# Answers exam ta3440 Petroleum Engineering

**22 March 2004**

### *Answers*

1a) See below. The NPV of scenario 2 is much higher.

1b) Subsea operations are time consuming and therefore take much more rig time.

| *Sub-sea development scenario* | | | | | | |
|---|---|---|---|---|---|---|
| *Time (year)* | *Capex ($10^6$ $)* | *Revenue ($10^6$ $)* | *Opex ($10^6$ $)* | *Royalties ($10^6$ $)* | *Cash flow ($10^6$ $)* | *Disc. c/f ($10^6$ $)* |
| *1* | *106* | *84* | *3* | *29* | *-59* | *-51* |
| *2* | *158* | *252* | *9* | *88* | *-16* | *-12* |
| *3* | | *235* | *8* | *82* | *133* | *87* |
| *4* | | *176* | *6* | *61* | *100* | *57* |
| *5* | | *126* | *4* | *44* | *71* | *35* |
| *6* | | *84* | *3* | *29* | *47* | *21* |
| *7* | | *50* | *2* | *18* | *28* | *11* |
| *NPV* | | | | | *305* | *148* |

| *Wellhead platform development scenario* | | | | | | |
|---|---|---|---|---|---|---|
| *Time (year)* | *Capex ($10^6$6 $)* | *Revenue ($10^6$ $)* | *Opex ($10^6$ $)* | *Royalties ($10^6$ $)* | *Cash flow ($10^6$ $)* | *Disc. c/f ($10^6$ $)* |
| *1* | *54* | *0* | *0* | *0* | *-54* | *-47* |
| *2* | *44* | *84* | *3* | *29* | *3* | *3* |
| *3* | *62* | *252* | *9* | *88* | *80* | *53* |
| *4* | | *235* | *8* | *82* | *133* | *76* |
| *5* | | *176* | *6* | *61* | *100* | *50* |
| *6* | | *126* | *4* | *44* | *71* | *31* |
| *7* | | *84* | *3* | *29* | *47* | *18* |
| *8* | | *50* | *2* | *18* | *28* | *9* |
| *NPV* | | | | | *409* | *192* |

2) The radial well has the highest PI because, on average, the oil has to travel the shortest distance to reach the well.

3) Assume a linear inflow relationship:

$$w_g(t) = J\left[p_R(t) - p_{wf}\right],$$

where $w_g$ is the gas mass flow rate, $t$ is time, $J$ is the productivity index, $p_R$ is the reservoir pressure and $p_{wf}$ is the flowing well bore pressure. The reservoir pressure is related to the mass of the gas in the reservoir $m_g$ according to the non-ideal gas law

$$p_R(t) = m_g(t)\frac{ZRT_{R,abs}}{V_R M} \ ,$$

where $Z$ is the gas deviation factor, $R$ is the universal gas constant, $T_{R,abs}$ is the reservoir temperature, $V_R$ is the reservoir volume and $M$ is the molar mass of the gas. Here we made two further assumptions, namely that $Z$ and $V_R$ are constants. The mass of the gas in the reservoir decreases over time according to

$$m_g(t) = m_g(0) - \int_0^t w_g(\tau)\,d\tau \ ,$$

where $m_g(0)$ is the initial gas mass. Combining these three expressions, the change of the mass flow rate can now be written as

$$\begin{aligned}\frac{dw_g(t)}{dt} &= J\frac{dp_R(t)}{dt} \\ &= \frac{JZRT_{R,abs}}{V_R M}\frac{dm_g(t)}{dt} \\ &= -\frac{JZRT_{R,abs}}{V_R M} w_g(t) = -C_1 w_g(t).\end{aligned}$$

This is a first-order differential equation which has the solution

$$w_g(t) = C_0 e^{-C_1 t} \ ,$$

i.e. an exponentially decaying mass flow rate with time. The integration constant $C_0$ can be determined from the initial condition

$$\begin{aligned} w_g(0) &= J\left[p_R(0) - p_{wf}\right] \\ &= J\left[m_g(0)\frac{ZRT_{R,abs}}{V_R M} - p_{wf}\right].\end{aligned}$$

4.a) The dogleg severity (DLS) is defined as $\gamma / \Delta s$, and is usually expressed in deg/30 m or deg/100 ft. The table below gives the steps to calculate the DLS. Note that it is not necessary to calculate the Northing, Easting and TVD.

*Dogleg severity calculation.*

| $\alpha_i$ (deg) | $\beta_i$ (deg) | $S_i$ (m) | $e_{x,i}$ (-) | $e_{y,i}$ (-) | $e_{z,i}$ (-) | $\mathbf{e}_{i-1} \bullet \mathbf{e}_i$ (-) | $\gamma_t$ (deg) | $\Delta s_i$ (m) | $\gamma_t / \Delta s_i$ (deg/30m) |
|---|---|---|---|---|---|---|---|---|---|
| 47.47 | 143.37 | 2001.31 | -0.59 | 0.44 | 0.68 | | | | |
| 49.96 | 145.54 | 2031.74 | -0.63 | 0.43 | 0.64 | 1.00 | 2.98 | 30.43 | 2.93 |
| 50.23 | 147.91 | 2060.89 | -0.65 | 0.41 | 0.64 | 1.00 | 1.84 | 29.15 | 1.89 |

4.b) The contact force $f$ is proportional to the axial force $T$ in the drill string and inversely proportional to the radius of curvature $R$, i.e. proportional to the DLS:

$$f = \frac{T}{R} = \frac{T\gamma}{\Delta s}.$$

The DLS in the top section exceeds the DLS in the bottom section. Because the drill string is in tension, the weight of the bottom section is carried by the top section. Therefore also the axial force in the top section exceeds the value in the bottom section and the highest contact forces must occur in the top section.

5) The peak in the curve corresponds with the bubble point pressure. Above the bubble point pressure the oil is compressed with increasing pressure and this is reflected in a decreasing FVF. However, below the bubble point pressure a second effect occurs. Gas dissolves in the oil with increasing pressure resulting in an increase in volume. The volume increase because of dissolving gas is much larger than the volume reduction because of compression, hence the FVF increases with increasing pressure.

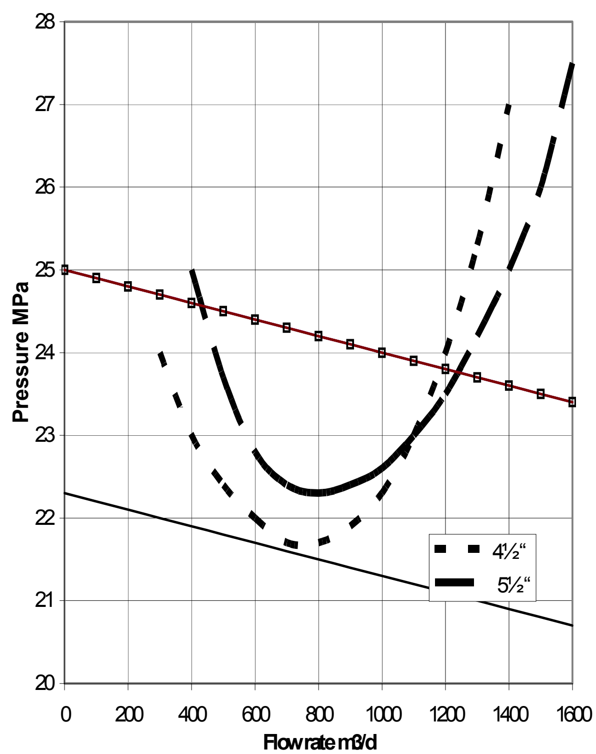
6a) Productivity Index = 1000/1000 = 1 $m^3$/(day*kPa)

6b) 4 ½ : ~1200$m^3$/day. 5 ½ :~1240 $m^3$/day

6c) 4 ½ inch. Will give higher production for a longer time in later stages of field life (expected answer). 5 ½ inch will give higher initial production (OK if argued properly)

6d) ~ 22.3 MPa

6e) Multiphase effects, liquid slipping back past the gas.



7a)

| *Gas properties.* | | | | |
|---|---|---|---|---|
| *Hydrocarbon* | *Weight (g)* | *M (g/mole)* | *Mole* | *Mole %* |
| methane | 88.2 | 16.04 | 5.499 | 93.8 |
| ethane | 8.5 | 30.07 | 0.283 | 4.8 |
| propane | 3.3 | 44.10 | 0.078 | 1.3 |
| total | 100 | | 5.860 | 100 |

$p_{pc} = (93.8 * 45.9 + 4.8 * 47.7 + 1.3 * 41.5)/100 = 45.9 * 10^5$ Pa

$T_{pc} = (93.8 * 191 + 4.8 * 305 + 1.3 * 370)/100 = 199$ K

$p_1 = 2904$ psi $= 202.7*10^5$ Pa, $p_2 = 1470$ psi $= 101.4*10^5$ Pa, $T_1 = T_2 = 95$ °F $= 308$ K

$p_{pr,1} = 202.7/45.9 = 4.4$, $p_{pr,2} = 101.1/45.9 = 2.2$, $T_{pr,1} = T_{pr,2} = 308/199 = 1.55$

With the aid of Standing-Katz chart: $Z_1 = 0.81$, $Z_2 = 0.83$.

The Z factors reflect the deviation of the gas mixture behaviour from the ideal gas law. In this case the is hardly any change in the Z factor between the two conditions.

8) See figure below. Because the production path in the reservoir crosses the dew point line, retrograde condensation occurs. This condensate drop-out in the pores may result in deteriorated inflow performance.