University of Stavanger

FACULTY OF SCIENCE AND TECHNOLOGY
Department of Petroleum Engineering

SUBJECT: PET 600 – Well Completion

DATE: 19 December 2016

TIME: 0900-1300

AID: Calculator

THE EXAM CONSISTS OF TWO SECTIONS ON 21 PAGES (INCLUDING FRONT PAGE). AFTER EACH SECTION, YOU FIND USEFUL EQUATIONS AND OTHER INFORMATION.

Section	Exam	Formula sheet
PART A	Page 1-4	Page 5
PART B	Page 6-17	Page 18-20

DO NOT WRITE YOUR ANSWERS ON THE EXAM SHEET.

<u>Academic contacts during the exam</u>

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Used acronyms and miscellaneous equations are given at the end of Part A

----- EXAM PART A -----

PART I

Five short questions with three alternative answers (multiple choice). Indicate on your answer sheet the answer that you think is **most** correct. Please write the letter (A, B or C) and not the wording as your answer for each question.

Maximum score is 20 points.

Question I-1: Lower completion C&P

A C&P lower completion gives …

Options:

A. … poor zone isolation.
B. … low skin factor in hard rock formations.
C. … the possibility of bypassing the region of drilling damage.

Question I-2: Lower completion OHGP

An OHGP lower completion in a near-vertical reservoir zone …

Options:

A. … shows low success rate since the alpha-wave does not develop.
B. … is operationally more complex than SAS.
C. … is usually restricted by the Saucier (1974) gravel sizing criterion.

Question I-3: Upper completion

Installing a tailpipe below the production packer is …

Options:

A. … not permitted on the NCS according to the Norsok D-010 standard.
B. … not required since there is a PBR installed in the completion below.
C. … useful during future recompletion.

Question I-4: Life of well operations

Well intervention operations such as WL and CT are not …

Options:

A. … considered during the well completion design.
B. … difficult on platform wells compared to subsea wells.
C. … needed as long as correct metallurgy is chosen for the flow conduit.

Question I-5: Well displacement type

Direct displacement of OBM ahead of running the completion in an offshore well …

Options:

A. … is a well suited option.
B. … does not require the use a viscous pill.
C. … implies that readily available seawater is used.

PART II

Five questions. Provide answers on your answer sheet.
Maximum score is 20 points.

Question II-1: Comparison of two OHGP methods
In terms of fluid loss during the gravel-pack operation and its consequence, how does a circulating pack differ from an alternate path gravel-pack?

Question II-2: Considerations for C&P lower completion
What are important parameters for perforation penetration? Minimum four parameters are required for full credit.

Question II-3: Tubing preloading caused by packer type
How is the initial condition for tubing design affected by the choice of using hydraulic set packer in comparison to hydrostatic set packer?

Question II-4: North Sea platform well field development
What is a predrilled well and what is its purpose?

Question II-5: Artificial lift
What is the most important method for artificial lift on the NCS and how does it work?

PART III

Three questions. Provide calculations and answers on your answer sheet.
Maximum score is 30 points.

A horizontal OHGP is performed through 5" drill pipe with capacity of 9 liter per meter. The pump rate is 900 liter per minute. The following data is available:

Pump time, minutes	0	30	90	90	110
Pump pressure, bar	40	40	40	40	150
Dune wave		Start alpha	End alpha	Start beta	End beta

Question III-1: Length of the drill pipe
What is the length of the well to the gravel-pack port?

Question III-2: Percent fill during the alpha wave
What is the percent of the annulus cross-sectional area that is filled during the alpha wave? Explain your reasoning.

Question III-3: Rate of pressure increase during the beta wave
How many bar per minute does the pump pressure increase during the beta wave? Explain the reason for the pressure increase.

PART IV

Five questions. Provide calculations and answers on your answer sheet.
Maximum score is 30 points.

Consider a well with SAS lower completion in the next three questions. The well deviation from vertical is 60 degrees. The vertical permeability is 10% of the horizontal permeability. The thickness of the horizontal reservoir is 30 meter and the well was drilled using a bit measuring 0.216 meter in diameter. The drilling damage skin is +2.

Question IV-1: Measured length of completion interval
Considering full reservoir penetration, how many meter of reservoir penetration is there?

Question IV-2: Well deviation skin
Considering the Cinco et al (1975) model, what is the well deviation skin? Explain how this skin impacts the inflow performance of the well and why.

Question IV-3: Total skin
Considering the Pucknell and Clifford (1991) model, what is the total skin factor for this well?

(PART IV continues on the next page...)

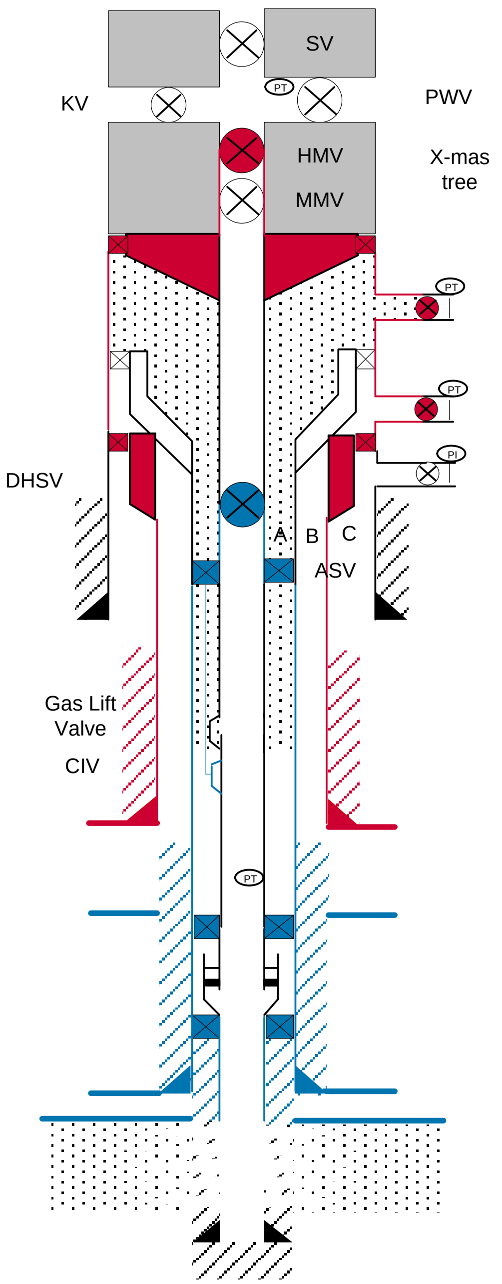
Question IV-4: Completion sequence

Please sort in the correct execution order the following operational steps in the completion program for a gas-lifted oil producer. Note that the shallow barrier plug is installed on drill pipe. Please write the letters in correct order and not the wording.

Operational steps in alphabetic order for a platform well
A - Displace well to packer fluid
B - Hand well to production
C - Install middle completion
D - Install sand screens
E - Install Xmas tree
F - Retrieve primary barrier plug
G - Perform OHGP
H - Remove dummy from SPM
I - Retrieve secondary barrier plug
J - Rig down BOP stack
K - Rig down WL
L - Rig up WL
M - Install tubing
N - Set shallow barrier plug
O - Install GLV
P - Set production packer

Question IV-5: Well barriers

Shown below is WBS for a gas-lifted oil producer with functioning ASV. Please explain how the primary well barrier envelope changes if the ASV no longer holds pressure from below. Are there any changes for the periodic barrier testing scheme? Are there other changes in terms of installed equipment?



Used acronyms

ASV – annulus safety valve
BOP – blowout preventer
C&P – cased and perforated
CT – coiled tubing
GLV – gas-lift valve
NCS – Norwegian continental shelf
PBR – polished bore receptacle
OBM – oil-based mud
OHGP – openhole gravel-pack
SAS – stand-alone screen
SPM – side-pocket mandrel
WBS – well barrier schematic
WL – wireline

Equations

$\frac{q_o - q_b}{q_{o(max)} - q_b} = 1 - 0.2\frac{p_w}{p_b} - 0.8\left(\frac{p_w}{p_b}\right)^2$	$S = \left(\frac{k}{k_d} - 1\right)\ln\left(\frac{r_d}{r_w}\right)$
$S_h = \ln\left(\frac{r_w}{\alpha(r_w + l_p)}\right)$	$S_h = \ln\left(\frac{4r_w}{l_p}\right)$
$S_{wb} = C_1 \exp(C_2 r_{wD})$	$S_v = 10^a h_D^{b-1} r_{pD}^b$
$S_t = \frac{h}{h_m}F(S_m + S_a) + S_c$	$S_a = \ln\left(\frac{2}{1+F}\right)$ $F = \frac{1}{\sqrt{\cos^2\theta + (k_v/k_h)\sin^2\theta}}$
$S_{dev} = -\left(\frac{\theta'}{41}\right)^{2.06} - \left[\left(\frac{\theta'}{56}\right)^{1.865}\log_{10}\left(\frac{h}{100r_w}\sqrt{\frac{k_h}{k_v}}\right)\right]$ $\theta' = \tan^{-1}\left(\sqrt{\frac{k_v}{k_h}}\tan\theta\right)$	

Part 1: Introduction and well-integrity

Question-1: Well integrity-(Short answer)

NORSOK D-10 well integrity defines three solutions in order to avoid or reduce uncontrolled leak during the life of the well. In the table below, please write these solutions along with their purpose/what they deal with.

#	Solution	What does it deal with?-Short answer!
1		
2		
3		

Question 2: Well integrity problem and Repair (Short answer)

Figure 1 is production well. Regularly, company-X is monitoring the A-annulus WH pressure. As you can see on the pressure plots, during OA production periods, the annular WH pressure is the expected normal pressure. However, during AB period, pressure anomaly is observed, which is abnormal and undesired.

a) For the **abnormal pressure**, there are **two** possible reasons. What are they?

b) How can we bring back the **abnormal pressure** to **normal pressure**?

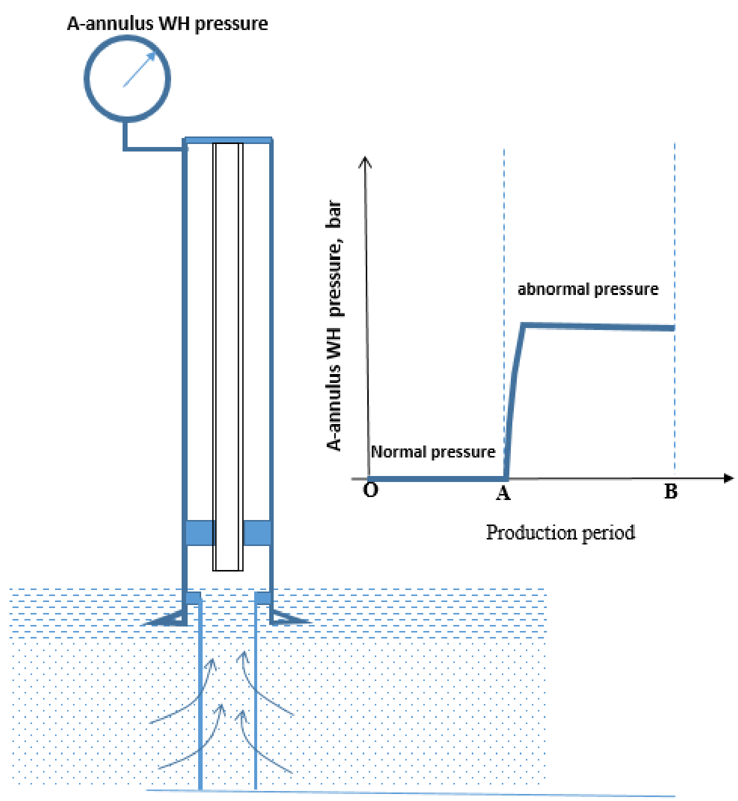


Figure 1: Production well and A-annulus pressure profile

Question 3: What is the difference between **VXT** and **HXT**? (Please mention at least two differences)

Part 2: Tubing and completion design

Question 1: Completion design

A company would like to produce hydrocarbon through one well, which contains four-reservoirs at different depth (Carbonate - Carbonate – Sandstone – Sandstone at the bottom).

Your task:

- Please sketch an appropriate completion design that allows producing through two tubing and the system contains four packers (2dual and 2 single) in order to isolate production fluid mixing. Remember to show the geological symbols on the formation and required material to avoid tubing damage.

Question 2: Stress in tubular

An engineer computed the stress distribution in an **open and closed end** thick walled cylinder that was loaded internally (Pa) and externally (Pb). For this particular case, the combination of the loads and the geometry resulted in zero axial stress. The inner radius was (**a= 1cm**). On **Figure 2**, the Hoop Stress is shown. Assume that the stresses are principal stress. The yield strength of the cylinder is **55 bar**.

Your task

a) What are the values of the inner and outer pressures in bar?
b) What is the size of outer radius? (**b=____cm?)**
c) Please sketch the axial and radial stresses across the wall thickness of the tubular.
d) According to Tresca failure theory, do the loadings cause the cylinder yielded at the inner radius?

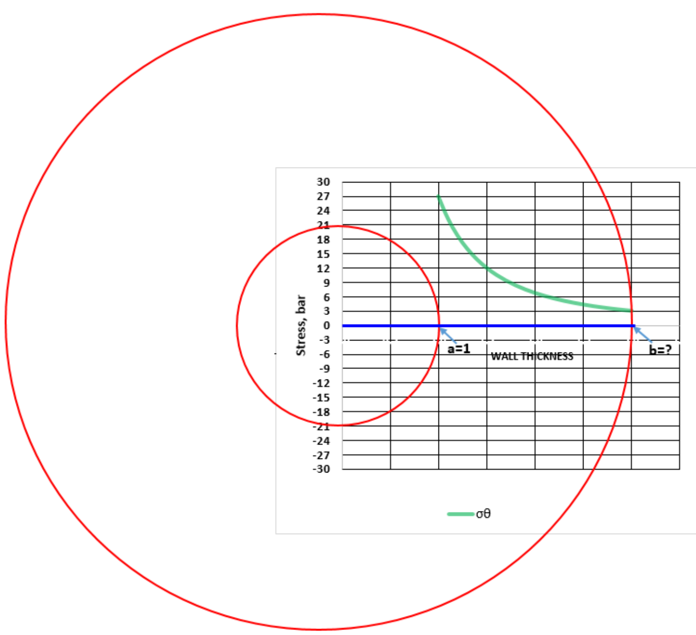


Figure 2: Stress fields in the wall thickness of thick walled cylinder

Question 3: Tubular Grading and Burst

Assume an **open-end thin walled** tubing (T) (**See Figure 3a**) and loaded internally only. Since the grading and other properties of the tubing were not obtained from the manufacturer, an engineer took a specimen out of the tubing and performed tensile test (**see Figure 3b**) **(NB: 1 kpsi = 1000 psi)**

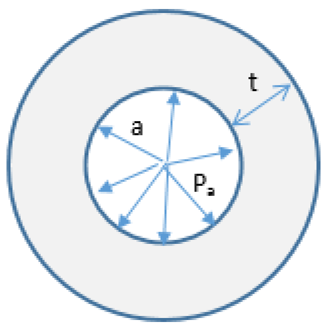


Figure 3a: Thin walled cylinder loaded internally

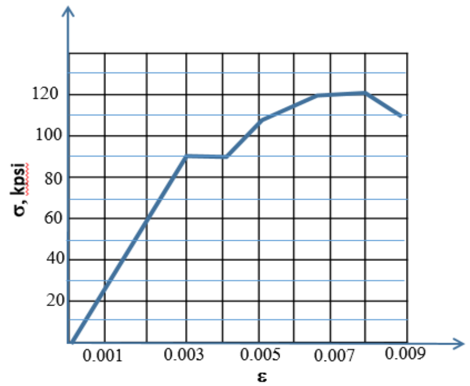


Figure 3b: Tensile test

__Your task__

a) What is the grade of the tubing? T- ___?

b) Using wall thickness tolerance and **Tresca failure** criteria theory, please __**derive**__ the maximum pressure that causes the inner wall yielding given as:

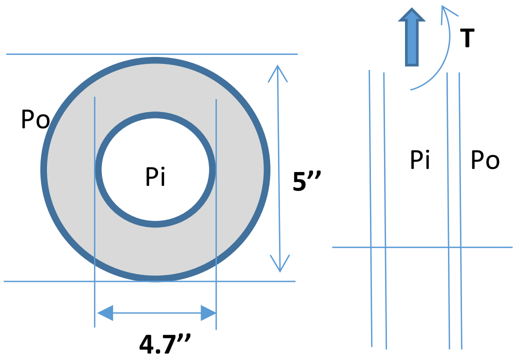
$$P_y = \_\_\_\_\_\_\_\_\_\_$$ **(Please show your work)**

Question 4: Applied Torque

Assume **a thin walled** drill string (ID= 4.7 inch and OD= 5.0 inch) is loaded with pressures (internally and externally) and torque. These loadings generate stresses in the wall thickness of the string. **Table 1** shows the stresses.

Radial stress, MPa	Hoop Stress, MPa	Axial stress, MPa	Von -Mises, MPa
1	2	2	$\sqrt{13}$

Table 1: Stresses and Von-Mises



__Your task__

- What was the approximate value of the applied **TORQUE** in Nm?

Question 5: Tri –axial and Bi-axial Collapse

If you are given a Tri-axial collapse equation,

$$P_o = \frac{-\sigma_a + 2\beta.P_i - P_i \pm \sqrt{-3\sigma_a^2 - 6\sigma_a P_i - 3P_i^2 + 4\sigma_y^2}}{2\beta}$$

Your task:

- Is it possible to write the Bi-axial collapse equation out of the tri-axial? If yes, please write the equation. If no, please give the reason.

Question 6: Combined load-Tubular Burst

Assume that a **thin walled** string (drilling string or casing) is loaded with an internal pressure and torque. These generate normal and shear stresses. In two-dimensional stress tensor, the stresses are shown below.

$$\sigma = \begin{bmatrix} \sigma_a & \tau \\ \tau & \sigma_\theta \end{bmatrix}$$

Your task

Assume that the tolerance is 1, and using the maximum principal stress failure criteria, please derive the pressure that causes the inner wall yielding:

$P_y =$ ______________ **(Please show your work)**

Question 7: Tubular Thermal Elongation

Figure 4 shows two different strings (L-80 and T-95) having different thermal and elastic properties. Both have the same length (1m) **at room temperature**, but when they are exposed to **a higher temperature**, they elongated differently as 1.001m and 1.003m respectively. Assume that the coefficient of linear thermal expansion of L-80 was $1.0x.10^{-6}/^oC$.

Your task

- What is the coefficient of linear thermal expansion of T-95?

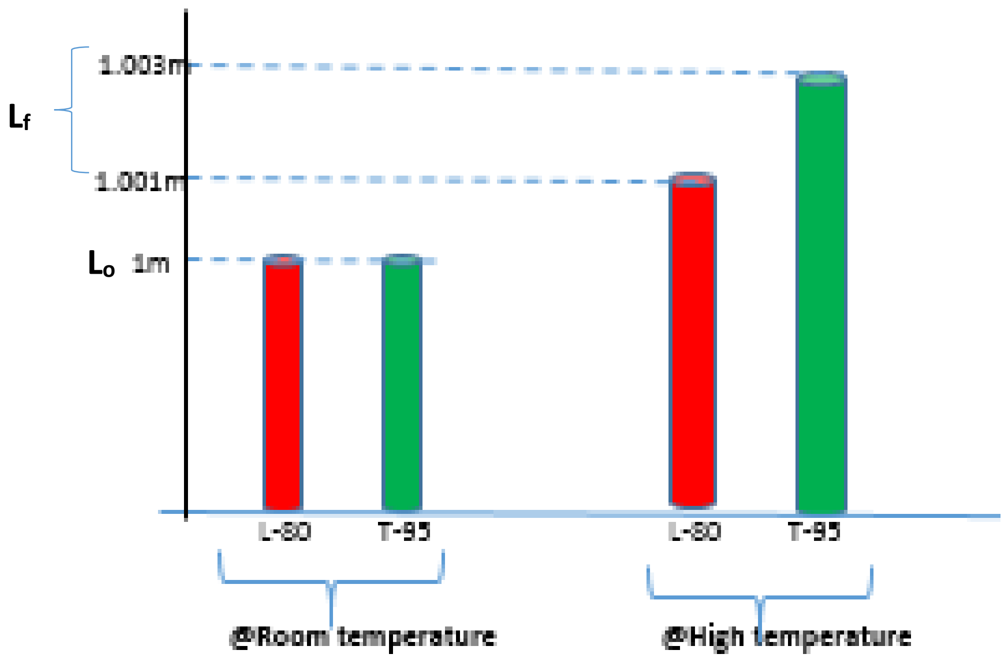


Figure 4: Tube length at room temperature and after exposed to high temperature

Question 8: Tri-axial Tubular Design

It is common practice to use L-80 tubing for production tubing. Based on the given tubing size, the geometrical factor is approximated as $\beta \approx 20.51$. The grade of L-80 tube normally given at the measured laboratory temperature (i.e 75 ^oF). As shown on **Figure 5**, the tube experiences higher temperature due to production fluid and this de-rate the yield strength by 0.05% /^oF.

Figure 5 shows the assumed pressure profiles in the annulus and in the tubing along with the generated axial stress and also temperature profile. **(NB: 1 kpsi = 1000 psi)**

The tubing wellhead (WH) pressure is **0.72kpsi** and hydrocarbon pressure gradient in the tubing is **0.20psi/ft**.

<u>Your task:</u>

- Assuming that the calculated safety factor for the given loading at 5000m depth was <u>the same as</u> the NORSOK-D10 Tri-Axial Safety factor value (i.e **1.25**), what was then the approximate annular pressure (Po) at the 5000m depth? **(Please show your work)**

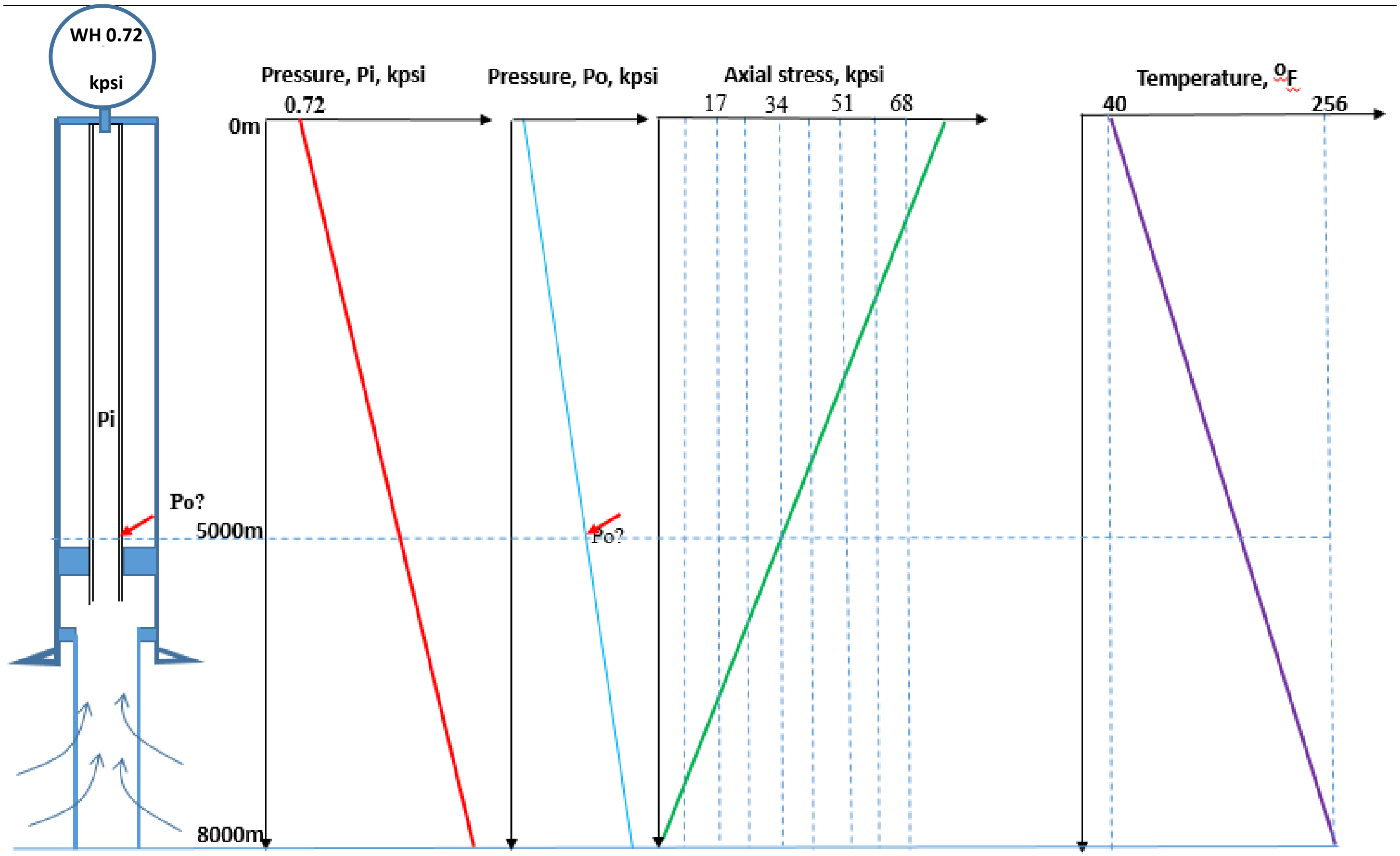
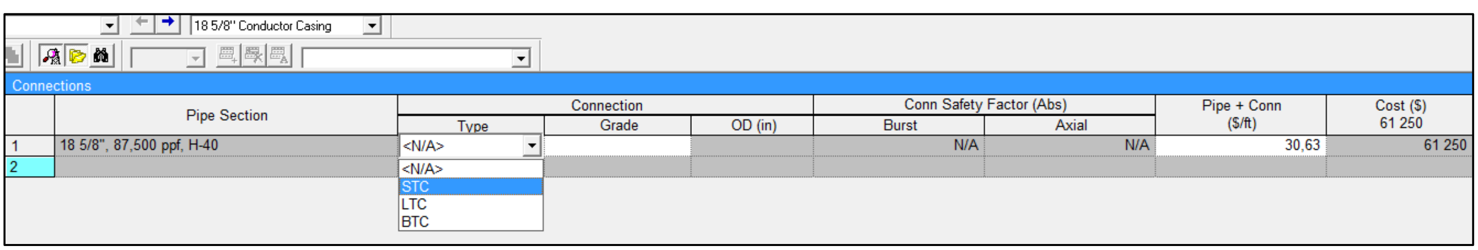


Figure 5: Well, Inner tube pressure (Pi), Outer tube pressure (Po), Axial stress (σ_a) and Tube temperature profiles (Please note that the depth increase from 0m to 8000m vertically) **(NB: 1 kpsi = 1000 psi)**

Simulation

Question 9: Coupling design

As shown on the snapshot of stress check **Figure 6**, during simulation, you used three types of connection for casing design.



	Pipe Section	Connection Type	Connection Grade	Connection OD (in)	Conn Safety Factor (Abs) Burst	Conn Safety Factor (Abs) Axial	Pipe + Conn ($/ft)	Cost ($) 61 250
1	18 5/8", 87,500 ppf, H-40	<N/A>			N/A	N/A	30,63	61 250
2								

Figure 6: Snapshot of connection spreadsheet (StressCheck)

a) What does STC, LTC, & BTC represents for? Please sketch the thread profiles of these connections and write the differences.

b) During simulation, which one was found out to be the best in terms of solving problems?

Question 10: Stress in circular cylinder

Assume a thick walled cylinder (**Figure 7**) loaded internally (P_a=50psi) and externally (P_b=100 psi). The inner and outer radii are not given, but the cylinder satisfies the condition that (t >0.1.a),

Your task: Which of the following figures below do you think would represent stress fields across the wall thickness? (**Please give also your reason. This is very important. If the reason is not correct, you will not get point even if you select the right figure**).

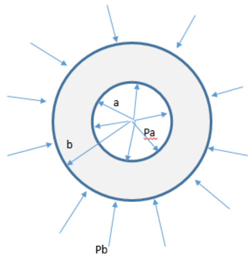


Figure 7: Thick-walled cylinder

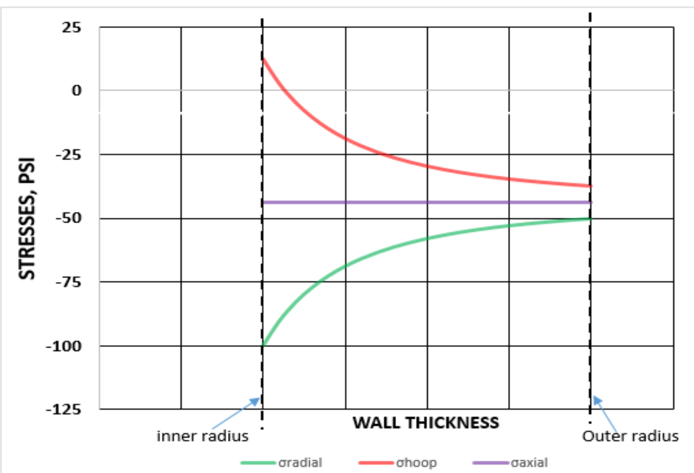


Figure (A)

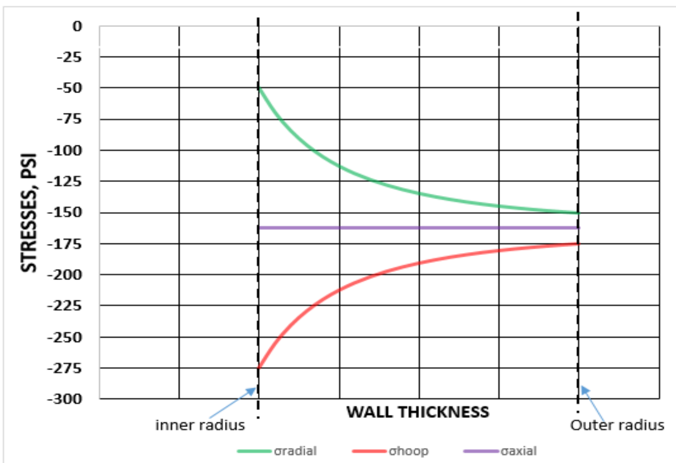


Figure (B)

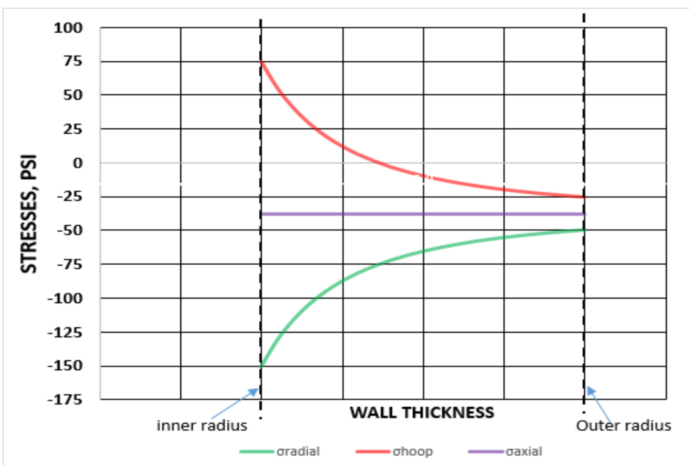


Figure (C)

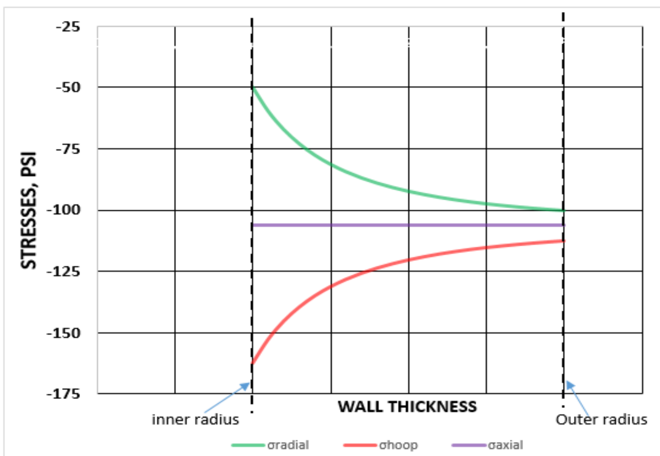


Figure (D)

Question 11: Coupling upset end

Figure 8 is API Extreme Line Casing connection. However, this was not available in the StredsCheck as shown on **Figure 6**.

<u>Your task</u>

- What is the **<u>upset end</u>** of this joint?

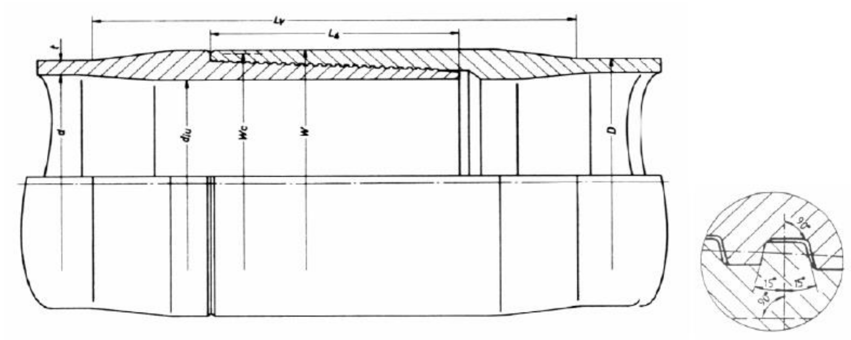


Figure 8: Extreme Line Casing and internally and externally threaded

Question 12: Collapse loading and re-design

Figure 9 shows design load and pipe rating. As you can see within MD8250 - 9000ft, you can see a strange anomaly on the design load line.

<u>Your task</u>

a) What was the reason for this anomaly?
b) Design a <u>cost effective</u> tubular that carry the collapse loading

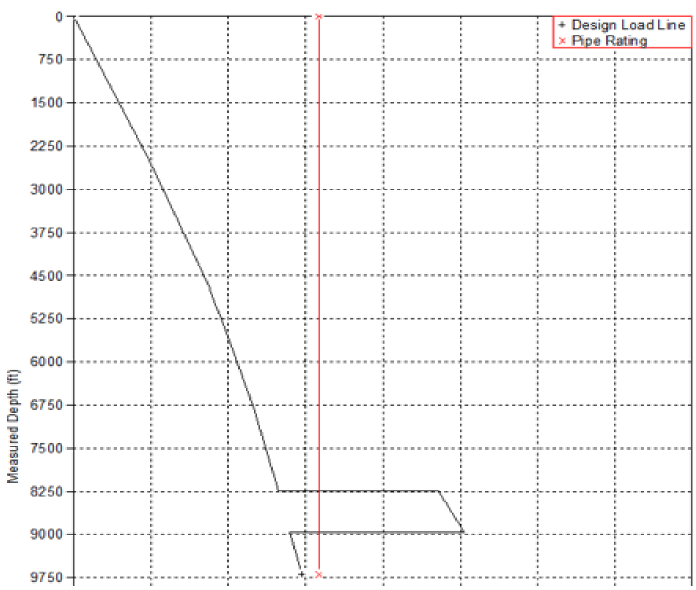


Figure 9: Design plot of tubing

Part 3: Material Testing

1. For design purpose, an engineer is interested in the Poisson ratio of a material. However, this data was not provided by manufactures, but only the torsion **(Figure 10a)** and tensile **(Figure 10b)** test data as shown below.

<u>Your task</u>

a) Using the test results (i.e **Figure 10a &b**), please estimate the Poisson ratio of the material.

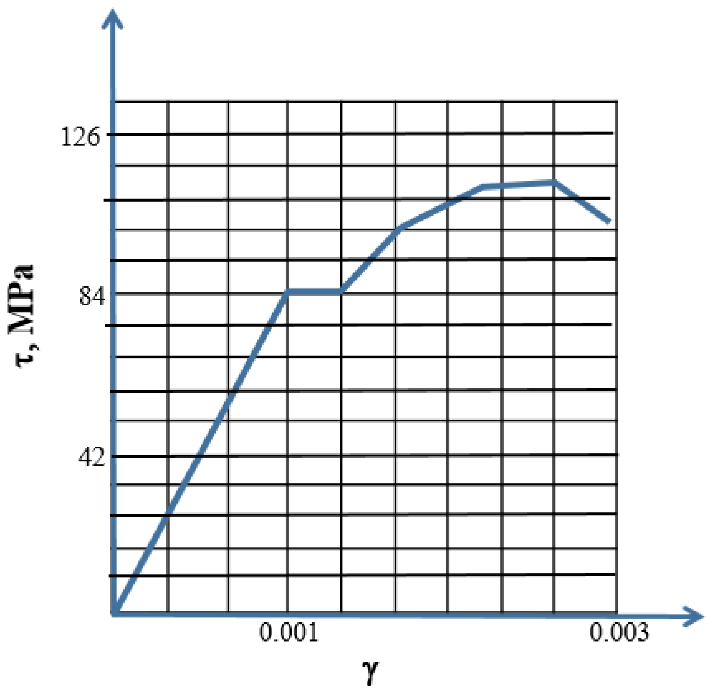


Figure 10a: Torsional test result

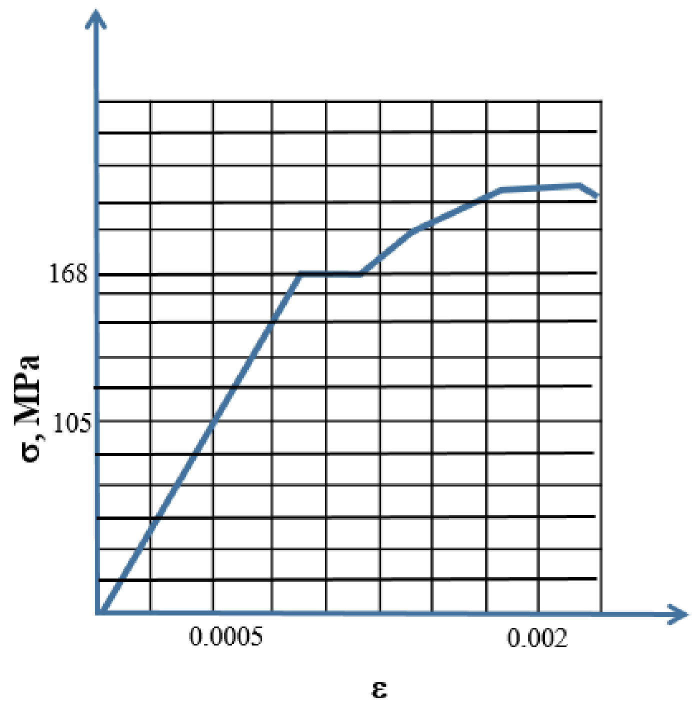


Figure 10b: Tensile test result

2. Assume that a material shows creep behavior since the material is exposed in a temperature higher than 40%$T_{melting}$. For the three temperatures higher than 40%$T_{melting}$, **your task** is to sketch (strain vs time graph) the effect of temperature on creep behavior of the material.

- $T_3 > T_2 > T_1$

Part 4: Material Selection

1. NORSOK-D10 **design** demands two important issues for casing and tubing states that ….

   Casing and tubing shall…………………………………………………………..

   Casing and tubing shall…………………………………………………………..

2. Correct material selection is a compromise among several issues. Among others what are the most important elements?

3. Assume that water injection tubing is going to be exposed to a very high corrosive environment such as the injection fluid contains air and chloride ion.

   Your task!

   - Which of these supper duplex stainless steel would you select for tubing? (**Please select and give your reason for the selection, which is very important**)

     (a) #1 (b) #2 (c) Both (d) None of these.

#	Cr (%)	Mo (%)	W (%)	N (%)
1	25,0	2,0	0,2	0,2
2	25,0	1,5	0,3	0,3

Part 5: Corrosion and Coating

1 Please write the four common corrosion control methods.

2 Assume multiphase flow in a tubing with the volume fraction of gas and oil shown on **Figure 11.** In addition, the C-factor for the tubing and the liner are also shown along with the tubing temperature, which off course varies depending on the production rate and the shut in period.

Assume that the density of gas and oil are the same throughout the depth section even though they are temperature and pressure dependent. This assumption is to simplify the problem. As shown on the figure, the flow is single phase between 6000-8000m. Above the 6000m, we can see two phases that oil and gas being mixed together in the production tube.

Table 2 shows the average (mixture) flow velocity and the multiphase fluid densities.

Density of gas	0.023sg
Density of oil	0.76 sg
Mixture fluid Average Flow Speed at 5000m,	15 ft/s

<u>Your task:</u>

- Does the average flow velocity erode the surface of tubing at **5000m?**

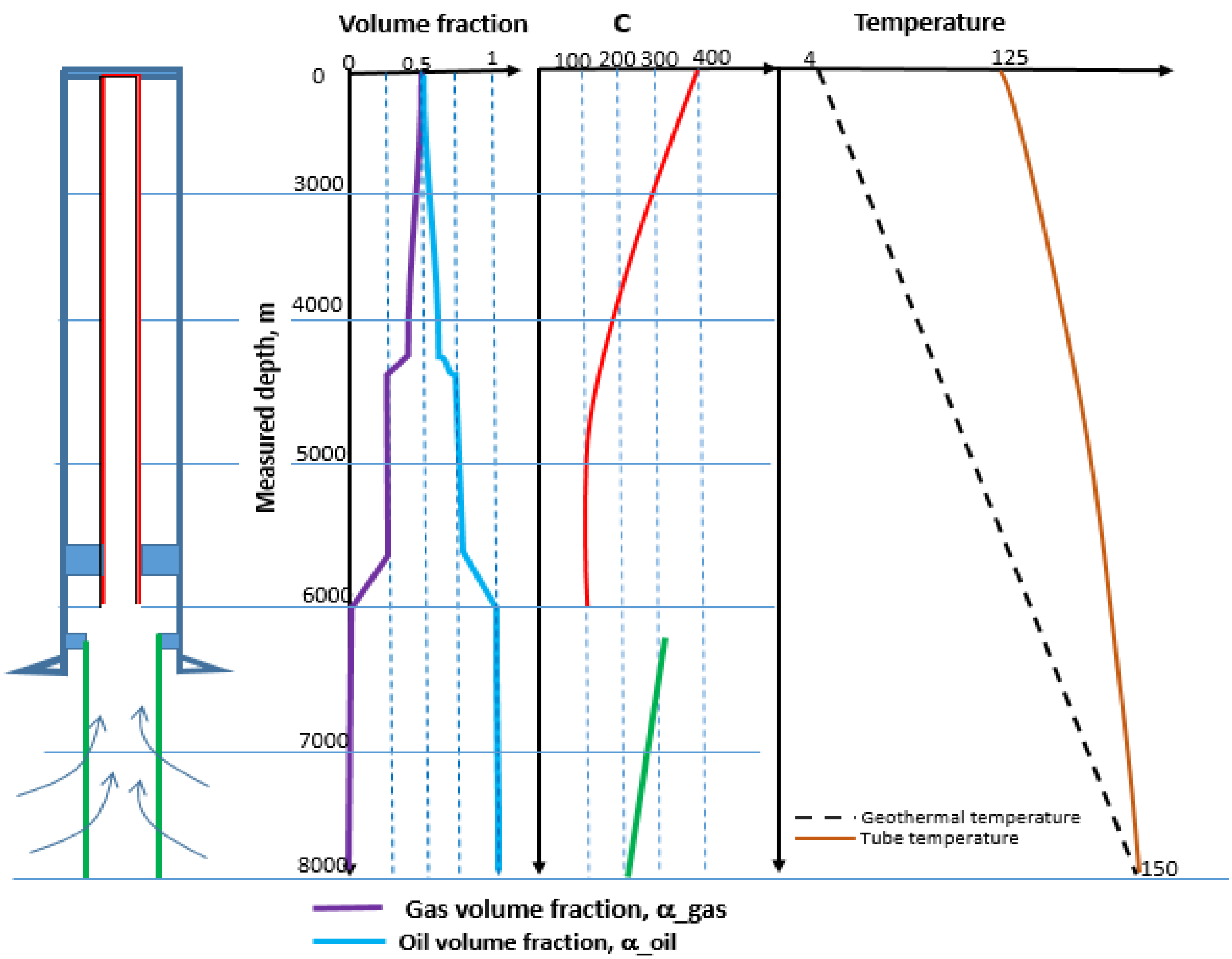


Figure 11: Multiphase flow and C-factor of tubular

Part 6: Petroleum Chemistry

1. According to NORSOK D10, what is the minimum placement depth of SSV and ASV below seabed? Please write the reason why?

2. **Your task** is to sketch a typical P-T hydrocarbon phase envelope and the three-petroleum chemistry related solid deposit envelops on the P-T plot.

3. **Figure 12** shows hydrate stability curves due to the fluids systems listed from **A-F**. **Your task** is to select fluid system and indicate to which curve on the figure it represents.
   - **A.** Sea water
   - **B.** Sea water, 50% by wt methanol
   - **C.** Sea water 50% by wt glycol
   - **D.** Sea water 20% by wt glycol
   - **E.** Sea water 30% by wt glycol
   - **F.** Pure water

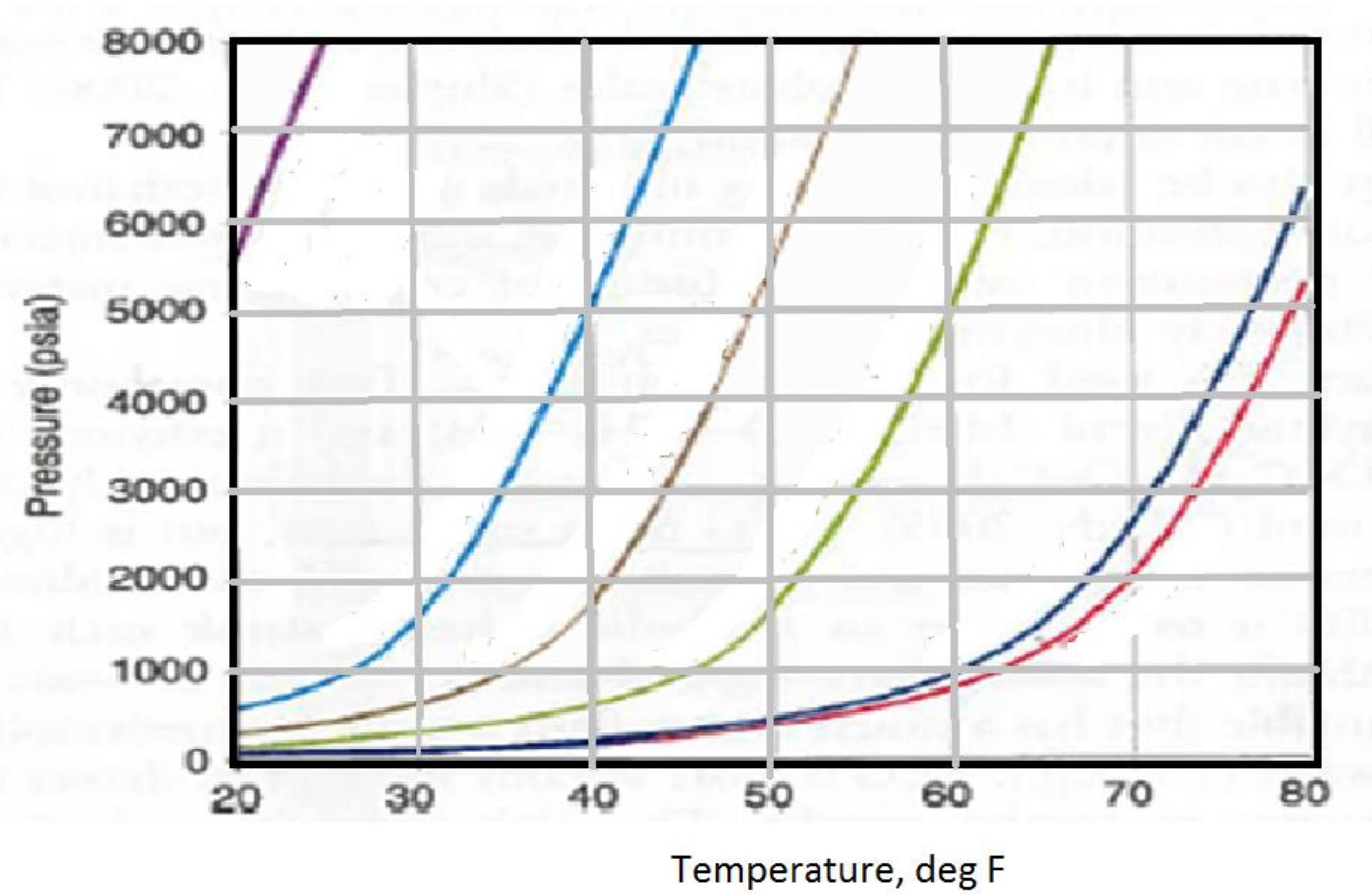


Figure 12: Thermodynamics hydrate stability

Part B

Formula sheet

Thin walled cylinder (loaded internally only)

$$\sigma_\theta = P\frac{r}{t} \quad , \sigma_r = -P \qquad \sigma_a = P\frac{r}{2t} \text{ (Closed end)}, \quad \sigma_a = 0 \text{ (open end)} \qquad 1$$

Thick walled cylinder (loaded internally and externally)

1 Radial stress

$$\sigma_r = \frac{p_a a^2 - p_b b^2}{b^2 - a^2} - \frac{a^2 b^2}{(b^2 - a^2) r^2}(p_a - p_b) \qquad 2$$

2 Hoop stress

$$\sigma_\theta = \frac{p_a a^2 - p_b b^2}{b^2 - a^2} + \frac{a^2 b^2}{(b^2 - a^2) r^2}(p_a - p_b) \qquad 3$$

3a: Axial stress (**Closed and open end**)

$$\sigma_a = \frac{p_a a^2 - p_b b^2}{b^2 - a^2}, \quad \sigma_a = \frac{1}{2}(\sigma_\theta + \sigma_r) \qquad \text{Open and closed end} \qquad 4$$

3b: Axial stress (Open end)

$$\sigma_a = 0 \qquad \text{Open end} \qquad 5$$

Failure criteria

Tresca: $\sigma_y = \sigma_{max} - \sigma_{min}$ 6

Von-Mises: $\sigma_y = \sqrt{\frac{1}{2}\left\{(\sigma_\theta - \sigma_r)^2 + (\sigma_r - \sigma_a)^2 + (\sigma_a - \sigma_\theta)^2\right\} + 3\tau^2}$ 7

Dimensionless failure envelope analysis

$$x = (p_i + \sigma_a)/\sigma_y \qquad 8$$

$$y = \beta(p_i - p_o)/\sigma_y \qquad 9$$

$$SF = \frac{1}{\left[x^2 - xy + y^2\right]^{0.5}} = \frac{\sigma_y}{\sigma_{VME}} \qquad 10$$

$$y = \frac{x}{2} \pm \sqrt{\frac{1}{SF^2} - \frac{3}{4}x^2} \qquad 11$$

Part B

Thin walled shear stress (τ) due to an applied torque (T)

$$\tau \approx \frac{T}{2\pi . r^2 t}$$, r = inner radius and t = wall thickness 12

API Bulletin 5C3, 1999 burst design

$$P_y = Tol * 2\sigma_y \frac{t}{OD}$$ (Tol= Tolerance) 13

Thermal effect on elongation

$$\Delta L = \alpha . L_o . \Delta T$$ 14

2D stress and principal stress

2D stress tensor

$$\sigma = \begin{bmatrix} \sigma_{xx} & \sigma_{xy} \\ \sigma_{yx} & \sigma_{yy} \end{bmatrix} = \begin{bmatrix} \sigma_1 & 0 \\ 0 & \sigma_2 \end{bmatrix}$$

Principal stresses (Maximum and Minimum)

$$\sigma_{1,2} = \frac{\sigma_{xx} + \sigma_{yy}}{2} \pm \sqrt{\left(\frac{\sigma_{xx} - \sigma_{yy}}{2}\right)^2 + \sigma_{xy}^2}$$

15

Yield stress temperature de-rating

$$\sigma_y(T) = \sigma_y(75^o F)[1 - x\%\{T - 75\}]$$

16

Pitting Resistance Equivalent Number (NACE)

- PREN = %Cr + 3.3(%Mo+0.5%W)+16%N 17

Part B

Stress –Strain (Hooke's law)

Torsional: $\boldsymbol{\tau} = G.\gamma$ Tensile: $\boldsymbol{\sigma} = E.\varepsilon$ 18

Relationship between elastic constants 19

Input Constants	Output Relations			
	E =	ν =	G =	K =
E, ν	-	-	$\frac{E}{2(1+\nu)}$	$\frac{E}{3(1-2\nu)}$
E, G	-	$\frac{E-2G}{2G}$	-	$\frac{EG}{3(3G-E)}$
E, K	-	$\frac{3K-E}{6K}$	$\frac{3KE}{9K-E}$	-

K=Bulk modulus, E-Young's modulus, G=Shear modulus and ν = Poisson ratio

API RP 14E recommended limiting erosional velocity

$$V_e = \frac{C}{\sqrt{\rho}} \quad (20)$$

- V_e=the maximum allowable erosional velocity in ft/s
- ρ=the density of fluid (single or multiphase) in lb/ft^3 at flowing conditions of temperature and pressure
- C=a constant known as the C-factor in ($lb^{0.5}$ $ft^{-0.5}$ s^{-1})

Multiphase flow:

- Density fluid mix for oil and gas as a function of **volume fractions** (α_o, α_g) and densities(ρ_o, ρ_g):

$$\rho_{mix} = \alpha_o\rho_o + \alpha_g\rho_g \quad (21)$$

$$1 = \alpha_o + \alpha_g \quad (22)$$

Unit conversion

1 lb/ft^3 = specific gravity x 62.4

1 inch = 0.0254m

1 MPa = 10^6 N/m^2

1 kpsi = 1000 psi

1m = 3.28 ft