Birla Institute of Technology and Science, Pilani

Semester II, 2022-2023

CHE F412 PROCESS EQUIPMENT DESIGN

Comprehensive Examination

Date: 06/05/2023 **Full Marks: 80**

Duration: 180 Minutes

Instructions

- **Be to the point, don't write essays**
- **Wrong units will fetch no credit**
- **Answer all parts of a question at one place only**
- **Write assumptions wherever required with proper justifications**
- **Symbols should have proper nomenclature**

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1. A distillation column 3 m outer diameter and 30 m height rests over a skirt support of 4.0 m in height. The following specification are given:

Design pressure	5 kg/cm^2
Operating temperature	300 °C
Tray spacing	0.6 m
Top disenergy space	1 m
Bottom separator space	2.5 m
Weir height	60 mm for all trays
Downcomer clearance	30 mm for all trays
The column is provided with an elliptical head with major to minor axis ratio 2:1 of weight 1550 kg	
Weight of tray excluding liquid	95 kg/cm^2 of tray area
Tray support rings	50 mm × 50 mm × 10 mm angles
The distillation column is insulated with 80 mm thickness asbestos insulation	
The column is provided with one caged ladder of 40 kg/m weight	
Permissible stress for shell material	960 kg/cm^2
Welded joint efficiency	85%
Corrosion allowance for shell	2 mm
Density of shell material	7850 kg/m^3
Density of insulation	640 kg/m^3
Density of water (for liquid on tray)	980 kg/m^3
Wind pressure acting over the vessel	125 kg/m^2

(a) Estimate the thickness of the shell, (b) stress due to dead weights, (c) axial stress, (d) stress due to wind pressure, (e) using internal pressure and upwind condition, calculate the height of the column and check if it is more than actual height (30 m). **[4×5=20]**

2. With a help of a neat schematic, derive the Lame's equation for stress analysis: $\sigma_h = \frac{\beta}{r^2} + \alpha$; $\sigma_r = \frac{\beta}{r^2} - \alpha$, where symbols have their usual significance. Further by choosing appropriate boundary conditions, evaluate the values of constants, i.e., α and β. **[10+10=20]**

3. A liquid with density of ethanol (800 kg/m^3) is stored in a cylindrical tank (carbon steel IS 2062) of inside diameter 30 m and height 10 m. Maximum permissible stress for the tank is 200 N/mm^2 and modulus of elasticity of the material is 4×10^5 N/mm^2. Assuming corrosion allowance as 2 mm and joint efficiency for spot radiography as 85%, calculate the shell thickness and the minimum thickness for the bottom course of the tank. Plates of 2 m height are available for fabrication. **[3+7=10]**

4. For a U-tube, 2 pass shell and tube heat exchanger, design pressure is taken as 15% excess of the operating pressure (1.5 N/mm^2). Such a requirement may be of a typical condenser in a refrigeration system. It is estimated that the tube layout is at a triangular pitch (30 mm) with 60 tubes per pass in a sheet (factor=0.9). For the overall shell to work, maximum allowable pressure is fixed at 100 N/mm^2 and the plates are joined at an efficiency of 75% for fabrication. Using a corrosion allowance of 2 mm and 60 mm as thermal allowance for the shell side, estimate the shell side diameter and thickness. **[5+5=10]**

5. In a steam operated pressure vessel, bursting absolute pressure of 30 bar is set for safety operations at a maximum heat rate of 3000 kJ/hr and a temperature of 318 K. Estimate the diameter of the rupture disc (in mm) that can be used for safety operation in this setup, assuming the molecular weight of steam as 18 Da and latent heat of vaporization as 1200 kJ/kg. Specific heat capacity of steam at constant pressure as 1.8 kJ/kg while that at constant volume being 1.4 kJ/kg. **[10]**

6. Write in brief about the following (Draw schematics wherever possible): (i) Different type of losses encountered due to storage of volatile liquids in normal fixed volume tanks; (ii) Different classifications of heat exchangers available as per TEMA standards; (iii) Dual flow and ripple tray; (iv) Utilities of CAD commands, like, TRIM, OFFSET and MIRROR; (v) Flash point and Ignition Temperature **[2×5=10]**

~All the Best~

~Happy Summer Holidays~

Supplementary Information

Table for standard thickness

Standard thickness available (in mm)	*5, 5.5, 6, 7, 8, 9, 10, 11, 12, 14, 16, 18, 20, 22, 25, 28, 32, 36, 40, 45, 50, 56, 63, 71, 80*

List of necessary formulas

$t = \frac{pD_i}{2fJ - P} = \frac{pD_o}{2fJ + P}$	$t = \frac{pD_i}{4fJ - P} = \frac{pD_o}{4fJ + P}$
$t = \frac{PD_0}{2fJ + P}$	$t_h = \frac{PD_0 V}{2fJ}$
$V = \frac{1}{6}(2 + K^2)$	$f_a = \frac{PD}{4(t - c)}$
$\text{Volume of ellipsoid} = \frac{\pi}{6}(D_0^3 - D_i^3) \times \rho_{shell}$	$f_{dx} = \frac{\text{weight of shell}}{\text{cross-section of shell}}$
$f_{d(ins)} = \frac{\pi D_{ins} t_{ins} \rho_{ins}}{\pi D_m (t_s - c)}$	$f_{d(liq)} = \frac{\sum \text{liquid weight per unit height}(X)}{\pi D_m (t_s - c)}$
$f_{d(att)} = \frac{\sum \text{weight of the attachment per unit height (X)}}{\pi D_m (t_s - c)}$	$f_{dx} = f_{ds} + f_{d(ins)} + f_{d(liq)} + f_{d(att)}$
Weight of pipe insulation=area of the pipe×Density×height of column=$\frac{\pi}{6}(D_{0\,ins}^2 - D_{i\,ins}^2) \times \rho_{shell}$	$p = \rho(H - 0.3) \times 9.807 \times 10^{-6}$
$f_{wx} = \frac{1.4 p_w X^2}{\pi D_0 (t_s - c)}$	(a) Internal pressure and upwind side $f_{t\,max} = (f_{wx}\ or\ f_{sx}) + f_{ap} - f_{dx}$
(c) Internal pressure and downwind side $f_{c\,max} = (f_{wx}\ or\ f_{sx}) - f_{ap} + f_{dx}$	Where, $f_{t\,max}$ and $f_{c\,max}$ maximum tensile and compressive stresses f_{wx} = stress due to wind load f_{sx} = stress due to seismic load f_{ap} = axial stress from internal or external pressure (uniform over the entire height) f_{dx} = stress due to dead loads
Number of trays=[(height-1)/tray spacing]+1	$t_b = 10^2 \sqrt{\frac{3\rho H l^2}{4f}}$
$a = n \times 0.866 S_T^2$	$A_s = \pi \frac{D^2}{4} = \frac{n \times 0.866 S_T^2}{\beta}$

$D = 0.72\sqrt{W/P}\left(T/\beta M\right)^{0.25;}\ mm$	$W = \Delta H_R/\lambda;\ where\ \Delta H_R = kJ/hr\ and\ \lambda = kJ/kg$
$\beta = k\left[\frac{2}{k+1}\right]^{\frac{k+1}{k-1}}$	$k = c_p/c_v$