TENTAMEN : Production Technology I (mp3440)
January 12 1998

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) If the reservoir pressure reduces by 1psi for every 1000 bbls extracted from the reservoir, after how many years will the well stop producing, and what is the total production in barrels up to that time ?

Question 2

a) A well is completed over two reservoirs, both at approximately the same depth of 10000 ft. The properties of the reservoirs are as follows :

Reservoir I	pressure 3000 psi
	PI 1 bbl/day/psi
	GOR 600 scf/bbl
	Watercut 0%
Reservoir II	pressure 2500 psi
	PI 2 bbl/day/psi
	GOR 1800 scf/bbl
	Watercut 0%

Determine the value of the downhole pressure at which all the production from Reservoir I is re-injected into Reservoir II (assuming the Injectivity Index of Reservoir II is the same as the PI).

b) Determine the downhole pressure at the following total production rates at surface : 500, 1000 bbl/day.

c) Show that the GOR (Gas/Oil Ratio) of the oil produced to surface is 600 scf/bbl at 500 bbl/day and 1000 scf/bbl at 1000 bbl/day.

d) The well is completed with a 4½" tubing. Use the Duns/Ros curves to estimate the tubing head pressure of the well at the production rate of 1000 bbl/day.

e) The pressure downstream of the wellhead choke is 200 psi. Show that the flow through the choke is critical. What is the size of the choke in 1/64th of an inch (use the Gilbert correlation for a choke in critical flow).

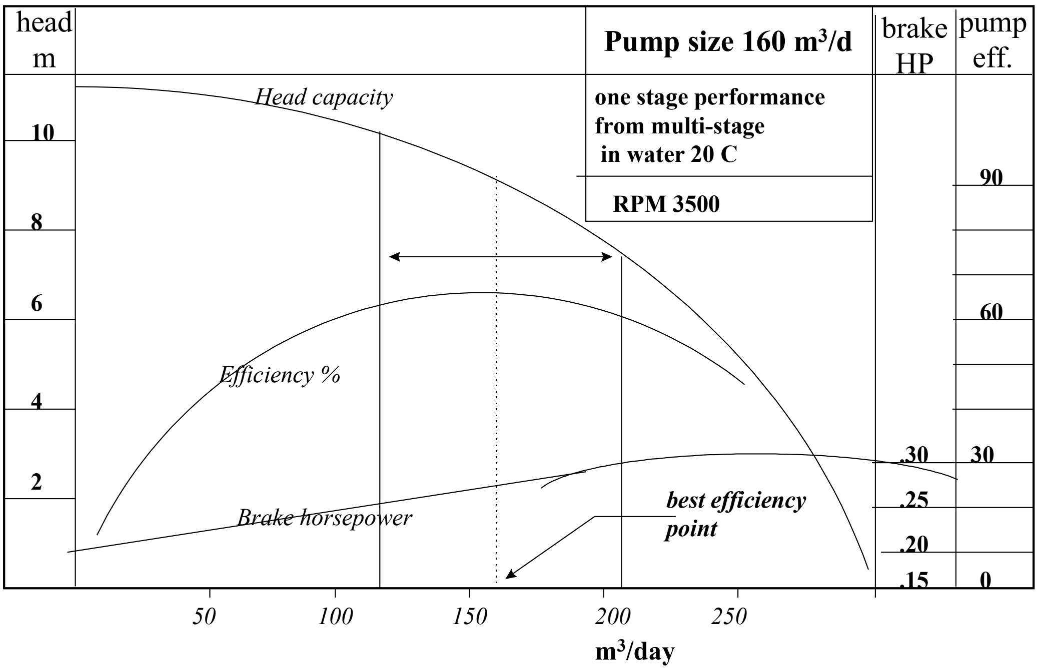
Question 3

a) A well is producing under the following conditions

Depth	7500 ft
GLR	600 scf/bbl
Watercut	0%
Tubing size	3½"
Reservoir pressure	1800 psi
Productivity Index PI	2.5 bbl/day/psi

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

b) This production rate of 1000 bbl/day is produced by an ESP installed at the bottom of the hole. The tubing head pressure is 500 psi. The ESP performance curve is given here (same as in the lecture notes).



Use this curve and the Duns/Ros gradient curves to calculate the number of stages required for the pump.

c) It is discovered that the Performance Curve given above is for a pump operating with a 60 Hz driving frequency, whereas the available frequency is 50 Hz. How many stages are required for the pump at this new operating frequency.

Question 4

a) An oil well has stopped producing through 3½" 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) If 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). Show that, for gaslift calculations, a 'safe' approximation to the flowing well gradient for gaslift is the line through 250 psi with gradient 0.1 psi/ft, for depths down to 7500 ft.

c) When the well is not flowing, the tubing head pressure is also 250 psi and the pressure gradient in the oil is 0.4 psi/ft. If 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 (i) without gaslift valves and (ii) with gaslift valves.

d) It is decided to place the bottom gaslift valve at the depth of 4500 ft. The gaslift valves are adjusted to operate at a pressure 100 psi above the approximation to the flowing well gradient chosen in (b). Calculate the setting depths of the valves.

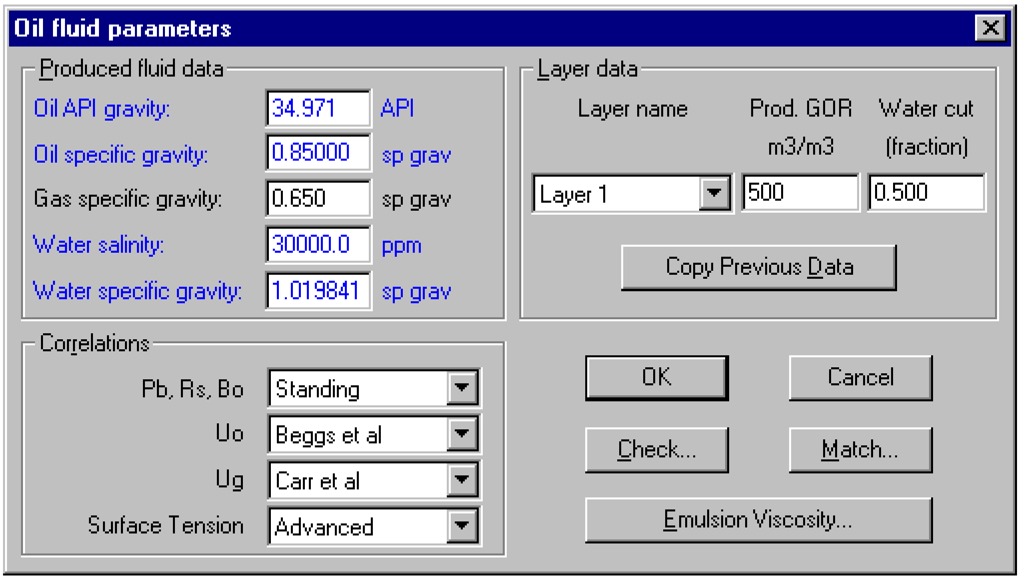
Additional Question using the WELLFLOW program

This question is not to be answered during the written examination on January 12. Grades (cijfers) based on the written examination can be improved by submitting answers to this question before January 31, with WELLFLOW file saved on a floppy.

Aim : Comparison of the predictions of the various flow correlations

A well is completed with 4½" tubing down to a depth of 3000 m. The tubing head pressure is maintained at 100 kPa.

Assume that the fluid properties are as shown on this screen :



N.B. note the watercut (50%, input as 0.5)

Compare the flowing bottomhole predictions over a range of rates (choose 9 rates, 500, 1000, 1500 ….10000 m^3/day) for the following vertical flow correlations.

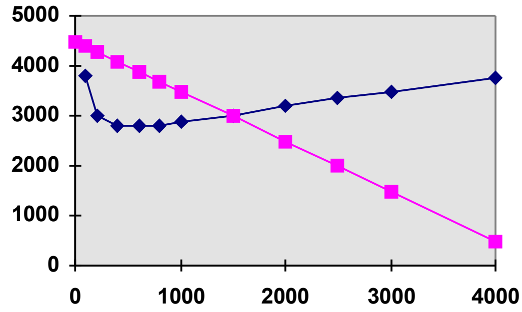
Duns and Ros (std)
Beggs and Brill (std)
Hagendoorn and Brown (std)
Gray
Dukler-Eaton-Flanigan

Plot your results on one graph, showing the predicted downhole pressure curve predicted by each correlation as a function of flow rate. (this plot cannot be made in Wellflow)

Solution to Question 1

a)

q bbl/day	p_{wf}	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*600 = 3400 psi

d)

bbl/day	bh.press.	res.press.	res.press. drop	bbls produced to cause res press drop	days at av.pr.rate	total days	cum prod. (thous. bbls)
1500	3000	4500	0				
1000	2900	3900	600	600000	480	480	600
800	2800	3600	300	300000	333	813	900
600	2800	3400	200	200000	286	1099	1100

Thus cumulative production is 1.1 million bbls, over 1099/365 = 3 years.

Question 2

a) If the outflow from Reservoir I is all injected into Reservoir II, then

outflow = (3000 - p_{wf})*1 = inflow = -(2500 - p_{wf})*2

Hence p_{wf} = [3000*1 + 2500*2]/[1 + 2] = 2666.7 psi

b) If total flow rate is q bbl/day, then :
q = q_1 + q_2, where q_1 = (3000 - p_{wf})*1 and q_2 = (2500 - p_{wf})*2
q = (3000 - p_{wf})*1 + (2500 - p_{wf})*2
p_{wf} = [3000*1 + 2500*2 - q]/3

If q = 500 bbl/day, then p_{wf} = [3000*1 + 2500*2 - 500]/3 = 2500 psi
q_1 = (3000 - p_{wf})*1 and q_2 = (2500 - p_{wf})*2
q_1 = (3000 - 2500)*1 = 500 and q_2 = (2500 - 2500)*2 = 0

If q = 1000 bbl/day, then p_{wf} = [3000*1 + 2500*2 - 1000]/3 = 2333 psi
q_1 = (3000 - p_{wf})*1 and q_2 = (2500 - p_{wf})*2
q_1 = (3000 - 2333)*1 = 667 and q_2 = (2500 - 2333)*2 = 333

c) The total gas produced by the well is [q_1*GOR_1 + q_2*GOR_2] scf/day
Hence, GOR = total gas per day/q = (q_1/q)*GOR_1 + (q_2/q)*GOR_2
If q = 500bbl/day
GOR = (q_1/q)*GOR_1 + (q_2/q)*GOR_2 =(500/500)*600 + (0/500)*1600 = 600
If q = 1000 bbl/day
GOR = (q_1/q)*GOR_1 + (q_2/q)*GOR_2 =(667/1000)*600 + (333/1000)*1800 = 1000

Summary table (including other rates)

Pressure	rate reserv.I	rate reserv.II	total rate	GOR
3000	0	-1000	-	-
2750	250	-500	-	-
2667	333	-333	0	-
2500	500	0	500	600
2333	667	333	1000	1000
2250	750	500	1250	1080
2000	1000	1000	2000	
1750	1250	1500	2750	

d) Duns/Ros gradient curve for 4½" tubing, GOR 1000 scf/bbl, 1000 bbl/day is used. With p_{wf} = 2333 and reservoir depth 10000 ft we find p_{th} = 625 psi.

e) The ratio of the pressures upstream and downstream of the choke is 625/200 = 3.1, 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^{th} inch.

$d^C = A\, q\, R^B/(p_1 - D)$. Hence $d = [A\, q\, R^B/(p_1 - D)]^{1/C}$
$d = [10*1000 * 1000^{0.546}/(625 - 14.7)]^{1/1.89}$ = 32.3. Hence have ½" choke.

Question 3

a) The flowing bottomhole pressure p_{wf} is given by (p_r-p_{wf})*PI = q
Hence p_{wf} = 1800 - 1000/2.5 = 1400 psi

b) From the Duns/Ros gradient curve, the flowing bottom hole pressure corresponding to tubing head pressure 500 psi is 2000 psi. The pump must provide the pressure difference of 2000 - 1400 = 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 = 46.15, implying 47 stages

c) If the pump operates at 50 Hz instead of 60 Hz, then the speed (RPM) is reduced by a factor 50/60. But the head is proportional to the square of the speed. Hence, the head of each stage is reduced by a factor $(50/60)^2$. To maintain the same head, the number of stages must be increased by the factor $(60/50)^2 = 1.44$ Thus the number of stages is increased to 46.15*1.44 = 66.5, implying 67 stages.

d) Question 4

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

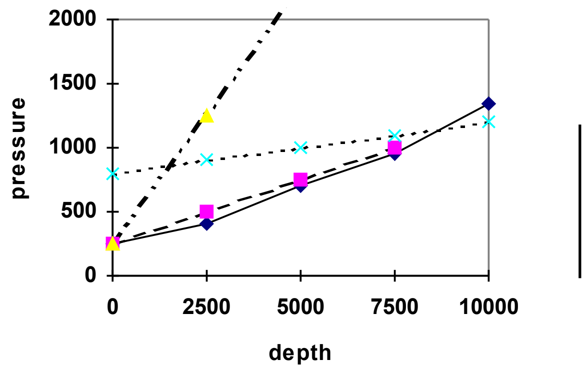
f) From the Duns/Ros gradient curve (3½" tubing, GOR 1000, watercut 0%) for production rate 1000 bbl/day, get the following pressures, assuming 250 psi tubing head pressure

Depth	flowing well pressure	flowing well approximation
0	250	250
-2500	400	500
-5000	700	750
-7500	950	1000
-10000	1350	

.

c)

Depth	flowing well pressure	flowing well approximation	static oil gradient	injection gas gradient
0	250	250	250	800
2500	400	500	1250	900
5000	700	750	2250	1000
7500	950	1000	3250	1100
10000	1350		4250	1200



Gas injection pressure is 800 + 0.04*d
Static oil gradient is 250 + 0.4*d
Depth without gaslift valves is where these are equal : 800 + 0.04*d = 250 + 0.4*d
d = (800-250)/(0.4-0.04) = 1528 ft
Hence maximum injection depth without gaslift valves is 1528 ft.

From graph, estimate maximum depth under flowing conditions is about 8300 ft

The gaslift valves are adjusted to operate at a pressure 100 psi above the approximation to the flowing well gradient chosen in (b). i.e at pressures given by

p = 250 + 100 + 0.1*d

We can either calculate the valve depths 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 1528 ft. At this depth, the gas-valve opening line gives the pressure 350 +0.1*1528 = 503 psi. This is the setting pressure of the first valve. The fluid gradient line through 503 psi, 1528 ft has equation

$$p = 503 + 0.4*(d - 1528)$$

This meets the gas gradient line when

$$800 + 0.04*d = 503 + 0.4*(d - 1528), \qquad \text{giving } d = 2523 \text{ ft}$$

Second valve. The second valve is placed at 2523 ft. At this depth, the gas-valve opening line gives the pressure 350 +0.1*2523 = 602 psi. This is the setting pressure of the second valve. The fluid gradient line through 602 psi, 2523 ft has equation

$$p = 602 + 0.4*(d - 2523)$$

This meets the gas gradient line when

$$800 + 0.04*d = 602 + 0.4*(d - 2523), \qquad \text{giving } d = 3353 \text{ ft}$$

Third valve. The third valve is placed at 3353 ft. At this depth, the gas-valve opening line gives the pressure 350 +0.1*3353 = 685 psi. This is the setting pressure of the second valve. The fluid gradient line through 685 psi, 3353 ft has equation

$$p = 685 + 0.4*(d - 3353)$$

This meets the gas gradient line when

$$800 + 0.04*d = 685 + 0.4*(d - 3353), \qquad \text{giving } d = 4045 \text{ ft}$$

Fourth valve. The fourth valve is placed at 4045 ft. At this depth, the gas-valve opening line gives the pressure 350 +0.1*4045 = 755 psi. This is the setting pressure of the second valve. The fluid gradient line through 755 psi, 4045 ft has equation

$$p = 755 + 0.4*(d - 4045)$$

This meets the gas gradient line when

$$800 + 0.04*d = 755 + 0.4*(d - 4045), \qquad \text{giving } d = 4619 \text{ ft}$$

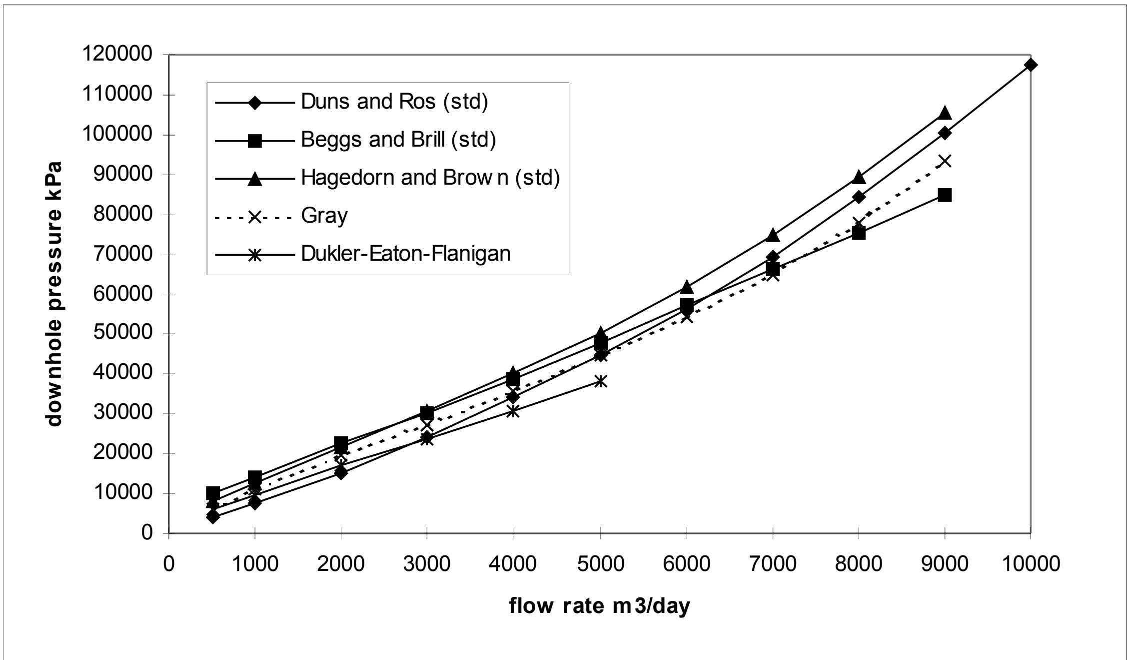
So fourth valve is set at 4500 ft.

Question 5

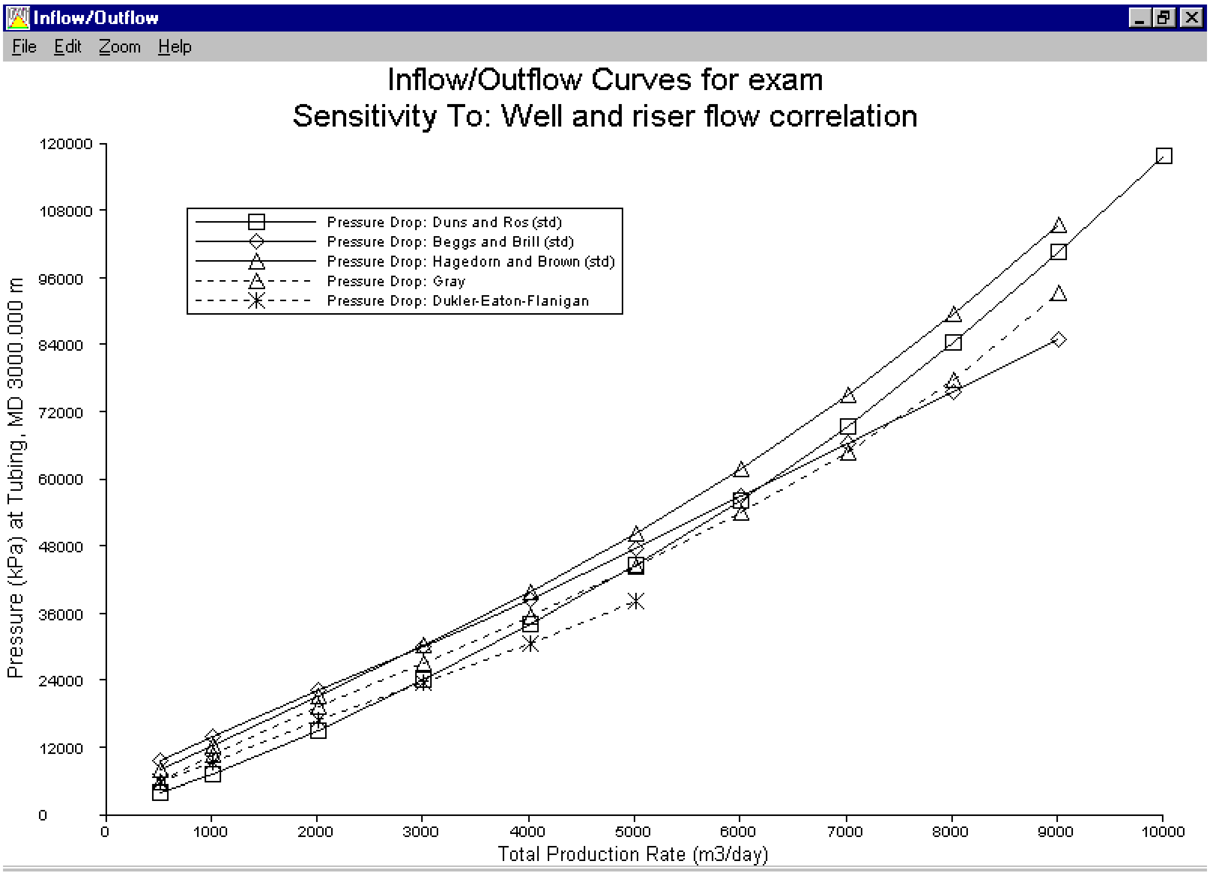
Taking the results from the Wellflow output report, these can be tabulated as follows.

Flow Rate m3/day	Bottom- hole flowing pressure kPa				
	Duns and Ros (std)	Beggs and Brill (std)	Hagedorn and Brown (std)	Gray	Dukler-Eaton-Flanigan
500	4099	9860	8202	6041	6053
1000	7362	14224	12558	10869	9500
2000	15036	22365	21385	19416	17011
3000	24329	30276	30386	27361	23814
4000	34199	38627	39933	35492	30801
5000	44757	47682	50334	44496	38134
6000	56143	57108	61921	54210	
7000	69352	66378	75024	64869	
8000	84363	75526	89493	77658	
9000	100481	84938	105485	93265	
10000	117634				

Using Excel to plot these, we get the following graph :



Actually it is possible to get the same plot from Wellflow. After calculating, click on “Results” then “Plot”. In the “Plot options” window, choose Inflow/outflow curves “ and under “Well and riser flow correlation” choose “All values”. Then click on “Plot”. You will get this plot (note the axes and plotting symbols can all be edited under “Edit”)



Comparing the results for the various flow correlations, we see that there is reasonable agreement between the Duns & Ros, the Hagendoorn & Brown and Gray correlations, but the other two correlations show different behaviour. For some of the correlations, Wellflow cannot produce any predicted pressure drop. This is because somewhere in the calculation of te pressure drop it has calculated an un-physical condition, often that the pressure is too low. .

Experience shows that the Duns/Ross prediction is likely to be most reliable.