Chemical Engineering (GATE & PSUs)

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GATE & Public Sectors

Plant Design & Economics

GATE 2015 Top Results
Chemical Engineering

1st Rank
Archhit Trichal

2nd Rank
Keval Pareta

GATE 2015 Result

Name: ARCHHIT TRICHAL
Registration Number: CH88041S1135
Gender: Male
Examination Paper: Chemical Engineering (CH)

Marks out of 100#	65.67	All India Rank in this paper	1
Qualifying Marks##	27.52 (General), 24.77 (OBC (NCL)), 18.34 (SC/ST/PwD)	GATE Score	947

Highest Result in GATE 2015

Rank 1, 2, 7, 8…….

Total 39 Ranks under AIR 100

GATE 2014 Topper
Chemical Engineering

1st Rank
Sandeep Kumar

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GATE 2015 Cut-off Marks				
BRANCH	GENERAL	SC/ST/PD	OBC(Non-Creamy)	Total Appeared
Chemical Engineering	27.52	18.34	24.77	15874

CONTENT

Syllabus : Plant Design and Economics: Process design and sizing of chemical engineering equipment such as compressors, heat exchangers, multistage contactors; principles of process economics and cost estimation including total annualized cost, cost indexes, rate of return, payback period, discounted cash flow, optimization in design

CHAPTER-1

PRESSURE VESSELS DESIGN

(1) In pressure vessels we include all vessels and pipe line.

(2) These pressure vessels carry, store or receive liquid, gases or steam at pressure above the atmospheric pressure.

Design Pressure

(1) We design the pressure vessels to withstand maximum working pressure.

(2) When pressure vessels is under internal pressure then we obtain design pressure by adding 5 to 10% to the maximum working pressure.

(3) If hydrostatic pressure in the column base is significant then added to the operating pressure.

(4) If pressure vessels subject to external pressure outside and inside vacuum. the we have to take into account maximum difference in pressure between inside and outside of the vessels.

Design temperature:

(1) Temperature used in the design should not be less than mean metal temperature expected under operating conditions because metal strength decreases with temperature increase.

(2) The design temperature shall be at least 25^0C or more than the maximum temperature expected where vessel are in direct internal heating or severe exothermic reaction takes place.

Maximum Allowable Stress:

(1) Maximum allowable stress is required for design purpose.

(2) Maximum allowable stress is calculated by applying a suitable safety factor to the maximum stress.

(3) The maximum stress of material could be expected to withstand without failure under standard test conditions.

(4) From standards and code used for design pressure vessels we can obtain values of maximum allowable stress for different material.

Materials:

(1) We have to select suitable material for process vessels construction from the list of acceptable material available in codes and standard.

(2) Selection of material depends on

  a. Suitability of material for fabrication.

  b. Suitability of material with process environment.

Weld joint efficiency factor (J):

(1) Weld joint efficiency factor (J) is the ratio of strength of an arbitrary strength of welded joint to the strength of plate welded.

(2) Weld joint efficiency factor depend on joint type and radiography amount required for the design code.

(3) Joint efficiency is 100% for seamless heads.

(4) Joint efficiency :

Spot radiography: 85%

No radiography: 70%

Corrosion allowance:

(1) Additional thickness of metal provided to allow for material loss by corrosion and erosion during the expected life of the vessel is called corrosion allowance.

(2) Unless a protective lining is employed a minimum corrosion allowance of 1.5 mm should be provided.

(3) Pressure vessels may be partially or fully lined with corrosion resistant material.

(4) We should not provided corrosion allowance against internal wastage of the base material.

(5) These lines are provided to exclude contact between base material and corrosive agent.

(6) These lining may be intermittently attached loose to the vessel base material. These lining may be internally banded to the vessel base material.

Materials of construction

Iron and Steel:

(1) Low carbon steel is most commonly used engineering material.

(2) Low carbon steel is also known as mild steel.

(3) Low carbon steel has good tensile strength and ductility.

(4) Low carbon steel can be easily welded.

(5) Iron and carbon steels are not resistant to corrosion, except in certain specific environments. Such as concentrated sulphuric acid, and caustic alkalies.

(6) Iron and carbon steels are suitable for use with most organic solved except chlorinated solvent.

(7) Mild steel is susceptible to stress corrosion cracking in certain environments.

(8) High silicon iron (14 to 15% Si) are particularly suitable for handling sulphuric acid at all concentration and temperature.

Stainless Steel:

(1) The stainless steels are the most frequent used corrosion resistant material in process industry.

(2) Nickel is added to improve the corrosion resistance in non oxidizing environment.

(3) Chromium is added to impart corrosion resistance in oxidizing conditions.

(4) Chromium content should be above 12 percent.

(5) Stainless steels can be divided into three types based on their micro structure:

a. Ferritic : 13-20% Cr, less than 0.1 % C, No Nickel

b. Austenitic: 18- 20% Cr, greater than 7% Ni

c. Martensitic: 12- 10% Cr, 0.2 to 0.4% C, up to 2% Ni.

(6) The austenitic stainless steels have greater strength than the plain carbon steels, particularly at high temperature.

(7) Important grades of austenitic steels are given below:

I. Type 304: It is most widely used stainless steel. Type 304 is also called 18/8 stainless steels. Type 304 have minimum Cr and Ni which provided a stable austenitic structure.

II. Type 304L: Type 304L is the low carbon version of type 304. Type 304L is used for thicker welded section.

III. Type 321 : Type 321 is stabilized with Ti to prevent carbide precipitation during welding.

IV. Type 347: Type 347 is stabilized with niobium.

V. Type 316: Type 316 have molybdenum which improve the corrosion resistance in reducing conditions such as in dilute sulphuric acid.

VI. Type 316L: - Type 316L is a low carbon version of type 316.

Nickel and Its Alloys:

(1) The important use of nickel alloy is for equipment handling caustic alkalies at temperature above $70^{O}C$.

(2) Important Ni-Cu alloy is monel which contain metal in radio of 2:1.

(3) Monel alloy has good mechanical properties up to $500^{O}C$.

(4) Monel alloy has good resistance to dilute mineral acid.

(5) Monel alloy used for equipment handling alkalies, organic acid and salt and sea water.

(6) Inconel have 76% Ni, 7% Fe and Cr 15%.

(7) Inconel is used primarily for acid resistance at high temperature.

(8) Inconel is resistant to furnace gases if S free.

(9) Hastelloys composition are given below:

a. Hastelloys B: Ni=65% Mo=28% Fe=6%

b. Hastelloys B: Ni=54% Mo=17% Fe=5% Cr=15%

(10) Hastelloys is useful for corrosion resistant to strong mineral acid particularly HCL.

Aluminum and Its Alloys:

(1) Pure Al has a higher resistance to corrosion than its alloys.

(2) Pure Al has less mechanical strength in compare to its alloy.

(3) Aluminum –Copper alloy (Composition: - 4% Cu, 0.5% Mg) is main structural alloy of aluminum.

(4) Aluminum-Copper alloy has tensile strength equivalent to that of mild steel.

(5) Pure aluminum can be apply as cladding on aluminum plate alloy. These combine corrosion resistance of pure metal and alloy is useful for concentrated nitric acid 80%.

(6) These are widely used in textile and food industries where use of mild steel would lead contamination.

Lead:

(1) Lead metal is a soft, ductile material and is mainly used in the form of sheets or pipe.

(2) Lead has a resistance to acid specially to sulphuric acid.

Copper and Its Alloy:

(1) Copper is used for small bore pipe and tubes.

(2) The important alloy of copper are the brasses and bronze.

(3) Brasses is alloy of Zink and copper.

(4) Bronze is alloy of copper and tin.

(5) The important use of these alloy in process industry for values and other small fittings, and for heat exchanger tube and tube sheet.

(6) The copper Ni alloy have a good resistance to corrosion –erosion.

(7) The copper – Ni alloy are used for heat exchanger tube specially where coolant is sea water.

Titanium:

(1) Titanium has a good resistance to chloride solution, including sea water and wet chlorine.

(2) Titanium is use for sea water and replacing for cupro- nickel alloy.

::::::::::::::::::::::::::Sample PART ONLY:::::::::::::::::::::

CHAPTER-2

VESSELS DESIGN UNDER INTERNAL PRESSURE

(1) Cylindrical and spherical shells:

(1) The minimum thickness of cylindrical shell is given by:

$$t=\frac{PD_i}{200fJ-p}=\frac{PD_O}{200fJ+P}$$

Where

P= design pressure, kg_f/cm^2

D_i= inside diameter of shell, mm

D_o= outside diameter of the shell, mm

f= allowance stress, Kg_f/mm^2

J= Joint factor

t=minimum thickness of shell plate exclusive corrosion allowance, mm.

(2) The minimum thickness of spherical shell is given by-

$$t=\frac{PD_i}{400fJ-p}=\frac{PD_O}{400fJ+P}$$

Heads and Closures:

(1) The ends of cylindrical vessels are closed by heads of various shapes. Important are:

(a) Ellipsoidal heads

(b) Torispherical heads

(c) Hemispherical heads

(d) Flat plates and formed flat heads

(2) Torispherical heads are often referred to as dished ends

(3) Hemispherical, ellipsoidal and torispherical head are collectively called as domed heads.

(4) Flat plates are used as covers for manways and as the channel covers of heat exchanges.

(5) Standard torispherical head are generally used end closure for vessels up to operating pressure of 15 bar. Torispherical head can be used for higher pressure but cost will compare above 10 bar with that of an equivalent ellipsoidal heads.

(6) Ellipsoidal head usually prove to the most economic closure to use above 15 bar.

(7) A hemispherical head is the strongest shape capable of resisting about two times the pressure of a torispherical heads of the same thickness.

(8) Hemispherical head are used for higher pressure

(9) Forming cost of hemispherical heads will be more than that for shallow torispherical heads.

FLATES ENDS:

(1) The minimum thickness required for flat ends is given by:

$$\boxed{t = C_p D\sqrt{\frac{P}{f}}}$$

Where

C_p = design constant

D = nominal plate diameter

f = allowable stress

P = Design pressure

(2) C_p depends on edge constraint.

(3) Value for nominal plate diameter design D and constant Cp are given in the design codes and standards for various arrangements of flat end enclosures.

Ligament Efficiency:

(1) When a shell is drilled with multiple holes , then shell strength is reduce in proportion to metal removed and according to relative hole arrangement. For example in tupe plate.

(2) When a cylindrical shell is drilled with tube holes parallel to its axis, the efficiency J of ligaments shall is calculated as :

(3) When a holes are spaced regularly along the line in question , the efficiency J is given by :

$$\boxed{J = \frac{P_t - d}{P_t}}$$

P_t = tube holes pitch

d = tube holes diameter.

(4) When the pitch of holes is unequal along the line in question , the efficiency J is given by: -

$$J=\frac{P_t-nd}{P_t}$$

Where

d = diameter of tube holes

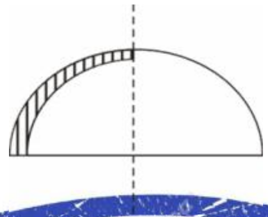
n = number of tubes holes in length P_t

P_t = Total length between centre corresponding to n consecutive ligaments.

Domed ends:

For various type of domes heads design equation and charts are given in IS : 2825-1969.

Hemispherical heads:



(1) For equal stress in the cylindrical section and hemispherical heads of vessels the thickness of the heads is equal to half that of the cylinder.

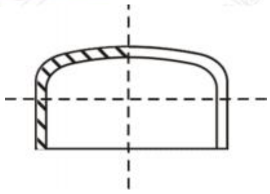
(2) Discontinuity stress would be set up at the head and cylinder Junction as the dilation of the two parts would be different.

(3) It between two parts no difference in dilation it is prove that for steel (poisson ratio =0.3) the ratio of the hemispherical head thickness to cylinder thickness should be 7/17.

(4) The stress in the head would be larger than that in the cylindrical section.

(5) Optimum thickness is ratio normally taken as 0.6

ELLIPSOIDAL HEADS



(1) Most standard ellipsoidal heads are made with major and minor axis ratio of 2:1.

(2) For this ratio the following equation used to calculate the minimum thickness required :

$$t=\frac{PD_i}{2fJ-0.2P}$$

Torispherical Heads:

(1) the minimum thickness required for torispherical head is given by:

$$t=\frac{PR_C C_S}{2fJ+P(C_S-0.2)}$$

Where,

R_C=crown radius

R_k=knuckle radius

C_S=stress concentration factor for torispherical heads

$$=\frac{1}{4}\left(3+\sqrt{\frac{R_C}{R_K}}\right)$$

(2) For formed heads the joint factor J is taken as 1.0

(3) To avoid bucking ratio of knuckle to crown radii should not less than 0.06 and the crown radius should not be greater than the cylindrical section.

CONICAL SECTIONS AND END CLOSERS:

(1) Conical sections are used to make a step reduction in diameter from one cylindrical section to another cylindrical section of smaller diameter.

(2) Application of conical ends are to facilitate the smooth flow and removal of solids from process equipment.

(3) The thickness required at any point on a cone is given by:

$$\boxed{t=\left(\frac{PD_i}{2fJ-P}\right)\frac{1}{\cos\alpha}}$$

Where,

α=half the cone apex angle

D_i=cone diameter at that point

Pressure vessels support:

There are various methods which are used for supporting pressure vessels. These methods depends on various factor such as weight of vessels, size and sphape of vessels, arrangement and internal and external fitting and attachments and vessel location.

Vertical vessels:

(1) Vertical vessels use various means of support such as skirt, posts or column, brackets or lugs.

(2) The supporting member under the bearing attachments would preferably be as close to the shell as clearance for insulation will permit in case of vessels are supported on brackets or lugs.

(3) In case if vessels are support on posts or column, then it may need stiffening. Stiffening is done by ring girder, internal partition to resist the force tending to buckle the vessel walls.

(4) In corroded condition skirt support for vertical vessels should not be less than 7mm thick.

Horizontal Vessels:

(1) Saddles, equivalent leg support or ring support are used for supporting horizontal vessels.

(2) When horizontal vessels's wall is not too thin then we can used saddles.

(3) Saddles should preferably extend at least beyond 120 degree of vessel circumference.

(4) In case of thin vessel saddles should be place at points near the vessel ends.

Note:

(1) Cylindrical vessel:

(a) Longitudinal stress:

$$t=\frac{pd}{4fJ}$$

(b) Circumferential stress: $t=\frac{pd}{2fJ}$

(2) Spherical vessels:

$$t=\frac{pd}{4fJ}$$

Where,

t= shell thickness

d=cylinder diameter

p=design pressure

f=allowable stress

J=joint efficiency

(3) In case of where fabrication cost is not important, then sphere would be more economical shape for vessels.

(4) Cylindrical vessels are largely used in chemical industry because of easily fabrication, simpler to erect, readily shipped.

(5) Since spherical structure provide minimum surface area per unit volume and also its wall thickness for given pressure is minimum, hence spherical shape is most favorable where matter of material saving and stress uniform distribution in material of walls from loads.

(6) With increase in temperature allowable stress decreases.

(7) Compressive stresses arise instead of tensile if shell operating under external pressure.

(8) Distillation columns are generally 18-24 inch apart.

(9) Packed column are generally used when column diameter is less than 3ft(1 m).

KEY POINTS TO REMEMBER

(1) The minimum thickness of cylindrical shell is given by:

$$t=\frac{PD_i}{200fJ-P}=\frac{PD_O}{200fJ+P}$$

(2) The minimum thickness of spherical shell is given by:

$$t=\frac{PD_i}{400fJ-P}=\frac{PD_O}{400fJ+P}$$

(3) Minimum thickness required for flat end is given by:

$$t=C_PD\sqrt{\frac{P}{f}}$$

(4) When the holes are spaced regularly along the line in questions, the efficiency J is given by:

$$t=\frac{P_t-d}{P_t}$$

Where d=tube hole diameter

(5) When the pitch of holes is unequal along the line in question, the efficiency J is given by:

$$J=\frac{P_t-nd}{P_t}$$

(6) Cylindrical Vessels:

(a) Longitudinal stress

$$t=\frac{Pd}{4fJ}$$

(b) Circumferential stress

$$t=\frac{Pd}{2f\,J}$$

(7) Spherical vessels:

$$t=\frac{Pd}{4f\,J}$$

Where t=shell thickness

d=cylinder diameter

p=design pressure

f=Allowable stress

J=Joint efficiency

CHAPTER-3

ESTIMATION OF COST

Aim of any process plants are to make profit. Hence an estimated cost of the investment needed.

Remember: The purpose of estimating is to develop cash flow projections – not to produce exact data about the future, which is virtually impossible.

Production cost is needed before the profitability of a project can be assessed.

Total Capital Investment:

(1) The capital required to supply the necessary manufacturing and plant facility is called fixed capital investment.

(2) The capital required for the operation of plant is called working capital.

(3) The sum of the fixed capital investment and working capital investment is called total capital investment.

(4) Total capital investment is written as:

$$\boxed{\text{Total capital investment}=(\text{fixed capital investment})+(\text{working capital investment})}$$

Fixed Capital Investment: (F.C.I)

(1) Fixed capital means total cost of plant ready for start up it is the cost paid to the contractors. It is a once – only cost that is not recovered at the end of the project life, other than scrap value. Fixed capital investment can be divided into-

(a) Manufacturing fixed capital investment

(b) Non-manufacturing fixed capital investment

(2) Manufacturing fixed capital investment represents the capital necessary for installed process equipment with all auxiliaries that are needed for complete process operation. Examples are piping, instrument, insulation, foundation and site operations.

(3) Fixed capital required for construction overhead and all plant components that are not directly related to the process operation is called non manufacturing Fixed capital investment. Examples are land, processing building, administration and other office ware houses, laboratories, transportation, shipping and receiving facility, utility and waste disposal facilities. Construction overhead cost consists of field office and supervision expenses, home office expenses, engineering expenses.

Working Capital:

(1) Working capital is the additional investment needed over and above the fixed capital to start the plant up and operate plant to the point when profit is earned.

(2) The working capital for an industrial plant consists of the total amount of money invested in:

(a) Raw materials and supplies carried in stock.

(b) Finished product in stock and semi finished product in the process of being manufactured.

(c) Account receivable.

(d) Cash kept on hand for monthly payment of operating expenses such as salaries, wages and raw material purchase.

(e) Account payable and taxes payable.

(f) Start up cost, catalyst charges.

(3) The ratio of working capital to total capital investment varies with different companies but most chemical plant use an initial working capital amounting 10 to 20 percent of the total capital investment.

(4) Most of the working capital is recovered at the end of the project.

Cost Escalation (Inflation):

A cost index is an index value for a given time showing the cost at that time relative to a certain base time. Cost index can be used to give a general cost estimate.

The present cost usually estimated from the past data by the use of published cost indices.

$$\text{cost in year X=(cost in year Y)}\times\left(\frac{\text{cost index in year X}}{\text{cost index in year Y}}\right)$$

Example Find the present cost of heat exchanger if its original cost was Rs x and cost index in present time is 2 times that of cost index in original time.

$$\Rightarrow \text{Present cost} = \text{Original cost}\left(\frac{\text{CI/ Present}}{\text{CI/ original time}}\right)$$

$$= x\times 2$$

present cost = 2x Rs

Method for Cost Estimating:

(1) Six Tenth Rule:

The capital cost of a project is related to capacity by following equation:

$$C_2 = C_1\left(\frac{P_2}{P_1}\right)^m$$

Where C_2=capital cost of project with capacity P_2

C_1= capital cost of the project with capacity P_1

value of index m is taken as 0.6

The six – tenths rule is widely used in approximates of equipment and even total process cost.

Example: The purchased cost of a 20m^2 shell and tube heat exchanger was Rs 7000 in 100m^2 heat exchanger in 2002. Given, Marshall and swift installed equipment indexes for process industry:

Year	Index
2000	1109.7
2002	1116.9

And chemical engineering plant cost index

Year	index
200	394.1
2002	390.4

The equipment cost versus capacity exponent is 0.44

$$\Rightarrow \text{cost based on chem.. Eng} = Rs7000\times\frac{390.4}{394.1}\times\left(\frac{100}{20}\right)^{0.44} = Rs14,078$$

Cost based on Marshal and Swift

$$= Rs7000\times\frac{1116.9}{1109.7}\times\left(\frac{100}{20}\right)^{0.44} = Rs14,302$$

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