

LECTURE NOTE ON PROCESS EQUIPMENT DESIGN

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Process Equipment Design

1. **Course no.** PFE -425(E)
2. **Course title:** Process Equipment Design
3. **Credit hours:** 3(2+1)
4. **General objective:** To impart knowledge and skill to the students on design of different process equipments
5. **Specific Objectives:**

Theory

By the end of the course the students should be able to

- Know the basics of design parameters and procedure
- Understand the theory and principles for design of different process equipments

Practical

By the end of the course the students should be able to

- Develop the skill of designing different process equipments
- Solve design problems

Course details

Introduction on process equipment design, Application of design engineering for processing equipments, Design parameters and general design procedure; Material specification, Types of material for process equipments; Design codes, Pressure vessel design; Design of cleaners; Design of tubular heat exchanger, shell and tube heat exchanger and plate heat exchanger; Design of belt conveyer, screw conveyer and bucket elevator; Design of grain dryers; Design of milling equipments; Optimization of design with respect to process efficiency, energy and cost; Computer Aided Design

Practical

Design of pressure vessel, Design of cleaners, Design of milling equipments, Design of tubular heat exchanger, shell and tube type heat exchanger, plate heat exchanger, Design of grain dryer, Design of belt conveyer, bucket elevator, screw conveyor.

Theory Lecture Outline

Lecture No.	Chapter	Courses to be covered
1	Introduction on process equipment design	Equipment classification, Drives for equipments
2	Design parameters and general design procedure	Design parameters, General design procedure, Fabrication techniques
3	Application of design engineering for processing equipments	Mechanical properties of materials, Stresses due to static and dynamic loads
4		Design stress and elastic instability, Combined stresses and theories of failure
5		Introduction to Design of machine elements, shaft, bearing, Belt and pulley, chain and gear drive
6	Material specification, Types of material for process equipments	Information required to specify any material for process equipment, Ferrous metals Carbon steel, Low alloy steel, High alloy steel,
7		Non-ferrous metals, Aluminum, Copper and Nickel alloys
8		Material specification for elevated temperature, low temperature and corrosive service, ,
9		Non-metals, carbon, glass , rubber, plastic Corrosion and its prevention, Coating and lining
10	Design Code	Design code, standards, testing
11	Pressure vessel design	Basics of pressure vessel design, , Design pressure, Design temperature, Corrosion allowance, weld joint efficiency factor, Factor of safety
12		Hoop stress, Longitudinal stress, Thickness calculation for cylindrical and spherical vessel under given design pressure
13		Pipe design, Pressure vessel Fabrication and testing
14	Design of cleaners	Type of cleaners. Design of cleaner, Effectiveness of cleaning
15	Design of heat exchanger	Types of heat exchanger, Basics of heat transfer, Heating surface area calculation for given heating load, Effectiveness of heat exchanger

16		Design of tubular heat exchanger
17		Design of shell and tube heat exchanger
18		Design of plate heat exchanger
19	Design of handling equipment	Characteristics of transported material, Types of conveying and elevating equipments, Selection criteria
20		Design of belt conveyer, (Capacity and power requirement calculation)
21		Design of screw conveyer (Capacity and power requirement calculation)
22		Design of bucket elevator (Capacity and power requirement calculation)
23	Design of grain Dryers	Types of grain dryers, Factors for design of grain dryer, Heat and mass balance in a dryer, Air flow requirement
24		Design of RPEC dryer
25		Design of LSU dryer
26	Design of milling equipments	Introduction to size reduction, Size reduction laws such as Rittinger, Kick and Bond's law for power requirement
27		Different milling equipments, Effectiveness of different milling, Critical speed of Ball mill
28	Optimisation of design with respect to process efficiency, energy and cost	Introduction to optimization, Analytical method
29		Lagrange multiplier method for design optimisation
30		Economic evaluation, Fixed capital, Working capital, Interest calculation, Depreciation, Pay back period, Rate of Return, Breakeven analysis
31		Process hazards and safety measures in equipment design
32	Computer Aided Design	Introduction to Computer Aided Design and Computer aided manufacturing, Design process

Lecture 1: Introduction on process equipment design, Equipment classification

Design refers to the creation of new and better equipments and improving the existing one which is more economical in the overall cost of production and safe in operation.

Design in processing industries can be of three types

- (a) Modification and addition to the existing plant
- (b) Increase in the capacity of the existing plant
- (c) Development of a new process based on laboratory research and pilot plant study

Design in processing industry can be divided in two phases.

1. Equipment design
2. Process design

Process equipments are classified into three groups depending on similar design procedure.

- a) Process vessel group – Spherical or cylindrical vessel to withstand variations in pressure and temperature, loading conditions etc.
- b) Structural group – These are stationary and have to sustain dead load. They should be elastic and structurally stable.
- c) Groups involving rotational motion – Drive system, power supply

Process equipments may be Static machines, rotary machines or other systems

Different types of mechanical loads are Friction load, Fluid viscosity load, accelerating load

In processing plants, all the equipments are made functional with the help of piping, electrical and instrumentation.

The mechanical design is required for the fabrication, erection, installation and commissioning of the equipment.

Process design

The technology applied to produce a required product is called process engineering. In the process of conversion of raw materials into desired product, number of physical and chemical operations are involved and during the process some by-product called as waste is produced. The study of unit processes and operations leads to process design.

Technical process considerations involve

1. Raw material selection and storage
2. Raw material preparation
3. Reaction
4. Product purification
5. Recycle, recovery
6. Product storage and packaging
7. Pollution control

Plant design

Good plant layout keeps overall cost, erecting cost, safety, appearance, convenience, operating and maintenance cost to the minimum. The unit should be planned in minimum space. Feed line and product lines should be planned in such a way that future

expansion is easily possible. Furnaces, fire hazard and explosive units should be isolated from other process units. The key to economical construction and efficient operation is a carefully planned, functional arrangement of equipments, piping and buildings.

The following parameters have to be considered while designing a plot plan

- a) Scale and scope of the operation
- b) Available property limitation
- c) Safety considerations
- d) Operating, supervision and labour scheduling
- e) Utilities supplied
- f) Solid material handling requirement
- g) Maintenance convenience
- h) Construction economics
- i) Possible future expansion

Grouped layout – Similar equipments are grouped together

Flow line pattern – equipments are arranged in the layout as they appear on the flow plan

Operation process chart – It is a graphic presentation of all the events in a process and their sequence

Flow process chart – It is a graphic presentation of all the operations and all intermediate events showing transportation, inspection, storage and delays.

Layout sheet is a graphical plot of operation or event locations showing the direction of flow of materials and labour.

Lecture 2: Design parameters and general design procedure

Equipment design

The overall satisfactory performance and reliability of the equipment would depend on the following factors/parameters

2. Optimum processing condition
3. Appropriate material of construction
4. Strength and rigidity of the components
5. satisfactory performance of mechanisms
6. reliable methods of fabrication
7. Ease of operation and control
8. Ease of maintenance and repair
9. safety requirements

The general design procedure involves the following steps

1. Specifying the problem
Recognition and understanding the goal
2. Analysing the probable solution
The solution may involve system, process or equipment to accomplish specific task optimally subjected to certain constraints
3. Applying chemical process principles and theories of mechanics satisfying the conditions of the problem
The method must be analysed to ensure working satisfactorily.
4. Selecting materials and stresses to suit processing conditions
The result should consistent with past experience and practical. The designer should realize the practical limitations involved in the application of work.
5. Evaluating and optimizing the design
Based on optimum theoretical and economic considerations, the final demension should be determined based on exact shape and standard size of material available. For new equipment, fabrication and testing of prototypes for satisfactory performance before final designing
6. Preparing the drawing and specification
Detailed assembly drawing can be made specifying properly all dimensions, material selected, tolerance, fits and limits etc.

Fabrication techniques/processes

- a) Techniques to give approximate shape to materials (primary shaping processes) – Exmp- casting, forging, rolling, extrusion, drawing, working
- b) Techniques adopted to give final shape as per planned dimension (machining processes)– turning, drilling, boring, grinding

- c) Techniques to provide good surface finish (Surface finishing processes)- polishing, grinding, electroplating
- d) Techniques to join different machine components (Joining processes) – welding, riveting, soldering, brazing
- e) Processes effecting change in properties so as to make them suitable for particular operations or uses – Heat treatment, hot and cold working

Drives for process equipment

AC motors or DC motors

Single phase or Three phase motor

- AC motor Single phase (domestic use), Three phase (Industrial use), VFD may be used to change speed,
- DC motor (used where variation of speed)
- Up to 160 kW, Low tension motors 415 V supply, Above this High Tension motors (3.3 kV supply)

DC motors are used where there is demand for a variation of speed. AC motors with VFD (Variable frequency drive) are now used for variation of speed and energy saving.

Three phase motor

- Synchronous motor: No variation of speed as load changes, used for low speed and power more than 35 hp
- Induction motor: Variation of speed with load, used commonly in plants
- Open enclosure or Closed enclosure (Totally enclosed fan cooled motor are used for safety reason)
- Continuous or intermittent application, high or normal starting torque, high or low starting current
- While selecting motor, the starting torque and current of motor should match with the driven equipment

Final choice of motor

- Torque response of driven unit
- Basic speed of driven unit
- Required shaft output
- Type of enclosure
- Input voltage and frequency for imported equipment
- Motor size, power
- Required dynamic response of driven unit
- Need for electric braking
- Speed adjustment range in case of variable speed ac motor with VFD

In some plants, cogeneration of electricity is done due to cost and non-availability of power. Expansion of steam to turbine, power is generated and exhaust steam is utilised as heating medium for process fluid.

Computer aided design

- Data files of properties of materials and products
- Database covering standard specification of equipments, materials, cost indices
- Subsystem for modelling and simulation for execution of data for evaluation of optimum design parameters

Lecture 3: Application of design engineering for processing equipments-Mechanical properties of materials

Designer has to be acquainted with different available materials and their properties.

Strength represents the capacity of the material to withstand external forces. Stiffness and rigidity are the measure of the ability of the material to resist deformation.

In design of most of the components, permanent deformation are generally avoided and the material is utilized with a view to retaining its elasticity.

Stress-strain diagram

The mechanical properties are determined by standard tensile test. This test consists of gradually loading a standard specimen of a material and noting the corresponding value of load and elongation until the specimen fractures. Stress is determined by original c/s area of the specimen. The values of stress and corresponding strain are used to draw the stress-strain diagram of the material.

Proportional limit – Point O to A is a straight line which represents that the stress is proportional to the strain. Beyond A, curve deviates from straight line. Hook's law holds good up to point A, known as proportional limit.

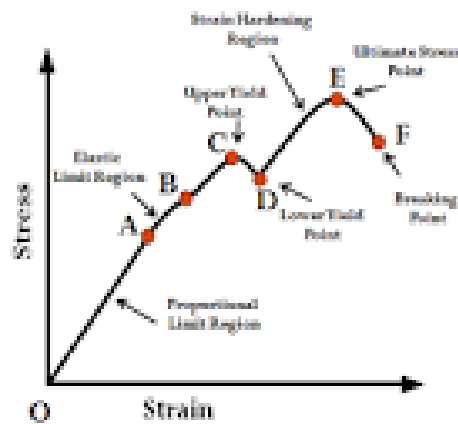
Elastic limit – If load is increased beyond point A up to point B, material will regain its shape and size when load is removed. The material has elastic properties upto point B known as elastic limit.

Yield point – If material is stressed beyond B, the plastic stage will reach i.e. on the removal of load, the material will not be able to recover its original size & shape. Strain increases at a faster rate with any increase in stress until point C. At this point, there is an appreciable strain without any increase in stress. Small load drops to D, immediately after yielding commences. C, D are called upper and lower yield points and the corresponding stress is called yield point stress.

Ultimate stress- At D, the specimen regains some strength and higher values of stress are required for higher strains than between A & D. The stress goes on increasing till point E. Increase in length is followed with reduction in c/s area. At E, the stress which attains its maximum value is known as ultimate stress.

Breaking stress- After reaching ultimate stress a neck is formed which decreases the c/s area of specimen. The stress necessary to break away the specimen is less than maximum stress. The stress is reduced until specimen breaks away at point F. The stress corresponding to F is called breaking stress.

Working stress- While designing, it is desirable to keep stress lower than the maximum or ultimate stress at which failure of material takes place. This stress is known as working or design stress.



Mechanical properties of metals

1. **Strength** – It is the ability of a material to resist the externally applied forces without breaking or yielding.
2. **Stiffness** – It is the ability of the material to resist deformation under stress. Modulus of elasticity is the measure of stiffness.
3. **Elasticity** – It is the property of a material to regain its original shape after deformation when external forces are removed.
4. **Plasticity** – It is the property of a material which retains the deformation produced under load permanently.
5. **Ductility** – It is the property of a material enabling it to be drawn into wire with the application of tensile force. It must be both strong and plastic.
6. **Brittleness** – It is the property of breaking of a material with little permanent distortion. It is opposite to ductility.
7. **Malleability** – It is a special case of ductility which permits material to be rolled or hammered into thin sheets. It should be plastic but not essentially strong.
8. **Toughness** – It is the property of a material to resist fracture due to high impact loads like hammer blows. Toughness decreases when it is heated. It is measured by the amount of energy that a unit volume of the material has absorbed after being stressed up to the point of fracture.
9. **Resilience** – It is the property of material to absorb energy and to resist shock and impact load. It is measured by the amount of energy absorbed per unit volume within elastic limit.
10. **Creep** – When a part is subjected to a constant stress at high temperature for a long period of time, it will undergo a slow and permanent deformation called creep.
11. **Hardness** – It embraces many different properties such as resistance to wear, scratching, deformation and machinability. It is the ability of a metal to cut another metal.

Lecture 4: Design stress and elastic instability, theories of failure

The most important characteristics to be considered when selecting a material of construction are:

1. Mechanical properties
 - (a) Strength- tensile strength
 - (b) Stiffness- elastic modulus (Young's modulus)
 - (c) Toughness- fracture resistance
 - (d) Hardness -wear resistance
 - (e) Fatigue resistance
 - (f) Creep resistance
2. The effect of high and low temperatures on the mechanical properties
3. Corrosion resistance
4. Any special properties required; such as, thermal conductivity, electrical resistance, magnetic properties
5. Ease of fabrication forming, welding, casting
6. Availability in standard sizes plates, sections, tubes
7. Cost

Factor of safety = Maximum stress/ working or design stress

For ductile material i.e. mild steel where yield point is clearly defined yield point stress is taken as the maximum stress whereas for brittle material like cast iron, ultimate stress is taken as the maximum stress. High factor of safety results in heavy sections and wastage of materials whereas there is risk of failure in low factor of safety. Failure occur in ductile material as a result of plastic deformation and in brittle material by fracture with little or no deformation.

Stresses

- Principal stress in principal plane having no shear stress
- Member subjected to biaxial stress f_1 , f_2 and shear stress f_s

Maximum Principal stress f_{t1}

$$(f_1+f_2)/2 + \frac{1}{2} \sqrt{(f_1-f_2)^2+4f_s^2}$$

Minimum Principal stress f_{t1}

$$(f_1+f_2)/2 - \frac{1}{2} \sqrt{(f_1-f_2)^2+4f_s^2}$$

Maximum shear stress = $f_{smax} = \frac{1}{2} \sqrt{(f_1-f_2)^2+4f_s^2}$

Theories of failure

- Maximum principal stress Theory (Brittle material)

Maximum principal stress = f_{yt}/FS or f_{us}/FS

- Maximum shear stress theory (Ductile material)
- $F_{smax} = f_{ys}/FS = \text{Shear stress at yield point}/FS = \text{Yield point in tension } f_{yt}/2 FS$
- **Elastic stability:** Sufficient stiffness or rigidity of a structure subjected to compression, bending, torsion or combination to prevent buckling, wrinkle or collapse
- Design to limit stress, geometrical shape, deflection or twist
- Stiffening rings are provided in tall vessels

Buckling may be in form of bending of column, wrinkling in thin cylindrical shell or deformation of shape in case of shell with external pressure. The critical stress should not exceed the yield point under compression of the material.

Lecture 5: Introduction to Design of machine elements

Shaft

A shaft is a rotating machine element which is used to transmit power from one place to another.

Medium Carbon steel having 0.15 to 0.4 % carbon used for shaft

Power delivered to shaft by torque (twisting moment)

Pulley and gears mounted on shaft cause shaft to bend

Shaft is used for transmission of torque and bending moment

Key: A shaft is rigidly attached to a hub or machine part by key, this transmits torque by preventing relative motion

keyway, reduces strength of shaft and permissible stress is taken as 75% of normal permissible stress

Couplings: Used to connect two shafts which are in line

$$f_s / r = T/J = C\theta/l$$

f_s = Torsional shear stress at the outer surface of the shaft or maximum shear stress

r = radius of the shaft

T = Torque or twisting moment

J = Polar moment of inertia

C = Modulus of rigidity or torsional rigidity

l = length of the shaft

θ = angle of twist

For solid shaft of diameter d , $J = (\pi/32) d^4$

$$T = (\pi/16) f_s d^3$$

For hollow shaft $J = (\pi/32) (d_o^4 - d_i^4)$

$$T = (\pi/16) f_s d_o^3 (1 - k^4) \text{ where } k = d_i/d_o$$

Power transmitted by shaft = $P = 2 \pi NT/60$

$$T_e = \sqrt{M^2 + T^2} = (\pi/16) f_s d^3$$

$$M_e = \frac{1}{2} (M + \sqrt{M^2 + T^2}) = (\pi/32) f_b d^3$$

Bending stress in straight beams

$$M/I = f_b/y = E/R$$

M = Bending moment acting at given section

f_b = Bending stress

I = Moment of inertia of c/s about neutral axis

y = Distance of neutral axis from extreme fibre

E = Young's Modulus of the material

R = Radius of curvature of beam

$$M y/I = f_b = M/I/y = M/Z$$

Axle- Stationary part i.e. Support for rotating body, transfer Bending Moment only

Joint

- Permanent fastening: Soldering, brazing, welding, rivetting (light material)
- Temporary fastening: Screw, key, cotter, pins
- Lap joint (overlap), Butt joint (U, V groove, single strap, double strap)
- Welding – Fusion (Heat only), Forging (Heat and pressure)
- Screwed joint- Nut and Bolt

Column

Eulers formula for long column

$$\text{Crippling load} = W_{cr} = \pi^2 EI/L^2$$

L = Equivalent length depending on column end condition

E = Modulus of elasticity

I = Moment of inertia of c/s of rod

$L=1$ for both end hinged, $1/2$ for both end fixed, $1/1.41$ one end fixed, other end hinged, $2l$ one end hinged other end free

Rankine formula

$$\text{Cripling load} = W_{cr} = f_c A / (1 + a(L/k)^2)$$

f_c = crushing strength or yield point in compression

$$K = \text{least radius of gyration} = \sqrt{I/A}$$

$$a = \text{Rankine constant} = f_c / \pi^2 E$$

Flat belt drive

Belts are used to transmit power from one shaft to another by means of pulley

Flat belt- Used in factories for moderate power transmission, pulleys are not more than 8 m apart, distance should not be less than 3.5 times dia of larger pulley

V belt- Great amount of power transmission and pulleys are very near to each other

Circular belt- Great amount of power transmission and pulleys are more than 8 m apart

Cotton fabric belt: used in farm machinery, conveyer

Rubber belt- where exposed to moisture in saw and paper mill

Maximum tension in belt = $f b t$

f = safe stress, b = width, t = thickness

$$N_2/N_1 = (d_1 + t)/(d_2 + t) \times (1 - s/100)$$

$$\text{Length of open belt drive} = \pi/2(d_1 + d_2) + 2x + (d_1 - d_2)^2/4x$$

$$\text{Length of cross belt drive} = \pi/2(d_1 + d_2) + 2x + (d_1 + d_2)^2/4x$$

$$\text{Power transmitted} = (T_1 - T_2)v$$

$$v = \pi D N / 60 \text{ of small pulley}$$

T_1 and T_2 Tension in tight and slack side

$$T_1/T_2 = e^{\mu\theta}$$

θ = Angle of contact;

μ = Co-eff of friction between belt and pulley

Angle of contact of smaller pulley is taken if both pulley of same material

$$\theta = (180 - 2\alpha) \pi / 180 \text{ (open belt)}$$

$$\theta = (180 + 2\alpha) \pi / 180 \text{ (cross belt)}$$

$$\sin \alpha = (r_1 - r_2)/x \text{ for open belt}$$

$$\sin \alpha = (r_1 + r_2)/x \text{ for cross belt}$$

Pulley

Flat belt pulley

- Width of pulley is 25% extra of width of belt
- Centrifugal stress = ρv^2

V belt pulley

A	1-5 hp	75 mm pitch dia
B	3-20 hp	125 mm
C	10-100 hp	200 mm

$$T_1/T_2 = e^{\mu\theta \operatorname{cosec} \beta}$$

Chain drive

- Used for power transmission, hoisting and conveying
- Consists of two sprocket wheels attached to shaft and a chain meshing with teeth of sprocket
- Enables positive drive
- If speed ratio < 2.5 , minimum centre distance is one half sum of sprocket dia plus pitch
- If speed ratio > 2.5 , centre distance equal to sum of sprocket dia
- Maximum centre distance should not exceed 80 times pitch

Gears

- Used in precision machines for definite velocity ratio , transmitting medium or large amounts of power, and distance between driver and follower is very small
- Gear wheels fixed to two shafts and remain in mesh throughout rotation
- Parallel and coplanar shaft- Spur gear (Teeth parallel to axis or inclined to axis i.e. helical gear
- Non parallel but coplanar- Bevel gear
- Non coplanar, non-intersecting, non-parallel- spiral gear or skew bevel gear
- Rock and pinion- Linear to rotational
- Circular pitch= $\pi D/T$
- $N_1/N_2 = T_2/T_1$

Bearing

- A machine component which acts as a support for a moving part, having rotary, oscillating and sliding motion
- Function is to supports the load of the moving part
- Radial bearing or journal bearing - Load acts perpendicular to direction of motion
- Thrust bearing- Load on bearing acts along the axis of rotation
- Sliding contact bearing: rotating member and bearing cause sliding action
- Anti-friction bearing (rolling contact):
- Ball bearing: limited load carrying capacity
- Roller bearing: higher load

Impact stress= $W/A(1 + 2hEA/WL)$

Hammer mill, pulveriser

W=Weight falling from height h

A, L area and length of rod

Packings

- Packings are provided for dynamic sealing of moving parts , stuffing box and gland
- Gaskets are static seals used for making pressure tight joint between two rigid elements usually flanges
- Packing materials: Fibre (rayon, nylon), metal (Al, Cu, lead foil) , plastic (Teflon, kel-F) rubber (natural rubber, neoprene, buna-N, butyl, silicone, leather in form of V, U, O rings
- Mechanical seals consists of two surfaces, one on rotating shaft, other is stationery and clearance is separated by thin fluid

Lecture 6: Material specification, Types of material for process equipments, Ferrous metals

Material specification

The primary factor for selection of material are mechanical strength , corrosion resistance and cost.

To specify any material for process equipment following informations are necessary.

1. Nature of service condition – Type of loading, service temperature, specific nature of fluid handled
2. Material characteristics – Strength and other mechanical properties like elongation and reduction in area, notch toughness, hardness, resistance to wear, creep and fatigue strength etc.
3. Processing factors – Effects of fabrication techniques like forming, cutting, heat treatment and weldability
4. Behaviour in the medium – Resistance to corrosion or other damage in the environment
5. Cost – Balance of cost considerations against service life and hazards of failure
6. Commercial availability

Types of material

Materials used for pressure vessel construction may be grouped as

1. Steel – carbon, low alloy, high alloy and clad with stainless steel or other metals
2. Non-ferrous – Aluminium, Copper, Nickel and their alloys
3. Specific purpose metal – Titanium, Zirconium
4. Non-metallic – Plastic, rubber, concrete

FERROUS METAL

Gray cast iron

- These are the most important metals which are known for their strength, wide availability and ease of forming and machining.
- According to the percentage of carbon present these are classified as wrought iron, cast iron and steel.
- Wrought iron is almost pure iron with a low carbon and manganese content. It has excellent resistance to atmospheric corrosion. Alkali and alkaline solutions and sulphuric acid and organic compounds cause very little attack on it
- Cast iron has usually 2.5 to 4.5% carbon. It is cheap and easy to cast even in complicated shapes because of its fluidity in molten state.
- The compressive strength is three to four times its tensile strength, and hardness number between 180 and 240. It is not corroded by alkali solution.

White cast iron

- Due to high brittle nature ,it is seldom used.
- Usually grey cast iron is chilled to produce a hard superficial depth of white cast iron.
- A high duty cast iron can be produced by the use of small quantities of calcium silicide . The resultant structure after heat treatment has a better tensile and shear strength.

Steel

- Steel is iron alloyed with carbon between 0.05 and 2%. It contains smaller proportion of phosphorus, sulphur , silicon and manganese.
- Low carbon steel-it has 0.05 to 0.3 % carbon. It is undoubtedly one of the most versatile materials available. It has good strength and ductility. Fabrication by welding and machining is also easily carried out.

- Medium carbon steel-it has carbon content between 0.3 and 0.5% which helps to improve its hardness ,strength and fatigue resistance. The material used for fabrication of shafts , springs ,gears , bolts . It is difficult to weld.
- High carbon steel- it has a carbon content of more than 0.5% and maximum up to 2%. It is much harder and stronger but less ductile.

1. Carbon steel – It is comparatively cheap and most commonly used for process vessels and piping. They are low carbon steels generally containing less than 0.25% carbon with some Mn and Si. Carbon steel with 0.4% carbon is used for bolts, nut and studs.

Depending on degree of deoxidation, steel may be

- a) Rimmed steel – Seldom used in process vessel due to lack of chemical homogeneity
 - b) Semi-killed steel – This corresponds to an intermediate de-oxidation state between rimming and killing. These are cheapest steel used for conventional light duty service. Plates used in process vessel upto 25mm thick for light duty service is semi-killed
 - c) Killed steel – Fully de-oxidised , silicon killed steels are more homogeneous. They are expensive and used for thicker vessels for more severe duty. Aluminium is frequently added in small quantity as grain refiner to improve the notch toughness of the material.
 - Low and intermediate strength at room temperature with good ductility and are easily formed and welded
 - Tensile strength at high temperature is reduced & temperature over 450-500°C produce rapid loss of metal due to scaling.
 - Suitable for non-corrosive service at ordinary or moderately elevated temperature
2. Low alloy steel – This group consists of steel with alloying elements less than 10%.
 - The alloying element generally used are Cr, Mo, Ni and contribute to increased strength and improved resistance to scaling, oxidation and graphitization at elevated temperature
 - They have higher creep-rupture strength than ordinary carbon steel
 - Require greater control of processing during fabrication and welding
 - Cr and Mo improve mechanical properties at high temperature and these steels finds extensive application in elevated temperature service
 - Ni increases notch-toughness property of low temperature (up to –85°C). So low alloy Nickel steel containing 2-3.5% are therefore used where resistance to brittle fracture at low temperature is important

Though more expensive than ordinary carbon steel their improved properties permit use of higher design stress and considerable saving in material.
 3. High alloy steel – These are used in power industries and in nuclear and chemical installations when it is necessary to have corrosion resistance material & whenever contamination has to be avoided.
 1. Ferritic stainless steel – It contains only Cr as alloying element and its content ranges 11-25%. Excellent resistance to corrosion and oxidation at high temperature.
 2. Austenitic stainless steel – It is the largest group of corrosion resistant steel. These are Cr-Ni alloy steel having austenitic structure and non-magnetic. Cr content vary from 18-25% , Ni 8-20% and carbon content varies from 0.04 to 0.25%.
 - ❖ Good strength and ductility
 - ❖ Not hardened by heat treatment

- ❖ Tensile strength and hardness increases on cold working
 - ❖ Readily formable and easily weldable and are suitable for high temperature service
3. Clad steel – A special product combining corrosion resistance of austenitic or ferritic steel, Ni or Nickel alloy with economy of carbon steel is clad steel. This is a composite with a base material of carbon steel and cladding of stainless steel on surface, 2 to 5 mm thick which is homogeneously bonded to the backing material by rolling.
- ❖ Mechanical properties are same as backing steel
 - ❖ Corrosion resistance is equal to cladding material

Cladding by weld deposition is the practical method that ensures good adherence, after deposition of cladding (before or after forming the plate) ground to the specific surface finish.

Lecture 7: Material specification-Non-ferrous materials

Non-ferrous materials

- Copper and its alloy- pure copper has good ductility, malleability, high electrical and thermal conductivity. It has fair mechanical strength and can be fabricated easily into a wide variety of shapes.
- Copper exhibits good corrosion resistance to strong alkali and organic solvent.
- Nickel and its alloy- nickel exhibits high corrosion resistance to most alkali. The strength and hardness of nickel is almost as great as that of carbon steel and metal can be fabricated easily.
- Chromium and its alloy- chromium is used either for plating of iron and steel or as an alloying element in low and high alloy steels. It helps to improve corrosion resistance and creep.

Aluminium, copper, Nickel or their alloys. Platinum, silver and lead used either alone or as liners.

Titanium, zirconium, niobium are also used.

Aluminium and alloys

- ❖ Readily available and relatively inexpensive
- ❖ These are very light, non-toxic, non-magnetic and good reflector of radiant heat
- ❖ High thermal conductivity

Pure aluminium has higher resistance to corrosion in chemical environment because of formation of their protective film of oxide on its surface on exposure to air. Pure aluminium has low strength, soft and ductile.

- ❖ Aluminium alloy retain their ductility at sub-zero temperature. They are used for construction of low temperature process vessel operating at -200°C . Widely used in dairy, food processing and refrigeration industry.
- ❖ Used for handling most organic solvents, food stuffs, hydrogen peroxide, nitric acid. Fresh water may cause some pitting.
- ❖ Due to reduction of mechanical strength with temperature, it is seldom used for vessel operating above 150°C .

Copper and copper alloy

- ❖ Used in food processing plants, in manufacture and recovery of organic solvents, in heat exchangers and evaporators
- ❖ Use is limited to fairly low temperature applications due to its poor creep strength above 150°C
- ❖ Good resistance to corrosion in sea water and large no. of chemicals
- ❖ It should not be used in contact with oxidizing acids, ammonia, carbon dioxide solutions, metallic salt susceptible to reduction

Brass- It is copper-zinc alloy with zinc content as high as 45%. Corrosion resistance is not as high as copper when zinc content is higher than 20% due to loss of zinc. High zinc brasses may fail by stress corrosion cracking. Used in tubes and tube plates for heat exchangers operating at low temperature.

Tin bronze are mainly used for castings such as valve bodies.

Al-Cu alloy bronze- These are very resistant to oxidation, corrosion and stronger than pure copper especially at temperature above 150°C .

10% Al-bronze with Fe and Ni is used for tube and tube plates upto 350°C .

All Al bronze resist mineral acid and sea water.

Cu-Ni alloy are used in steam condensers operating with polluted cooling water or sea water.

Nickel and its alloys

- ❖ Used for handling of variety of corrosive fluids at low or elevated temperature where it is essential to prevent contamination of contained fluid
- ❖ Are very expensive and in process vessel construction used only as cladding material

Monel – N-Cu alloy containing 67% Ni & 30% Cu combines high strength, ductility and excellent corrosion resistance in no of chemical media. Used in marine water service and organic chemical industries. Used as lining or cladding material on carbon steel or low alloy steel.

Inconel – Ni-Cr-Fe alloy containing 16% Cr, 8% Fe, 1% Mn and balance Ni has good strength and toughness at both elevated and low temperature with excellent corrosion resistance.

- ❖ Used in dairy and food processing equipments for alkalies and alkaline solutions, organic acid
- ❖ Useful for high temperature applications where resistance to oxidation, nitriding or halogen bearing atmosphere is important.

Incoloy – Ni-Cr-Fe alloy containing 21% Cr, 44% Fe, 1.5% Mn and balance Ni. Property similar to Inconel. It is a high temperature alloy with high creep-rupture strength and structural stability at elevated temperature of 850-900°C.

Table 1. Mechanical properties of common metals and alloys (typical values at room temp.)

	Tensile strength (N/mm ²)	0.1% proof stress (N/mm ²)	Modulus Elasticity (kN/mm ²)	Hardness Brinell	Specific gravity
Mild steel	430	220	210	100-200	7.9
Low alloy steel	420-660	230-460	210	130-200	7.9
Cast iron	140-170	-	140	150-250	7.2
Stainless steel	>540	200	210	160	8.0
Nickel	500	130	210	80-150	8.9
Monel	650	170	170	120-250	8.8
Copper	200	60	110	30-100	8.9
Brass	400-600	130	115	100-200	8.6
Aluminium	80-150	-	70	30	2.7
Dural	400	150	70	100	2.7
Lead	30	-	15	5	11.3
Titanium	500	350	110	150	4.5

Table 2 Specification of stainless steel

Type of SS	C (max)	Cr	Ni	Mo	Others
304	0.08	18-20	8-10.5		
304 H	0.1	18-20	9		Mn 2, Si 0.75
316	0.08	16-18	10-14	2-3	
316H	0.1	16-18	12	2-3	Mn 2, Si 0.75

H stands for high temperature application

When carbon content in SS 316 is less than 0.03%, identified as SS 316L which exhibit high corrosion resistance

Lecture 8: Material specification for elevated temperature, low temperature and corrosive service

Material specification for specific environment

- A. **Elevated temperature service** – For high temperature service, the important material properties are short time tensile properties, creep strength at high temperature, internal and surface stability (resistance to scaling and corrosion). Plain carbon steel has low creep strength, poor internal and surface stability.
The addition of Cr, Mo, and V improves strength at elevated temperature as well as resistance to scaling and oxidation. The higher Cr content, the greater is the limiting temperature without excessive scaling.
- B. **Low temperature service** – The important mechanical properties for low temperature service (below 0°C) are notch toughness that means the ability to deform plastically at stress-concentrations and resistance to brittle fracture in conditions of multi-axial stresses at notches.
 - ❖ Ferritic steel exhibit decrease in notch toughness at low temperature. A large group of non ferrous alloys and austenitic steel has good ductility at low temperature.
- C. **Corrosion service** – Design engineer select the most practical material of construction by proper balance of corrosion resistance, mechanical properties and cost
 - ❖ Oxidative corrosion – Metal undergoes chemical oxidation reverting to its ore. At ordinary temperature moisture and environment oxidize metal and at high temperature dry gas directly attack and oxidize most metals. Factors – light, heat, surface homogeneity,
 - ❖ In non-oxidative corrosion, metal dissolves and disintegrates

DESIGN FOR CORROSION RESISTANCES

The life of equipment subjected to corrosive environments can be increased by proper attention to design details. Equipment should be designed to drain freely and completely. The internal surfaces should be smooth and free from crevasses where corrosion products and other solids can accumulate. Butt joints should be used in preference to lap joints. The use of dissimilar metals in contact should be avoided, or care taken to ensure that they are effectively insulated to avoid galvanic corrosion. Fluid velocities and turbulence should be high enough to avoid the deposition of solids, but not so high as to cause erosion-corrosion.

1. General wastage of material-uniform corrosion
2. Galvanic corrosion-dissimilar metals in contact.
3. Pitting-localised attack.
4. Inter-granular corrosion.
5. Stress corrosion.
6. Erosion-corrosion.
7. Corrosion fatigue.
8. High temperature oxidation.
9. Hydrogen embrittlement.

Corrosion prevention measures

1. Material selection
2. Anodic or cathodic protection
3. Engineering design of components
4. Control of process environment
5. Protection methods.

Lecture 9: Material specification-Non-metals

Non-metals: Carbon and graphite, glass, rubber, Plastics

- **Carbon and graphite** - these materials are isotropic and therefore, their properties vary with grain orientation. The corrosion resistance of both carbon and graphite is almost unsurpassed. Graphite is generally inert to all chemicals except in strongly oxidising applications. The low thermal conductivity of carbon is advantageous when carbon bricks are used to line vessels for high temperature reaction.
- **Glass** – commonly available glass has a low strength, but a high compressive strength. It is brittle and is damaged by thermal shock. Coating of steel by glass gives a material which has the corrosion resistance of glass and the strength of steel.
- **Rubber** – Natural and synthetic rubbers are primarily used as linings for chemical equipment. Some other components such as gaskets and bushes are also made of rubber. The hardness of rubber can be improved by addition of various ingredients. Natural rubber is resistant to dilute acids, alkalis and salts, but is affected by oxidizing media, oils, benzene etc. Some of the important synthetic rubbers are polychloroprene, or neoprene, nitrile, butyl, silicone, hypalon fluoro- elastomer like viton and polyurethane. They are resistant to oils and solvents. Silicon and viton have excellent high temperature resistance, while urethane rubber has good abrasion resistance, hardness and resilience. Due to its resistance to acids and alkalis, rubber lining is used for stirrers, fans, centrifuge baskets, pumps, valves, storage vessels, pickling vats, etc.

Plastics

These materials are classified in two main categories:

Thermoplastics, which soften under the application of heat

Thermosetting plastics, which under pressure and heat are cured and become hard and will not deform when subjected to heat again.

Thermoplastic: The most common thermoplastics are cellulose acetate, polyethylene, polystyrene, polyvinyl chloride, polypropylene, nylon, methacrylate, etc. and available in the form of films, sheets, rods and pipes. The main applications are in reaction vessels, storage tanks, gas washing towers, ducting, ventilating systems, fans, pipes, pipe fittings, gaskets, etc.

Thermosetting plastics: These comprise, phenol formaldehyde, urea formaldehyde, melamine formaldehyde, polyester, epoxy and silicone resins. Polyester and epoxy resins with glass fibre reinforcements are used for fabrication of pipes and fittings, ducts, vessels and tanks and used as lining materials.

- **Protective coating** : Quite often limitations are imposed by cost and fabrication requirements, on the choice of the most desirable material for resisting corrosion. A coating should be applied on clean surface. Presence of grease, oil, dirt and scale adversely affect adherence, continuity and durability of coating. Categories of coating: Metallic, Inorganic coating (vitreous enamels), Organic coating (synthetic resins, Paint, lacquer, powder)
- **Lining:** Storage tanks, reaction vessels, pipes, ducting, etc., are covered with linings in order to (a) give the underlined structure protection against chemical attack, (b) prevent contamination of the materials being processed, and (c) minimize the effect of abrasion. Materials used for lining: Rubber, lead, glass, Plastics, bricks

Lecture 10: Design Code, standards, testing

1. Materials, properties and compositions.
2. Testing procedures for performance, compositions, quality.
3. Preferred sizes; for example, tubes, plates, sections.
4. Design methods, inspection, fabrication.
5. Codes of practice, for plant operation and safety.

The terms STANDARD and CODE are used interchangeably, though CODE should really be reserved for a code of practice covering say, a recommended design or operating procedure; and STANDARD for preferred sizes, compositions, etc.

Design preliminaries for pressure vessels

Design code – Code gives the guideline for safety design of process equipment which are mostly pressure vessels. Keeping in view the safety first principle, it is the designer's responsibility to make his design the most economical.

Besides outlining the standard procedure for safe design, code suggests the preferred dimensions of process vessels and structural components. This helps in large scale production and thus reducing manufacturing cost.

Foreign standards widely used in India for pressure vessel design

BS 1500 and 1515

ASME section VIII

DIN

AD Merkblaetter

India's first code IS:2825-1969 (For unfired pressure vessel)

IS-4503-1967 Specifications for Shell and Tube type heat exchangers

IS-5036-1969 Plate and frame type filter press

IS-3503-1966 Steel plates for pressure vessel

IS-3382-1965 Specifications for stainless steel milk pipes and fittings

INSPECTION AND NON-DESTRUCTIVE TESTING OF EQUIPMENT

Inspection is necessary at the various stages of fabrication depending on the classification of vessels. In case of class 1 vessels, for example, the requirements are :

1. Visual inspection of surface for objectionable defects.
2. Assembly and alignment of vessel sections prior to welding.
3. Identification and stamping of weld test plates.
4. Inspection during welding in progress, including second side welding grooves after preparation by chipping, gouging, grinding or machining.
5. Inspection of main seams after dressing.
6. Calibration and dimensional check after completion.

Lecture 11: Pressure vessel design-Basics of pressure vessel design

Maximum working pressure – This is the maximum gauge pressure expected under any operating conditions of the process. This pressure limit should not be exceeded for the vessel in operation to avoid the failure of the vessel. The design pressure should corresponds to the maximum working pressure.

Design pressure – The pressure used in design calculations for the purpose of determining the minimum thickness of the various component parts of the vessel is design pressure.

For vessel under internal pressure, the design pressure is obtained by adding a minimum of 5% to the maximum working gauge pressure. When there is uncertainty in fixing the maximum working pressure, value may be more than 1.05 times the maximum operating pressure for safety reasons.

Design pressure shall not exceed 200 bar to make use of the code equations as per IS:2825-1969

Design temperature – It is important to find the allowable stress value of the material of construction which is temperature dependent.

- For unheated part, the highest temperature of the stored material is taken.
- For body parts heated by means of steam, hot water or similar heating media- The highest temperature of the heating media or 10°C higher than the maximum temperature that any body part is likely to attain during operation.
- For vessel where direct internal or external heating is employed by fire, flue gas or electricity

If vessel is shielded – highest temp. of inside material + 20°C

If vessel is unshielded - highest temp. of inside material + 50°C

The minimum design temperature shall not be less than 250°C.

Design stress – It is always less than the damaging stress which is the least unit stress that will render a member unfit for service before the end of its normal life. The lower limit of design stress is suggested because of uncertainty as to the conditions of service, non-uniformity of material and inaccuracy of stress analysis. The magnitude of this uncertainty is defined as factor of safety or design stress factor and this indicates the margin between the design stress and the damaging stress.

Design stress at design temp. = ultimate stress or stress at elastic point at design temp./factor of safety

Design wall thickness – Thickness calculated from the stress consideration alone gives the design wall thickness which gives a safe value against induced stresses caused by internal or external pressure or similar loads. This doesnot concern with the rigidity of the equipment or fabrication feasibility or availability.

Minimum actual wall thickness of pressure vessel is therefore a standard available sheet metal or pipe wall thickness which satisfies the design thickness requirement and takes into account the factors like rigidity, weldability etc. and also the appropriate allowance for non-uniformity in sheet metal thickness, corrosion-erosion allowance etc.

Corrosion allowance – Designer has to provide some extra thickness to safeguard against reduction in thickness to any danger level during the life period of the equipment due to corrosion, erosion or abrasion.

- For carbon steel & cast iron pressure parts 1.5 mm on all parts where severe conditions are not expected and 3 mm where severe conditions are expected.
- For stainless steel and non-ferrous pressure parts, no corrosion allowance is required.

Corrosion can be avoided by selecting proper material and taking anti-corrosion measures.

Weld joint efficiency factor – Joint section is comparatively weaker than plate metal due to uncertainty in quality of joint. Weld joint efficiency factor of 1.0 to 0.85 is commonly used in designing process equipments.

Pressure vessels are of three types

Class I – When vessel are to contain lethal or toxic substances and operated under severe conditions Fully radiographed joints are needed. Weld joint efficiency factor is taken as 1.0 for double welded butt joint and 0.9 for single welded butt joint with backing strip.

Class II – These are for medium duty operation. Joints are required to be spot radiographed. Thickness should not exceed 38 mm. Weld joint efficiency factor is taken as 0.85 for double welded butt joint and 0.8 for single welded butt joint with backing strip.

Class III – These vessels are for relatively light duty having plate thickness not in excess of 16 mm. (Temp less than 250°C and unfired. No radiography is necessary. Weld joint efficiency factor is taken as 0.7 for double welded butt joint and 0.65 for single welded butt joint with backing strip.

Design loading – In design of pressure vessel apart from design pressure, interaction and combination of various loadings involved in a particular circumstances should be taken into account for safe design.

Main loading

1. Design pressure including static head
2. Weight of the vessel and normal contents or weight of the vessel and maximum contents of water specified for the pressure test
3. Wind and earthquake loadings in combination with other loadings

Supplementary loadings

Poisson's ratio- It is the ratio of unit lateral strain to unit axial strain which is constant within elastic limit for a particular material.

Dilation of pressure vessel – It is the radial growth of a pressure vessel under internal pressure which is important in determining discontinuity stress.

Thermal stress – When the expansion or contraction that would normally result from the heating or cooling of a body is prevented, thermal stresses are developed.

Criteria for failure – Ductile material which exhibit marked plastic deformation at a fairly definite stress like yield point and considerable elongation. Ex- mild steel

Brittle material for which beginning of plastic deformation is not clearly defined and which exhibit practically negligible ultimate elongation. Ex- cast iron. . Ultimate elongation of 5% is the dividing line between the two classes of metals.

Ductile material failed when it has suffered elastic failure i.e. when marked plastic deformation has begun. Under uniaxial tension when stress reaches yield point or elastic limit failure occurs.

Theories of failure

Maximum stress theory – When maximum tensile stress becomes equal to yield point stress.

Maximum strain theory – Elastic failure occurs when maximum tensile strain equals strain at yield point i.e. δ_y/ϵ

Maximum shear theory – Elastic failure occurs when maximum shear stress equals ζ_y

Brittle material can't be considered to have definitely failed until it has broken and this takes place through tensile fracture when maximum tensile stress reaches the ultimate strength.

Elastic stability – Under certain circumstances, maximum load a member will sustain is determined not by the strength of the material but by the stiffness of the member. If the body is not elastically stable, the shape of the structure will be altered as a result of insufficient rigidity. Exmp- Buckling of thin cylindrical shell and horizontal vessel Elastic stability for an equipment and its parts are essential for proper functioning.

Lecture 12: Pressure vessel design-Thickness calculation

Pressure vessel Design

Any vessel which operates under pressure or in which pressure more than atmospheric is maintained can be called as pressure vessels. Various equipments which may operate under pressure are reaction vessels, heat exchangers, digesters etc. When pressure is maintained inside the vessel it is called as vessel subjected to internal pressure. When pressure lower than atmospheric is maintained inside the vessel, it is termed as subjected to external pressure or operating under vacuum.

The vessel used for the operation may be cylindrical or spherical. Spherical vessels are better in strength and lower in cost but due to difficulties in manufacturing cylindrical vessels are commonly used.

The main function of pressure vessel is to contain a media under desired pressure and temperature. The final thickness of pressure vessel should be such that it is adequate against induced stress caused by internal pressure and ensure safety against stresses caused by extraneous agencies like support loading and thermal shock.

Parameters considered before designing a pressure vessel

1. Type of fluid handled or processed
2. Type of service required (continuous, intermittent)
3. Geometry and type of vessel which can be fabricated economically
4. Availability of different materials of construction and their cost data

Thickness of vessel depends on operating pressure and temperature.

For low pressure thin walls are used. If thickness to diameter ratio is less than 0.1, the shell is considered thin wall.

A. Thin vessel

For a cylindrical vessel

$$\text{Hoop stress} = \delta_{\theta} = pD_i / 2t$$

$$\text{Longitudinal stress} = \delta_z = pD_i^2 / 4tD \quad \text{where } D = D_i + t$$

Since hoop stress is greater than longitudinal stress, calculation of design thickness is based on hoop stress.

D , t = dia. and thickness of cylindrical vessel subjected to internal pressure p

$$\text{Radial deflection} = pr^2/Et$$

For thin sphere subjected to internal pressure hoop stress is equal to longitudinal stress and same as longitudinal stress in cylinder.

The required thickness for spherical vessel for a given set of conditions is one half that necessary for a cylinder.

When thickness of the cylindrical vessel is relatively large, the variation in the stress from the inner surface to the outer surface becomes appreciable. The radial stress acting along the radius varies with the radius.

$$\text{Radial stress} = \delta_r = \frac{r_i^2 p_i - r_o^2 p_o}{r_o^2 - r_i^2} - \frac{r_i^2 r_o^2 (p_i - p_o)}{r^2 (r_o^2 - r_i^2)}$$

$$\text{Hoop Stress} = \delta_{\theta} = \frac{r_i^2 p_i - r_o^2 p_o}{r_o^2 - r_i^2} + \frac{r_i^2 r_o^2 (p_i - p_o)}{r^2 (r_o^2 - r_i^2)}$$

$$\text{Maximum shear stress} = \frac{r_i^2 r_o^2 (p_i - p_o)}{r^2 (r_o^2 - r_i^2)}$$

$$\text{Longitudinal stress} = \delta_z = \frac{r_i^2 p_i - r_o^2 p_o}{r_o^2 - r_i^2}$$

Where r_i and r_o are internal and external radius of the cylindrical vessel subjected to internal pressure p_i and external pressure p_o

It should be noted that δ_{θ} is greater than δ_r and it is maximum at the inner periphery of the cylinder. For design purpose, the hoop stress at $r = r_i$ should be taken as critical or allowable stress (f = allowable stress value of the material of construction at design temperature). The chemical process equipments generally fabricated with sheet metals necessitating the end joints, which reduces the allowable strength of the material with a factor called joint efficiency factor denoted by j

If t is the minimum wall thickness required for the cylindrical shell subjected to only internal pressure p

$$t = p D_i / (2 f j - p) = p D_o / (2 f j + p) = p D / 2 f j$$

As per limitation stipulated in IS:2825-1969 $D_o / D_i \leq 1.5$

Maximum value of $t/D_i = 0.25$

For spherical vessel under internal pressure, the induced hoop and longitudinal stresses are equal and the magnitude is same as the longitudinal stress in a cylinder.

$$t = p D_i / (4 f j - p) = p D_o / (4 f j + p) = p D / 4 f j$$

This is the theoretical required minimum wall thickness to withstand internal pressure p safely. Extra allowance should be added to take care of corrosion, non-uniformity in sheet metal thickness etc. After obtaining the theoretical calculated wall thickness, the final value is to be chosen from the standard thickness of sheet metal available in the market which should be higher than the calculated value.

B. Thick cylindrical vessel ($D_o / D_i > 1.5$)

In case of cylinders of ductile material the value of circumferential stress may be taken as 0.8 times the yield point stress and for brittle material it may be taken as 0.125 times the ultimate tensile stress.

Optimum proportion of vessel $L/D = 6$ for plate thickness upto 50 mm

$L/D = 8$ for plate thickness above 50mm.

Maximum radial deflection is at the inner surface.

Lecture 13: Pipe design, Pressure vessel Fabrication and testing

- If $d/t > 10$ Thin vessel (Boiler, tank, pipe)
- If $d/t < 10$ Thick vessel (Gun barrel, Tanks)
- For ductile material circumferential stress f_t is 0.8 times yield stress
- For brittle material circumferential stress f_t is 0.125 times ultimate tensile stress
- In design of steam boiler, wall thickness calculated is compared with minimum plate thickness as provided in boiler code
- $T = pD/2f_t$

Cylinder head and cover plate

- Flat plate, Slightly dished plate,
- Freely supported or rigidly fixed
- Circular flat plate $t_1 = k_1 d \sqrt{p/f_t}$
- Rectangular flat plate $t_1 = abk_2 d \sqrt{p/(f_t(a^2+b^2))}$

		k_1	k_2
• Cast iron	Freely	0.54	0.75
	Fixed	0.44	0.62
• Mild steel	Freely	0.42	0.60
	Fixed	0.35	0.4

- $Q = \pi D^2 v / 4$ Determine D from flow rate
- $t = pD/2f_t + c$
- c in mm CI- 9, MS-3, Copper-4, Lead-5
- p= Internal pressure
- f_t - yield stress

5.5.1. Wall thickness: pipe schedule

The pipe wall thickness is selected to resist the internal pressure, with an allowance for corrosion. Processes pipes can normally be considered as thin cylinders; only high- pressure pipes, such as high-pressure steam lines, are likely to be classified as thick cylinders and must be given special consideration.

The British Standard 5500 gives the following formula for pipe thickness:

$$t = \frac{Pd}{20\sigma_d + P}$$

where P = internal pressure, bar

d = pipe od, mm,

σ_d = design stress at working temperature, N/mm².

Pipes are often specified by a schedule number (based on the thin cylinder formula).

The schedule number is defined by:

$$\text{Schedule number} = \frac{P_s \times 1000}{\sigma_s}$$

Different non-destructive test procedures

Pressure tests

Pneumatic pressure tests

Radiography (X-rays) test

Dye penetrant test

Freon tests

Magnetic tests

Ultrasonic tests

Lecture 14: Design of cleaners

CLEANING

All food raw materials need cleaning before processing.

It is important to remove contaminants: physical, chemical and biological.

For example, it is essential to remove sand, stones, or metallic particles from wheat prior to milling to avoid damaging the machinery.

The main contaminants are:

- Unwanted parts of the plant such as leaves, twigs, husks;
- Soil, sand, stones, and metallic particles from the growing area;
- Insects and their eggs;
- Animal excreta, hairs, and so on;
- Pesticides and fertilizers;
- Mineral oil;
- Microorganisms and their toxins.

Cleaning is essentially a separation process, in which some difference in physical/chemical properties of the contaminants and the food units is exploited.

There are a number of cleaning methods available, classified into dry and wet methods, but a combination would usually be used for any specific material

Dry Cleaning Methods

The main dry cleaning methods are based on screens, aspiration, or magnetic separations.

Dry methods are generally less expensive than wet methods and the effluent is cheaper to dispose of, but they tend to be less effective in terms of cleaning efficiency.

A major problem is recontamination of the material with dust.

Screens

Screens are essentially size separators based on perforated beds or wire mesh by which larger contaminants are removed from smaller food items (e.g., straw from cereal grains, or pods and twigs from peas). This is termed “*scalping*”

Alternatively “*de-dusting*” is the removal of smaller particles (e.g., sand or dust) from larger food units.

Abrasion, either by impact during the operation of the machinery, or aided by abrasive disks or brushes, can improve the efficiency of dry screens.

Screening gives incomplete separations and is usually a preliminary cleaning stage.

Aspiration

It is based on aerodynamic properties of the food and the contaminants.

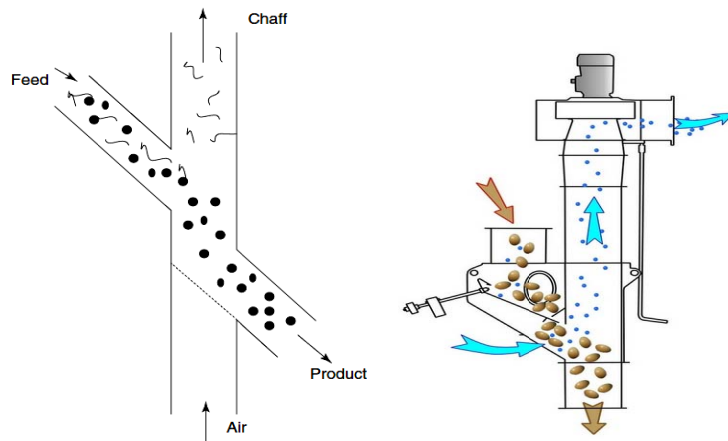
It is widely used in the cleaning of cereals, but is also incorporated into equipment for cleaning peas and beans.

The principle is to feed the raw material into a carefully controlled upward air stream.

Denser material will fall, while lighter material will be blown away depending on the terminal velocity.

By using different air velocities, it is possible to separate, say, wheat from lighter chaff or denser small stones.

Very accurate separations are possible, but large amounts of energy are required to generate the air streams.



Magnetic cleaning

This is the removal of ferrous metal using permanent or electromagnets.

Metal particles derived from the growing field or picked up during transport or preliminary operations constitute a hazard both to the consumer and to processing machinery (e.g. cereal mills).

Foods may be passed over magnetized drums or magnetized conveyor belts, or powerful magnets may be located above conveyors.

Electromagnets are easy to clean by turning off the power.

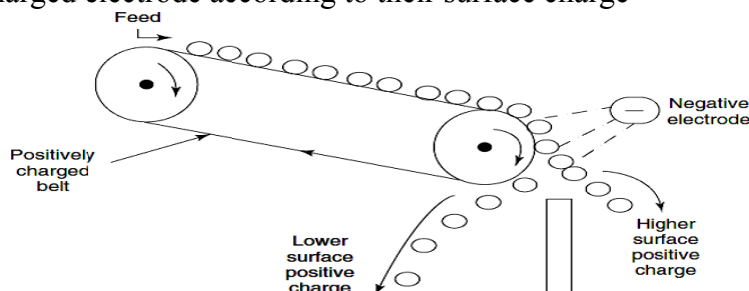
Metal detectors are frequently employed prior to sensitive processing equipment as well as to protect consumers at the end of processing lines.

Electrostatic cleaning

This can be used in a limited number of cases where the surface charge on raw materials differs from contaminating particles.

The principle can be used to distinguish grains from other seeds of similar geometry but different surface charge, and has also been described for cleaning tea.

The feed is conveyed on a charged belt and charged particles are attracted to an oppositely charged electrode according to their surface charge



Effectiveness of the Separation

$$\epsilon_A = \frac{(X_F - X_D)X_C(X_F - X_C)(1 - X_D)}{(X_D - X_C)^2 X_F(1 - X_F)}$$

Where:

ϵ_A is the separating effectiveness for a mixture of two components A and B

F is the rate of feeding to the separator, kg/h

C is the rate of separating the product, kg/h

D is the rate of reject, kg/h

X_F , X_C , and X_D are fractions of component A in the feed, separated product, and reject, respectively

Testing of Cleaner

SPECIFICATION SHEET

TO BE FILLED IN BY

Manufacturer Testing Station

1. General:

- a) Make
- b) Model
- c) Type
- d) Year of manufacture

2. Power Unit:

- a) Type of prime mover
- b) Recommended power, kW
- c) Type of drive

3. Main Drive:

- a) Type
- b) Size of belt
- c) Size of pulley
- d) Diameter of main shaft

4. Screens:

- a) Type
- b) Number
- c) Total length and width
- d) Effective length and width
- e) Number of holes per cm³
- f) Size of hole
- g) Sieve clearance
- h) Screen slope range
- j) Recommended screen slope
- k) Provision for screen cleaning

APPENDIX B
(Clause 6.2)

DATA SHEET FOR MATERIAL OF CONSTRUCTION

1. Date of Test:
2. Material of construction:

Sl.No. (1)	COMPONENT (2)	MATERIAL (3)	SIZE (4)	MASS (5)
1.	Frame			
2.	Feeding Chute			
3.	Blower/Aspirator			
4.	Main shaft			
5.	Blower shaft			
6.	Screen			
7.	Shoe			
8.	Elevator			
9.	Transport material			
10.	Pulleys			
11.	Others			

APPENDIX C
(Clause 6.3)

DATA SHEET FOR VISUAL OBSERVATIONS AND PROVISION FOR ADJUSTMENTS

1. Observations:
 - a) Adequacy of marking of inlet and outlets
 - b) Adequacy of protection of bearings against the ingress of dust
 - c) Adequacy of safety arrangements, specially at moving points and at inlet
 - d) Provision for lubrication of moving parts
 - e) Provision for belt tightening
 - f) Provision for transportation
 - g) Provision for easy changing of components requiring frequent replacement
 - h) Provision for easy replacement and cleaning of screens
 - i) Provision for anti-corrosive coatings
 - j) Tighten of bolts, nuts and other fasteners
 - m) Welding of seams
 - n) Other observations
2. Provision for Adjustments of:
 - a) Feed rate
 - b) Shaking speed
 - c) Screen slope
 - d) Air displacement

Testing Engineer

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APPENDIX D
(Clauses 7.1.3 and 7.2)

DATA SHEET FOR TEST AT NO-LOAD

1. Power Consumption:
 - a) Source of power
 - b) Type of drive
 - c) Total time of run
 - d) Average power consumption for one hour
2. Observations:
 - a) Presence of any marked vibration during operation
 - b) Presence of undue knocking or rattling sound
 - c) Frequent slippage of belts
 - d) Smooth running of shafts in their respective bearings
 - e) Any marked unusual wear or slackness in any component
 - f) Any marked rise in bearing temperature
 - g) Other observations

Testing Engineer

APPENDIX E
(Clauses 8.1.4, 8.1.5.4 and 8.1.5.5)

DATA SHEET FOR TEST AT LOAD

1. Source of Power
2. Power Rating
3. Type of Drive
4. Variety of Paddy
5. Moisture Content
6. Percentage of Foreign Matter in Paddy Before Feeding
7. Screen Slope
8. Sieve Clearance
9. Air Flow
10. Maximum Input Capacity

APPENDIX H
(Clause 8.2)

DATA SHEET FOR LONG-RUN TEST

1. Total Running Time
2. Continuous Running Time
3. Breakdowns in Cleaning Unit
4. Breakdowns in Elevation Unit
5. Breakdown in Body
6. Any Major Repairs Conducted
7. Any Other Observations

Testing Engineer

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APPENDIX J
(Clause 9.1)
SUMMARY REPORT

1. Name of Manufacturer
2. Model Number
3. Name of Testing Station
4. Brief Description of the Cleaner
5. Variety of Paddy Used
6. Percentage of Foreign Matter Before Feeding
7. Moisture Content Before Feeding

8. Provisions for Adjustment:
 - a) Shaking speed
 - b) Screen slope
 - c) Air displacement
 - d) Feed rate

9. Power requirement, kW:
 - a) Recommended power
 - b) Observed power at no-load
 - c) Observed power at load at rated input capacity
 - d) Observed power at maximum input capacity

10. Cleaning Efficiency
11. Rated Input Capacity
12. Any Marked Observation Affecting Performance
13. Any Marked Breakdowns
14. Other Observations

Testing Engineer

Lecture 15: Design of heat exchangers-Basics

Heat exchanger is an efficient device in which the process of heating and cooling occurs. They are used in chemical process industries, food processing industries, steam power plants, air conditioning and refrigeration plants. Design is based on economics, size and weight of heat exchanger.

Classification-

1. Based on principle of operation
 - a) Recuperative – Cold and hot fluid flow through the unit without mixing with each other. Heat transfer occurs through metal wall. Exmp- boiler, heater, cooler, condenser
 - b) Regenerative – Some heating surface is alternatively exposed to hot and cold fluid. Heat associated with hot fluid is stored and absorbed by packings, then hot fluid supply is shut off and cold fluid is passed over packings to regenerate the heat
 - c) Direct contact – Hot and cold fluid are in direct contact and mixing occurs among them during the process of heat transfer. Mass transfer also occurs simultaneously.
2. Based on flow pattern
 - a) Co-current – Hot and cold fluid flow in the same direction (parallel flow)
 - b) Counter current – Hot and cold fluid move in opposite directions
 - c) Cross flow – Hot and cold fluid move at right angle to each other
3. Based on function of heat exchanger
 - a) cooler b) Chiller c) Heater d) evaporator e) condenser
4. Based on types of construction
 - a) Double pipe b) Shell and tube type c) Plate type
 - d) Spiral type e) Air cooled

Fouling factors – After a period of operation the heat transfer surfaces of a heat exchanger may become coated with various deposits present in the flow system or the surfaces may become corroded. This coating represents an additional resistance to the heat flow and thus decreased performance. This is usually represented by fouling factor or fouling resistance that must be included with other thermal resistances making up overall heat transfer co-efficient. Higher the velocity of fluid lower will be the fouling factor.

LMTD (log mean temperature difference) It is the temperature difference at one end of the heat exchanger less the temperature difference at other end divided by the natural log of the ratio of these temp. difference. If a heat exchanger other than the double pipe type is used, the heat transfer is calculated by using correction factor applied to the LMTD for a counterflow double pipe arrangement with the same hot and cold fluid temperatures.

$$Q = U A F T_m$$

For condensation and boiling where phase change occurs at constant temperature $F=1$.

Effectiveness-NTU method

LMTD approach to heat exchanger analysis is useful when the inlet and outlet temperature are known or easily determined. When inlet and exit temperatures are to be evaluated for a given heat exchanger, the analysis is performed easily by utilizing a method based on the effectiveness of heat exchanger in transferring a given amount of heat. This method is advantageous in comparison between various types of heat exchanger for purpose of selecting the best type suited to accomplish a particular heat transfer objective.

Effectiveness , ϵ = Actual heat transfer / maximum possible heat transfer

N = No. of transfer units = $NTU = UA/C_{\min}$

C = capacity ratio = $C_{\min} / C_{\max}$

Effectiveness indicates the performance of a heat exchanger whereas NTU indicates the size of heat exchanger (as NTU is proportional to A)

Heat exchanger design considerations

Factors that are to be considered for design of heat exchanger are

1. Heat transfer requirement (thermal design)
2. Mechanical design
3. Cost
4. Physical size (based on capacity and heat transfer area required)
5. Pressure drop characteristics

By forcing fluids through the heat exchanger at high velocities, U may be increased but higher velocity results in larger pressure drops and correspondingly larger pumping cost. If surface area of heat exchanger is increased, U and P need not be large, however their may be limitation to physical size and a larger physical size results in a higher cost for the heat exchanger. So prudent judgement and considerations of these factors will result in proper design.

Lecture 16: Design of tubular heat exchanger

It is the simplest type of heat exchanger. It consists of two concentric pipes and the hot and cold streams flow through the inner pipe and annulus either co-currently or counter-currently according to the process requirement. In this type arrangement, each tube has own shell forming annular space for shell side fluid. Usually hot fluid flows through the annulus. The exchanger is especially suitable for high pressure in tube above 20 kg/cm^2 .

Though the construction is very simple, the main disadvantage is that the heat transfer area available is very small. So this is uneconomical where more heat transfer area is required. The time and cost required for dismantling and periodical cleaning are on the higher side. It is advantageous and beneficial for small heat loads and for heat transfer area up to 20 m^2 .

Forced convection

a) For streamline flow through pipes

$$Nu = 1.62 (Re \cdot Pr \cdot D/L)^{0.33}$$

L = length of pipe, m

When $Re \cdot Pr \cdot D/L > 120$ and all physical properties measured at mean bulk temperature of the fluid.

b) For turbulent flow through pipes

$$Nu = 0.023 Re^{0.8} Pr^n$$

$n = 0.4$ for heating and 0.33 for cooling

for $Re > 10000$, $Pr > 0.7$, $L/D > 60$

Viscosity measured at mean film temperature and other properties measured at mean bulk temperature of the fluid.

Nu = Nusselt Number = $h_c D/k$

Prandtl Number = $Pr = C_p \mu/k$

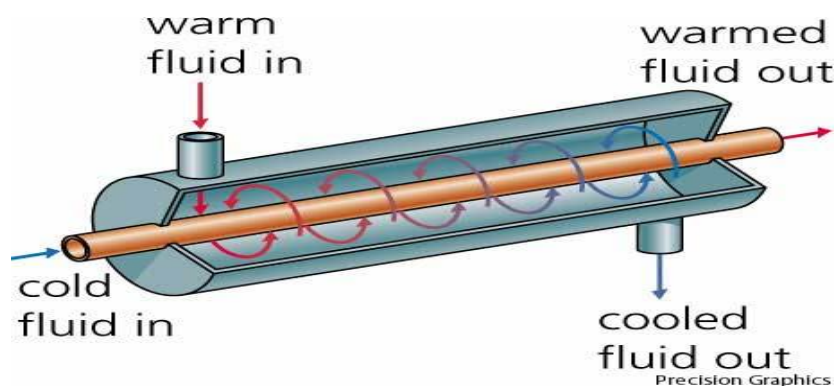
H_c = convective heat transfer co-efficient at solid-liquid interface, $\text{W/m}^2\text{°K}$

D = Characteristics dimension, m (dia or length)

k = Thermal conductivity of the fluid, $\text{W/m}^2\text{°K}$

C_p = sp. Heat at constant pressure, $\text{J/kg}^{\circ}\text{K}$

μ = viscosity, Ns/m^2



Lecture 17: Design of shell and tube heat exchanger

These are commonly used in process industries. It consists of a tube bundle mounted on two tube sheets and enclosed in a casing called the shell. It can be built in any size as per the requirement. These units are useful where very large heat transfer surface and high heat load are to be handled. One fluid flows on the inside of the tubes while the other fluid is forced through the shell and over the outside of the tubes. To ensure that the shell side fluid will flow across the tubes and thus induce higher heat transfer, baffles are placed in the shell. Depending upon the head arrangement at the ends of the exchanger, one or more tube passes may be utilized.

There are five resistances to transfer of heat

1. Resistance due to fluid film on inner surface of wall
2. Resistance due to fluid film on outer surface of wall
3. Resistance due to metal wall
4. Resistance due to fouling on inner surface of wall
5. Resistance due to fouling on outer surface of wall

The overall heat transfer co-efficient

$$1/U = 1/h_o + 1/h_i + x/k + R_i + R_o$$

Two types of baffles are used in shell and tube heat exchanger.

a) Transverse baffle – These are either perpendicular or inclined to the tube bundle. The function of these baffles are to

1. increase the residence time for shell side fluid
2. increase the turbulence so that rate of heat transfer is high,
3. provide support to the tube bundle,
4. Maintain the pressure drop limit,
5. also helps to reduce induced vibrations in tubes.

Flow pattern on shell side depends upon types of baffle.

b) Longitudinal baffle – Shell side passes are arranged by longitudinal baffles. It divides shell into two sections. It is a flat plate which extends along the shell length. The important function are

1. It offers higher velocity for the shell side fluid and increases turbulence.
2. It provides counterflow of shell side fluid

Tubes – Number of tubes in a shell and tube heat exchanger depends upon the surface area required for heat transfer. It is observed that tube diameter between 19-20mm gives highest heat transfer co-efficient. Tube thickness depends upon internal and external pressure over tubes and corrosion allowance. Tubes are attached to the tube sheets. Usually tubes are fixed on one side and they are free to expand on the other side. The ends of the tubes are fitted in two tube sheets. Tube pitch is usually 1.25 to 1.5 times the outside dia. of tubes.

Tube sheet – It is a circular plate on which holes are drilled either on triangular pitch or square pitch.

Tube bundle dia can be estimated as

$$D_b = d_o (N/k)^{1/n}$$

$$D_b = \text{tube bundle dia in mm}^2$$

N = total no of tubes

Outside dia of tubes = d_o in mm

k, n are constants depends on no of passes and pitch arrangement

Mechanical design

Thickness of shell $t = pD/2f_j$

P = design pressure = 1.05 X maximum operating pressure

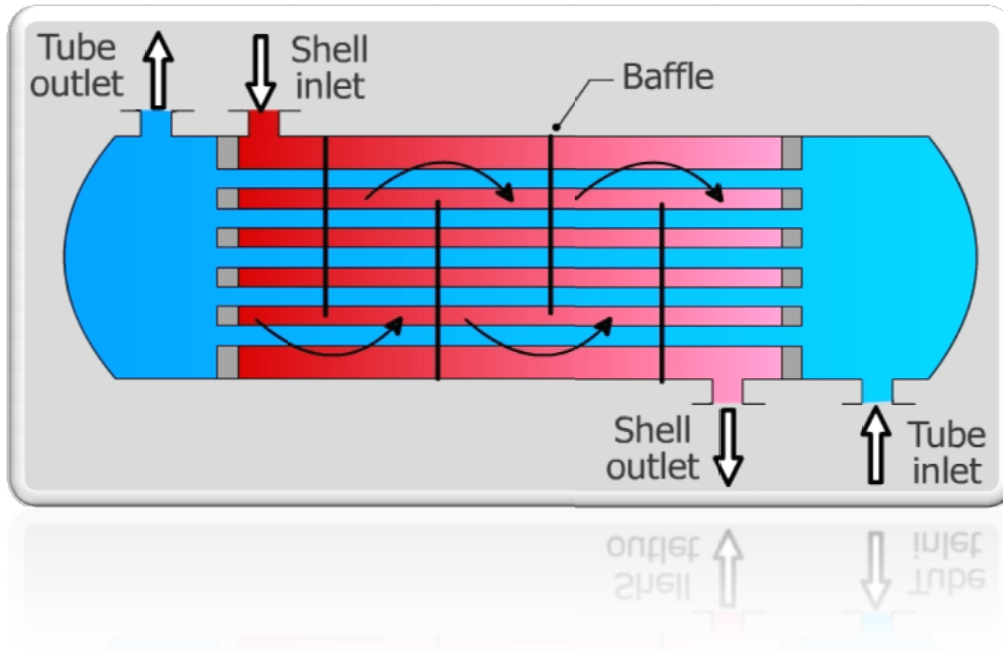
Usually carbon steel is used for shell fabrication.

Shell cover – For elliptical head

$T = pDV/2f_j$

V = stress intensification factor = $1/6(2+k^2)$

k = major axis/minor axis



Lecture 18: Design of plate heat exchanger

These are formed by a series of parallel plates held firmly together between frames. The heat transfer surface is provided by adjacent corrugated plates which offer high surface area, strength to plate and cause turbulence for fluids. Plates can be easily cleaned and replaced. These units are useful for high viscous fluids. No welding stresses are developed since plates are not welded and offer low pressure drop. Plate type units are inexpensive, light in weight, easy to clean and can be shaped as per the requirements. The plates form parallel channels and liquid food and heating medium are pumped through alternate channels in counter-current pattern. Each plate is fitted with synthetic rubber gaskets.

It is an efficient heat exchanger equipment as compared to shell and tube heat exchanger.

Advantages-

1. ease in cleaning
2. Flexible in operation
3. Versatile nature
3. High heat transfer area in a very compact space
4. High turbulence at very low velocities
5. No problem of leakage or intermixing of fluids
6. efficiency is high compared to others
7. closer temperature approach is achieved
8. pressure drop is low
9. Non-weldable material can be used.

There are three flow patterns in plate heat exchanger

1. Series flow pattern- The fluid streams change in direction after every vertical passes
2. Looped flow pattern – The fluid streams divide into parallel flow channels and reconverge again at exit in a single stream
3. Complex flow pattern- It is the combination of series and looped flow pattern

While designing plate heat exchanger following assumptions are made

1. Overall heat transfer co-efficient is constant
2. Temp and flow gradient is negligible
3. Heat loss to surrounding are negligible
4. No phase change occurs during the flow through the heat exchanger

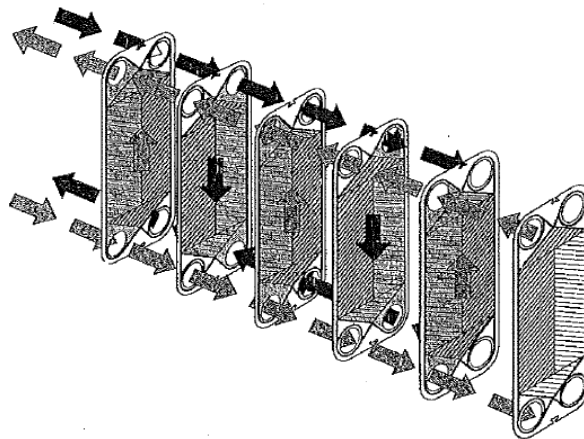
Thermal design considerations

$$Q = m_h C_{ph} \Delta t_h = m_c C_{pc} \Delta t_c = U_{av} A_T \Delta t_{lm} F$$

$$\text{Number of plates } N = A_T / A_p$$

A_T = Total required heat transfer area

A_p = projected area of single plate



Lecture 19: Design of handling equipments-basics

Material handling includes a number of operations that can be executed either by hand (manual) or by mechanical means or devices to convey material and to reduce the human drudgery.

Right place, right time, right quant

The selection of proper conveying system is important for ease in operation and getting desired capacity for a particular product.

- a) The following principles should be taken into account before selecting conveying systems.
- b) The conveying device has to be selected according to the characteristics of the materials being conveyed.
- c) In a conveying system possibility of use of gravity should be taken into consideration.
- d) The stability of the conveyor must be ensured under all normal working and climatic conditions.
- e) The dead load of the conveyor should be low in relation to the weight of transported product.
- f) The capacity of handling/conveying equipment should match with the capacity of processing unit of units.
- g) Spillage of conveyed products should be avoided.
- h) Pollution of the environment due to noise or dust by the conveying system should also be avoided.

Material Handling

Advantages:

Better adoptability to control
Better coordination with suppliers and costs
Continuous flow of material
Fewer delays between operations and depart
Higher level of equipment utilization
Improved scheduling
Less product damage
Lower labour cost
Optimum return on investmet
Reduced inventories
Reduced space needs
Safer, more systematic work procedure

The most common types of mechanical devices for grain handling are

1. Belt conveyor
2. Bucket elevator
3. Screw conveyor
4. Chain Conveyor
5. Pneumatic conveyor

Selection of material Handling machines and Conveyors

The selection of proper conveying system is important for ease in operation and getting desired capacity for a particular product. Principles based on which the material handling equipment is selected:

- a) Based on the characteristics of the products being conveyed
- b) Working and climatic conditions.
- c) The capacity of conveying
- d) In a conveying system possibility of use of gravity.
- e) The capacity of handling / conveying equipment should match with the capacity of processing unit or units.
- f) Spillage of conveyed products should be avoided.
- g) Pollution of the environment due to noise or dust by the conveying system should also be avoided.

Lecture 20: Design of Belt conveyer

A belt conveyer is essentially an endless belt operating between two or more pulleys with its load supported on idlers. Usually the pulley at the discharge end is driven by some source of power and this serves to move the belt. Materials are conveyed by the belt supported by the rollers i.e. idlers. The initial cost of belt conveyor is **high for short distances**, but for longer distances the initial cost of belt conveying system is low

The belt may be flat for transporting bagged material or V-shaped.

Flat belt – It is used for sacks and boxes or other package materials.

Troughed belt – It has higher loading capacity without danger of spillage and suitable for almost any materials in bulk, whether dry or damp.

Belt conveyer may be horizontal, inclined or combination of both. The degree of inclination is limited and depends on the size and nature of material.

Advantages

1. High mechanical efficiency
2. Damage to product is slight
3. carrying capacity is high
4. Noise level and hp requirement is low

Disadvantages

1. Limit to the angle of elevation
2. high initial cost
3. not potable
4. Discharge at any point other than end is difficult

The belt conveyor consists of a belt, drive mechanism and end pulleys, idlers and loading and discharge devices.

Components of belt conveyer

1. Belt – Made of stitched canvas or woven materials impregnated with vulcanized rubber and coated top and bottom with a rubber surface.
2. Idler pulley- These may be single pulley or multiple pulley unit spaced 4 to 8 feet beneath the belt to carry the idled belt. Pulleys may be plain wood or light steel construction.
3. Drive mechanism – It should be driven at the discharge end of the belt. Dual motor drives for heavy belt tensions may be provided. The pulley should be large enough or an idle pulley can be used to increase the wrap contact area and insure positive drive.
4. Tension mechanism – These are necessary to adjust for the stretch of the belt while in service.
5. Feeding mechanism – Material may be fed onto the belt at any point by hand or mechanical feeder.
6. Discharge mechanism – Simplest method is over the end of the belt. Materials can be removed from any section of the belt by scrapers. Trippers which consists of two idler pulleys which double the belt into a letter S. Discharge is over the top of the pulley and into a chute that directs the material to one side of the belt.
7. Belt cleaner- When conveying moist sticky materials, brushes, high pressure water or air nozzle must be used.

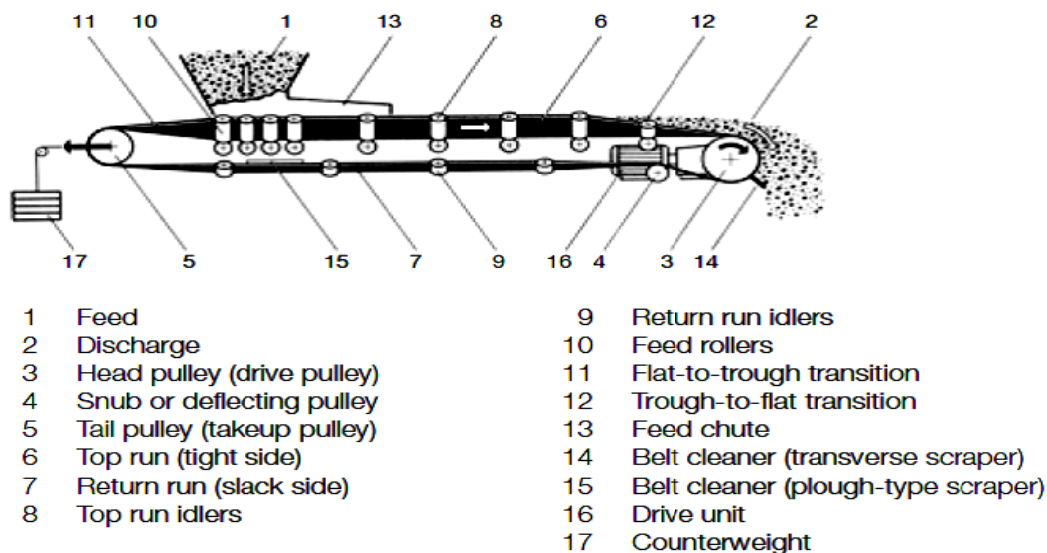
Maximum inclination depends on co-efficient of friction between material and belt and angle of repose of the material. It should be 7-10° less than angle of friction. Normally 15 to 23° is taken

as the belt inclination. In inclined belt, safety devices like electrically operated brakes and ratchet and pawl type hold back to prevent accident in case of power failure.

Conveyor belt (expensive part) should meet

- a) low hygroscopicity
- b) high strength
- c) low self weight
- d) small specific elongation
- e) high flexibility
- f) high resistivity to ply separation
- g) long service life

The width of belt and no. of plies should be such to provide sufficient rigidity to prevent sagging. For efficient joint, vulcanised splicing is adopted. The load carrying idler pulleys for flat belt are of 75-150mm dia and mounted on ball or ceramic bush bearing. To increase the capacity, belt is given trough shape by using three rollers. The central roller is horizontal and side ones are inclined at an angle 20° . Troughed belt can be used for steeper inclines.



Design calculations

The following data are to be known for design of belt conveyor

1. Characteristics of the material
2. Distance over which material is to be conveyed
3. For inclined conveyor the height of lift
4. Quantity of material to be conveyed per hour i.e. average and peak capacity
5. Bulk density of material
6. Average size of lump and maximum lump
7. Temperature of conveying material if hot and other special features
8. operating conditions

The first step in the design of a belt conveyor with a specified conveying capacity is to determine the speed and width of the belt. The belt speed should be selected to minimise product spillage or removal of fines due to velocity of the belt. For transportation of grains, the belt speed should not increase 3.5 m/s. Generally, for grain conveying, belt speed of 2.5 to 2.8 m/s is recommended. The selection of belt width will depend upon the capacity requirement, speed of operation, angle of inclination of belt conveyor, trough angle and depth.

The capacity of belt conveyer can be calculated as:

Capacity (m³ /h = area of cross section (m²) x belt speed (m/min) x 60

Capacity (kg/h) = capacity m³/h x bulk density

Belt width

Fore bulk load, belt width is determined by conveyer capacity and size of material conveyed.

For unit load- No of pices and overall dimension

Let B = Width of belt

B = spread of material on belt i.e. base of the triangle

On a belt supported by flat idlers, free flowing material assume the shape of an isosceles triangle.

To prevent spill of belt edges

b = 0.8 B (for general purposes)

or b = (0.9B - 0.05) m

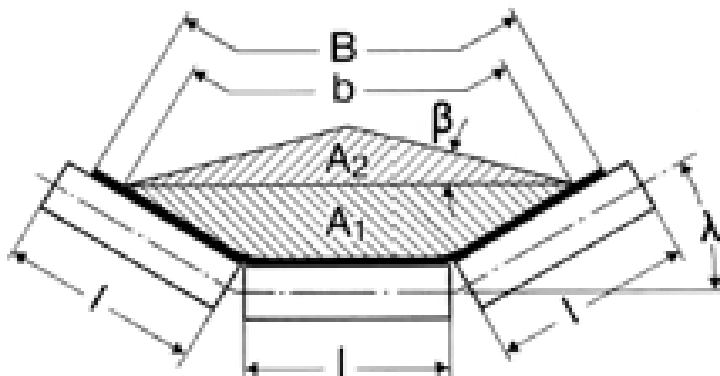
The angle of triangle base $\Phi_1 = 0.35 \Phi$

Where Φ = static angle of repose of load

The c/s area of load on flat belt

$$F = \frac{1}{2} bh = \frac{b}{2} \times \frac{b}{2} \times \tan \Phi_1$$

$$= (0.8 B \times 0.8 B \times \tan(0.35 \Phi)) / 4$$



Cross sectional area of load on troughed belt = area of trapezoid = area of triangle

$$= b^2 \tan \Phi_1 + (0.4B + b) 0.2B \tan 20^\circ$$

Capacity of belt conveyer , Q (t/h) = 3600 F v γ c₁

Where v = belt speed, m/s

γ = bulk density, t/m³

c₁ = factor taken into account the inclination of belt (1 for horizontal conveyer)

Belt speed depends upon nature of load conveyed, belt width and conveyer inclination. The belt width computed is checked with lump size of load. The belt width finally chosen is rounded off to the nearest larger standard width.

Horse power requirement

The total power required to drive a belt conveyor are accounted for

- a) power required to drive empty belt, P_e
- b) power required to convey material horizontally, P_h
- c) power required for elevating the material for inclined conveyor, P_i

There are few secondary resistances to keep belt in central position, frictional resistance at places of feeding and discharge and resistance due to cleaning. For rough estimation, all resistances are taken up by secondary resistance factor.

$$\text{HP at drive shaft, KW } P_t = c (P_e + P_h) \pm P_i \\ = c (G_o L f v / 1000 + G_m L f v / 1000) \pm G_m H v / 1000$$

where c = a factor that takes care of the effects of secondary resistances which depends on length of conveyor

G_o = Weight of belt and roller for top and bottom run per m, N/m

G_m = Weight of material per meter length, N/m

L = length of conveyor assuming material is conveyed by the entire length

H = height of lift, (m) = $L \sin \theta$

θ = inclination angle of conveyor

V = velocity of belt, m/s

f = friction factor for idler pulley

0.025 for friction bearing/roller bearing

0.05 un metal bush

0.1 for other type bush

$$\text{Actual power} = P_m (\text{primemover}) = P_t / (\eta_d \eta_t)$$

η_d = efficiency of overall conveying

η_t = Transmission efficiency

Salient points

For grain conveying, Belt speed – 2.5-2.8 m/s

Troughed angle of 20° for paddy

Paddy form surcharge angle of 20°

Pull of load is taken by longitudinal strength of belt

Transverse strength supports the load

Idlers maintain a permanent, well balanced smooth running alignment

Fat belt idler: Low capacity, For inexpensive low cost conveying, angle of repose not less than 35°

Troughed idler with 20° trough: For bulk materials

Troughed idlers 35° and 45° trough: small particle light weight material, crushed stone

Idler dia 10-15 cm, Belt speed 91-244 m/min, Belt width 50.5-91 cm

Incorrect idler spacing: Belt undulation

Pitch of depends on Idler load rating, belt sag, tension, speed

Idler spacing = belt width but not more than 1.2 m

Additional shock absorbing idler at loading point

In inclined belt operation, spacing of troughed idler is about one half of normal

Grain can be unloaded at intermediate point by a scraper plough or tripper

Product leaving at end pulley flow path is parabola

Inclined conveyor conveying angle of 12°

Lecture 21: Design of screw conveyer

The screw conveyers do not have a flexible pulling member. It consists of a shaft mounted screw rotating in a horizontal, inclined or vertical trough and of the drive unit setting the shaft in rotary motion. As the shaft rotates, the material fed to it is moved forward by the thrust of the screw or flights. The shaft or screw rotates along the longitudinal axis of the U-shaped trough. The material to be conveyed is filled into trough by one or more feed hopper and discharged at the end of the trough or along the run through opening in the trough.

The screw conveyor consists of a tubular or U-shaped trough in which a shaft with spiral screw revolves. The screw shaft is supported by hanger bearings at ends. The rotation of screw pushes the grain along the trough. The screw conveyor is used in grain handling facilities, animal feed industries and other installations for conveying of products generally for short distances. Screw conveyor requires relatively high power and is more susceptible to wear than other types of conveyors. The pitch of a standard screw which is the distance from the centre of one thread to the centre of the next thread is equal to its diameter.

As the screw conveyor's driving mechanism is simpler, and no tensioning device is required, the initial cost of the conveyor is lower than any other conveyor with the same length and capacity.

The main parts of a screw conveyor are screw blade, screw shaft, Coupling, Trough, Cover, Inlet and outlet gates, Bearings and drive mechanism.

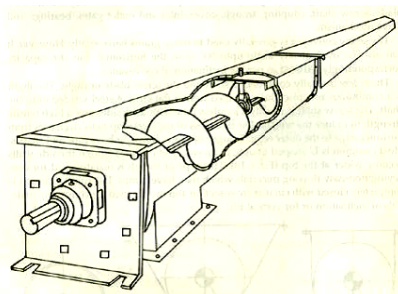
The screw conveyor is generally used to move grains horizontally. However, it can also be used at any angle up to 90° from the horizontal, but the capacity correspondingly reduced as per the inclination of conveyance.

The screw basically consists of a shaft and the screw blade or flight. The flight is a continuous one piece helix shaped from a flat strip of steel welded onto the shaft. The screw shaft is usually a joint less tube with thick sides and a high tensile strength to reduce the weight. The thickness of the steel strip helix decreases from the inner edge to the outer edge.

Troughs of screw conveyor have different shapes. Most common is U shaped trough.

In an enlarged or flared trough the side walls become wider at the top. This type of trough is usually used for conveying non-easy flowing materials which may have lumps.

The tubular trough is completely closed with circular cross-section and mostly used for conveying materials at inclination or for vertical lift



Advantage –

1. Simple design
2. Easy to maintain and disassemble
3. of small width
4. permits intermediate discharge
5. dust tight by jacketing the trough

Disadvantages –

1. Materials satisfactorily handled is few
2. cannot be used for large lumped, abrasive and sticky materials
3. Effective when uniformly fed. Overload cause bottleneck near intermediate bearing and stop the screw
4. Friction of material against screw and trough responsible for high power consumption
5. Crushing of material
6. Considerable wear of conveyer parts

It is generally used for low and medium capacities (upto 100m³/h) for short runs (40m horizontal or 30m height). It is used to handle finely divided powders, heavy viscous material, granular materials etc. They are used for moving food products. They are also used for batch or continuous mixing, for feeding where fairly accurate rate is required, short run conveying and elevating job.

The screw of conveyer may be of 4 types

Continuous spiral screw – Used for granular and powdered materials

Ribbon screw- wet or sticky substances, lumpy

Paddle flight screw – used for packed materials

Cut flight screw- used for mixing and conveying.

Cut flight and paddle flight conveyer have lower capacity and higher power consumption because of intensive mixing of the load.

The screw is made of 4 to 8 mm sheet steel which are welded to the shaft. A ribbon screw is secured on shaft by means of radial rods. The shaft may be solid or hollow. The standard pitch screw has a pitch approximately equals to its diameter.(used for horizontal and incline upto 20°). Half standard pitch screw are used for inclination greater than 20°.

The main bearing is generally located at the discharge end of the conveyer. It is a thrust bearing taking up the force of frictional resistances directed along the longitudinal axis of the conveyer. The intermediate bearing are hangers of T-design that are secured to the trough edge. The trough is made of sheet steel ranging from 3 to 8mm depending on screw diameter and abrasivity of material. Flanged angles are welded across the trough and its edges serve as stiffeners. The inner diameter of trough is slightly larger than the screw. The clearance is 6 to 9.5mm. The intermediate discharge spout have gates with rack gear and crank for opening and closing. The drive unit consists of electric motor, an enclosed gear or worm reducer and the coupling connecting motor with reducer and reducer with conveyer shaft.

Capacity

The capacity of a screw conveyer depends on the screw diameter D in m, screw pitch S in m, its speed n in rpm and the loading efficiency of the vertical c/s area of the screw Ψ . The capacity per hour of a screw conveyer with a continuous screw

$$Q \text{ (t/h)} = V\gamma = 60 \pi / 4 D^2 S n \Psi \gamma c$$

V = capacity in m³/h

Γ = bulk density in t/m³

C = factor taking into account the incline of the conveyer

Conveyer angle β	0°	5°	10°	15°	20°
C	1	0.9	0.8	0.7	0.65

Screw pitch $S = D$ for typical design
 $S = 0.8D$ for slow flowing & abrasive materials

The loading efficiency Ψ is taken relatively low
 $= 0.125$ for slow flowing abrasive materials
 $= 0.25$ for slow flowing mildly abrasive
 0.32 for free flowing mildly abrasive materials
 $= 0.4$ for free flowing non-abrasive materials

The rotating speed of screw depends on the required capacity, screw diameter and nature of the material conveyed. The maximum rotating speed of screw is applied to light non-abrasive loads like grain and seed.

$$F = \pi/4 (D^2 - d^2) \text{ where } d = \text{shaft diameter}$$

The required screw diameter is calculated according to the required capacity Q . The lump size of material affects screw diameter.

The total resistance to motion in a screw conveyer is made up of the following resistances.

- friction of the material against the trough
- Friction of the material against the surface of the screw
- Friction in the intermediate and terminal bearing
- Friction in the axial thrust bearing
- Additional resistances due to packing, mixing, of materials and friction on the edge of the screw against particle drawn into the clearance between screw and trough

In inclined conveyer power expended against gravity.

For horizontal conveyer power required on the screw shaft

$$N_o = QLw_o/367 \text{ KW}$$

For inclined conveyer with an angle β to horizontal

$$\text{The required power } N_o = Q/367(Lw_o \pm H)$$

$$= QL/367 (w_o \pm \sin \beta)$$

$w_o = 2.5$ for air-dry brown coal, nut coal, rock salt

$w_o = 4.0$ lumpy, fine dry clay, cement ash

Torque capacity for screw shaft rotating at n rpm

$$M_o = 102 N_o/w = 102 \times 60 \times N_o / 2\pi n = 975 N_o/n$$

The power requirement of screw conveyors for horizontal operation is determined by the following equation.

Horse power = $QLWF/4560$

where, Q = conveyor capacity, m³/hr

L = conveyor length, m

W = bulk material weight, kg/m³

F = material factor (for paddy 0.4)

If the calculated horsepower is less than 1.0, double the value.

horse power = 1 to 2 multiply the value by 1.5

horse power = 2 to 4 multiply the value by 1.25

horse power = 4 to 5 multiply the value by 1.1

For horsepower values of more than 5, no correction is required.

Salient points

For conveying short distance

High power and susceptible to wear

Standard screw pitch = diameter

Initial cost is lower

Screw blade, shaft, coupling, trough, cover, inlet outlet gate, Bearing, Drive mechanism

Enlarged or flared trough- Non-easy flowing material, lump

Tubular trough- inclined, vertical lift

U-trough- More common for granular material

Inclined conveyor capacity: 15° - 0.75; 25° - 0.5

Power requirement = $QLWF$

F material factor paddy 0.4

Lecture 22: Design of bucket elevator

Bucket elevator consists of an endless chain or belt to which buckets are attached and mounted on overhead (driving) and foot wheel (take up pulley). It is generally used for elevating pulverized, granular or lumpy materials along a vertical or steeply incline path. It is not suited for sticky materials or material which will not flow freely. Inclined elevator require carrying idlers or supporting rail. It is commonly used for handling ore, coal, granular materials, cement and similar loose easily flowing material.

The vertical lift of the elevator may range between few metres to more than 50 m.

Capacities of bucket elevators may vary from 2 to 1000 t/hr.

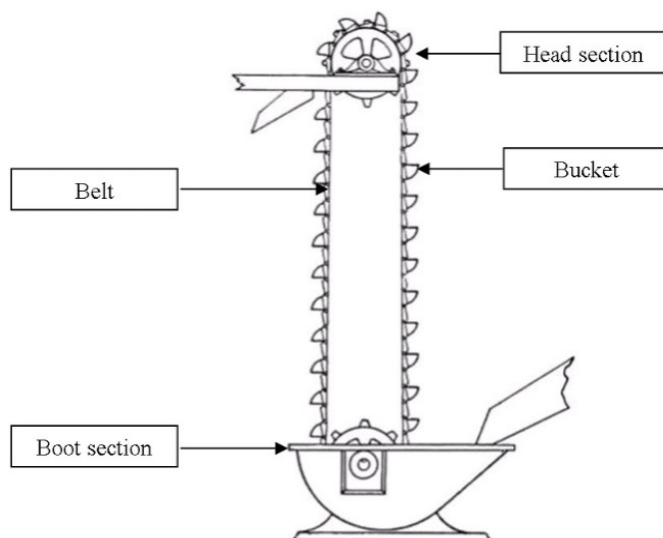
Bucket elevators are broadly classified into two general types

- (1) Spaced bucket elevators
- (2) Continuous bucket elevators.

The spaced bucket centrifugal discharge type is most commonly used for elevating the grains. Bucket elevators are usually mounted at a fixed location, but they can also be mounted in a mobile frame. Bucket elevators have high capacities and it is a fairly cheap and efficient means of vertical conveyance.

Construction

1. Bucket or fork to carry the material
2. A belt or chain usually two strand of chain to carry the bucket and transmit the pull
3. The driving link having motors, reduction gears, drum or sprocket mounted on the top of the structure
4. Accessories for loading the bucket, receiving the discharge material, maintaining the belt tension, casing and supporting structures



Advantage

- a) Small cross sectional dimension (transverse compactness)
- b) Possibility for lifting load to an appreciable height
- c) Wide range of throughput capacity

Limitation –

- a) material must be supplied in an uniform flow rate. On overloading buckets may break off from belt or chain

Classification

- a) Vertical or inclined
- b) Bucket arrangement with or without spacing
- c) Belt or chain (single or double strand)
- d) High speed centrifugal or low speed gravity discharge

The pulling member with the buckets receives motion from drive unit and is initially stressed by take up. Bulk material is loaded into the feed hopper at the lower conveyer end where it is dredged by digging action of the buckets, lifted and discharged over the upper pulley into the discharge spout. The drive contains hold back brake preventing reversal of the moving part. Casing for elevator runs may be made of wood/ply wood or mild steel sheet. The buckets may be enclosed in a single housing called leg or two legs may be used.

The buckets are shaped with either sharp or rounded bottoms to facilitate discharge. Width of belt is 35-40mm wider than the bucket width. The buckets are bolted to the belt with special flat head bolts. Usually chains are preferred for high capacity units intended to carry heavy materials to a great height. The buckets are attached to the chain by means of angular attachment or are bolted or riveted to specially shaped link plates. For bucket width 160-250mm, single chain is used and for wide bucket having width 320-630mm, two chains are used. The driving pulley diameter depends on the number of belt plies (125 to 150 in mm) and usually 400-1250mm. The no. of teeth of chain elevator sprockets are generally 6-20 at speed 4.75 to 75.5 rpm.

Types of bucket

The thickness of metal used for buckets is 2 to 6 mm mild steel. The spacing between buckets is generally 300-600mm.

Deep bucket – The front edge of buckets of this type is sheared off at an angle of 65° , giving them considerable depth. They are used to convey dry free flowing bulk materials. Width- 135-450mm, height – 101-240mm, capacity-0.75 to 14.5 lit.

Round bottom shallow – Used for conveyance of moist, packing, slow flowing bulk materials. Width – 160-450mm, h = 100-285mm, capacity- 0.65 to 15 lit. low lip and shallowness facilitate discharge. They are used for spaced bucket elevator.

V-bucket – Used for continuous discharge elevator and for conveyance of heavy, lumpy and abrasive materials. Width – 160-900mm, h=155-620mm, capacity- 1.5 to 130lit.

Rubberised textile belt holds the bucket less firmly and endure less effort than chain. However it is able to run at higher speed and wears less than chain. Belt are so used in high speed elevator at low and medium capacity and medium height of elevation for conveying powder and small lumped materials. Bucket speed for belt elevator – 0.8 to 2.5 m/s. for chain elevator 0.4 to 1.25 m/s.

Discharge from bucket elevator

Centrifugal discharge– It is extensively used for handling small grains in elevator. The material is discharged by centrifugal action as the bucket pass over the head pulley or sprocket and falls directly into the discharge spout of the upper casing. Before reaching the pulley, the bucket moves uniformly along a rectilinear path and only force of gravity acts on the load. When bucket begins to turn around the pulley, the centrifugal force is added to the gravity. It is used for high speed elevator with spaced buckets handling free flowing, powdered, small lumped and granular materials. Bucket speed 1-2 m/s. Bucket spacing should be such that particle ejected from one bucket should not hit the preceding bucket.

Gravity discharge – Material is discharged by gravity when buckets are inverted. Used for slow flowing powder, moist, flaky and wet materials. Snub pulley are used below the head sprocket to bring the bucket into an inverted position above the discharge chute. Bucket speed – 0.6 to 0.8 m/s.

Continuous type (Direct gravity) – The buckets are mounted continuously along the chain. They are loaded after they round the foot wheel. At the head, the discharge from each bucket is over the front of the preceeding bucket which forms a chute or guide to the fixed discharge spout. Used in slow speed units. Bucket speed 0.4 to 0.8 m/s. handling mainly heavy, large lumped and abrasive materials.

Design calculations

Elevator type and bucket shape depends on characteristics of load to be elevated and the required handling capacity.

$$Q = 3.6 v \gamma \Psi i_o / a$$

Where i_o = capacity of bucket in lit

A = Bucket spacing in m = (2.5 to 3) h for shallow and deep bucket
= h for continuous V bucket

h = height of bucket

γ = Bulk density of load in t/m^3

Ψ = bucket loading efficiency 0.8 to 1 for fine and 0.4-0.5 for big lump

Q = capacity in t/h

V = speed of elevator bucket

The theoretical hp of a bucket elevator is calculated

$$HP = vqH/75 + v/75 (qH + q_oH') \mu_n$$

$$= Q_t H/270 + (Q_t H/270 + q_o v H'/75) \mu_n$$

Where v = speed of elevator bucket, m/s

Q_t = capacity of elevator, t/h

H = Height of lift, m

H' = length of belt and bucket

Q_o = weight of elevator belt and bucket per mtr length

μ_n = Co-efficient of friction between belt and pulley

Actual hp = theoritical hp / efficiency of bucket elevator

Required motor power on the drive shaft

$$N_o = 1.15 QH/367 + k_3 q_o H v / 367 \quad KW$$

First term denotes the power consumed to lift the load and second term denotes the frictional resistance of moving part.

Thickness of belt $t = \delta z + 1.5 + 1$

Z = no. of plies

$\Delta = 1.25$ for light, 1.9 for medium and 2 for high strength belt

Salient points

Spaced bucket centrifugal discharge are used for grains

Cheap means of vertical conveying

Curved hood for proper centrifugal discharge

Boot is loaded from front, back or both

Bucket elevator with belt carrier- $2.5-4$ m/s

Low belt speed- discharge difficult

High speed- Buckets are not fed well

Gravitational discharge- low belt speed, buckets mounted closely together

Centrifugal discharge- High belt speed, small drive pulley

Head section, Boot section, leg, belt, bucket, drive

Product is not thrown well into discharge chute and fall in down leg- Bulk logging

Adjustable cut off plate to avoid bulk logging

To increase friction co-efficient- Lagging head pulley with rubber

Shaft- Resist bending, torque carrying capacity, level

Antifriction properly lubricated bearing

Pick up of product by loading chute above centre line of return pulley

Requires adequate maintenance, service and inspection –openings provided

Total stretch of belt should not be more than $1-2\%$

Belt: Polyester or polyamide with synthetic rubber/PVC

Bolted clamp joint, Lap joint or butt strap joint

Belt width 25 mm more than bucket width

Pulley width $80-100$ mm more than belt

Inside casing width $150-200$ mm more than belt

Buckets should have wide open mouth and resultant force directed towards lip of bucket

Top angle of bucket 80° , bottom angle $20-30^\circ$

Spacing is 2 to 3 times the projected width of bucket

Flat disc head bolt to fix to belt

Power requirement = $QHFg$

$F=1.5$ elevator loaded upside, 1.2 bottom side, $10-15\%$ more for friction

Lecture 23: Design of grain Dryers

Drying refers to the removal of relatively small amount of moisture from a solid or nearly solid material by evaporation. Drying involves both heat and mass transfer operations simultaneously. In drying, the final m.c. is generally more than 2.5%, whereas dehydration refers to removal of more water so that the final m.c. is less than 2.5%.

Thin layer drying refers to the grain drying process in which all grains are fully exposed to the drying air under constant drying conditions, i.e., at constant air temperature, and humidity. Generally up to 20 cm thickness of grain bed (with a recommended air-grain ratio) is taken as thin layer. All commercial flow dryers are designed on thin layer drying principles.

DEEP BED DRYING

In deep bed drying all the grains in the dryer are not fully exposed to the same condition of drying air.

The condition of drying air at any point in the grain mass changes with time and at any times it also changes with the depth of the grain bed.

Over and above the rate of air flow per unit mass of grain is small compared to the thin layer drying of grain.

All on-farm static bed batch dryers are designed on deep bed drying principle

Remarks on Deep Bed Drying

1. If drying air is at high relative humidity and relatively low temperature is used, then the total drying time will be very long due to slow rate of drying, which may cause spoilage of grains.
2. The correct choice of airflow rate is very important.

Drying air at high temperature cannot be used due to development of moisture gradients within the grain bed. It leads to nonuniform drying of grain. In general, an air temperature of 40°C (15°C rise) is recommended for deep bed drying.

Preliminary dryer selection parameters

- Physico-chemical properties of the crop
- Drying characteristics of the crop
- Flow of crop to and from the dryer
- Product qualities
- Dust recovery problem
- Facilities available at the site of installation

Final selection of the dryer

1. The dryer should be of proper size matching with the demand of a farmer, Miller, or any organization.
2. The price of the dryer should be reasonable.
3. The dryer should be simple in design and should be made of different, cheap, and locally available materials so that it can be manufactured locally.
4. It should be easy to operate.
5. It should be possible to make the dryer portable, if necessary.
6. The operating cost should be minimum. Solar-cum-furnace (fired with Agricultural waste like husk, shells, etc.) air heating system should be introduced in grain drying to minimize the cost of drying
7. The repair and maintenance requirements should be minimum.

8. It should be possible to use the dryer for different grains and to be used as a storage bin later for its maximum utilization.

Design of Grain Dryers

As indicated earlier, heated air grain dryers can be divided into three major groups:

1. Static deep bed batch dryers
2. Continuous flow batch dryers (either mixing or non-mixing type)
3. Continuous dryers. Grain dryers mainly consist of (a) drying chamber; (b) air distribution system; (c) direct or indirect air heating system; (d) blower; (e) control system (if any); and (f) grain conveying system (for flow dryers)

The following important factors are taken into consideration in the design of Heated air grain dryers:

1. Dryer factors

- a. Size, shape, and type of dryer
- b. Grain feeding rate
- c. Total drying time
- d. Airflow pattern and air distribution system
- e. Depth of grain bed in the dryer
- f. System of cooling grain (if any)

2. Air factors

- a. Velocity and airflow rate per unit mass of the grain
- b. Temperatures and relative humidities of the heated air and exhaust air
- c. Static pressure of the air at which it is blown
- d. Average ambient conditions

3. Grain factors

- a. Type, variety, and condition of grain
- b. Initial and final moisture contents of grain
- c. The usage of dried grain
- d. Latent heat of vaporization of grain moisture

4. Heating system

- a. Type of fuel and rate of fuel supply
- b. Type of burner (for liquid fuel) or type of furnace (for solid fuel)
- c. Type of heat exchanger (for indirect heating system)

Simple Method

A simple test procedure is so designed as to determine the approximate performance of the grain dryer.

Simple Test Procedure for Continuous Flow Dryer

Besides the test items tabulated in the "Specifications" section, the following items are to be taken into consideration for continuous flow dryers:

1. Moisture content after each pass (9%)
2. Residence time in the dryer for each circulation (h)
3. Number of passes
4. Tempering time (h)
5. Average rate of moisture reduction or rate of moisture evaporation in each circulation (kg/h)
6. Rate of grain recirculation (tons/h)
7. Drying air temperature at each pass (°C)
8. Weight of remaining grain in the dryer, elevator, etc. (kg)

Rigorous Method

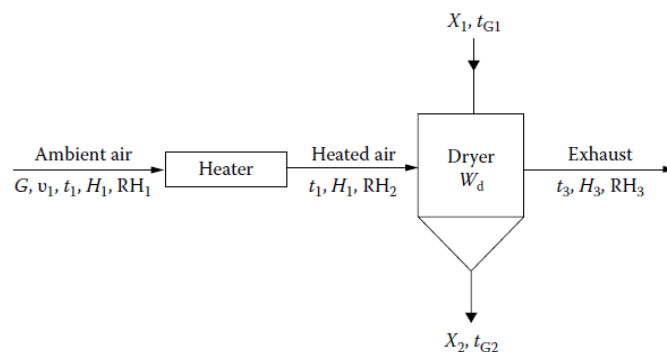
Rigorous test procedures for some batch and continuous flow dryers are given as follows. The whole test procedure can be grouped into the following major heads:

1. Checking construction
2. Drying performance test
3. Fanblower performance test
4. Control system performance test
5. Handling equipment performance test
6. Checking of different dryer parts after disassembling (after the drying tests)

Calculation of Air, Heat, and Fuel Requirements for Heated Air Dryers

The airflow rate required for heated air drying systems can be calculated as follows.

The rate of airflow required for drying may be calculated by making heat balance. The heated air drying system is represented by



where

G is the airflow rate, m³/min

H_1 and H_2 are humidities of ambient and heated air, kg/kg

H_3 is the humidity of exhaust air, kg/kg

RH_1 , RH_2 , and RH_3 , are relative humidities of ambient, heated, and exhaust air. respectively, %

t_1, t_2, t_3 , are dry bulb temperatures of ambient, heated, and exhaust air.

respectively, °C

W is the total weight of bone dry grain in the dryer, kg

X_1 and X_2 are initial and final moisture contents of grain (d.b.), kg/kg

t_{G1} and t_{G2} are initial and final grain temperatures, °C

V_1 is the initial humid volume, m³/kg

Heat supplied by drying air, q_2 , kcal:

$$q_2 = (0.24 + 0.45 H_1) G' \times (t_2 - t_3) \theta$$

where

G' is the rate of air supply, kg/min

θ is the total drying time, min

AMOUNT OF HEAT REQUIRED

Heat required for evaporation of moisture from the grain, q_1 , kcal

$$q_1 = W_d (X_1 - X_2) \lambda$$

where λ is the average value of latent heat of vaporization of moisture from the grain, kcal/kg.

Sensible heat required to raise the temperature of the grain and its moisture,

q , kcal:

$$q = W_d C_g (t_{G2} - t_{G1}) + W_d C_w (t_{G2} - t_{G1}) X_1$$

where C_g and C_w are specific heats of grain and water, respectively, kcal/kg °C.

Therefore,

$$q_2 = q_1 + q$$

or

$$G' = (0.24 + 0.45 H_1) (t_2 - t_3) \theta$$

$$= W_d [(X_1 - X_2) \lambda + C_g (t_{G2} - t_{G1}) + C_w (t_{G2} - t_{G1}) X_1]$$

Or

$$G' = \frac{W_d [(X_1 - X_2) \lambda + C_g (t_{G2} - t_{G1}) + C_w (t_{G2} - t_{G1}) X_1]}{(0.24 + 0.45 H_1) (t_2 - t_3) \theta}$$

where, v is the humid volume.

Fuel consumption

The rate of fuel consumption can be calculated as follows:

$$f = \frac{q_a'}{\eta_x \eta_b \eta_{ex} \times C_n}$$

Where,

f is the fuel rate, kg/h

q_a' is the total heat required to heat the drying air, kcal/h

C_n , is the calorific value of fuel, kcal/kg of fuel

η is the efficiency of the heating system

η_{ex} is the efficiency of the heat exchanger

η_b is the efficiency of the boiler, if any

Lecture 24: Design of RPEC grain Dryer

Problems on Dryer Design

Solved Problems

1. Design a PHTC-recirculating batch dryer (Figure 6.1) having holding capacity of 2 tons of paddy with 15% m.c. (w.b.).

Assume the following data:

Ambient air temperature = 30°C

Relative humidity of ambient air = 70%

Initial m.c. of paddy = 30% (w.b.)

Final m.c. of paddy = 15% (w.b.)

Grain inlet temperature = 30°C

Grain outlet temperature = 70°C

Heated air temperature = 85°C

Exhaust air temperature = 40°C

Latent heat of water vapor = 600 kcal/kg

Angle of repose = 45°

Thickness of grain bed to be dried = 20 cm

Bulk density of paddy grain at 15% m.c. = 575 kg/m³

Diameter of plenum chamber = 135 cm

Diameter of dryer = 175 cm

Hopper angle = 50°

Drying time = 3 h

Solution

Assumptions

1. Distance between top of dryer and top of plenum chamber = 15 cm
2. Angle of conical portion of plenum chamber = 45°
3. Diameter of grain outlet = 15 cm
4. Specific heat of grain = 0.4 kcal/kg °C

Height of the dryer

$$\text{Height, } H = H_1 + H_3$$

$$H_1 = H_2 + \frac{135}{2} \tan 45^\circ + 15 = H_2 + 82.5$$

$$H_3 = \frac{175 - 15}{2} \tan 50^\circ = 95.34 = 96 \text{ cm}$$

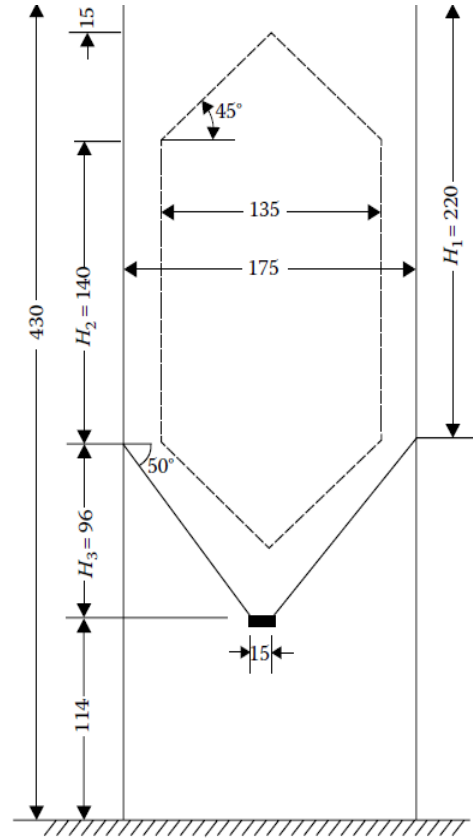


Figure 6.1 Specifications of PHTC dryer as per solution of Problem 1.

Volume of plenum chamber

V_1 = volume of inner cylinder + volume of inner cones

$$V_1 = \frac{\pi}{4} (135)^2 H_2 + 2 \times \frac{1}{3} \times \pi \left(\frac{135}{2} \right)^2 \left(\frac{135}{2} \tan 45^\circ \right)$$

$$\text{or } V_1 = 14,313.88 H_1 - 536,770.53$$

Suppose V_2 = Volume of outer cylinder and hopper bottom

$$\begin{aligned} \text{Therefore, } V_2 &= \frac{\pi}{4} (175)^2 H_1 + \frac{1}{3} \times \pi \times \tan 50^\circ \left[\left(\frac{175}{2} \right)^3 - \left(\frac{15}{2} \right)^3 \right] \\ &= 24,055.9 H_1 + 831,557 \text{ cm}^3 \end{aligned}$$

Volume of the drying chamber = $V_2 - V_1$

$$\begin{aligned} &= 24,055.9 H_1 + 831,557 - 14,313.88 H_1 + 536,770 \\ &= 9742.02 H_1 + 1,368,327 \end{aligned}$$

$$\begin{aligned}\text{Volume of the drying chamber} &= \frac{2000}{575} = 3.478 \text{ m}^3 \\ &= 3,478,000 \text{ cm}^3\end{aligned}$$

Hence, from Equations 6.3 and 6.4

$$9742.02H_1 + 1,368,327 = 3,478,000$$

$$H_1 = 216 \text{ cm}$$

$$H_1 = 220 \text{ cm}$$

$$H_2 = 220 - 82.5 = 137.5 \text{ cm}$$

$$\text{Therefore, } H_2 \approx 140 \text{ cm}$$

$$H_3 = 90 \text{ cm}$$

Air requirement

$$\text{Bone dry paddy} = 2000 (1 - 0.15) = 1700 \text{ kg}$$

$$\text{Initial moisture content} = 30\% \text{ (w.b.)} = 42.857\% \text{ (d.b.)}$$

$$\text{Final moisture content} = 15\% \text{ (w.b.)} = 17.647\% \text{ (d.b.)}$$

Weight of moisture evaporated

$$= \text{Weight of bone dry paddy} \times (X_1 - X_2)$$

$$= 1700(0.42857 - 0.17647)$$

$$= 428.57 \text{ kg}$$

From psychrometric chart

$$\text{Absolute humidity of ambient air} = 0.019 \text{ kg/kg}$$

$$\text{Humid heat of ambient air}$$

$$S = 0.24 + 0.45H$$

$$= 0.24 + 0.45 \times 0.019$$

$$= 0.24855 \text{ kcal/kg } ^\circ\text{C}$$

Let G be the rate of air supply in kg/min.

Heat supplied by the air in 180 min

$$= G \times S \times (t_2 - t_1) \times \theta$$

$$= G(0.24855)(875 - 40) \times 3 \times 60$$

$$= 2013.255G$$

Heat utilized

1. As sensible heat of grain

$$= \text{B.D. grain} \times \text{specific heat of grain} \times \text{temperature rise}$$

$$= 1700 \times 0.4 \times (70 - 30)$$

$$= 27,200 \text{ kcal}$$

2. As sensible heat of water

$$\begin{aligned} &= \text{Total weight of water} \times \text{specific heat of water} \times \text{temperature rise} \\ &= 1700 \times 0.42857 \times 1.0 \times (70 - 30) \\ &= 29,140 \text{ kcal} \end{aligned}$$

3. As latent heat of water vapor

$$\begin{aligned} &= \text{Water evaporated} \times \text{latent heat of water} \\ &= 428.57 \times 600 \\ &= 257,100 \text{ kcal} \end{aligned}$$

$$\begin{aligned} \text{Total heat utilized} &= \text{sum of 6.6 through 6.8} \\ &= 313,440 \text{ kcal} \end{aligned}$$

Suppose, heat loss = 10%

$$\text{Net heat required} = \frac{313,440}{0.9} = 348,266.6 \text{ kcal}$$

Hence, $2013.255 \text{ G} = 348,266.6$

$$G = 172.987 \text{ kg/min}$$

From the psychrometric chart, humid volume of the ambient air = $0.88 \text{ m}^3/\text{kg}$

$$\begin{aligned} \text{So, air required} &= 172.987 \times 0.884 \\ &= 152.92 \text{ m}^3/\text{min} \end{aligned}$$

$$\text{Air requirement} = 155 \text{ m}^3/\text{min}$$

Static pressure drop

Surface area of plenum chamber

$$\begin{aligned} &= \pi \times 135 \times 140 + \left[\frac{1}{2} \pi \times 135 \times \left(\frac{135}{2} \sec 45^\circ \right) \right] \times 2 \\ &= 59,383.8 + 28,627.76 \\ &= 88,011.56 \text{ cm}^2 \end{aligned}$$

Since maximum 50% of the area is perforated, area through which air passes = 44,005.78 cm²

$$\begin{aligned} \text{Air requirement per m}^2 &= \frac{155}{44,005.78} \\ &= 35.1 \text{ m}^3/\text{min}/\text{m}^2 \end{aligned}$$

From Shedd's curve (*Agri. Engg. Handbook*), static pressure drop for 32.12 m³/min/m² = 8.13 cm of water per 30.48 cm grain depth.

Depth of grain = 20 cm

$$\text{So, pressure drop} = \frac{8.13}{30.48} \times 20 = 5.42 \text{ cm of water}$$

Density of air = 1.13/kg/m³

$$\begin{aligned} \text{Pressure drop in terms of air column} &= \frac{5.42}{100} \times \frac{1000}{1.13} \\ &= 47.95 \text{ m} \end{aligned}$$

Hp required

$$\begin{aligned} &= \frac{\text{Height of air column (m)} \times \text{air flow rate (kg/min)}}{4500} \\ &= \frac{47.95}{4500} \times 172.987 \\ &= 1.868 \text{ hp} \\ &\approx 2 \text{ hp} \end{aligned}$$

Lecture 25: Design of LSU grain Dryer

2. Design a LSU dryer of 2 tons holding capacity with paddy at 15% m.c. (w.b.).
Data for grain and air parameters are the same as in the previous problem.
Additional data are given as follows.

Cross section of the dryer = $1.2 \times 1.2 \text{ m}^2$

Air velocity in the air ports = 5 m/s

Pitch of the air ports = 40 cm

Row to row spacing = 20 cm

Grain residence time = 30 min

Solution

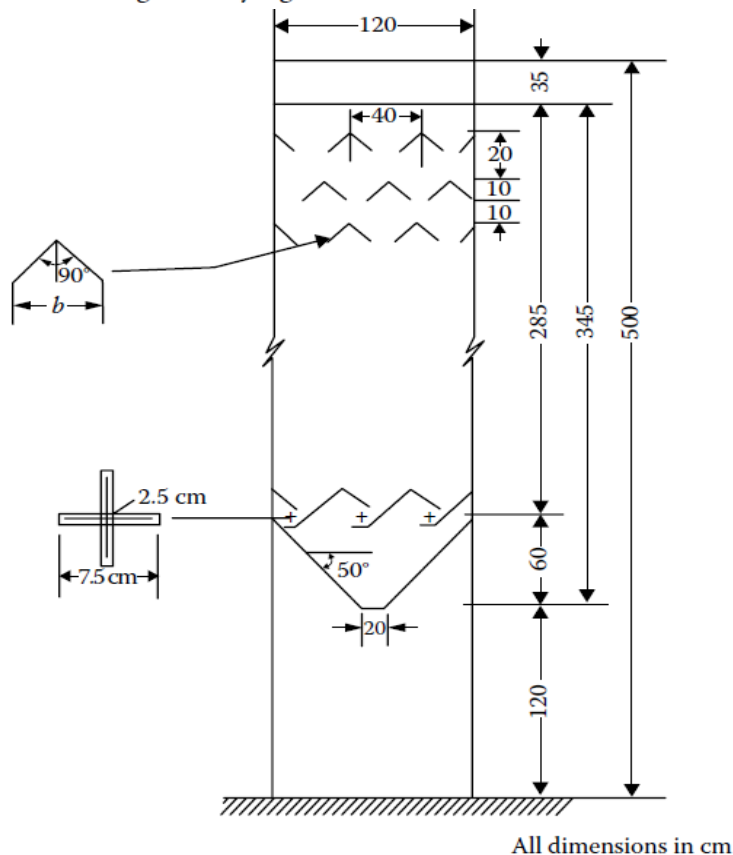
The heat and mass balance for the dryer are the same as those in the previous problem.

Hence, air required = $155 \text{ m}^3/\text{min}$.

Since velocity of air inside the air port or duct is 5 m/s, total cross-sectional area of ducts required

$$= \frac{155}{5 \times 60} = 0.5167 \text{ m}^2$$

Let the height of drying chamber be $b \text{ cm}$.



Specifications of LSU dryer as per solution of Problem 2.

Therefore, volume of drying chamber

$$\begin{aligned} V &= \text{Volume of the drying chamber} - \text{volume of ducts} \\ &= 1.2 \times 1.2 \times h - 0.5167 \times 1.2 \end{aligned} \quad (1)$$

$$V = (1.44h - 0.62) \text{ m}^3$$

The holding capacity of the dryer is given as 2 tons of paddy at 15% m.c. (w.b.) and the bulk density of paddy at 15% m.c. is 575 kg/m³.

$$\text{Hence, volume } V = \frac{2000}{575} = 3.478 \text{ m}^3 \quad (2)$$

Substituting for V in Equation (1)

$$1.44h - 0.620 = 3.478$$

$$1.44h = 4.098$$

$$h = 2846 \text{ m}$$

Height of the grain holding bin = 35 cm (assumed).

Height of the hopper bottom = 60 cm (approximately).

According to spacing, number of ducts in a row = 3 and number of rows in 285 m = 14.

Total number of ducts = 39 (leaving 1 row for discharge rolls).

$$\begin{aligned} \text{Cross-sectional area of each duct} &= \frac{0.5167}{39} \times 10^4 \text{ cm}^2 \\ &= 132.5 \text{ cm}^2 \end{aligned}$$

$$\text{Cross-sectional area of each duct} = \frac{1}{2}b \times \frac{b}{2}$$

$$\text{or } \frac{b^2}{4} = 132.5$$

$$\text{or } b = 23.02 = 23 \text{ cm}$$

Let there be three discharge rolls having shaft diameter 2.5 cm and flute diameter 7.5 cm.

Volume discharged by each roll in one revolution

$$\begin{aligned} &= \frac{\pi}{4}(D_o^2 - D_i^2) \times L \\ &= \frac{\pi}{4}(7.5^2 - 2.5^2) \times 120 \\ &= 4712.39 \text{ cm}^3 \end{aligned}$$

Therefore, volume discharged by 3 rolls = $0.014137 \text{ m}^3/\text{revolution}$

Weight of paddy discharged = $0.014137 \times 575 = 8.129 \text{ kg/revolution}$

Since the grain retention time in the dryer is 30 min,

$$\text{Grain discharge rate} = \frac{2000}{30} = 66.67 \text{ kg/min}$$

$$\text{roller speed} = \frac{66.67}{8.129} = 8.2 \text{ rpm} \approx 8 \text{ rpm}$$

Specifications of the LSU dryer (Figure 6.2) of 2 tons grain holding capacity:

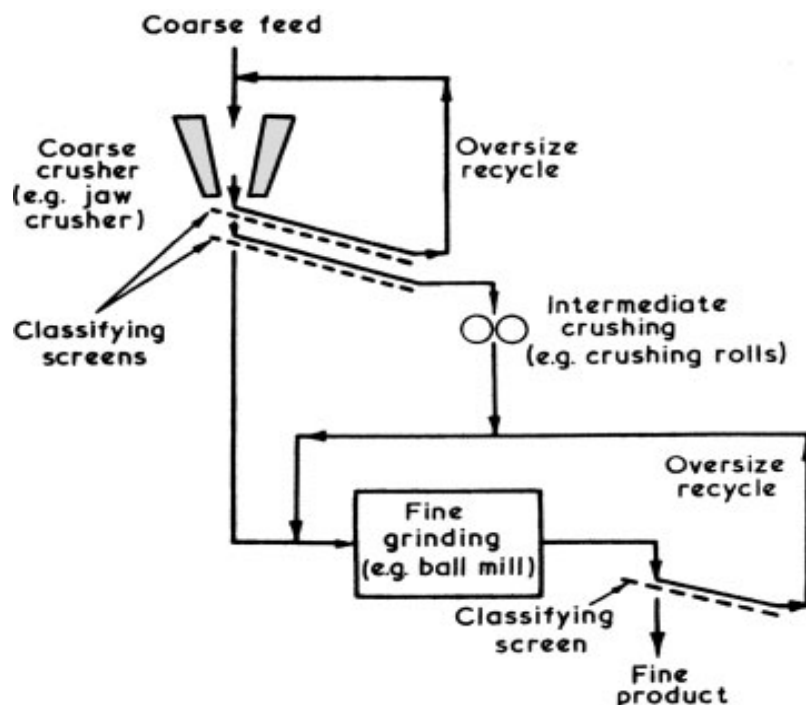
- Total height of the dryer = 3.8 m
- Height of drying chamber = 2.85
- Height of the holding bin = 0.35 m
- Height of the hopper bottom = 0.60 m
- Number of feed rolls = 3
- Grain outlet diameter = 20 cm
- Space between inlet and outlet duct = 20 cm
- Pitch of ducts in a row = 40 cm
- Blower capacity = $155 \text{ m}^3/\text{min}$ with static pressure 5 cm (W.G.)
- Blower motor hp = 2
- Duct dimensions: height = 11.5 cm, width = 23 cm
- Speed of the discharge roll = 8.0 rpm

Lecture 26: Design of milling equipments- Laws

- Milling of cereal grains to obtain flour
- Fine grinding (refining) of chocolate mass
- Flaking of soybeans prior to solvent
- Cutting of vegetables and fruits to desired shapes (cubes, strips, slices...)
- Fine mashing of baby food
- Homogenization of milk and cream.

Size reduction is a widespread, multipurpose operation. Its may serve a number of different objectives, such as:

- Accelerating heat and mass transfer (flaking of soybeans or grinding coffee
- in preparation to extraction, atomization of milk as a fine spray into hot air in spray-drying)
- Facilitating separation of different parts of a material (milling wheat to obtain flour and bran separately, filleting of fish)
- Obtaining a desirable product texture (refining of chocolate mass, meat grinding)
- Facilitating mixing and dispersion (milling or crushing ingredients for dry- mixing, homogenization of liquids to obtain stable emulsions)
- Portion control (slicing cold-cuts, bread, cakes)
- Obtaining pieces and particles of defined shapes (cubing meat for stew, cutting pineapple to obtain the familiar wheel-shaped slices, cutting dough to make cookies)



Crushing efficiency is defined as the ratio of the increment in surface energy to the total energy imparted to the material:

$$\eta_c = \frac{E_s}{E_a} = \frac{\sigma(A - A_0)}{E_a}$$

where:

E_s = surface energy increment per unit mass of material (J/kg)

E_a = total energy transferred to the material per unit mass (J/kg)

σ = surface tension of the solid (J/m² or N/m)

A, A_0 = surface area per unit mass (specific surface area) of the milled material and of the feed, respectively (m²/kg).

Crushing efficiency is very low, usually a few percent or less.

Mechanical efficiency η_m of a size reduction device is defined as the ratio of the energy transferred to the material to the total energy consumption W of the device, per unit mass of material treated.

$$\eta_m = \frac{E_a}{W} = \frac{\sigma(A-A_0)}{cW}$$

Noting that the specific surface area of a (spherical) particle is inversely proportional to its diameter, one can write:

$$W = K(1/x - 1/x_0)$$

where:

x, x_0 = mean Sauter diameter of the milled material and the feed, respectively

K comprises the surface tension and the two efficiencies. Assuming that these values are constant. K is a constant.

relationship). Kick's law is written as follows:

$$W = K' \log(x_0/x)$$

Rittinger's equation is said to fit better fine milling while Kick's expression describes better coarse grinding (Earle, 1983).

EXAMPLE

Sugar crystals were ground from an average Sauter diameter of 500 μ m to powder with an average Sauter diameter of 100 μ m. The net energy consumption was 0.5 kWh per ton. What would be the net energy consumption for grinding the crystals to 50 μ m powder.

- according to Rittinger's law
- according to Kick's law.

Solution:

a. Rittinger's law:

$$W = K(1/x - 1/x_0)$$

K is calculated from the first milling data and applied to the second milling:

$$K = 0.5 / (1/100 - 1/500) = 62.5 \text{ kWh.m/ton}$$

$$E = 62.5 (1/50 - 1/500) = 1.125 \text{ kWh/con}$$

b. Kick's law:

$$E = K \log(x_1/x_2)$$

$$K = 0.5 / \log(100/500) = -0.715$$

$$E = 0.715 \log(50/500) = 0.715 \text{ kwh/ton}$$

- Compressive forces are generally used for the coarse crushing of hard materials.
- Impact forces are used to mill a wide variety of materials, including fibrous foods.
- Shear forces are best applied to relatively soft materials, again including fibrous foods.
- Roller mills compression is the dominant force.
- Impact forces feature strongly in hammer mills.
- Shear forces are dominant in disc attrition mills.

Reduction ratio, which is the average size of the feed particles divided by the average size of the products particles

$$\cos \frac{\alpha}{2} = \frac{D_r + D_p}{D_r + D_f}$$

Where D_f is the average diameter of the feed particles,

D_p is the average diameter of the product particles, corresponding to the clearance between the rolls,

and D_r is the diameter of the rolls.

For the particle to be nipped down through the rolls by friction:

$$\tan \frac{\alpha}{2} = \mu$$

Where μ is the coefficient of friction between the particle and the rolls.

The theoretical mass flow rate M (kg/s) of product from a pair of rolls of diameter D_r (m) and length l (m) when the clearance between the rolls is D (m). the roll speed is N (rpm) and the bulk density of the product is (kg/m^3) is given by

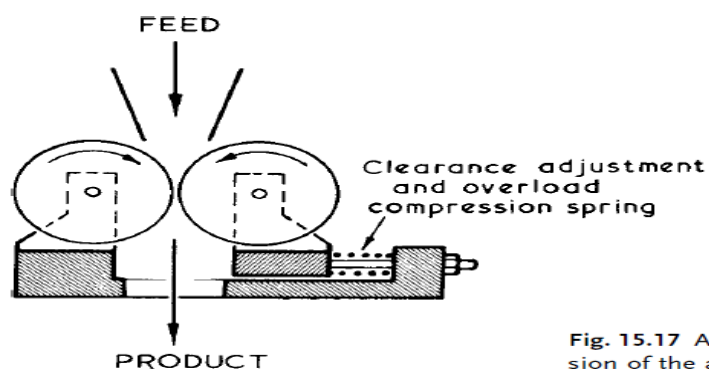


Fig. 15.17 A
sion of the a

Each of the various types of separators employed in flour and grain milling is designed on the basis of the difference in the following physical characteristics of grain: (1) width and thickness of the grain for sieves, screen cleaners, sifters, thickness graders, grading reels, inclined sifters, etc.; (2) length of the grain for indented- type or disk-type pocket separators; (3) aerodynamic properties for husk aspirators, cyclone separators; (4) form and state of the surface for separators for coarse grain, spiral separators, and belt-type separators; (5) specific gravity and coefficient of friction for separating tables and stone separators; (6) ferromagnetic properties for magnetic and electromagnetic separators; (7) electrical properties for electrostatic separators; and (8) color for electronic separators.

Effectiveness of the Separation

$$\mathcal{E}_a = \frac{(X_F - X_D)X_C(X_F - X_C)(1 - X_D)}{(X_D - X_C)^2 X_F(1 - X_F)}$$

where

$\mathcal{E}_a$ is the separating effectiveness for a mixture of two components A and B

F is the rate of feeding to the separator, kg/h

C is the rate of separating the product, kg/h

D is the rate of reject, kg/h

X_F , X_C and X are fractions of component A in the feed, separated product, and reject, respectively

Methods of Husking

The operation of husking and scouring machines can be divided according to the following three basic principles (Figure 10.4):

1. Compression and shear: Compression and shear can compress, split, and strip off the husk from grain. Concave type of husking machine, rubber roll husker, etc., are designed on the basis of this principle.
2. Abrasion and friction: Hollanders are based on the friction of grain on an abrasive surface (emery).
3. Impact and friction: Husk can be stripped off by the action of impact and frictional force. Centrifugal-type paddy sheller comes under this group.

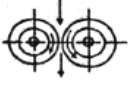
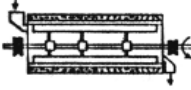
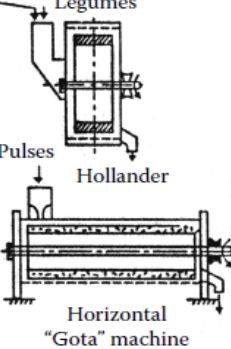
Name, characteristics of hull and kernels (14% moisture content)	For millets with free hulls around non- brittle kernels I	For paddy with free husk around brittle kernels II	For oats with hulls around elastic kernel III	For barley with tightly joined hulls over strong kernel IV	For legumes with tightly held hulls with the kernels (to be split into two cotyledons) V
Hulling methods and machines	 Concave huller	 Rubber roll husker	 Under runner, disk sheller	 Blade-type emery scourer	 Legumes Pulses Hollander Horizontal "Gota" machine
Hulling mechanism	Shear and compression	Shear and compression	Shear, compression, and friction	Impact, abrasion, and friction	Friction and abrasion

Figure 10.4 Classification of husking/scouring/hulling methods.

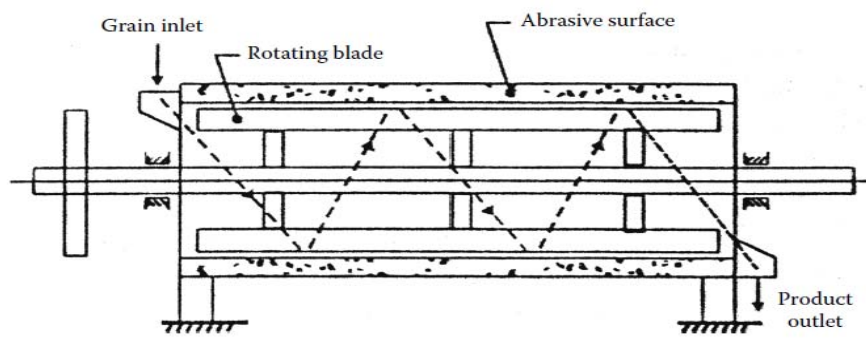


Figure 10.8 Principle of husking by blade-type emery scourer.

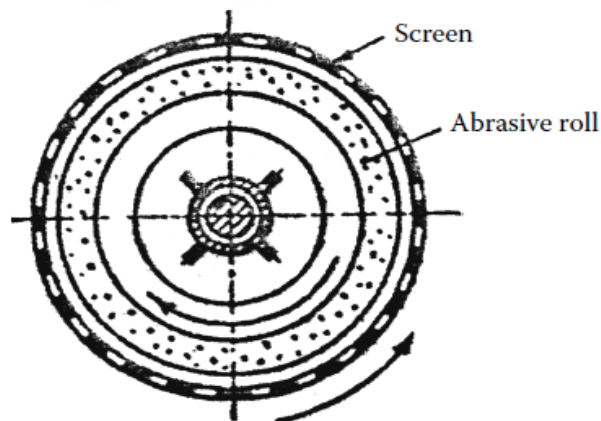


Figure 10.9 Working principle of batch-type Hollander.

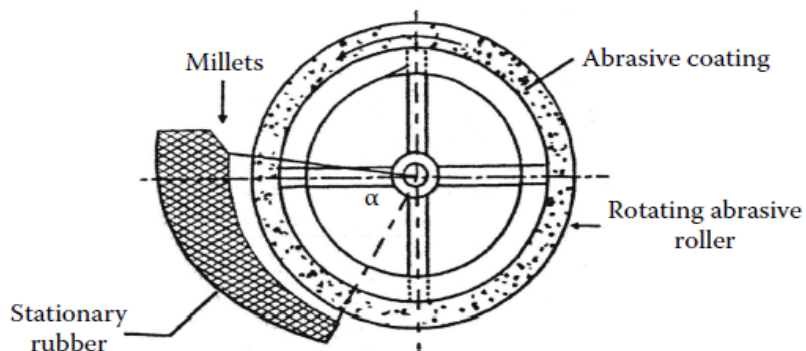


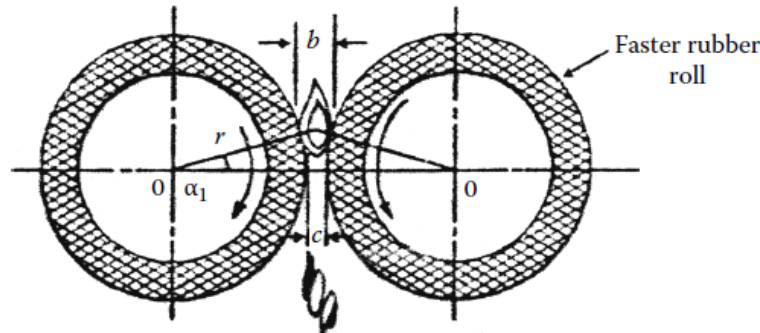
Figure 10.5 Principle of hulling by concave-type huller.

Usually the following specifications of rolls and concaves (Kuprits, 1967) are used:

Diameter of concave	50-60 cm
Length of concave	19-30 cm
Angle of contact	40°-70°
Peripheral speed	10-15 m/s

Lecture 27: Different milling equipments

Suppose a grain having thickness b (Figure 10.6) is brought into contact with the rolls at points A and A₁. The grain is then acted upon by the rolls until it leaves the working zone.



If α_1 is the angle between the line connecting the centers of the rolls and the radius drawn through the point at which the grain contacts the roll,

$$\text{Then } \cos \alpha_1 = \frac{r + (C/2)}{r + (b/2)} = \frac{d + C}{d + b}$$

where,

r is radius of the rolls, cm

d is diameter of the rolls, cm

C is clearance between the rolls, cm

b is size of the grain, cm

$$\text{Hence, } \alpha_1 = \cos^{-1} \frac{(d+C)}{(d+b)}$$

The full length of the husking zone from the point at which the grain is caught by the rolls to the point where the grain is no longer in contact with the roll will correspond to the length of the arc l_h and angle $2\alpha_1$.

Length of the husking zone l_h can be expressed as follows:

$$l_h = \frac{2\pi d}{360} \cos^{-1} \frac{(d+C)}{(d+b)}$$

The length of the husking zone l_h depends on the diameter of the rolls, the thickness of grain to be husked, and the linear distance between the centers of the rolls.

When the size of the grain, b , and the clearance, C , are fixed, then the length of the husking zone increases with the increase in diameter of the roll:

$$\text{Period of husking, } t = l_h / V_f (\text{faster roll})$$

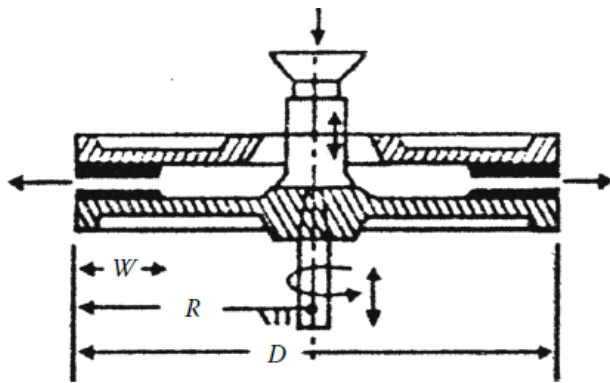
$$\text{Period of husking, } t = (l_h - l_{ad}) / V_s (\text{slower roll})$$

where l_{ad} is the difference between the paths of faster and slower roll:

$$l_{ad} = l_h \frac{(V_f - V_s)}{V_f}$$

This equation shows that the difference between the paths of the two rolls depends not only on the geometrical parameters but also on the peripheral speeds of the rolls, their relative velocities, and the differential speeds.

If $V_f = 15-17.5$ m/s and $V_s = 12.5-15$ m/s, then $V_f - V_s$ should not be less than 2.5 m/s (Kuprits, 1967).



Under runner disk husker.

Principle

The under runner disk husker consists of two horizontal and coaxial cast iron disks, partly coated with an abrasive material. The top disk is stationary and provided with an opening at the center for feeding, while the bottom disk is rotating. The clearance between the two disks can be adjusted by changing the position of the lower rotating disk vertically.

The grains that fall on the lower disk through the central opening are pulled along by its rotation and move outward by centrifugal force. During rotation around the axis of the disk and simultaneous movement toward the edge, grains tend to take a vertical position. At this point, their tips strike against the hard surface of the top disk, which exerts pressure and a slight friction resulting in splitting of husk apart.

The effective width of the abrasive coating should not be more than one-sixth of the stone diameter and the optimum peripheral speeds should be about 14 and 20 m/s for paddy and oats, respectively.

Effectiveness of Hulling/Husking/Scouring

The coefficient of hulling E_{hulling} is defined by the percentage of husked grain obtained from the total amount of grain input

$$E_{\text{hulling}} = (n_1 - n_2)/n_1 = 1 - \frac{n_2}{n_1}$$

where

n_1 is the amount of grain before hulling
 n_2 is the amount of unhulled grain after hulling

The coefficient of wholeness of the kernels E_{wk} is defined by the proportion of whole kernels to the total amount of kernels (kernel crushed grain mealy waste) extracted by the given system:

$$E_{wk} = \frac{k_2 - k_1}{(k_2 - k_1) + (d_2 - d_1) + (m_2 - m_1)}$$

where

$k_2 - k_1$, is the yield of whole kernels
 $d_2 - d_1$ is the yield of crushed kernels mm,
 $m_2 - m_1$ is the yield of mealy waste in the product

Effectiveness of Grinding

The main criteria for evaluation of effectiveness of grinding of any solid body including grain are the degree of grinding, specific power consumption, and specific load of the initial product on the working tool of the grinder. Degree of grinding, i , is expressed as follows:

$$i = \frac{S_a}{S_b}$$

where

S_a is the overall surface area of the product after grinding, cm^2
 S_b is the overall surface area of the product before grinding, cm^2

The term "overall extraction" E_x expressed in percent refers to the difference between the percentage of undersized particles C , in the final ground product and the percentage of undersized particles / in the initial feed entering the grinder:

$$E_x = C_1 - \dot{I} \quad C_1 = \frac{u_1}{u_1 + o_1} \times 100$$

$$\dot{I} = \frac{u_2}{u_2 + o_2} \times 100$$

where

u_1 , is the weight of undersized particles obtained by sifting the ground product
 O_1 is the weight of oversized particles obtained by sifting the ground product
 u_2 is the weight of the undersized particles in the initial product to be ground
 O_2 is the weight of oversized particles in the initial product to be ground
 E_x depends upon structural-mechanical properties of the material, dimensions of the roll (Le, diameter, etc.), geometry of the surface of the rolls, kinematic parameters of the rolls, and specific load on the rolls

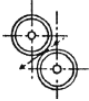
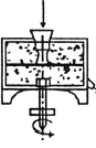
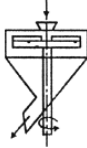
Grinding machines					
					
	Break roll				
	Reduction roll				
	Roller mill	Burr mill	Attrition mill	Hammer mill	Flatting mill
Grinding mechanism	Compression and shear	Compression and shear	Impact and friction	Impact and crushing	Compression

Figure 10.10 Classification of grinding machinery.

Kinematic parameters of the rolls

The important kinematic parameters of the rolls are speed of the fast roll, V_f and ratio of the speeds between fast and slow rolls (i.e., $k=V_f/V_s$). The efficiency of grinding depends upon the kinematic parameters.

Capacity of the Roller Mills and Power Consumption for Their Operation

The capacity of a roller mills is the amount of product in kilograms, ground per Unit time. The theoretical capacity of a pair of rolls can be determined from the following Formula (Kuprits, 1967):

$$Q_r = 3.6 \rho_1 L V_z b \psi$$

Q_r is the theoretical capacity of the roll pair, kg/h

ρ_1 is the bulk density of the product before grinding, kg/cm

L is the length of the rolls, cm

V_z is the mean calculated velocity of the product in the grinding zone, cm/h

b is the clearance between the rolls, cm

Ψ is the coefficient of filling of the grinding zone, where $\psi = Q_a/Q_r$ (Q_a is the actual capacity of the roll pair)

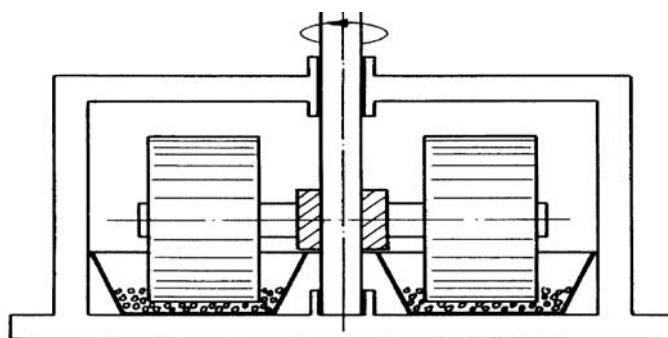


Fig. 15.18 Edge mill; from [8] with kind permission of Springer Science and Business Media.

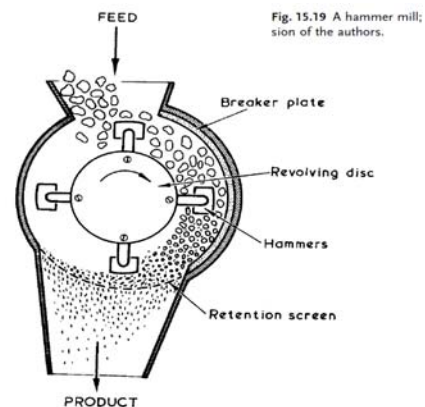
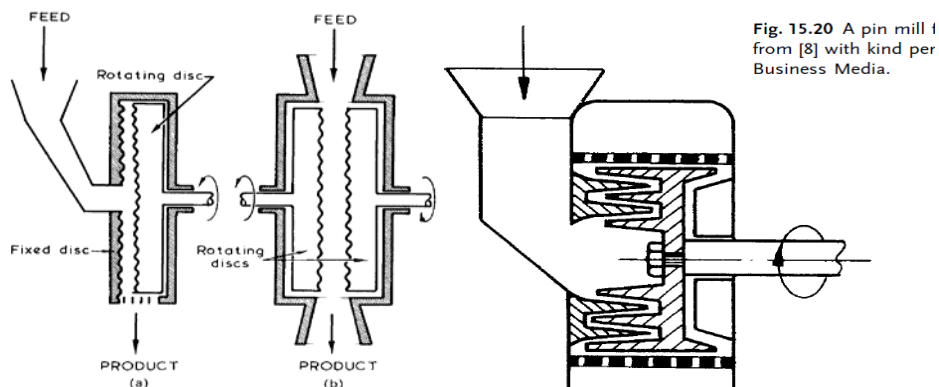


Fig. 15.19 A hammer mill; sion of the authors.



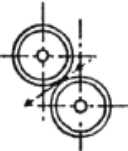
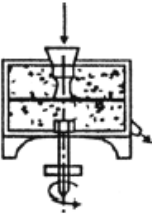
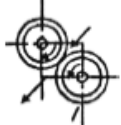
Grinding machines	 Break roll				
	 Reduction roll				
	Roller mill	Burr mill	Attrition mill	Hammer mill	Flatting mill
Grinding mechanism	Compression and shear	Compression and shear	Impact and friction	Impact and crushing	Compression

Figure 10.10 Classification of grinding machinery.

Lecture 28 Optimisation of design with respect to process efficiency, energy and cost,

Analytical method

If N_v is the number of possible variables in a design problem and N_r the number of design relationships, then the “degrees of freedom” N_d is given by:

$$N_d = N_v - N_r$$

N_d represents the freedom that the designer has to manipulate the variables to find the best design.

If $N_v = N_r$, $N_d = 0$ and there is only one, unique, solution to the problem. The problem is not a true design problem, no optimisation is possible.

If $N_v < N_r$, $N_d < 0$, and the problem is over defined; only a trivial solution is possible.

If $N_v > N_r$, $N_d > 0$, And there is an infinite number of possible solutions. However, for a practical problem there will be only a limited number of feasible solutions. The value of

N_d is the number of variables which the designer must assign values to solve the problem.

How the number of process variables, design relationships, and design variables defines a system can be best illustrated by considering the simplest system; a single-phase, process stream.

Optimisation

Selection of best answer to a problem out of the multiplicity of potential solutions is possible by optimization technique.

Optimisation of process equipment is based on

- ❖ Equipment and system should operate at maximum efficiency
- ❖ Improving the economy
- ❖ Energy saving during the operation
 - a) First decide ‘what to optimise’ – For this an objective function is selected first. This may be related to cost, material consumption, surface area, efficiency, energy
 - b) Determine the parameters which may influence the objective function
 - c) A relationship is to be derived between objective function and the influencing parameters

How to optimize

The various methods are 1. Analytical 2. case study 3. Search

Analytical method – Calculus method is used. The first derivative of a differential function is set equal to zero. In multi-variable function, partial derivatives are taken with respect to each of the n variables and set of n simultaneous equations are obtained. Introducing Lagrange multipliers, the no. of independent equations and no of unknowns are made identical and solution is obtained.

Limitation _ Function must be in mathematical form and differentiable. Many design problems are iterative type and solved by trail and error and numerical methods. It gives only the solution and does not give any indication of the direction or path to reach the solution.

Case study method – It consists of evaluating various solutions to the problem. Case after case is tried and results are presented graphically or in tabular form. Analysing the graph or tabl, the best combination of variable is arrived at.

Search method – A base point in all cases is assumed known i.e. one set of conditions as a solution to the problem but not necessarily the optimum solution. The method must select the next set of values for the variables and evaluate the objective function once again, hoping that the solution will be closer to the optimum solution. There should be only one optimum solution.

Optimisation techniques (application in optimizing chemical equipments)

C. Function of one variable system

2. Extremes of a function can occur only where first derivative becomes zero.
3. If second derivative is -ve, then maximum exists. If second derivative is +ve, then minimum exists.

Lecture 29 Optimisation of design with respect to process efficiency, energy and cost, Lagrange multipliers method

This method is used when there are equality constraints or restrictions on the variables. The objective is to determine the value of independent variables that will maximize or minimize some objective function

1. The no. of Lagrange multipliers must be equal to no. of constraining equations.
2. The Lagrange expression must be equal to the objective function plus the product of the Lagrange multipliers and constraints. This constraints must be in the form of an equation set equal to zero.

If $u(x,y,...) = \text{objective function}$

$v_1(x,y,...) = 0$ and $v_2(x,y,...) = 0$ are constraining equations

λ_1 and λ_2 are Lagrange multipliers

$w(x,y,...) = \text{Lagrange expression}$ and $x,y,...$ are independent variables

Lagrange expression $w(x,y,...) = u(x,y,...) + \lambda_1 v_1(x,y,...) + \lambda_2 v_2(x,y,...)$

3. Take partial derivatives of Lagrange expression with respect to independent variables and each must be set equal to zero. N simultaneous equations are to be solved for N independent variables to solve maximum and minimum conditions. One lagrange multiplier is introduced for each constraining equation.

Search by Golden section – It is an efficient technique to arrive at the optimum value. In this method, search points are symmetrically placed from both the ends of search region.

Suppose that two search points are placed at a distance '1' from each end of the search region. On the basis of these two calculations, a portion of the region can be eliminated, where optimum value cannot lie. This region elimination is done by examining the two results. The system considered here is unimodal i.e. it will have only one peak point.

$$L^2 = 1 - L \Rightarrow L = 0.618$$

By placing the first two points a distance 0.618 of the original region of isolation from the sides, symmetry will be preserved. Each new point reduced the region of isolation by 0.618.

Operation research is a scientific approach to decision making. It begins by describing some system by a model and then it manipulates the model to find the best way of operating the system.

The major phases of operation research are

1. Formulating the problem
2. Constructing a model to represent the system under study
3. Deriving a solution from the model
4. Testing the model and the solution derived from it
5. Establishing control over the solution
6. Putting the solution to work/implementation

Linear programming – It is a mathematical means of assigning a fixed amount of resources to satisfy a number of demands in such a way that some objective is optimized and other defined conditions are still satisfied.

It is possible to express both the objective and the restrictions mathematically and the relationship must all be linear. It deals with optimization (maximization or minimization) of linear functions subjected to linear constraints. It can be solved by

1. Graphical interpretation

2. Algebraic solution
3. Simplex computation
4. Artificial variable
5. Queueing model
6. Dual simplex method

Computer techniques used to solve Linear programming

LP 88 & LP 90

LINDO

TORA

Multi-objective programming can be solved by GOAL programming.

Non-linear programming can be solved by

1. Lagrangean multipliers
2. Fibonacci series
3. Golden search method
4. Quadratic programming

TORA programming (software)

The following steps are followed

1. Enter no. of variables
2. Enter co-efficients of objective function and constraining inequalities
Specify whether maximum or minimum type in objective function and $\leq$
and $\geq$ in constraining equations
3. Run the programme
4. The result will give the optimum value of independent variables and optimum value of objective function will be obtained.

Lecture 30: Economic evaluation

While selecting a process for manufacturing a product feasibility is to be studied.

- A. Technical feasibility – Technical details of the process has to be worked out.
- B. Economic feasibility – Profitability of the product has to be assessed.

Economic evaluation

FIXED AND WORKING CAPITAL

Fixed capital is the total cost of the plant ready for start-up. It is the cost paid to the contractors. It includes the cost of:

1. Design, and other engineering and construction supervision.
2. All items of equipment and their installation
3. All piping, instrumentation and control systems.
4. Buildings and structures.
5. Auxiliary facilities, such as utilities, land and civil engineering work.

It is a once-only cost that is not recovered at the end of the project life, other than the scrap value.

Working capital is the additional investment needed, over and above the fixed capital, to start the plant up and operate it to the point when income is earned. It includes the cost of

1. Start-up.
2. Initial catalyst charges.
3. Raw materials and intermediates in the process.
4. Finished product inventories.
5. Funds to cover outstanding accounts from customers.

Most of the working capital is recovered at the end of the project. The total investment needed for a project is the sum of the fixed and working capital.

The factorial method of cost estimation is often attributed to Lang (1948). The fixed capital cost of the project is given as a function of the total purchase equipment cost by the equation:

$$C_f = f_L * C_e$$

where C_f = fixed capital cost,

C_e = the total delivered cost of all the major equipment items: storage tanks, reaction vessels, columns, heat exchangers, etc.,

f_L = the "Lang factor", which depends on the type of process.

$f_L = 3.1$ for predominantly solids processing plant

$f_L = 4.7$ for predominantly fluids processing plant

$f_L = 3.6$ for a mixed fluids-solids processing plant

Capital cost = Fixed capital + non-depreciable cost + Working capital

% rate of return = (Annual profit/ In vested capital) X100

Pay out period = Capital investment (C) / annual net cash inflow(A)

A = annual cash income – annual capital expenditure

Break even analysis – It is the minimum production capacity at which no profit no loss condition exists. The intersection of direct production cost and sales cost decides the break even capacity.

Some method has to be used to update old cost data for use in estimating at the design stage, and to forecast the future construction cost of the plant.

$$\text{Cost in year A} = \text{Cost in year B} \times \frac{\text{Cost Index in year A}}{\text{Cost Index in year B}}$$

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

$$C_2 = C_1 (S_2/S_1)^n$$

where C_2 capital cost of the project with capacity S_2 .

C_1 = capital cost of the project with capacity S_1

The value of the Index n is traditionally taken as 0.6; the well-known six-tenths rule.

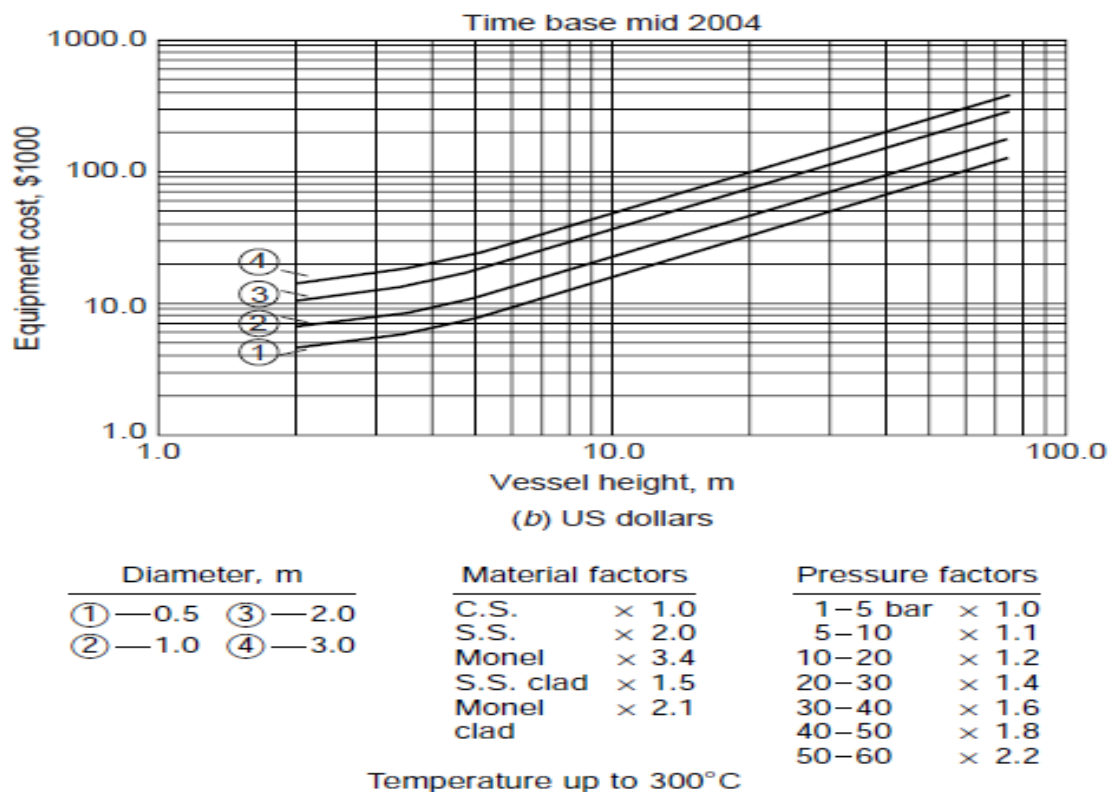


Figure 6.5a, b. Vertical pressure vessels. Time base mid-2004.
Purchased cost = (bare cost from figure) × Material factor × Pressure factor

Table 6.1. Typical factors for estimation of project fixed capital cost

Item	Process type		
	Fluids	Fluids– solids	Solids
1. Major equipment, total purchase cost	PCE	PCE	PCE
f_1 Equipment erection	0.4	0.45	0.50
f_2 Piping	0.70	0.45	0.20
f_3 Instrumentation	0.20	0.15	0.10
f_4 Electrical	0.10	0.10	0.10
f_5 Buildings, process	0.15	0.10	0.05
* f_6 Utilities	0.50	0.45	0.25
* f_7 Storages	0.15	0.20	0.25
* f_8 Site development	0.05	0.05	0.05
* f_9 Ancillary buildings	0.15	0.20	0.30
2. Total physical plant cost (PPC)			
PPC = PCE (1 + f_1 + ... + f_9)			
= PCE ×	3.40	3.15	2.80
f_{10} Design and Engineering	0.30	0.25	0.20
f_{11} Contractor's fee	0.05	0.05	0.05
f_{12} Contingency	0.10	0.10	0.10
Fixed capital = PPC (1 + f_{10} + f_{11} + f_{12})			
= PPC ×	1.45	1.40	1.35

*Omitted for minor extensions or additions to existing sites.

Procedure

1. Prepare material and energy balances, draw up preliminary flow-sheets, size major equipment items and select materials of construction.
2. Estimate the purchase cost of the major equipment items. Use Figures 6.3 to 6.6 and Tables 6.2 and 6.3, or the general literature.
3. Calculate the total physical plant cost (PPC), using the factors given in Table 6.1

$$PPC = PCE(1 + f_1 + \dots + f_9) \quad (6.8)$$

4. Calculate the indirect costs from the direct costs using the factors given in Table 6.1.
5. The direct plus indirect costs give the total fixed capital.
6. Estimate the working capital as a percentage of the fixed capital: 10 to 20 per cent.
7. Add the fixed and working capital to get the total investment required

Operating cost

1. Fixed operating costs: costs that do not vary with production rate. These are the bills that have to be paid whatever the quantity produced.
2. Variable operating costs: costs that are dependent on the amount of product produced.

Fixed costs

1. Maintenance (labour and materials).
2. Operating labour.
3. Laboratory costs.
4. Supervision.
5. Plant overheads.
6. Capital charges.
7. Rates (and any other local taxes).
8. Insurance.
9. Licence fees and royalty payments.

Variable costs

1. Raw materials.
2. Miscellaneous operating materials.
3. Utilities (Services).
4. Shipping and packaging.

COSTING AND PROJECT EVALUATION

Table 6.6. Summary of production costs

<i>Variable costs</i>	<i>Typical values</i>
1. Raw materials	from flow-sheets
2. Miscellaneous materials	10 per cent of item (5)
3. Utilities	from flow-sheet
4. Shipping and packaging	usually negligible
Sub-total A	
<i>Fixed costs</i>	
5. Maintenance	5–10 per cent of fixed capital
6. Operating labour	from manning estimates
7. Laboratory costs	20–23 per cent of 6
8. Supervision	20 per cent of item (6)
9. Plant overheads	50 per cent of item (6)
10. Capital charges	10 per cent of the fixed capital
11. Insurance	1 per cent of the fixed capital
12. Local taxes	2 per cent of the fixed capital
13. Royalties	1 per cent of the fixed capital
Sub-total B	
Direct production costs A + B	
13. Sales expense	20–30 per cent of the direct
14. General overheads	production cost
15. Research and development	
Sub-total C	
Annual production cost = A + B + C =	
$\text{Production cost } \text{£/kg} = \frac{\text{Annual production cost}}{\text{Annual production rate}}$	

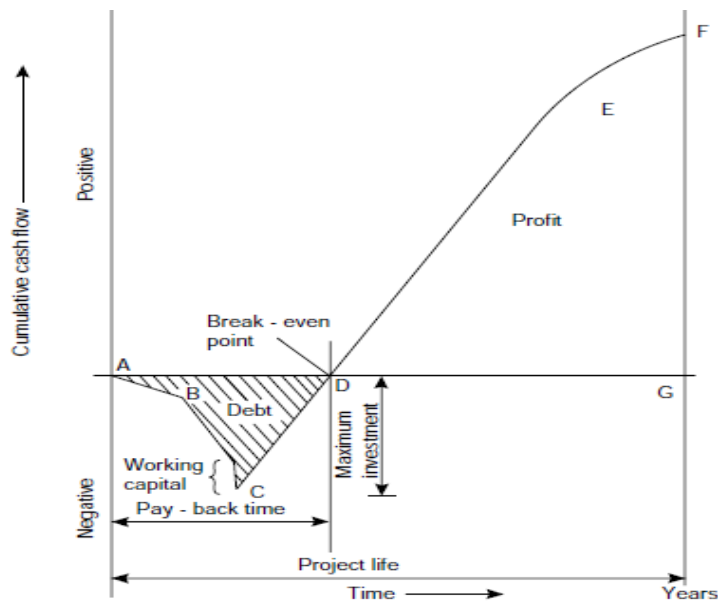


Figure 6.8. Project cash-flow diagram

A-B The investment required to design the plant.

B-C The heavy flow of capital to build the plant, and provide funds for start-up.

C-D The cash-flow curve turns up at C, as the process comes on stream and income is generated from sales. The net cash flow is now positive but the cumulative amount remains negative until the investment is paid off, at point D. Point D is known as the break-even point and the time to reach the break-even point is called the pay-back time. In a different context, the term "break-even point" is used for the percentage of plant capacity at which the income equals the cost for production

D-E In this region the cumulative cash flow is positive. The project is earning a return on the investment.

E-F Toward the end of project life the rate of cash flow may tend to fall off, due to increased operating costs and falling sale volume and price, and the slope of the curve changes. The point F gives the final cumulative net cash flow at the end of the project life.

$$\text{Net present worth (NPW)} = \frac{\text{Estimated net cash flow in year } n \text{ (NFW)}}{(1+r)^n}$$

of cash flow in year n

where r is the discount rate (interest rate) per cent/100 and

$$\text{Total NPW of project} = \sum_{n=1}^{n=t} \frac{\text{NFW}}{(1+r)^n}$$

t = life of project, years.

$$\text{ROR} = \frac{\text{Cumulative net cash flow at end of project}}{\text{Life of project} \times \text{original investment}} \times 100 \text{ per cent}$$

$$\text{Cumulative income} = F - C$$

$$\text{Investment} = C$$

$$\text{Life of project} = G$$

$$\text{then, ROR} = \frac{F-C}{CXG} \times 100 \text{ per cent}$$

Lecture: 31 Process hazards and safety measures in equipment design

The basic components of an automatic trip system are:

1. A sensor to monitor the control variable and provide an output signal when a preset value is exceeded (the Instrument).
2. A link to transfer the signal to the actuator, usually consisting of a system of pneumatic or electric relays.
3. An actuator to carry out the required action; close or open a valve, switch off a motor.

Safety and loss prevention in process design can be considered under the following broad headings:

1. Identification and assessment of the hazards.
2. Control of the hazards: for example, by containment of flammable and toxic materials.
3. Control of the process. Prevention of hazardous deviations in process variables (pressure, temperature, flow), by provision of automatic control systems, interlocks, alarms, trips; together with good operating practices and management.
4. Limitation of the loss. The damage and injury caused if an incident occurs: pressure relief, plant layout, provision of fire-fighting equipment.

The designer will be concerned more with the preventative aspects of the use of hazardous substances. Points to consider are:

1. Substitution: of the processing route with one using less hazardous material.
Or, substitution of toxic process materials with non-toxic, or less toxic materials.
2. Containment: sound design of equipment and piping, to avoid leaks. For example, specifying welded joints in preference to gasketed flanged joints (liable to leak).
3. Ventilation: use open structures, or provide adequate ventilation systems.
4. Disposal: provision of effective vent stacks to disperse material vented from pressure relief devices; or use vent scrubbers.
5. Emergency equipment; escape routes, rescue equipment, respirators, safety showers, eye baths.

In addition, good plant operating practice would include:

1. Written instruction in the use of the hazardous substances and the risks involved.
 2. Adequate training of personnel.
 3. Provision of protective clothing.
 4. Good housekeeping and personal hygiene.
 5. Monitoring of the environment to check exposure levels. Consider the installation of permanent instruments fitted with alarms.
 6. Regular medical check-ups on employees, to check for the chronic effects of toxic materials.
- A. **Toxic materials** the presence of toxic substances after an incident will make the task of the emergency personnel more difficult. The factor applied ranges from 0 for non-toxic materials, to 0.8 for substances that can cause death after short exposure.
- B. **Sub-atmospheric pressure**, allows for the hazard of air leakage into equipment. It is only applied for pressure less than 500 mmHg (9.5 bara).

- C. **Operation in or near flammable range** covers for the possibility of air mixing with material in equipment or storage tanks, under conditions where the mixture will be within the explosive range.
- D. **Dust explosion** covers for the possibility of a dust explosion. The degree of risk is largely determined by the particle size. The penalty factor varies from 0.25 for particles above 175 μm , to 2.0 for particles below 75 μm .
- E. **Relief pressure:** this penalty accounts for the effect of pressure on the rate of leakage, should a leak occur. Equipment design and operation becomes more critical as the operating pressure is increased. The factor to apply depends on the relief device setting and the physical nature of the process material. It is determined from Figure 2 in the Dow Guide.
- F. **Low temperature** this factor allows for the possibility of brittle fracture occurring in carbon steel, or other metals, at low temperatures (see Chapter 7 of this book).
- G. **Quantity of flammable material** the potential loss will be greater the greater the quantity of hazardous material in the process or in storage. The factor to apply depends on the physical state and hazardous nature of the process material, and the quantity of material. It varies from 0.1 to 3.0, and is determined from Figures 3, 4 and 5 in the Dow Guide.
- H. **Corrosion and erosion:** despite good design and materials selection, some corrosion problems may arise, both internally and externally. The factor to be applied depends on the anticipated corrosion rate. The severest factor is applied if stress corrosion cracking is likely to occur (see Chapter 7 of this book).
- I. **Leakage-joints and packing** this factor accounts for the possibility of leakage from gaskets, pump and other shaft seals, and packed glands. The factor varies from 0.1 where there is the possibility of minor leaks, to 1.5 for processes that have sight glasses, bellows or other expansion joints.
- J. **Use of fired heaters:** the presence of boilers or furnaces, heated by the combustion of fuels, increases the probability of ignition should a leak of flammable material occur from a process unit. The risk involved will depend on the siting of the fired equipment and the flash point of the process material. The factor to apply is determined with reference to Figure 6 in the Dow Guide.
- K. **Hot oil heat exchange system:** most special heat exchange fluids are flammable and are often used above their flash points; so their use in a unit increases the risk of fire or explosion. The factor to apply depends on the quantity and whether the fluid is above or below its flash point: see Table 5 in the Guide.
- L. **Rotating equipment** this factor accounts for the hazard arising from the use of large pieces of rotating equipment: compressors, centrifuges, and some mixers
1. Adequate, and secure, water supplies for fire fighting.
 2. Correct structural design of vessels, piping, steel work.
 3. Pressure-relief devices.
 4. Corrosion-resistant materials, and/or adequate corrosion allowances.
 5. Segregation of reactive materials.
 6. Earthing of electrical equipment.
 7. Safe location of auxiliary electrical equipment, transformers, switch gear.
 8. Provision of back-up utility supplies and services.
 9. Compliance with national codes and standards.
 10. Fail-safe instrumentation.
 11. Provision for access of emergency vehicles and the evacuation of personnel.
 12. Adequate drainage for spills and fire-fighting water.
 13. Insulation of hot surfaces.

14. No glass equipment used for flammable or hazardous materials, unless no suitable alternative is available.
15. Adequate separation of hazardous equipment.
16. Protection of pipe racks and cable trays from fire.
17. Provision of block valves on lines to main processing areas.
18. Protection of fired equipment (heaters, furnaces) against accidental explosion and fire.
19. Safe design and location of control rooms.

Safety measures in equipment design

The following design considerations are important to prevent failures.

1. Unit reliability
2. Ease of operation
3. Provisions for future expansion, inspection and maintenance
4. Adequate emergency shutdown facilities
5. Equipment standardization for rapid replacement
6. Design to anticipated pressure range- with overpressure controls
7. Design to anticipated temperature range – with over temperature controls

Pressure vessels

1. The design and construction of pressure vessels and storage tanks should follow Indian standard codes and vessels should be tested at 1.3 times the design pressure.
2. Attempt should be made to keep the vessel as simple as possible, consistent with the fulfilment of its function. It should not be overburdened with manways and inspection openings for which there is only a remote chance of usage.
3. Careful attention should be given to any weld made on vessel, particularly if they are thick.
4. If the vessel is to work under pressure cycling, system changes, vibrations or similar factors which are likely to create fatigue conditions, it is essential to check the fatigue strength.
5. Flange joints must be leak proof. This can be ensured by checking the gasket position, flange faces and bolt holes.
6. Pressure relief devices should be provided on all pressure vessels.

Heat transfer equipment

1. Sufficient heating surface must be provided to avoid excessive rate of heat input per unit surface, so as to minimize excessive liquid film temperatures.
2. The heat absorbed by the tubes must be removed by the circulating fluids and the liquid film coefficient inside the tubes must be sufficiently high to prevent an excessive temperature rise through the liquid film.
3. Inspection openings must be sufficient in number and location to permit complete periodic inspection of the vaporizer.
4. Vent valves should be provided at all high spots in the equipment.
5. Liquid phase systems must include an expansion or surge tank.
6. Heater tubes must be tightly secured to headers and vapour drums.
7. In case of furnaces, combustion space should be designed to avoid flame impingement on tubes.
8. Pressure relief devices must be designed for high temperatures.
9. Care should be taken allow for stresses due to thermal expansion.
10. Appropriate choice of insulation must be made consistent with the material handled by the equipment.

Lecture: 32 Computer Aided Design (CAD)

CAD and CAM are technologies concerned with use of digital computers to perform certain functions in design and production.

CAD can be defined as the use of computer systems to assist in the creation, modification, analysis or optimization of a design. The computer system consists of the hardware and software to perform the specialized design functions required by the firm. The CAD hardware typically includes the computer, one or more graphics display terminals, key boards and other peripheral equipments.

The CAD software consists of the computer programmes to implement computer graphics on the system plus application programme to facilitate the engineering functions of the user company. Examples of application programme includes stress-strain analysis of components, dynamical response of mechanisms, heat transfer calculations and numerical control part programming.

CAM can be defined as the use of computer systems to plan, manage and control the operations of a manufacturing plant through either direct or indirect computer interface with plants production resources.

Automation is defined as the technology concerned with the application of complex mechanical, electronic and computer based systems in the operation and control of production.

CAD involves any type of design activity which makes use of the computer to develop, analyse and modify an engineering design. Modern CAD system are based on interactive computer graphics (ICG). ICG denotes a user-oriented system in which the computer is employed to create, transform and display data in the form of pictures or symbols. The user in computer graphics design system is the designer who communicates data and commands to the computer through input devices. The computer communicates with the user via a cathode ray tube (CRT). The designer create an image on the CRT screen by entering commands to call the desired software subroutine stored in the computer. The image is constructed out of basic geometric elements like points, lines, circles and so on. It can be modified, moved, rotated and other transformations.

CAD system - ICG system (speed of calculation, visual display, storage of large amount of data)

Human designer – That part of design requiring human intellectual skill i.e. conceptualization, independent thinking

Reasons for implementing CAD

1. To increase the productivity of designer
2. To improve quality of design
3. To improve communication through better drawing and documentation
4. To create database for manufacturing

The design process

Recognition of need (realization of problem)

Definition of problem (thorough specification of item)

Synthesis (iterative approach of design optimization within the constraints)

Analysis and optimization

Evaluation (measuring the design against specification established in problem definition phase)

Presentation (Documentation of design by drawing with material specification and assembly list)

The design task performed by modern CAD system can be grouped into 4 functional group

1. Geometric modeling
2. Engineering analysis
3. Design review and evaluation
4. Automated drafting

Geometric modeling – In CAD, geometric modeling is concerned with the computer compatible mathematical description of the geometry of the object.

The mathematical description allows the image of the object to be displayed and manipulated on a graphics terminal through signals from the CPU of the CAD system.

To create graphical image of the object on the CRT screen of ICG system, 3 types of command

- a) Generate basic geometric element
- b) To accomplish scaling, rotation and transformation
- c) Various elements to be joined into desired shape of the object being created on ICG system

It may be represented by Wire frame geometric modeling – Displayed by interconnecting lines (2D, 2.5D/3D)

Solid modeling in three dimension

Colour graphics – to clarify components in an assembly

Engineering analysis – In formulation of any engineering design, analysis like stress-strain calculations, heat transfer computations, use of differential equations to describe the dynamic behaviour of the system are required. Specific programmes may be developed to solve a particular design problem. Engineering analysis software may be called to operate on the current design model.

Analysis of mass properties – Property of solid object like weight, volume, CG, MOI being analysed.

Finite element method – The object is divided into large no. of finite elements and the entire object can be analysed for stress-strain, heat transfer etc. If finite element analysis indicates behaviour of the design which is undesirable, the designer can modify the shape and recompute the finite element analysis for the revised design.

Design review and evaluation – Checking the accuracy of design can be accomplished on the graphics terminal.

Semiautomatic dimensioning and tolerancing routine to check the dimensioning error.

Layering helps in design review.

Interference checking – Analysis of assembled structure in which risk of component occupying same space.

Kinematics – To animate the motion of designed mechanisms and enhance visualization of designer on the operation of mechanism and interference with other components.

ADAMS – Automatic Dynamic analysis of mechanical systems

Automated drafting – It involves creation of hard copy engineering drawing directly from CAD database. It includes automatic dimensioning, scaling of drawing, capability to develop sectional/enlarged view of particular part.

Part classification and coding – Grouping of similar part designs into classes and relating by coding scheme. Designer can use the system to retrieve existing part design.

Manufacturing database – CAD system offers the opportunity to develop the data base needed to manufacture the product. It is integrated CAD/CAM database include data on product generated during design. And additional data required for manufacturing i.e. geometry data, bill of materials, material specification.

Computer software used for CAD

1. Auto CAD
2. Pro/ENGINEER

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