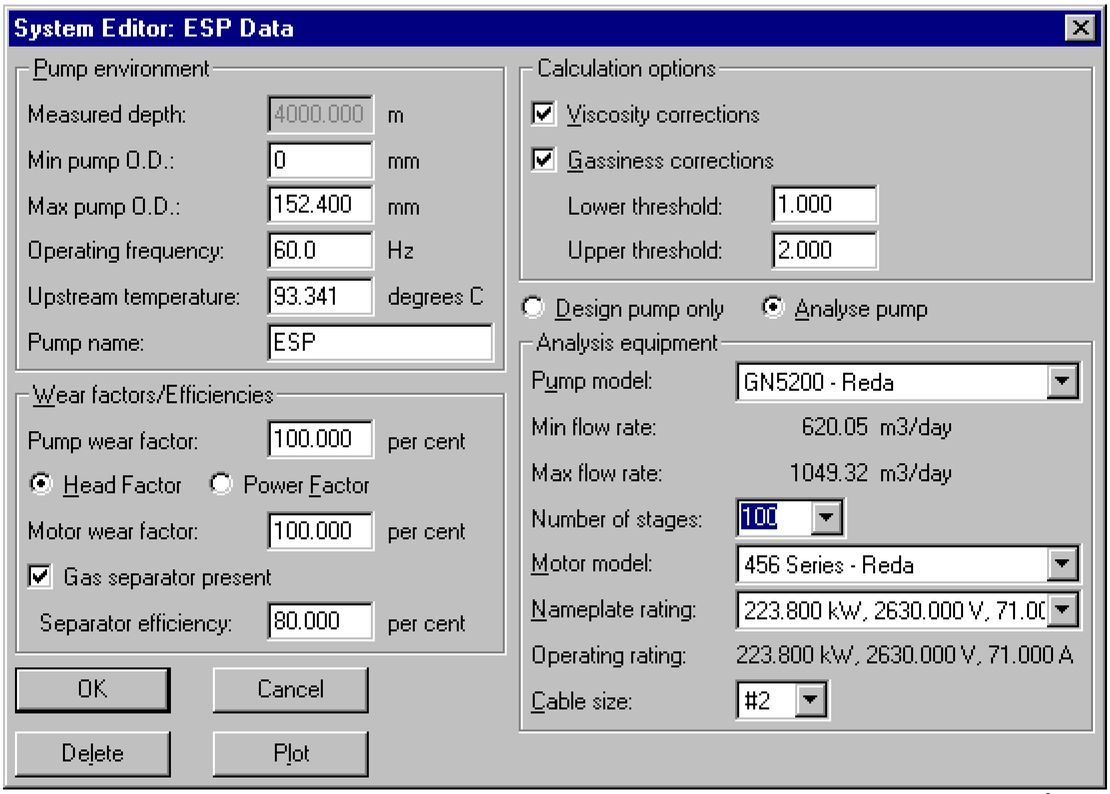


The well has the following configuration. The tubings all have internal diameter 125 mm. The first tubing is 300m long, with deviation angle 0, the next section of tubing is 1200 m long with deviation angle 30 and the bottom tubing is 2500 m long with deviation angle 50. The ESP is therefore at along-hole depth of 4000 m. The casing has internal diameter 160 mm, length 200 m and deviation angle 0.

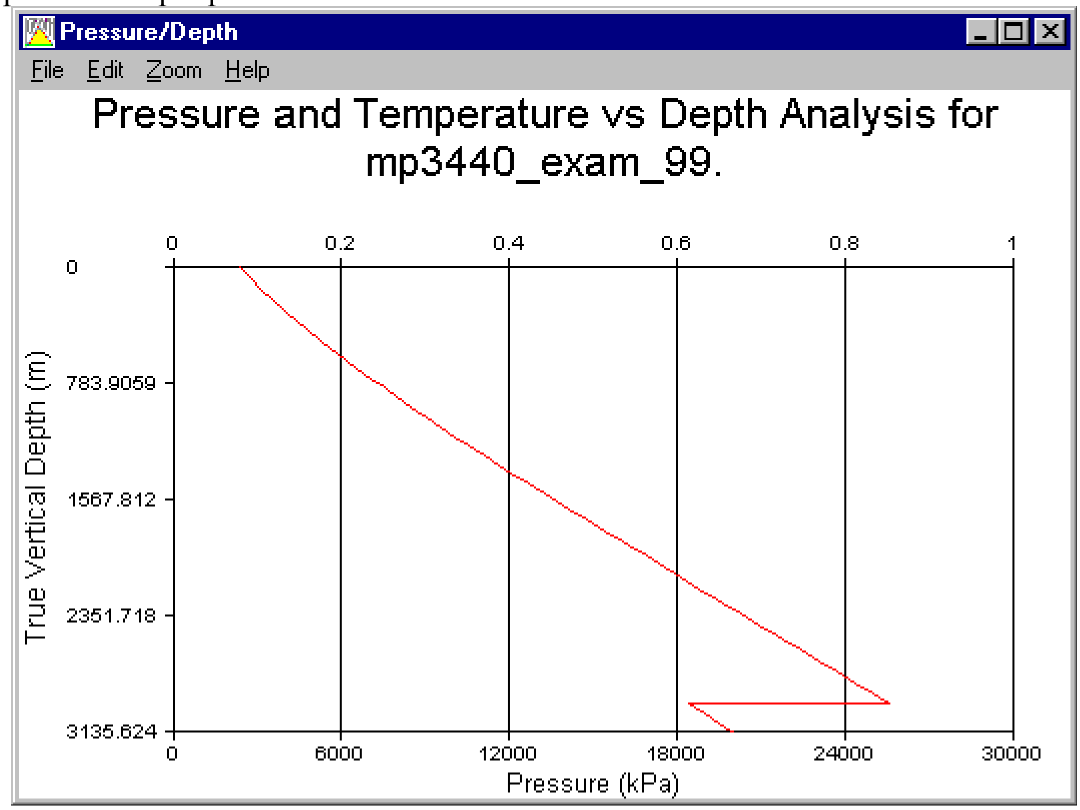


What does Wellflow predict for the TVD of the ESP ?

The ESP properties are given in the following screen

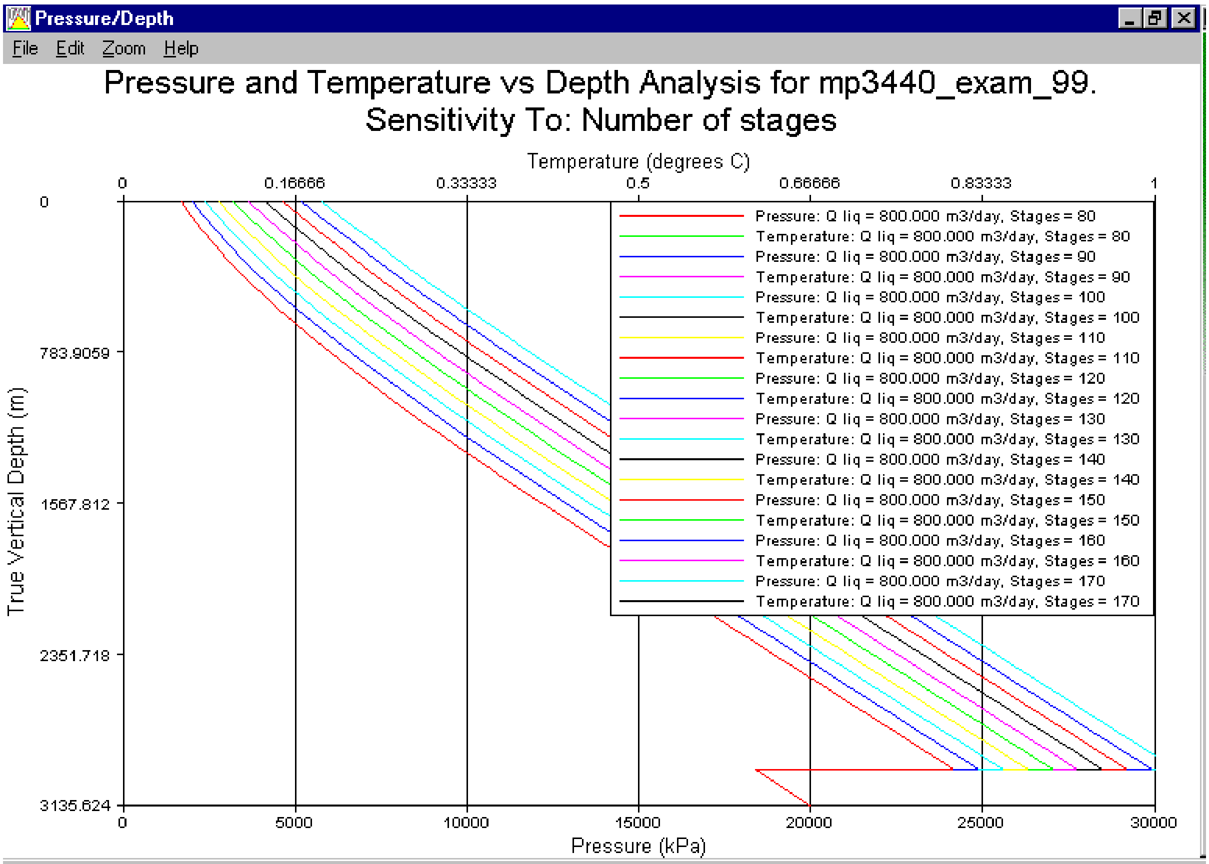


The flowing bottom-hole pressure is 20 MPa. Show that at production rate 800 m^3/day the pressure- depth plot looks like :



Use the sensitivity option to determine the number of ESP stages required if the tubing head pressure is 5000 kPa at this flow rate.

Would you use this pump for a production rate of 1500 m^3/day? If not, suggest a Reda pump that you could use.


Pressure/Depth
File Edit Zoom Help
Pressure and Temperature vs Depth Analysis for mp3440_exam_99.
Sensitivity To: Number of stages
Temperature (degrees C)
0 0.16666 0.33333 0.5 0.66666 0.83333 1
True Vertical Depth (m)
0 783.9059 1567.812 2351.718 3135.624
Pressure (kPa)
0 5000 10000 15000 20000 25000 30000
Pressure: Q liq = 800.000 m3/day, Stages = 80
Temperature: Q liq = 800.000 m3/day, Stages = 80
Pressure: Q liq = 800.000 m3/day, Stages = 90
Temperature: Q liq = 800.000 m3/day, Stages = 90
Pressure: Q liq = 800.000 m3/day, Stages = 100
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Pressure: Q liq = 800.000 m3/day, Stages = 110
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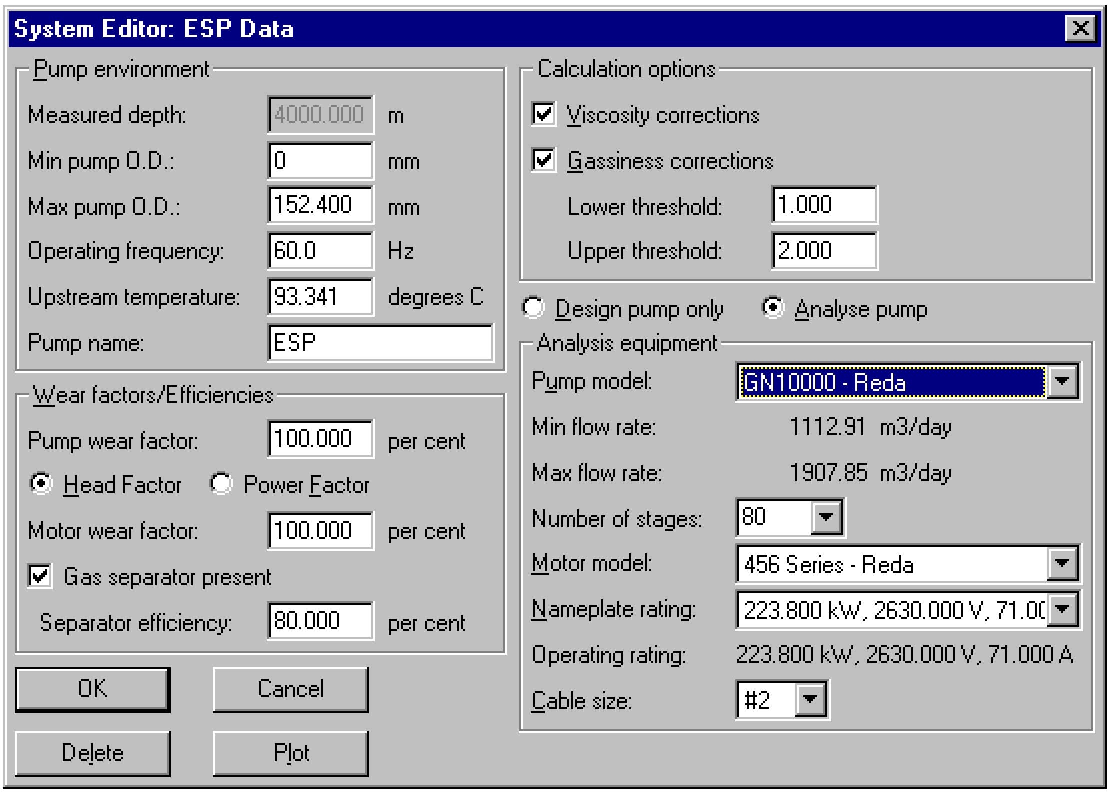
System Editor: ESP Data
Pump environment
Measured depth: 4000.000 m
Min pump O.D.: 0 mm
Max pump O.D.: 152.400 mm
Operating frequency: 60.0 Hz
Upstream temperature: 93.341 degrees C
Pump name: ESP
Wear factors/Efficiencies
Pump wear factor: 100.000 per cent
Head Factor
Power Factor
Motor wear factor: 100.000 per cent
Gas separator present
Separator efficiency: 80.000 per cent
OK
Cancel
Delete
Plot
Calculation options
Viscosity corrections
Gassiness corrections
Lower threshold: 1.000
Upper threshold: 2.000
Design pump only
Analyse pump
Analysis equipment
Pump model: GN10000 - Reda
Min flow rate: 1112.91 m3/day
Max flow rate: 1907.85 m3/day
Number of stages: 80
Motor model: 456 Series - Reda
Nameplate rating: 223.800 kW, 2630.000 V, 71.00
Operating rating: 223.800 kW, 2630.000 V, 71.000 A
Cable size: #2