B.PHARM SEMESTER III · THEORY

BP307T Pharmaceutical Engineering

Unit IV — Materials & Material Handling

Pills & Python Notes

Material handling · Storage systems · Safety · Waste management · Corrosion

Unit IV

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CHAPTER 1: Material Handling Equipment & Storage Systems

1. Learning Objectives

After studying this chapter, the student will be able to:

- Define material handling and explain why it is important in a pharmaceutical plant.
- List the different material handling equipment and techniques.
- Describe the construction and working of conveyors: belt, screw/auger, pneumatic, bucket and roller conveyors.
- Explain the working of hoists: chain hoists, electric hoists and fork-truck concepts.
- Define AGVs (automated guided vehicles) and describe how they work, their sensors and their advantages in pharma warehouses.
- Compare bins and silos as storage systems.
- Explain silo types: cylindrical silos, conical-bottom silos, and the concepts of mass flow and funnel flow.
- Describe warehouse layout and the zones inside it: receiving, quarantine, approved (released), packaging and dispatch areas.
- Calculate the storage capacity of a cylindrical silo and a rectangular bin using volume and bulk density.

2. Definitions

- **Material handling:** The movement, storage, control and protection of materials (raw materials, in-process materials, finished goods) from the time they enter the plant till the finished product is dispatched. It includes lifting, carrying, loading and unloading.
- **Conveyor:** A machine that moves materials continuously from one place to another along a fixed path, without manual carrying.
- **Hoist:** A device used to lift heavy loads vertically (up and down) using a chain, wire rope or hydraulic power.
- **Forklift (fork truck):** A small powered vehicle with two steel forks in front, used to lift and move pallets and heavy loads in a warehouse.
- **AGV (Automated Guided Vehicle):** A driverless vehicle that moves materials automatically along a fixed route on the factory floor, guided by sensors, magnetic tape, wires or lasers.
- **Bulk density:** The mass of a powder or granular material divided by the total volume it occupies (including the air spaces between particles). It is expressed in kg/m^3.
- **Bin:** A relatively small container or hopper, usually box-shaped, used to store and dispense powders and granules inside a plant.
- **Silo:** A large, tall, usually cylindrical storage vessel used to store bulk powders, granules or liquids in large quantities.
- **Warehouse:** A building where raw materials, packaging materials and finished goods are received, stored and dispatched in a controlled way.
- **Quarantine area:** A separate, clearly marked area in a warehouse where incoming materials are kept and isolated until they are tested and approved by quality control.

3. Terminology

Term	Plain-English meaning
Material handling	Moving and storing materials safely inside a factory
Conveyor	A moving belt/machine that carries material continuously from one point to another
Auger / Screw conveyor	A rotating screw inside a tube that pushes powder forward — like a hand-operated grain crusher screw
Pneumatic conveyor	Moves powder through a pipe using air pressure or vacuum — like blowing dust through a tube
Bucket conveyor / Bucket elevator	A belt with attached buckets that lift material upward — like a Persian wheel (rahat) lifting water
Roller conveyor	A row of free-spinning rollers; cartons slide over them by gravity or pushing
Hoist	A lifting device that raises and lowers heavy loads vertically
Chain hoist	A manual hoist operated by pulling a hand chain
Electric hoist	A motor-driven hoist for heavier, repeated lifting
Forklift	A powered vehicle with front forks that lifts pallets and moves them around
Pallet	A flat wooden or plastic platform on which goods are stacked for easy lifting by a forklift
AGV	A driverless robot vehicle that follows a marked path to carry materials
Sensor	A device on the AGV that "sees" the path, obstacles or position — like its eyes
Bin	A small box-like storage container for powders inside the plant
Silo	A very tall, large storage tank for bulk powder or grain
Bulk density	Weight of powder per unit volume it fills, e.g. 800 kg/m^3
Mass flow	Flow pattern in a silo where ALL the powder moves down together, uniformly
Funnel flow	Flow pattern where only the centre powder flows and the sides stay still, forming a funnel
Quarantine	Isolation area: "keep apart until tested and approved"
Approved / Released area	Warehouse area for materials that have passed quality testing
Rejected area	Separate area for materials that failed testing — never mixed with good stock
First-in, first-out (FIFO)	Rule: use the oldest stock first, like a shopkeeper selling old packets first
GMP	Good Manufacturing Practice — rules that keep medicines safe and clean

4. Explanations

4.1 Introduction to material handling equipment and techniques

A pharmaceutical plant receives tonnes of raw materials every week — powders like lactose and starch, granules, bottles, cartons, solvents. All these materials must be:

1. Unloaded from trucks.
2. Carried to the warehouse.
3. Moved to the production area when needed.
4. Carried from one machine to another (e.g., from mixer to tablet press).
5. Taken back to the warehouse as finished goods and loaded into trucks.

Material handling is the organised system of doing all this movement and storage safely, quickly and without damaging or contaminating the materials.

Why material handling matters in pharma:

- Powders and tablets are easily contaminated by dust, moisture and wrong mixing. Proper handling protects product quality.
- Many materials are heavy (50 kg bags, 200 L drums). Safe handling protects workers from injury.
- Wrong material reaching the wrong machine can spoil a whole batch. Organised handling with labels prevents mix-ups.
- Time saved in transport means faster production and lower cost.

Material handling techniques are of three types:

- **Manual handling:** Workers carry, lift and push materials by hand or with simple tools like trolleys and hand carts. Used for light, short-distance jobs.
- **Mechanical handling:** Machines do the work — conveyors, hoists, forklifts, cranes. Used for heavy, repeated or long-distance movement.
- **Automated handling:** Machines run by themselves with little human help — AGVs, robotic arms, automatic storage systems. Used in modern, high-volume plants.

4.2 Conveyors

A **conveyor** moves material continuously along a fixed route. Think of the luggage belt at an airport — bags keep arriving without anyone carrying them. In pharma plants, conveyors carry powders, granules, tablets, bottles and cartons.

(a) Belt conveyor

- **Construction:** A long, endless (loop-shaped) belt made of rubber, PVC or food-grade plastic, stretched over two end pulleys (rollers). One pulley is driven by an electric motor; the other rotates freely. Supporting rollers (idlers) hold the belt between the ends.
- **Working:** The motor rotates the drive pulley. The pulley pulls the belt, and the belt moves forward continuously. Material is placed on the top surface of the moving belt and is carried from the feeding end to the discharge end, where it falls off into the next machine or container.
- **Used for:** Granules, tablets (coated), cartons, bottles — horizontal or slightly inclined transport.
- **Pharma note:** The belt must be smooth, non-shedding (should not release fibres) and easy to clean, so that the medicine is not contaminated.

(b) Screw conveyor (auger)

- **Construction:** A helical (spiral) screw blade fixed on a central shaft, fitted inside a U-shaped trough or a cylindrical tube. The shaft is rotated by a motor.
- **Working:** When the screw rotates, its spiral flights push the powder or granules forward along the tube, just like the screw of a hand-operated grain mill pushes flour forward, or like a screw pushes wood when turned. Material enters at one end and is discharged at the other end.
- **Used for:** Dry powders and granules — lactose, starch, dried granules — over short distances, including inclined transport.
- **Advantage:** Enclosed design keeps dust inside, so the plant stays clean.

(c) Pneumatic conveyor

- **Construction:** A system of closed pipes, a blower or vacuum pump, a feeding device, and a separator (cyclone) at the receiving end.
- **Working:** Air is blown through the pipe (pressure system) or sucked through it (vacuum system). Powder fed into the fast-moving air stream is carried along with the air, like dust carried by a strong wind. At the end, a cyclone separator separates the powder from the air and collects it.
- **Used for:** Fine powders (e.g., active drug powders) moved over long distances or between floors, where a clean, enclosed transfer is needed.
- **Advantage:** Fully closed — no dust escapes, no contamination enters. Very hygienic.

(d) Bucket conveyor (bucket elevator)

- **Construction:** A vertical or inclined belt (or chain) with many small buckets attached at regular intervals, enclosed in a casing. There is a boot (bottom) pulley and a head (top) pulley.
- **Working:** At the bottom, buckets scoop up granules or powder. The belt carries the filled buckets upward. At the top, the buckets turn over the head pulley and empty their contents into a discharge chute — exactly like a Persian wheel (rahat) lifting water from a well in buckets.
- **Used for:** Lifting granules and powders vertically to the top of mixers, tablet presses or silos.

(e) Roller conveyor

- **Construction:** A frame fitted with a series of parallel cylindrical rollers that spin freely on their axles.
- **Working:** Cartons or trays placed on the rollers move forward when pushed, or roll down by gravity if the conveyor is slightly inclined. Powered versions use a motor to rotate the rollers.
- **Used for:** Packing halls — moving cartons, bottles and finished-goods boxes from the packing line to the dispatch area.

4.3 Hoists

A **hoist** lifts heavy loads straight up and down. Think of the pulley used to lift water buckets from a well — a hoist is the industrial version of that idea.

(a) Chain hoist (manual)

- **Construction:** A compact metal block containing gears, a load chain with a hook, and a separate endless hand chain.
- **Working:** The worker pulls the hand chain. The gears multiply the pulling force, and the load chain winds up, lifting the heavy load slowly. Releasing or pulling in the opposite direction lowers the load.
- **Used for:** Occasional lifting of motors, machine parts or drums during maintenance.

(b) Electric hoist

- **Construction:** Like a chain hoist, but an electric motor replaces the hand chain. It runs on an overhead beam (gantry) so it can also travel sideways.
- **Working:** Pressing a button starts the motor, which winds the chain or wire rope and lifts the load. It can lift heavier loads faster and repeatedly, with less worker effort.
- **Used for:** Lifting 200 L drums of solvents, heavy machine parts, and loading/unloading in the warehouse.

(c) Fork-truck (forklift) concepts

- A forklift is a small four-wheeled powered vehicle. In front it has two flat steel **forks** that slide under a **pallet** (a flat platform on which bags or boxes are stacked).
- The forks are raised by hydraulic power, lifting the whole pallet. The driver then drives the loaded forklift to the required place and lowers the forks.
- **Used for:** Moving pallets of raw-material bags from trucks to the warehouse, and finished-goods cartons from the packing hall to dispatch.
- **Safety note:** Only trained, licensed drivers may operate forklifts. Loads must be stable and within the rated capacity.

4.4 AGVs — Automated Guided Vehicles

Definition: An AGV is a driverless, battery-powered vehicle that carries materials automatically along a fixed route on the factory or warehouse floor.

How an AGV works (step by step):

1. **Route:** A path is marked on the floor — by magnetic tape, coloured line, embedded wire, or stored as a map in the AGV's memory.
2. **Guidance sensors:** Sensors under the AGV "read" the path (e.g., a magnetic sensor follows the magnetic tape; a laser scanner reads reflectors on walls) and steer the vehicle along it.
3. **Load handling:** The AGV stops at a station, picks up a pallet or trolley (by its own lift deck or by coupling), and carries it to the destination station.
4. **Obstacle detection:** Safety scanners (laser or ultrasonic sensors) watch ahead. If a person or object blocks the path, the AGV slows down and stops automatically, and restarts when the path is clear.
5. **Control:** A central computer (fleet manager) sends jobs to each AGV by radio/Wi-Fi — "go to raw-material store, pick pallet 12, deliver to granulation area."

Sensors on an AGV (simple meanings):

- **Guidance sensor:** follows the marked path — the AGV's "eyes on the road".
- **Laser safety scanner:** detects people and obstacles ahead — the AGV's "watchman".
- **Proximity sensor:** detects when the AGV has reached a station or docking point.
- **Battery sensor:** warns when charging is needed; many AGVs drive themselves to a charging dock.

Advantages of AGVs in pharma warehouses:

- **No human contact:** Materials move without workers touching them — less contamination risk, which GMP demands.
- **Accuracy:** The AGV delivers the right pallet to the right station every time — fewer mix-ups of materials.
- **24-hour working:** AGVs can work in shifts without rest, useful in large plants.
- **Clean and quiet:** Battery-powered, no exhaust fumes inside the warehouse.
- **Safety:** Built-in obstacle detection stops the vehicle before hitting people.
- **Traceability:** The control computer records every movement — useful for batch records and audits.

4.5 Storage systems: bins, silos and warehouses

Raw materials must be stored safely before use, and finished goods before dispatch. Storage systems keep materials clean, dry, labelled and easy to find.

(a) Bins

- A **bin** is a relatively small storage container, usually box-shaped (rectangular) with a sloped or hopper bottom and an outlet valve at the bottom.
- Bins are kept inside the plant near the machines. Powder flows out through the bottom valve when needed — like grain flowing from the bottom of a kitchen storage dabba with a tap.
- **Used for:** Day-to-day quantities of powders and granules — e.g., a bin of lactose beside the tablet granulation area.
- **Advantage:** Small, movable, easy to clean between different materials.

(b) Silos

- A **silo** is a very large, tall storage vessel for bulk materials — like the big water tanks seen on top of buildings, but for powders and granules.
- **Cylindrical silo:** The main body is a vertical cylinder (round tube). It stands on legs or a support structure. Material is filled from the top and discharged from the bottom.
- **Conical-bottom silo:** The bottom of the silo is cone-shaped (like an inverted funnel / ice-cream cone pointing down). The cone shape helps powder flow out smoothly by gravity through the outlet at the tip of the cone.
- Most powder silos combine both: a cylindrical top portion with a conical bottom portion.

Silo flow patterns — mass flow vs funnel flow:

- **Mass flow:** When the outlet opens, the ENTIRE contents of the silo move downward together, uniformly — the powder at the walls and the powder at the centre all flow at the same time. This is the ideal pattern: no stagnant (non-moving) powder is left behind, first-in material comes out first, and there is no spoilage of old powder stuck at the sides.
- **Funnel flow:** Only the powder in the centre flows down, forming a funnel-shaped channel, while the powder near the walls stays still (stagnant zones). The stagnant powder may cake, absorb moisture or degrade over time — a quality risk.
- **Design point:** A steep, smooth conical bottom with a large enough outlet promotes mass flow. Funnel flow happens with shallow cones or rough walls.

(c) Warehouses

A **warehouse** is the building where materials are received, stored and dispatched. A pharma warehouse is not just a big room — it is divided into clearly marked **zones**:

1. **Receiving bay:** Trucks unload here. Materials are checked against the purchase order (right item, right quantity, undamaged packing).
2. **Quarantine area:** Incoming materials are kept here, physically separated and labelled "QUARANTINE — NOT TESTED", until Quality Control tests and approves them. Nothing moves out of quarantine without QC approval.
3. **Approved / released goods area:** Materials that passed testing are stored here with green "APPROVED" labels. Only approved materials go to production.
4. **Rejected materials area:** Materials that failed testing are kept here under lock with red "REJECTED" labels, away from good stock, until they are returned or destroyed.
5. **Packaging materials store:** Bottles, caps, cartons, labels stored separately.
6. **Finished goods store:** Packed medicines stored here before dispatch.
7. **Dispatch bay:** Finished goods are loaded into trucks here.
8. **Sampling booth / dispensing area:** A clean, controlled area where QC draws samples and production weighs raw materials.

Warehouse layout principles:

- Clear separation of quarantine, approved and rejected areas (walls, railings or marked lines).
- Temperature and humidity control for sensitive materials (many drugs degrade in heat and moisture).
- FIFO (first-in, first-out) arrangement so older stock is used first.
- Wide aisles for forklift movement; clearly labelled racks and locations.
- Pest control and cleanliness as per GMP.

4.6 Worked numericals — storage capacity

Formula: Volume of cylindrical silo = $\pi \times D^2 \times H \div 4$, where D = internal diameter and H = cylindrical height. **Mass stored = Volume × bulk density.**

Numerical (a): A cylindrical silo has diameter 3 m and cylindrical height 10 m. The powder has a bulk density of 800 kg/m³. Find the volume and the mass of powder stored.

Step 1 — Volume: $V = \pi \times D^2 \times H \div 4$ $V = 3.1416 \times (3\ m)^2 \times 10\ m \div 4$ $V = 3.1416 \times 9\ m^2 \times 10\ m \div 4$ $V = 282.74\ m^3 \div 4$ **$V = 70.69\ m^3$**

Step 2 — Mass: Mass = Volume × bulk density Mass = $70.69\ m^3 \times 800\ kg/m^3$ **Mass = 56,549 kg ≈ 56.55 tonnes**

So the silo holds about 70.69 cubic metres of powder, weighing about 56.55 tonnes.

Numerical (b): A rectangular bin measures 2 m × 2 m × 1.5 m (length × width × height). The granules have a bulk density of 600 kg/m³. Find the volume and the mass stored.

Step 1 — Volume: V = length × width × height $V = 2\ m \times 2\ m \times 1.5\ m$ **$V = 6.0\ m^3$**

Step 2 — Mass: Mass = $6.0\ m^3 \times 600\ kg/m^3$ **Mass = 3,600 kg = 3.6 tonnes**

So the bin holds 6 cubic metres of granules, weighing 3.6 tonnes.

5. Classifications

5.1 Material handling equipment — classification

1. **By mode of movement:**
    - **Continuous movement:** Belt conveyor, screw conveyor, pneumatic conveyor, bucket elevator, roller conveyor — material flows without stopping.
    - **Intermittent (batch) movement:** Hoists, forklifts, AGVs, cranes — one load is moved at a time.
2. **By direction:**
    - **Horizontal:** Belt conveyor, roller conveyor, AGV.
    - **Vertical:** Hoists, bucket elevator.
    - **Inclined:** Screw conveyor, belt conveyor (inclined), bucket elevator.
3. **By power source:**
    - **Manual:** Hand trolley, chain hoist.
    - **Powered:** Electric hoist, forklift, belt conveyor.
    - **Automated:** AGV, robotic systems.

5.2 Conveyors — classification by material carried

Conveyor type	Best suited for
Belt conveyor	Granules, tablets, cartons, bottles (general purpose)
Screw (auger) conveyor	Dry powders, short distances
Pneumatic conveyor	Fine, dusty powders over long distances
Bucket conveyor/elevator	Vertical lifting of granules and powders
Roller conveyor	Cartons, boxes, trays in packing halls

5.3 Storage vessels — classification

- **By size:** Bins (small, in-plant) → Silos (large, bulk storage).
- **By shape:** Cylindrical silos; conical-bottom silos; rectangular bins; hopper-bottom bins.
- **By flow pattern:** Mass-flow silos (whole contents move) vs funnel-flow silos (centre channel only).

5.4 Warehouse zones — classification by material status

Quarantine (untested) → Approved/released (passed QC) → Rejected (failed QC), plus packaging store, finished goods store, receiving bay and dispatch bay.

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6. Mechanisms

6.1 Belt conveyor — working mechanism (step by step)

1. The electric motor rotates the **drive pulley**.
2. Friction between the drive pulley and the belt drags the endless belt forward.
3. **Idler rollers** support the belt and keep it flat between the two end pulleys.
4. Material is fed onto the moving belt at the **tail (feeding) end**.
5. The belt carries the material to the **head (discharge) end**.
6. At the head pulley the belt turns back; material falls off by gravity into a chute, bin or the next machine.

6.2 Screw conveyor — working mechanism

1. Motor rotates the central shaft.
2. The helical screw flights rotate inside the trough.
3. Each turn of the screw pushes a pocket of powder forward by one pitch (one screw-turn distance).
4. Powder enters through the inlet hopper and travels along the trough.
5. Powder drops out through the discharge opening at the far end.

6.3 Pneumatic conveyor — working mechanism

1. The blower (or vacuum pump) creates a fast-moving air stream in the closed pipe.
2. Powder is fed into the air stream through a rotary valve or venturi feeder.
3. Air drag carries the particles along the pipe — like leaves carried by wind.
4. At the receiving end, a **cyclone separator** spins the air; centrifugal force throws powder to the walls, and clean air exits from the top.
5. Collected powder drops into the receiving bin or silo.

6.4 Bucket elevator — working mechanism

1. Buckets at the bottom (**boot**) scoop up granules from the boot pit.
2. The moving belt/chain carries filled buckets upward.
3. At the top (**head pulley**), buckets tip over and empty by gravity/centrifugal force.
4. Emptied material falls into the discharge chute leading to the silo or machine.
5. Empty buckets travel back down to repeat the cycle.

6.5 AGV — working mechanism (material transport cycle)

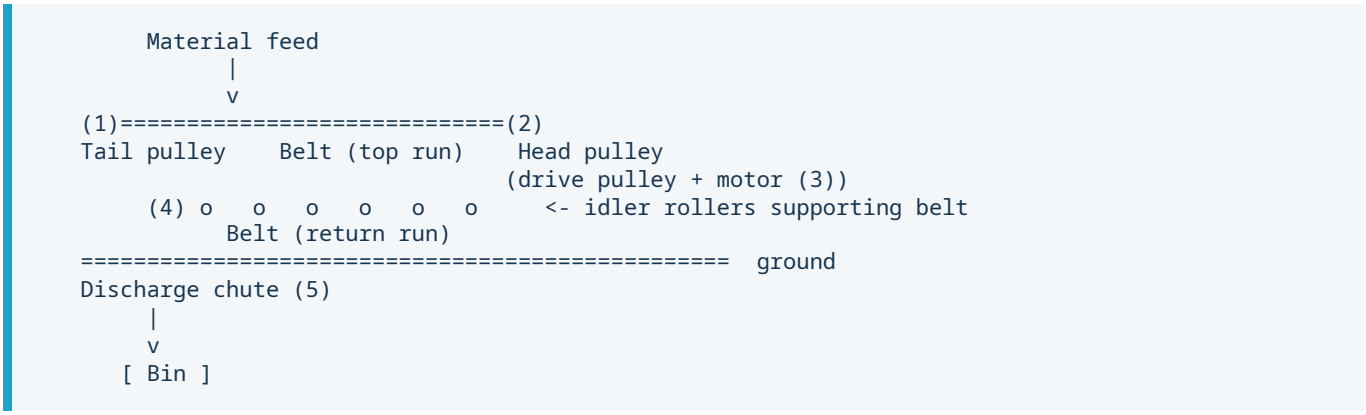
1. The central computer sends a transport order to the AGV by wireless signal.
2. The AGV follows its guided path using guidance sensors to the pickup station.
3. Proximity sensors confirm arrival; the AGV picks up the pallet (lifting deck rises).
4. The AGV travels the path to the destination station, with laser scanners watching for obstacles.
5. If an obstacle appears, the AGV stops; it restarts automatically when the path is clear.
6. At the destination, it lowers/places the load and reports "job complete" to the computer.

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7. Diagrams

Draw each diagram on paper using the numbered labels given.

Diagram 1 — Belt conveyor (side view)



Labels: 1 — Tail (feeding-end) pulley; 2 — Head (discharge-end) pulley; 3 — Electric motor driving the head pulley; 4 — Idler rollers supporting the belt; 5 — Discharge chute where material falls off.

Diagram 2 — Screw (auger) conveyor (side sectional view)

```
Inlet hopper (1)
     |
     v
======================================
|  ////  ////  ////  ////  ////      |  (2) Helical screw flights
|  ------ central shaft (3) --------  |  rotating inside
======================================
Trough/tube (4)              Discharge opening (5)
                                      |
                                      v
                                   [ Bin ]
Motor (6) coupled to shaft at left end
```

Labels: 1 — Inlet hopper; 2 — Helical screw flights; 3 — Central rotating shaft; 4 — Enclosed trough/tube; 5 — Discharge opening; 6 — Drive motor.

Diagram 3 — Chain hoist (front view)

```
     Overhead beam / support (1)
               |
          [ Hoist block (2) ]  <- gears inside
           /           \
Hand chain (3)    Load chain (4)
(endless loop)        |
pulled by worker   Hook (5)
                      |
                   [ Load (6) ]
```

Labels: 1 — Overhead support beam; 2 — Hoist block with gears; 3 — Hand chain (worker pulls this); 4 — Load chain; 5 — Hook; 6 — Load being lifted.

Diagram 4 — AGV path layout (warehouse floor plan, top view)

```
+-------------------------------------------------+
|  RAW MATERIAL   - - - - - - - - - - ->  (path)  |
|  STORE (A)        magnetic tape path            |
|       |                                         |
|       | path                                    | path
|       v                                        v
|  [AGV 1] --->------>------>------>  PRODUCTION (B)|
|                    charging dock (C)            |
|  PACKING (D)  <-----<-----<-----<----  [AGV 2]     |
+-------------------------------------------------+
Sensors: (1) guidance sensor under AGV follows tape;
(2) laser safety scanner at front watches for obstacles;
(3) station markers at A, B, C, D for pickup/drop.
```

Labels: 1 — Guidance sensor (follows floor path); 2 — Laser safety scanner (obstacle detection); 3 — Pickup/drop stations; 4 — Charging dock.

Diagram 5 — Bin vs silo (comparison sketch)

```
   BIN (small)                SILO (large)
  +------------+            +------------------+
  |            |            |                  |
  |  powder    |            |                  |
  |            |            |    bulk powder     |
  +------------+            |                  |
   \          /             +------------------+
    \  cone  /                        \        /
     \______/  (1)                cone  \______/  (2)
         | outlet valve                   | outlet
       [drum]                         [conveyor]
  (1) small hopper bottom with valve  (2) large conical bottom
```

Labels: Bin — 1. Hopper bottom with outlet valve. Silo — 2. Conical bottom for gravity discharge; cylindrical body above.

Diagram 6 — Warehouse layout (top view with zones)

```
+-------------------------------------------------------+
| RECEIVING  | QUARANTINE  | APPROVED   |  REJECTED     |
| BAY (1)    | AREA (2)    | STORE (3)  |  AREA (4)     |
| trucks     | "NOT TESTED"| green label| red label,    |
| unload     | isolated    | QC passed  | locked        |
|-------------------------------------------------------|
| PACKAGING STORE (5)  | FINISHED GOODS STORE (6)       |
| bottles, cartons     | packed medicines               |
|-------------------------------------------------------|
| SAMPLING / DISPENSING BOOTH (7)  | DISPATCH BAY (8)   |
+-------------------------------------------------------+
Wide aisles (9) between zones for forklift movement
```

Labels: 1 — Receiving bay; 2 — Quarantine area; 3 — Approved store; 4 — Rejected area; 5 — Packaging store; 6 — Finished goods store; 7 — Sampling/dispensing booth; 8 — Dispatch bay; 9 — Forklift aisles.

Diagram 7 — Mass flow vs funnel flow in a silo (sectional view)

```
 MASS FLOW                      FUNNEL FLOW
+----------+                   +----------+
|vvvvvvvvvv|  all powder       |  ::::::: |  stagnant
|vvvvvvvvvv|  moving down      |  :vvvvv: |  powder at
|vvvvvvvvvv|  together        |  :vvvvv: |  walls (::)
|vvvvvvvvvv|                   |  :vvvvv: |  flowing
 \vvvvvvvv/                    \ :vvvv: /   centre (vv)
  \vvvvvv/  steep cone           \::vv::/  shallow cone
   ||||||                         ||||||
```

Labels: Mass flow — entire contents move uniformly, no stagnant zones (needs steep, smooth cone). Funnel flow — only central channel flows; side powder stays still and may cake or degrade.

8. Flowcharts

Flowchart 1 — Selecting a conveyor for a material

```
START: What material must be moved?
        |
        v
Is it a fine, dusty powder needing long-distance / multi-floor transfer?
   |YES -> Use PNEUMATIC CONVEYOR (closed, hygienic)
   |NO
   v
Must the material be lifted vertically to a height?
   |YES -> Use BUCKET ELEVATOR
   |NO
   v
Is it a dry powder over a short distance?
   |YES -> Use SCREW (AUGER) CONVEYOR
   |NO
   v
Is it cartons, bottles or packed boxes in the packing hall?
   |YES -> Use ROLLER CONVEYOR
   |NO
   v
Use BELT CONVEYOR (general purpose: granules, tablets, cartons)
        |
        v
Check: belt material is non-shedding, food/pharma grade, easy to clean -> END
```

Flowchart 2 — Material movement through the warehouse

```
Truck arrives
    |
    v
RECEIVING BAY: check items vs purchase order
    |
    v
Move to QUARANTINE AREA (label: NOT TESTED)
    |
    v
QC SAMPLING & TESTING
    |
    +---- PASS ----> APPROVED STORE (green label) --> issued to PRODUCTION
    |
    +---- FAIL ----> REJECTED AREA (red label, locked) --> return / destroy
```

9. Infographic Concept Box

Concept: "The Journey of One Bag of Lactose" — a single visual panel for this chapter.

Design idea: One wide horizontal panel showing a 50 kg bag of lactose travelling left to right through the plant: (1) truck unloading at the receiving bay; (2) forklift carrying the pallet to quarantine; (3) QC stamp "APPROVED"; (4) forklift moving it to the approved store; (5) the bag tipped into a bin; (6) a screw conveyor carrying the powder up; (7) a silo with mass-flow arrows; (8) a bucket elevator lifting granules to the tablet press; (9) a roller conveyor carrying packed cartons; (10) an AGV gliding along a marked floor path with a sensor beam; (11) truck at dispatch. Caption strip at the bottom: "Move it right — no contamination, no mix-up, no injury." Key icons: pallet, forklift, conveyor belt, silo, AGV, green APPROVED tag. This one journey covers every equipment and zone in the chapter.

10. Tables

Table 1 — Conveyor types compared

Conveyor	Moves	Direction	Key advantage	Pharma example
Belt	Granules, tablets, cartons, bottles	Horizontal / inclined	Simple, high capacity	Cartons to dispatch
Screw (auger)	Dry powders	Horizontal / inclined, short distance	Enclosed, dust-free	Lactose powder to mixer
Pneumatic	Fine powders	Any direction, long distance	Fully closed, hygienic	Active drug powder between floors
Bucket elevator	Granules, powders	Vertical	Lifts to height	Granules to top of tablet press
Roller	Cartons, trays, boxes	Horizontal	Simple, cheap	Packed boxes in packing hall

Table 2 — Bins vs silos

Feature	Bin	Silo
Size	Small (holds kg to a few tonnes)	Large (tens of tonnes)
Shape	Usually rectangular box with hopper bottom	Usually cylindrical body with conical bottom
Location	Inside plant, near machines	Inside or outside, bulk storage
Mobility	Often movable / portable	Fixed installation
Use	Day-to-day feeding of machines	Bulk stock of raw materials
Example	Bin of starch beside granulator	50-tonne lactose silo

Table 3 — Hoists compared

Hoist	Power	Capacity	Best use
Chain hoist	Manual (hand chain)	Light–medium	Occasional lifting, maintenance
Electric hoist	Electric motor	Medium–heavy	Repeated lifting of drums, machine parts
Forklift	Engine/battery	Heavy (pallets)	Moving pallets around warehouse

11. Examples

- **Belt conveyor:** In a tablet packing hall, a belt conveyor carries strips of packed tablets from the blister machine to the cartoning machine.
- **Screw conveyor:** Lactose powder is fed by a screw conveyor from a day-bin directly into a high-shear mixer granulator.
- **Pneumatic conveyor:** Micronised (very fine) paracetamol powder is transferred through closed pipes from the milling room on the ground floor to the blending room on the first floor — no dust escapes into the plant.
- **Bucket elevator:** Dried granules are lifted by a bucket elevator to the top of a fluid-bed dryer discharge silo.
- **Roller conveyor:** In the finished-goods packing area, sealed cartons roll down a slightly inclined roller conveyor to the dispatch bay.
- **Chain hoist:** During maintenance, a chain hoist lifts the heavy punch-and-die assembly out of a tablet press.
- **Electric hoist:** 200 L drums of isopropyl alcohol are lifted by an electric hoist from the truck to the solvent store.
- **Forklift:** Pallets of 50 kg sugar bags are moved from the receiving bay to the quarantine area.
- **AGV:** In a large modern warehouse, an AGV carries a pallet of approved raw material from the store to the dispensing booth without a driver.
- **Bin:** A stainless-steel bin holding starch paste granules stands beside the tablet compression machine.
- **Silo:** A 56-tonne cylindrical silo with a conical bottom stores bulk lactose; mass flow ensures old powder never stays stuck at the walls.

12. Analogies

- **Conveyor belt = airport luggage belt.** You put your bag at one end; it arrives at the other end without you carrying it.
- **Screw conveyor = hand grain-mill screw / meat-mincer screw.** Turning the spiral pushes material forward, bit by bit.
- **Pneumatic conveyor = wind carrying dry leaves.** Fast air carries light powder through a pipe, just as wind carries leaves.
- **Bucket elevator = Persian wheel (rahat) at a village well.** Buckets fill at the bottom, rise up, tip over at the top and empty.
- **Hoist = well pulley.** Pull the rope on one side; the bucket (load) rises on the other side. Gears in a chain hoist make a weak pull lift a heavy load — like a small person lifting a heavy bucket with a good pulley.
- **AGV = driverless toy car following a drawn line.** It follows the path on the floor and stops if something comes in front — like a careful auto-rickshaw that never needs a driver.
- **Silo = overhead building water tank.** Tall, cylindrical, filled from the top, emptied from the bottom — but for powder instead of water.
- **Quarantine area = railway waiting room for new passengers.** New arrivals wait separately until their tickets (QC test reports) are checked.
- **FIFO = milkman's rule.** Sell yesterday's milk before today's — use old stock first.
- **Mass flow vs funnel flow = emptying a grain sack.** If the whole sack slides down evenly, that is mass flow. If only the middle pours out and the sides stick, that is funnel flow.

13. Pharmacy Relevance

- **Contamination control:** Enclosed conveyors (screw, pneumatic) keep drug powders away from dust and people — a direct GMP requirement.
- **No mix-ups:** Labelled bins, AGV routing by computer, and separated warehouse zones prevent the wrong material reaching the wrong batch — a major cause of product recalls.
- **Powder quality:** Mass-flow silos prevent old, caked or moisture-damaged powder from entering production; funnel-flow stagnant zones can spoil a batch.
- **Worker safety:** Hoists and forklifts replace manual lifting of 50 kg bags and 200 L drums, reducing back injuries.
- **Batch traceability:** AGV control systems and warehouse records log every material movement — auditors check these records during GMP inspections.
- **Cleanability:** Pharma-grade conveyors and stainless-steel bins are designed for easy cleaning between products, preventing cross-contamination.

14. India Context

- Large Indian pharma plants in industrial areas around **Hyderabad, Bengaluru, Mumbai, Ahmedabad and Visakhapatnam** operate warehouses with quarantine, approved and rejected zones as per **Schedule M** (the Indian GMP rules) — this zone system is a legal requirement, not optional.
- Indian plants commonly use belt conveyors in packing halls, screw conveyors for powder feeding, and forklifts for pallet movement; AGVs are found in newer, larger facilities.
- **Monsoon humidity** affects stored powders: lactose, starch and many drug powders absorb moisture and cake in humid months, so warehouses use dehumidifiers and moisture-proof packing — and silos must be kept dry to maintain flow.
- **Indian labour-safety norms:** Under the Factories Act, workers must be trained for lifting machinery; only trained operators handle forklifts and hoists, and safe manual-lifting practices (bend knees, keep load close) are taught to reduce back injuries common in manual loading work.
- Pallets in India are commonly wooden; pharma warehouses increasingly use plastic or stainless-steel pallets because wood can shed splinters and harbour pests.

15. Key Points

- Material handling = movement + storage + protection of materials from entry to dispatch.
- Techniques: manual, mechanical, automated.
- Five conveyors: belt (general), screw/auger (powders, short), pneumatic (fine powders, long, closed), bucket (vertical lift), roller (cartons).
- Hoists lift vertically: chain (manual, occasional), electric (motor, repeated/heavy); forklifts move pallets.
- AGV = driverless guided vehicle; sensors: guidance, laser safety scanner, proximity, battery; advantages: no human contact, accuracy, 24-h work, traceability.
- Bins are small in-plant containers; silos are large bulk vessels (cylindrical body + conical bottom).
- Mass flow: all powder moves together (ideal). Funnel flow: centre flows, sides stagnant (risk of caking/spoilage).
- Warehouse zones: receiving → quarantine → QC → approved / rejected; plus packaging store, finished goods, dispatch, sampling booth.
- Silo volume = $\pi D^2 H/4$; mass = volume × bulk density. Example: 3 m × 10 m silo at 800 kg/m^3 holds ≈ 70.69 m^3 ≈ 56.55 tonnes.

16. Common Confusions

- **Bin vs silo:** A bin is small and sits near machines inside the plant; a silo is a huge bulk vessel. They are not the same size class.
- **Hoist vs forklift:** A hoist lifts loads vertically in one place; a forklift lifts AND carries loads around the warehouse.
- **Chain hoist vs electric hoist:** Both lift vertically, but the chain hoist is hand-operated (occasional, lighter jobs) while the electric hoist uses a motor (heavier, repeated jobs).
- **Mass flow vs funnel flow:** Mass flow is the GOOD pattern (everything moves); funnel flow is the PROBLEM pattern (sides stay still). Students often reverse these.
- **Quarantine vs rejected:** Quarantine = not yet tested (may still pass). Rejected = tested and FAILED. Different areas, different labels.
- **AGV vs forklift:** A forklift needs a driver; an AGV is driverless and follows a guided path automatically.
- **Pneumatic conveyor vs belt conveyor:** Pneumatic uses air in closed pipes (best for dusty powders); belt is an open moving surface (best for granules/cartons).

17. Common Mistakes

- Writing that funnel flow is desirable — it is mass flow that is preferred in pharma.
- Calling any vertical lifter a "hoist" for pallet transport — pallet transport around a warehouse is the forklift's job.
- Forgetting units in the silo numerical: volume in m^3, mass in kg (convert to tonnes where asked).
- Using diameter instead of radius incorrectly: the formula $\pi D^2 H/4$ already uses diameter — do NOT divide by 2 again.
- Mixing up bulk density units (kg/m^3) with true density — bulk density includes air gaps between particles.
- Listing warehouse zones without quarantine — quarantine is compulsory under GMP and is almost always asked in exams.
- Describing AGV sensors vaguely — name them: guidance sensor, laser safety scanner, proximity sensor.

18. Mnemonics

- **Conveyor types — "BSP-BR" (say "BSP-Bhar"): B**elt, **S**crew, **P**neumatic, **B**ucket, **R**oller.
- **Warehouse zones in order — "R Q AR P F D S": "Rani Queen Approved, Rejected, Packing Finished, Dispatch Sample": R**eceiving → **Q**uarantine → **A**pproved / **R**ejected → **P**ackaging store → **F**inished goods → **D**ispatch (+ **S**ampling booth).
- **Mass flow = "Mass Moves"** — the whole MASS MOVES together. Funnel flow = "Funnel in the middle" — only the centre flows like a funnel.
- **AGV sensors — "GLPB": "Good Lorry, Please Brake": G**uidance, **L**aser scanner, **P**roximity, **B**attery.
- **Hoist types — "C E F": "Chain, Electric, Fork": C**hain hoist, **E**lectric hoist, **F**orklift.

19. Exam Summary

Material handling is the movement, storage and protection of materials in the plant, done manually, mechanically or automatically. Conveyors move materials continuously: belt (general purpose), screw/auger (dry powders, enclosed), pneumatic (fine powders through pipes using air, fully closed and hygienic), bucket elevator (vertical lifting), roller (cartons in packing halls). Hoists lift vertically — chain hoists are manual, electric hoists are motor-driven; forklifts lift and transport pallets. AGVs are driverless battery vehicles guided along floor paths by sensors (guidance, laser safety scanner, proximity, battery), giving contamination-free, accurate, traceable transport in warehouses. Bins are small in-plant powder containers; silos are large bulk vessels with cylindrical bodies and conical bottoms. Mass flow (all powder moves together) is ideal; funnel flow (only the centre flows, sides stagnant) risks caking and spoilage. Warehouses are zoned: receiving → quarantine (untested) → QC testing → approved or rejected areas, plus packaging store, finished goods store, sampling booth and dispatch, arranged FIFO with forklift aisles. Storage capacity: silo volume = $\pi D^2H/4$; mass = volume × bulk density (e.g., 3 m diameter × 10 m high silo at 800 kg/m^3 ≈ 70.69 m^3 ≈ 56.55 tonnes).

20. One-Minute Revision

- Handling techniques: manual, mechanical, automated.
- Conveyors: Belt, Screw, Pneumatic, Bucket, Roller — "BSP-BR".
- Hoists: chain (manual), electric (motor); forklift moves pallets.
- AGV: driverless, guided path, sensors GLPB (Guidance, Laser, Proximity, Battery).
- Bin = small, in-plant; Silo = large, bulk (cylinder + cone bottom).
- Mass flow = all moves (good); Funnel flow = centre only (bad).
- Warehouse: Receiving → Quarantine → Approved/Rejected → Packing/Finished → Dispatch.
- FIFO: first-in, first-out.
- Volume of silo = $\pi D^2H/4$; mass = V × bulk density.

21. Exam Questions

Long / Essay Questions (5)

1. Describe the construction and working of a belt conveyor, a screw conveyor and a pneumatic conveyor. Compare their suitability for handling pharmaceutical powders.
2. What is a silo? Explain cylindrical and conical-bottom silos with sketches. Discuss mass flow and funnel flow patterns and explain why mass flow is preferred in pharmaceutical storage.
3. Draw a labelled layout of a pharmaceutical warehouse. Describe each zone — receiving, quarantine, approved, rejected, packaging store, finished goods store and dispatch — and explain the flow of materials through them.
4. Define AGV. Explain its working mechanism, the sensors used, and discuss its advantages in pharmaceutical warehouses.
5. Write short notes on: (a) chain hoist vs electric hoist, (b) forklift, (c) bucket elevator. Give one pharmaceutical example for each.

Short Questions (8)

1. Define material handling and name its three techniques.
2. What is bulk density? State its unit.
3. List the five types of conveyors with one use of each.
4. Differentiate between a bin and a silo.
5. What is a quarantine area? Why is it compulsory under GMP?
6. Name the four sensors of an AGV and state the function of each.
7. Define mass flow and funnel flow in a silo.
8. State the FIFO principle and give one warehouse example.

MCQs (10)

1. Which conveyor moves fine powders through closed pipes using air?
   a) Belt conveyor b) Screw conveyor c) Pneumatic conveyor d) Roller conveyor
2. A bucket elevator is mainly used for:
   a) Horizontal transport of cartons b) Vertical lifting of granules c) Mixing powders d) Packing tablets
3. The flow pattern in which the entire silo contents move down uniformly is:
   a) Funnel flow b) Mass flow c) Plug flow d) Laminar flow
4. Incoming materials are kept in the ____ area until QC approves them.
   a) Approved b) Rejected c) Quarantine d) Dispatch
5. Which sensor makes an AGV stop when a person steps in its path?
   a) Guidance sensor b) Battery sensor c) Laser safety scanner d) Proximity sensor
6. FIFO in a warehouse means:
   a) Fast in, fast out b) First-in, first-out c) Fill in, fill out d) First-in, first-opened
7. A cylindrical silo of diameter 2 m and height 5 m has a volume of approximately:
   a) 10 m^3 b) 15.7 m^3 c) 31.4 m^3 d) 62.8 m^3
8. Which hoist is operated by pulling a hand chain?
   a) Electric hoist b) Chain hoist c) Hydraulic lift d) Forklift
9. The conical bottom of a silo helps in:
   a) Cooling the powder b) Smooth gravity discharge of powder c) Mixing two powders d) Weighing the powder
10. Pallets are lifted and moved around the warehouse by a:
    a) Belt conveyor b) Screw conveyor c) Forklift d) Bucket elevator

Answer key: 1-c, 2-b, 3-b, 4-c, 5-c, 6-b, 7-b, 8-b, 9-b, 10-c

(MCQ 7 check: $V = \pi \times 2^2 \times 5 / 4 = 15.708\ m^3 \approx 15.7\ m^3$.)

Viva Questions (5)

1. **What is material handling?** — The movement, storage, control and protection of materials from plant entry to finished-goods dispatch.
2. **Name the five conveyors.** — Belt, screw (auger), pneumatic, bucket elevator, roller.
3. **Bin or silo — which is bigger?** — Silo; bins are small in-plant containers, silos are large bulk vessels.
4. **Why is mass flow preferred over funnel flow?** — All powder moves together, so no stagnant powder cakes, absorbs moisture or degrades at the walls.
5. **What does an AGV's laser scanner do?** — Detects obstacles/people ahead and stops the vehicle automatically for safety.

Application-Based Questions (3)

1. A plant must transfer micronised drug powder from the ground-floor mill to a first-floor blender without any dust escaping into the clean area. Which conveyor will you select, and why? *(Pneumatic conveyor — fully closed pipe system, hygienic, handles fine powders over distance/between floors.)*
2. A warehouse receives a consignment of starch bags. QC testing will take 3 days. Where should the bags be stored meanwhile, and how should they be labelled? *(Quarantine area, labelled "QUARANTINE — NOT TESTED"; nothing leaves without QC approval.)*
3. A silo shows old, caked powder stuck to its walls while fresh powder flows through the centre. Name the flow pattern, state one quality risk, and suggest one design correction. *(Funnel flow; risk — degraded/caked powder contaminating batches; correction — steeper, smoother conical bottom with a larger outlet to promote mass flow.)*

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22. References

- Banker, G. S. Pharmaceutical Engineering (preferably latest edition)
- Sambamurthy, K. Introduction to Pharmaceutical Engineering (preferably latest edition)
- Kennedy, T. F. Good Design Practices for GMP Pharmaceutical Facilities (preferably latest edition)
- Banker, G. S. and Rhodes, C. T. Modern Pharmaceutics (preferably latest edition)
- Hickey, A. J. Pharmaceutical Process Engineering (preferably latest edition)
- Cole, G. C. Pharmaceutical Facilities: Design, Layouts and Validation (preferably latest edition)

CHAPTER 2: Safety, Waste Management & Corrosion

1. Learning Objectives

After studying this chapter, the student will be able to:

- Explain the safety rules for manual material handling and lifting.
- Describe machine guards, PPE and forklift safety practices.
- Explain the dangers of static electricity and dust explosions in pharma plants.
- Classify pharmaceutical waste into solid, liquid and gaseous types with examples.
- Describe waste segregation, treatment methods (incineration, ETP) and recycling basics.
- Define corrosion and explain seven types: uniform, pitting, crevice, galvanic, stress-corrosion cracking, intergranular and erosion-corrosion — with mechanism and one pharma example each.
- Discuss the impact of corrosion on pharmaceutical processes: product contamination, equipment failure and GMP issues.
- Discuss the impact of corrosion on the environment.

2. Definitions

- **Safety (in material handling):** The set of rules, devices and practices that prevent injury to workers and damage to materials and machines during lifting, moving and storage.
- **Machine guard:** A fixed cover or barrier on a machine that prevents workers' hands, clothes or hair from touching moving parts.
- **PPE (Personal Protective Equipment):** Equipment worn by a worker for personal protection — gloves, safety shoes, helmets, goggles, masks, aprons.
- **Static electricity:** Electric charge that builds up on surfaces (especially powders and plastic) due to friction, and discharges as a spark.
- **Dust explosion:** A violent explosion that happens when a cloud of fine combustible powder in air is ignited by a spark or flame in a closed space.
- **Waste segregation:** Separating different types of waste at the point where they are produced, so each type can be treated or disposed of correctly.
- **ETP (Effluent Treatment Plant):** A plant inside or near the factory that treats liquid waste (effluent) to remove pollutants before the water is discharged or reused.
- **Incineration:** Burning waste at very high temperature to destroy it completely, used for hazardous and biomedical waste.
- **Corrosion:** The gradual destruction of a metal by chemical or electrochemical reaction with its environment (air, water, chemicals) — commonly seen as rusting.
- **GMP issue (here):** Any failure to follow Good Manufacturing Practice rules, which can lead to batch rejection, warning letters or plant shutdown during inspection.

3. Terminology

Term	Plain-English meaning
Manual handling	Lifting/carrying by workers' own strength
Ergonomics	Designing work so the human body is not strained — "work fitting the worker"
Machine guard	Safety cover over dangerous moving parts
PPE	Protective gear worn by workers (gloves, goggles, masks, shoes, helmet)
Forklift safety	Rules for driving forklifts without accidents
Static electricity	Charge built up by rubbing; released as a spark
Dust explosion	Explosion of a powder-dust cloud in air when sparked
LEL (Lower Explosive Limit)	Minimum dust concentration in air that can explode
Effluent	Liquid waste flowing out of the plant
ETP	Plant that cleans liquid waste before discharge
Incineration	Burning waste at very high heat to destroy it
Segregation	Separating wastes by type at the source
Recycle	Reusing waste material after processing
Corrosion	Eating away of metal by air, water or chemicals
Rust	Reddish-brown corrosion product of iron/steel
Passivation	Forming a thin protective oxide layer on stainless steel
Pitting	Small deep holes eaten into metal surface
Galvanic corrosion	Faster corrosion when two different metals touch in liquid
Stress-corrosion cracking	Cracks in metal under stress + corrosive environment together
Contamination	Unwanted material (e.g., metal particles) entering the medicine
Leachables	Chemicals leaking from corroded equipment into the product

4. Explanations

4.1 Safety considerations in material handling

Pharma plants move heavy bags (50 kg), drums (200 L) and machines daily. Without safety rules, workers suffer back injuries, crushed fingers and falls. Safety has several parts:

(a) Manual lifting rules

- **Assess the load:** Check the weight and shape before lifting. If it is too heavy, ask for help or use a trolley/hoist — never be a hero.
- **Correct posture:** Bend your **knees**, not your back. Keep the back straight. Hold the load **close to the body**. Lift smoothly — no jerking or twisting.
- **Clear path:** Make sure the walking route is clear and the floor is not slippery before carrying.
- **Team lifting:** Heavy or awkward loads need two or more people lifting together on a count ("1-2-3 lift").
- **Rest and rotation:** Workers doing repeated lifting should rotate tasks to avoid strain injury.

(b) Machine guards

- Moving parts — conveyor belts, pulleys, gears, rotating shafts — must be covered with **fixed guards** (metal covers, railings, mesh screens).
- Guards prevent fingers, loose clothes, hair or dupattas from getting caught.
- Guards must never be removed while the machine runs; they are replaced immediately after maintenance.

(c) PPE (Personal Protective Equipment)

- **Gloves:** protect hands from cuts, chemicals and rough surfaces.
- **Safety shoes (steel-toe):** protect feet if a drum or bag falls.
- **Safety goggles:** protect eyes from dust and chemical splashes.
- **Dust masks / respirators:** protect lungs when handling fine powders.
- **Helmet / hard hat:** protects the head in areas with overhead lifting (hoists, cranes).
- **Apron / overalls:** protect body and clothes from chemicals.
- PPE must be worn where the safety signboard demands it — "PPE is the last line of defence."

(d) Forklift safety

- Only **trained and authorised** drivers may operate a forklift.
- Never exceed the **rated load capacity** written on the forklift plate.
- Keep the load **low and tilted slightly back** while driving, for stability.
- Drive **slowly**, sound the horn at crossings and blind corners.
- Never carry passengers on the forklift; never walk under raised forks.
- Park with forks lowered flat on the ground.

(e) Static electricity

- When powders flow through pipes, chutes or pneumatic conveyors, friction between particles builds up **static charge** — like rubbing a plastic comb on dry hair and seeing it attract paper bits.
- The charge can discharge as a **spark**. Near flammable solvents (alcohol, acetone) or explosive dust clouds, one spark can start a fire or explosion.
- **Controls: Earthing/grounding** — metal equipment is connected by wires to the earth so charge drains away safely. Use anti-static (conductive) bags, hoses and footwear; control humidity, since dry air increases static.

(f) Dust explosion basics

- Many pharma powders (starch, lactose, paracetamol, sugar) are **combustible** — a cloud of fine powder in air can explode like a bomb if ignited.
- Five conditions must ALL be present (the "dust explosion pentagon"): (1) combustible dust, (2) dust cloud in air, (3) oxygen, (4) an ignition source (spark, hot surface), (5) confinement (inside a room, duct or vessel).
- **Controls:** Keep dust levels low (good housekeeping, dust extraction), eliminate ignition sources (earthing, no open flames, flame-proof electrical fittings), and use explosion vents or suppression systems on risky equipment like mills and dryers.

4.2 Waste management in pharma plants

A pharma plant produces waste at every step — rejected tablets, used solvents, dirty wash water, smoke from boilers, packing scrap. This waste cannot be thrown anywhere; it must be managed so it does not harm people or the environment.

(a) Types of waste

- **Solid waste:** Rejected tablets and capsules, expired medicines, used filter cloths, contaminated packing material, sludge from the ETP, broken glass, metal scrap.
- **Liquid waste (effluent):** Wash water from equipment cleaning, spent solvents, laboratory waste liquids, cooling water containing chemicals.
- **Gaseous waste (emissions):** Boiler smoke, solvent vapours from manufacturing areas, dust from powder handling, fumes from laboratories.

(b) Segregation

- Waste is separated **at the place it is produced** into colour-coded bins/bags: e.g., general waste, recyclable waste (clean paper, plastic, glass), hazardous chemical waste, expired/rejected medicines, biomedical waste (from QC labs/ clinics).
- Segregation matters because mixing makes everything hazardous — clean recyclable plastic mixed with solvent waste must all be treated as hazardous.

(c) Treatment basics

- **Incineration:** Hazardous solid waste and expired medicines are burned at very high temperature in an incinerator, which destroys drugs and germs completely. The remaining ash is disposed of safely.
- **ETP (Effluent Treatment Plant):** Liquid waste goes through stages — **screening** (removes large solids), **primary treatment** (settling tanks remove suspended solids), **secondary/biological treatment** (microbes digest dissolved organic pollutants), **tertiary treatment** (filtration, disinfection) — before the treated water is discharged or reused for gardening/flushing.
- **Solvent recovery:** Used solvents (like isopropyl alcohol) are purified by distillation and reused — this is both waste reduction and cost saving.
- **Air pollution control:** Dust collectors, bag filters and scrubbers clean dust and vapours from exhaust air before release.

(d) Recycling

- Clean, non-contaminated materials — paper, cardboard cartons, clean plastic, glass bottles, metal scrap — are collected separately and sent to recyclers.
- Water recycling: treated ETP water is reused for cooling, gardening and toilet flushing, reducing fresh-water use.

4.3 Types of corrosion

Corrosion is the slow eating-away of metal by reaction with air, water or chemicals. The commonest example is **rust** — the reddish-brown layer on iron. In pharma plants, corrosion attacks stainless-steel vessels, pipes, tablet punches and water systems. Seven important types:

(a) Uniform corrosion

- **What:** The metal surface corrodes evenly all over, like a candle melting uniformly.
- **Mechanism:** The whole exposed surface acts as anode and cathode in tiny local cells; metal dissolves steadily and the surface thins uniformly.
- **Pharma example:** A carbon-steel support frame in a humid area slowly rusts all over.

(b) Pitting corrosion

- **What:** Small, deep, narrow holes ("pits") eaten into the metal surface, while the surrounding area looks almost untouched — like acne pits on skin.
- **Mechanism:** The protective oxide layer on stainless steel breaks at weak points (often due to chloride ions, e.g., from common salt or cleaning agents). A tiny anode forms inside the pit and corrodes rapidly downward, hidden from view.
- **Pharma example:** Pits in stainless-steel purified-water pipelines caused by high chloride levels in water.

(c) Crevice corrosion

- **What:** Corrosion in narrow gaps — under gaskets, washers, bolt heads, or where two surfaces overlap tightly.
- **Mechanism:** Liquid gets trapped in the crevice and its oxygen is used up; the oxygen-poor crevice becomes anodic relative to the outside, and corrosion concentrates inside the hidden gap.
- **Pharma example:** Corrosion under the gaskets of a tablet-coating pan or under bolted joints of a mixing vessel.

(d) Galvanic corrosion

- **What:** When two DIFFERENT metals touch each other in the presence of a liquid (electrolyte), the more reactive metal corrodes much faster — like a battery eating one terminal.
- **Mechanism:** The two metals form a galvanic (battery-like) cell; the less noble (more reactive) metal becomes the anode and dissolves, while the more noble metal is protected.
- **Pharma example:** A copper pipe joined directly to a stainless-steel pipe carrying water — the copper (or the steel, depending on conditions) corrodes fast at the joint. Remedy: use insulating fittings between different metals.

(e) Stress-corrosion cracking (SCC)

- **What:** Fine cracks appear in metal that is under mechanical stress (pulled or pressurised) in a corrosive environment — the metal cracks even though neither stress nor corrosion alone would break it.
- **Mechanism:** Tensile stress opens microscopic cracks; the corrosive chemical attacks the fresh metal at the crack tip, deepening it step by step until sudden failure.
- **Pharma example:** Cracking of stainless-steel steam pipes or pressure-vessel parts exposed to hot chloride-containing environments.

(f) Intergranular corrosion

- **What:** Corrosion along the boundaries between the metal's crystal grains — the grains themselves stay intact but the "glue" between them dissolves, so the metal crumbles like a biscuit breaking along its cracks.
- **Mechanism:** In stainless steel, heating (e.g., during welding) causes chromium to combine with carbon at grain boundaries, leaving those boundaries chromium-poor and unable to form the protective layer — so they corrode preferentially.
- **Pharma example:** Welded joints of stainless-steel vessels corroding along weld lines. Remedy: use low-carbon stainless steel (316L) and proper welding practice.

(g) Erosion-corrosion

- **What:** Metal worn away by fast-flowing liquid or slurry hitting the surface — corrosion made worse by mechanical rubbing, like river water wearing away rocks.
- **Mechanism:** The flowing fluid strips off the protective oxide layer as fast as it forms, exposing fresh metal that corrodes again — a continuous wear-plus-corrosion cycle.
- **Pharma example:** Inside of pump parts and pipe bends carrying fast-flowing suspensions or cleaning liquids.

4.4 Impact of corrosion on pharmaceutical processes

- **Product contamination:** Corroded metal releases tiny metal particles and dissolved metal ions into the medicine. Iron rust particles in tablets or metal ions in injections are dangerous to patients and cause batch rejection.
- **Leachables:** Corrosion products can leach (dissolve) into liquid products like syrups and injections, changing their colour, odour or safety.
- **Equipment failure:** Corroded pipes leak, vessels weaken, tablet punches pit and produce defective tablets. Sudden failure stops production and is costly.
- **Cleaning problems:** Pitted and rough corroded surfaces trap product residues and microbes, making cleaning validation fail — the surface can no longer be cleaned to GMP standards.
- **GMP issues:** Inspectors expect equipment to be clean, smooth and non-reactive. Visible corrosion is recorded as a GMP deficiency; repeated findings can lead to warning letters, batch recalls or loss of manufacturing licence.

4.5 Impact of corrosion on the environment

- **Metal pollution:** Corroded plant structures, pipelines and storage tanks release metals (iron, chromium, nickel) into soil and wastewater, polluting land and water bodies near the plant.
- **Leaking tanks and pipes:** Corrosion holes in solvent or chemical storage tanks let hazardous liquids seep into the ground and groundwater.
- **More waste:** Corroded equipment must be replaced more often, generating metal scrap waste.
- **Higher chemical use:** Corroded systems need stronger, more frequent chemical cleaning, increasing the chemical load on the ETP.
- In short, corrosion does not only damage the plant — its rust, leaks and extra waste reach the soil, water and air around it.

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5. Classifications

5.1 Safety in material handling — classification

1. **By hazard type:** Mechanical hazards (moving parts, falling loads) → machine guards, forklift rules; Ergonomic hazards (back strain) → lifting rules; Electrical/fire hazards → static control, dust-explosion prevention.
2. **By control level:** Engineering controls (guards, earthing, dust extraction) → Administrative controls (training, signboards, work rotation) → PPE (last line of defence).

5.2 Pharma waste — classification

Waste type	Examples	Typical treatment
Solid	Rejected tablets, expired drugs, filter cloths, ETP sludge, packing scrap	Segregation → incineration (hazardous) / recycling (clean scrap)
Liquid (effluent)	Equipment wash water, spent solvents, lab liquids	ETP (screening → settling → biological → filtration); solvent recovery by distillation
Gaseous (emissions)	Boiler smoke, solvent vapours, powder dust	Bag filters, dust collectors, scrubbers

5.3 Corrosion — classification (7 types)

1. **Uniform** — even surface attack (rusting all over).
2. **Localised: Pitting** (deep small holes), **Crevice** (in narrow gaps).
3. **Galvanic** — two different metals touching in liquid.
4. **Stress-assisted: Stress-corrosion cracking** (stress + corrosive medium).
5. **Microstructural: Intergranular** (grain-boundary attack, often at welds).
6. **Flow-assisted: Erosion-corrosion** (fast fluid strips protection).

6. Mechanisms

6.1 Dust explosion — step-by-step mechanism

1. Fine combustible powder (starch, lactose) becomes airborne, forming a dust cloud.
2. The cloud mixes with air (oxygen) inside a confined space (duct, room, vessel).
3. An ignition source appears — a static spark, hot surface or electrical spark.
4. The dust cloud ignites; burning spreads from particle to particle in milliseconds.
5. Rapid burning releases hot gases that expand violently → explosion pressure bursts the enclosure.

6.2 Static charge build-up and discharge

1. Powder flows through a pipe/chute → friction between particles and wall.
2. Electrons transfer → charge builds up on powder and equipment surfaces.
3. If equipment is NOT earthed, charge accumulates to high voltage.
4. A spark jumps (discharge) to a nearby grounded object or person.
5. If flammable vapour or dust cloud is present → fire or explosion. Earthing drains the charge safely at step 3.

6.3 Pitting corrosion — step-by-step

1. Chloride ions (from salt, cleaners) attack weak spots in stainless steel's protective oxide film.
2. The film breaks at a tiny point; a small anode forms inside the forming pit.
3. Metal dissolves inside the pit; the pit becomes acidic, speeding further attack.
4. The pit grows deep and narrow while the surrounding surface looks normal.
5. Result: hidden deep holes that can perforate pipes and harbour microbes.

6.4 Galvanic corrosion — step-by-step

1. Two different metals (e.g., copper and steel) are joined and wetted by a liquid.
2. They form a battery-like galvanic cell.
3. The more reactive metal becomes the anode and gives up electrons.
4. Anode metal dissolves into the liquid as ions — it corrodes fast.
5. The less reactive metal (cathode) is protected and hardly corrodes.

6.5 ETP treatment — step-by-step flow

1. **Screening:** bars/mesh remove large solids (tablets, rags).
2. **Primary treatment:** settling tanks let suspended solids sink as sludge.
3. **Secondary (biological) treatment:** microbes digest dissolved organic pollutants.
4. **Tertiary treatment:** filtration + disinfection (chlorination/UV) polishes the water.
5. Treated water is discharged safely or reused; sludge is dewatered and disposed.

---

7. Diagrams

Diagram 1 — Correct manual lifting posture (side view of worker)

```
        head up, back straight (1)
              O
             /|\
            / | \
              |   <- straight back, NO bending at waist
         ____/ \____
        |  knees bent (2)
        |  |
       _|  |_
      |      |  feet apart for balance (3)
=============  floor
[ load held CLOSE to body (4) ]
```

Labels: 1 — Back straight, head up; 2 — Knees bent (legs do the lifting); 3 — Feet apart for balance; 4 — Load held close to the body. WRONG way (for contrast): bending at the waist with straight knees and load held away — strains the spine.

Diagram 2 — Machine guard on a conveyor pulley (side view)

```
   Belt moving ->
   ============================
   |   PULLEY (rotating) (1)     |
   ============================
   +--------------------------+  (2) Fixed metal guard covering
   |//////////////////////////|      the nip point where belt
   +--------------------------+      meets pulley
   Danger zone (3): finger/cloth trap point — COVERED by guard
```

Labels: 1 — Rotating pulley (hazard); 2 — Fixed guard (mesh/metal cover); 3 — Nip/trap point now enclosed. Note: guard is removed only when the machine is stopped and locked out.

Diagram 3 — Dust explosion pentagon

```
            Combustible dust (1)
                   /\
                  /  \
                 /    \
  Ignition source (2) --+-- Oxygen/air (3)
                 \    /
                  \  /
                   \/
            Dust cloud (4) + Confinement (5)
  All FIVE must be present for an explosion.
  Remove ANY ONE (e.g., control dust, remove sparks) -> NO explosion.
```

Labels: 1 — Combustible dust; 2 — Ignition source (spark/heat); 3 — Oxygen in air; 4 — Dust dispersed as cloud; 5 — Confinement (closed space).

Diagram 4 — Waste segregation station (top view)

```
  +-----------+-----------+-----------+-----------+
  | GENERAL   | RECYCLABLE| HAZARDOUS | EXPIRED / |
  | WASTE (1) | (2) clean | CHEMICAL  | REJECTED  |
  |           | paper,    | WASTE (3) | DRUGS (4) |
  |           | plastic   | solvents, |           |
  +-----------+-----------+-----------+-----------+
  Colour-coded bins (5) with labels; kept at the point of generation.
  -> (1) to municipal disposal; (2) to recycler; (3)+(4) to incinerator/
     authorised hazardous-waste facility.
```

Labels: 1 — General waste bin; 2 — Recyclable bin; 3 — Hazardous chemical waste bin; 4 — Expired/rejected drugs bin; 5 — Colour coding + labels.

Diagram 5 — ETP flow (block diagram)

```
Effluent in
    |
    v
[Screening (1)] -> large solids removed
    |
    v
[Primary settling tank (2)] -> suspended solids settle as sludge
    |
    v
[Biological treatment (3)] -> microbes digest dissolved organics
    |
    v
[Filtration + disinfection (4)] -> clean water
    |
    v
Treated water OUT -> safe discharge / reuse (gardening, flushing)
Sludge -> dewatered -> safe disposal
```

Labels: 1 — Screening; 2 — Primary settling; 3 — Secondary/biological; 4 — Tertiary filtration + disinfection.

Diagram 6 — Corrosion types sketches (surface views)

```
(a) UNIFORM:  ================  even thinning all over
(b) PITTING:  ====v===v=====  small deep pits (v)
(c) CREVICE:  ==|__gap__|==  attack hidden in the gap
(d) GALVANIC: [Metal A]|~liquid~|[Metal B]  A corrodes fast at joint
(e) SCC:      =====/\/\/\====  fine cracks under stress
(f) INTERGRANULAR: grain boundaries eaten (weld line crumbles)
(g) EROSION:  ====>>>>worn====  flow direction >>>> strips surface
```

Labels: (a) Uniform — whole surface thins evenly; (b) Pitting — deep narrow holes; (c) Crevice — attack inside narrow gaps (gaskets, bolts); (d) Galvanic — two different metals + liquid = fast attack on one; (e) Stress-corrosion cracking — cracks under combined stress and corrosion; (f) Intergranular — grain boundaries dissolve (common at welds); (g) Erosion-corrosion — fast flow wears away the protective layer.

Diagram 7 — Corrosion impact chain (cause → effect)

```
 Corrosion of vessel/pipe
        |
        +---> Metal particles/ions into medicine -> CONTAMINATION -> batch rejected
        |
        +---> Pits trap residue/microbes -> CLEANING FAILURE -> GMP deficiency
        |
        +---> Pipe/vessel weakens -> LEAK or BREAKDOWN -> production stops
        |
        +---> Tank leaks to soil/water -> ENVIRONMENTAL POLLUTION
```

8. Flowcharts

Flowchart 1 — Safe manual lifting decision

```
START: Need to move a load by hand
        |
        v
Is the load too heavy, awkward, or the path unclear?
   |YES -> Do NOT lift alone: get help / use trolley, hoist or forklift
   |NO
   v
Check: floor dry and clear? PPE worn (gloves, safety shoes)?
        |
        v
Bend KNEES, back straight, load CLOSE to body
        |
        v
Lift smoothly, no twisting -> carry -> set down by bending knees
        |
        v
END: report any strain/injury immediately
```

Flowchart 2 — Waste segregation and disposal flow

```
Waste generated at workstation
        |
        v
Identify type: solid / liquid / gaseous?
   |
   +-- SOLID: hazardous (drugs, chemicals)? --YES--> sealed bags --> INCINERATOR /
   |                                                  authorised facility
   +-- SOLID: clean recyclable? --YES--> recycling bin --> RECYCLER
   |
   +-- LIQUID: effluent/solvent? --YES--> drains to ETP; solvents --> RECOVERY
   |                                      (distillation) for reuse
   |
   +-- GASEOUS: dust/vapour? --YES--> dust collector / bag filter / scrubber
                                      --> clean air released
        |
        v
Records maintained for every hazardous-waste movement -> END
```

Flowchart 3 — Corrosion prevention decision (pharma equipment)

```
Equipment shows rust/pits/cracks?
        |
        v
Identify corrosion TYPE (uniform, pitting, crevice, galvanic, SCC,
intergranular, erosion)
        |
        v
Choose control:
 - Right material: stainless steel 316L for pharma contact parts
 - Passivation: acid treatment to rebuild protective oxide layer
 - Avoid different-metal joints (or insulate them) -> stops galvanic
 - Smooth welds, crevice-free design -> stops crevice/intergranular
 - Control chlorides in water -> stops pitting/SCC
 - Limit flow velocity at bends -> stops erosion-corrosion
 - Regular inspection + maintenance schedule
        |
        v
Verify: surface smooth, cleanable, no visible corrosion -> GMP compliant
```

9. Infographic Concept Box

Concept: "STOP — Safety, Trash, Oxidation, Protection" — a single shield-shaped panel for this chapter.

Design idea: A large shield divided into three coloured bands. TOP band (red): "SAFETY" — icons of a worker lifting with bent knees, a machine guard, PPE (helmet, goggles, gloves, mask), a forklift with a "trained driver only" badge, and a lightning spark crossed out (static earthing) beside a dust-cloud warning triangle. MIDDLE band (green): "WASTE" — four colour-coded bins (general, recyclable, hazardous, expired drugs) feeding into an incinerator flame icon, an ETP tank with water drops, and a recycling loop arrow. BOTTOM band (orange-brown): "CORROSION" — a metal plate showing the 7 corrosion types as small icons (even rust, pits, gap, two-metal battery, cracks, grain boundaries, flow wear), with arrows to three warning signs: "contaminated medicine", "broken equipment", "polluted soil/water". Bottom caption: "Protect people, protect product, protect planet." This one shield summarises every section of the chapter.

10. Tables

Table 1 — Seven corrosion types: cause, mechanism, pharma example

Type	Cause	Mechanism (in brief)	Pharma example
Uniform	General exposure to air/moisture	Whole surface corrodes evenly	Rusting of carbon-steel supports
Pitting	Chlorides break protective film	Deep narrow pits grow hidden	Pits in purified-water pipelines
Crevice	Trapped liquid in narrow gaps	Oxygen-poor gap becomes anodic	Corrosion under gaskets of coating pan
Galvanic	Two different metals + liquid	Reactive metal becomes anode, dissolves fast	Copper–steel pipe joint corroding
Stress-corrosion cracking	Tensile stress + corrosive medium	Cracks grow from crack tip attack	Cracked stainless-steel steam pipes
Intergranular	Welding heat depletes grain-boundary chromium	Grain boundaries dissolve	Weld-line corrosion on vessels (use 316L)
Erosion-corrosion	Fast-flowing liquid/slurry	Flow strips protective layer repeatedly	Worn pump parts, pipe bends

Table 2 — PPE: item vs protection

PPE item	Protects against
Gloves	Cuts, chemicals, rough surfaces
Safety shoes (steel toe)	Falling drums/bags on feet
Safety goggles	Dust, chemical splashes to eyes
Dust mask / respirator	Inhaling fine powders
Helmet	Falling objects in lifting areas
Apron/overalls	Chemical contact with body/clothes

Table 3 — Waste types vs treatment

Waste	Examples	Treatment
Solid (hazardous)	Expired drugs, rejected tablets, chemical waste	Incineration / authorised facility
Solid (recyclable)	Clean paper, cartons, glass, metal scrap	Segregate → recycler
Liquid (effluent)	Wash water, lab liquids	ETP: screening → settling → biological → filtration
Liquid (solvent)	Spent isopropyl alcohol	Distillation recovery → reuse
Gaseous	Dust, solvent vapours, boiler smoke	Bag filters, dust collectors, scrubbers

11. Examples

- **Manual lifting:** A worker bends knees and keeps back straight while lifting a 25 kg bag of starch onto a trolley.
- **Machine guard:** The nip point of a packing-line belt conveyor is covered with a fixed mesh guard so operators' fingers cannot be trapped.
- **PPE:** Operators wear dust masks and goggles while charging fine paracetamol powder into a mixer.
- **Forklift safety:** A trained driver carries a pallet of cartons with forks low and tilted back, sounding the horn at a warehouse crossing.
- **Static electricity:** Earthing wires on a pneumatic conveying line drain static charge so no spark forms near alcohol vapours.
- **Dust explosion:** A starch dust cloud inside a mill, ignited by a static spark, explodes — prevented by dust extraction and earthing.
- **Solid waste:** Rejected blister strips and expired tablets are collected in sealed bags and sent for incineration.
- **Liquid waste:** Equipment wash water flows to the ETP; treated water is reused for gardening.
- **Solvent recovery:** Used isopropyl alcohol is distilled and reused for cleaning — less waste, lower cost.
- **Uniform corrosion:** A mild-steel staircase railing in a humid corridor rusts evenly.
- **Pitting:** Chloride-rich water pits a stainless-steel storage tank's inner wall.
- **Galvanic:** A brass valve fitted directly on a stainless-steel line corrodes rapidly at the joint.
- **GMP impact:** An inspector finds rust inside a tablet coating pan — recorded as a GMP deficiency; the batch is held.

12. Analogies

- **Machine guard = mixer-grinder lid.** You never run a mixer without the lid — the guard is the machine's lid.
- **PPE = raincoat and umbrella.** You don't stop the rain, but you protect yourself — PPE doesn't remove the hazard, it protects the worker.
- **Static spark = winter sweater spark.** Touching a metal door after removing a sweater gives a tiny shock — in a plant, that tiny spark near solvent vapour can start a fire.
- **Dust explosion = bursting a flour-filled balloon near a diya.** Fine powder in air burns all at once — like crackers bursting together instead of one by one.
- **ETP = village pond cleaning system.** Big stones are sieved out, mud settles, and natural microbes clean the water — the ETP does the same in engineered tanks.
- **Segregation = sorting vegetables at home.** You don't mix rotten tomatoes with fresh ones — mixed waste spoils the recyclable part.
- **Uniform corrosion = iron gate rusting in rain.** The whole gate turns brown evenly.
- **Pitting = acne pits on skin.** The surface looks mostly fine, but deep holes hide underneath.
- **Galvanic corrosion = two classmates fighting when forced to sit together.** Two different metals "fight" in water, and the weaker one loses (corrodes).
- **Stress-corrosion cracking = bending a plastic scale repeatedly at one point.** Stress plus weakness at one spot finally snaps it.
- **Intergranular corrosion = termites eating the joints of a wooden frame.** The frame looks whole until the joints give way.
- **Erosion-corrosion = river wearing away rocks.** Continuous flow rubs away the surface layer again and again.

13. Pharmacy Relevance

- **Patient safety:** Corrosion releases metal particles and ions into medicines — contamination that can harm patients and force batch recalls.
- **GMP compliance:** Smooth, corrosion-free, cleanable equipment surfaces are a GMP requirement; inspectors treat visible corrosion as a deficiency.
- **Dust explosions** are a real killer hazard in tablet granulation areas handling starch and lactose — safety systems protect both workers and the plant.
- **Static control** near flammable solvents (alcohol, acetone used in coating and cleaning) prevents fires.
- **Waste management** is legally compulsory: hazardous pharma waste must go to authorised incineration/treatment facilities with records — illegal dumping risks prosecution and licence loss.
- **ETP-treated water reuse** cuts water cost, which matters in water-scarce regions.
- **Solvent recovery** by distillation is both green and economical — a classic pharma engineering win.

14. India Context

- Indian pharma plants follow **Schedule M** (GMP rules) and hazardous-waste rules: hazardous waste must be segregated, stored safely and sent only to authorised treatment/incineration facilities with proper records (manifests).
- Plants in industrial clusters around **Hyderabad, Mumbai, Ahmedabad, Bengaluru and Visakhapatnam** operate ETPs; treated water is commonly reused for gardening and flushing.
- **Monsoon humidity** accelerates corrosion of steel structures, outdoor pipelines and storage tanks — plants increase inspection frequency and repaint/protective-coating maintenance before and after the monsoon.
- Coastal plants (e.g., near **Mumbai, Chennai, Visakhapatnam**) face faster corrosion because sea air carries chloride salts — a classic cause of pitting and stress-corrosion cracking of stainless steel.
- **Indian labour-safety norms:** Under the Factories Act, workers must be trained before operating lifting machinery; safety signboards in local languages, PPE use and first-aid provisions are inspected by factory inspectors.
- Dust explosions in starch and grain-handling areas are a known industrial hazard in India — good housekeeping and dust extraction are emphasised in safety audits.

15. Key Points

- Manual lifting: assess load, bend knees, back straight, load close, no twisting; get help or machines for heavy loads.
- Machine guards cover moving parts; never removed while running.
- PPE: gloves, safety shoes, goggles, masks, helmet, apron — the last line of defence.
- Forklift: trained drivers only, rated capacity, load low, horn at crossings.
- Static electricity: friction builds charge → spark; control by earthing, anti-static materials, humidity control.
- Dust explosion needs 5 conditions: combustible dust + dust cloud + oxygen + ignition + confinement — remove any one to prevent it.
- Waste types: solid (incineration/recycling), liquid (ETP; solvent recovery), gaseous (filters, scrubbers).
- Segregation at source into colour-coded bins; hazardous waste to authorised facilities with records.
- 7 corrosion types: uniform, pitting, crevice, galvanic, stress-corrosion cracking, intergranular, erosion-corrosion.
- Corrosion impact on processes: product contamination, leachables, equipment failure, cleaning failure, GMP deficiencies.
- Corrosion impact on environment: metal pollution of soil/water, leaking tanks, extra scrap and chemical load.

16. Common Confusions

- **PPE vs engineering controls:** PPE (gloves, masks) protects the worker; it does NOT remove the hazard. Guards, earthing and dust extraction remove/reduce the hazard itself. PPE is the LAST resort, not the first.
- **Static electricity vs dust explosion:** Static is an ignition SOURCE (the spark); dust explosion is the EVENT (the blast). Static can cause a dust explosion but they are not the same thing.
- **Incineration vs ETP:** Incineration burns SOLID hazardous waste; ETP treats LIQUID waste. They are not interchangeable.
- **Pitting vs uniform corrosion:** Uniform attacks the whole surface evenly and is visible; pitting makes hidden deep holes while the surface looks fine — pitting is more dangerous because it is hidden.
- **Galvanic vs uniform:** Galvanic needs TWO DIFFERENT metals touching in a liquid; uniform needs only one metal and a corrosive environment.
- **Crevice vs pitting:** Both are localised, but crevice corrosion happens in narrow GAPS (gaskets, bolts), while pitting starts at weak points on OPEN surfaces.
- **Segregation vs treatment:** Segregation is SEPARATING waste by type at source; treatment is PROCESSING it (burning, ETP). Segregation comes first.

17. Common Mistakes

- Listing only some corrosion types — the syllabus needs all seven: uniform, pitting, crevice, galvanic, stress-corrosion cracking, intergranular, erosion-corrosion.
- Writing "rust" as the definition of corrosion — rust is only the corrosion product of IRON; corrosion is the general process for all metals.
- Confusing incineration (solids) with ETP (liquids) in waste-treatment answers.
- Forgetting the fifth condition (confinement) of the dust explosion pentagon.
- Saying PPE is the first safety step — it is the LAST line of defence after engineering and administrative controls.
- Omitting GMP consequences of corrosion — examiners expect contamination, cleaning failure and inspection findings, not just "metal gets damaged".
- Describing galvanic corrosion without mentioning TWO DIFFERENT metals and a liquid — all three are needed.

18. Mnemonics

- **Corrosion 7 types — "UP CGS IE" (say "up CGS IE"): U**niform, **P**itting, **C**revice, **G**alvanic, **S**tress-corrosion cracking, **I**ntergranular, **E**rosion-corrosion. Memory line: "**U**ncle **P**rem's **C**ycle **G**ot **S**cratched, **I**t's **E**aten."
- **Dust explosion pentagon — "C-D-O-I-C": "Can Dust Often Ignite Confined": C**ombustible dust, **D**ust cloud, **O**xygen, **I**gnition source, **C**onfinement.
- **Safe lifting — "BBL": "Bend, Back, Body": B**end knees, **B**ack straight, load close to **B**ody.
- **Waste types — "SLG": "Solid, Liquid, Gas"** — and treatments: "**I**ncinerate solids, **E**TP liquids, **F**ilter gases" (I-E-F).
- **Corrosion impacts — "C-E-G": "Contamination, Equipment, Green (environment)":** product **C**ontamination, **E**quipment failure, **G**MP issues + environmental harm.

19. Exam Summary

Safety in material handling covers manual lifting rules (bend knees, back straight, load close, team lifting), machine guards over moving parts, PPE as the last line of defence (gloves, safety shoes, goggles, masks, helmet, apron), and forklift rules (trained drivers, rated capacity, low loads, horn use). Static electricity from powder friction can spark fires near solvents — controlled by earthing. Dust explosions need five conditions (combustible dust, dust cloud, oxygen, ignition, confinement); prevention removes any one of them. Pharma waste is solid (rejected drugs, packing scrap — incinerated or recycled), liquid (wash water, solvents — treated in ETP through screening, settling, biological and filtration stages; solvents recovered by distillation) and gaseous (dust, vapours — bag filters, scrubbers), always segregated at source into colour-coded bins. Corrosion — the eating away of metal — has seven types: uniform (even attack), pitting (hidden deep holes from chlorides), crevice (in gaps under gaskets), galvanic (two different metals + liquid), stress-corrosion cracking (stress + corrosive medium), intergranular (grain-boundary attack at welds), erosion-corrosion (fast flow strips protection). Corrosion contaminates products with metal particles, causes equipment failure and cleaning/GMP failures, and pollutes soil and water through leaks and metal release.

20. One-Minute Revision

- Lifting: bend knees, back straight, load close (BBL).
- Guards cover moving parts; PPE is last defence.
- Forklift: trained driver, rated load, low forks.
- Static → spark → fire: control by earthing.
- Dust explosion: C-D-O-I-C (dust, cloud, oxygen, ignition, confinement).
- Waste: Solid (incinerate/recycle), Liquid (ETP), Gas (filters) — segregate first (SLG → I-E-F).
- Corrosion 7: Uniform, Pitting, Crevice, Galvanic, SCC, Intergranular, Erosion ("UP CGS IE").
- Impacts: Contamination, Equipment failure, GMP issues, Environmental pollution (C-E-G).

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21. Exam Questions

Long / Essay Questions (5)

1. Describe the seven types of corrosion with their mechanisms and give one pharmaceutical example of each.
2. Discuss the safety considerations in material handling: manual lifting rules, machine guards, PPE and forklift safety. Add a note on static electricity and dust explosions.
3. Classify pharmaceutical waste into solid, liquid and gaseous types. Describe segregation practices and explain incineration and ETP treatment with a flow diagram.
4. Explain the impact of corrosion on pharmaceutical processes (product contamination, equipment failure, GMP issues) and on the environment.
5. Write short notes on: (a) dust explosion pentagon and its prevention, (b) solvent recovery, (c) intergranular corrosion and its prevention in stainless-steel vessels.

Short Questions (8)

1. List the five conditions of the dust explosion pentagon.
2. How is static electricity controlled in a pharma plant?
3. Name four PPE items and state what each protects against.
4. Differentiate between incineration and ETP treatment.
5. What is galvanic corrosion? Give one pharma example.
6. Why is pitting corrosion considered dangerous although the surface looks normal?
7. State two GMP consequences of corroded equipment.
8. What is waste segregation and why is it done at the source?

MCQs (10)

1. The correct manual lifting posture is:
   a) Bend the back, keep knees straight b) Bend the knees, keep back straight c) Twist while lifting d) Hold the load away from the body
2. Which of the following is an ignition source for a dust explosion?
   a) Earthing wire b) Static spark c) Dust mask d) Machine guard
3. Expired tablets are best disposed of by:
   a) Throwing in general bins b) Incineration c) Flushing down drains d) Burying near the plant
4. In an ETP, microbes digest dissolved pollutants in the:
   a) Screening stage b) Primary settling tank c) Secondary/biological treatment d) Dispatch bay
5. Pitting corrosion of stainless steel is commonly caused by:
   a) Chloride ions b) Distilled water c) Dry air d) Low temperature
6. Galvanic corrosion occurs when:
   a) One metal rusts evenly b) Two different metals touch in a liquid c) Metal is painted d) Metal is kept dry
7. Corrosion along weld lines due to chromium depletion at grain boundaries is:
   a) Uniform corrosion b) Pitting c) Intergranular corrosion d) Erosion-corrosion
8. Which PPE protects the feet from falling drums?
   a) Goggles b) Safety shoes c) Dust mask d) Helmet
9. Used isopropyl alcohol is recovered for reuse by:
   a) Incineration b) Filtration c) Distillation d) Settling
10. A GMP consequence of corroded product-contact equipment is:
    a) Faster production b) Batch contamination and possible recall c) Lower power use d) Better mixing

Answer key: 1-b, 2-b, 3-b, 4-c, 5-a, 6-b, 7-c, 8-b, 9-c, 10-b

Viva Questions (5)

1. **Name the seven types of corrosion.** — Uniform, pitting, crevice, galvanic, stress-corrosion cracking, intergranular, erosion-corrosion.
2. **What are the five conditions for a dust explosion?** — Combustible dust, dust cloud, oxygen, ignition source, confinement.
3. **What does ETP stand for and what does it treat?** — Effluent Treatment Plant; treats liquid waste (effluent) before discharge or reuse.
4. **Why is PPE called the last line of defence?** — Because engineering controls (guards, earthing) and safe procedures come first; PPE only protects the worker when hazards remain.
5. **How does corrosion cause a GMP problem?** — Metal particles contaminate the product, pitted surfaces cannot be cleaned/validated, and inspectors record visible corrosion as a deficiency.

Application-Based Questions (3)

1. A maintenance worker must lift a 60 kg motor onto a bench alone. What will you advise, and which equipment could help? *(Do not lift alone — assess the load, get help or use a chain/electric hoist; follow BBL posture if team-lifting.)*
2. A QC lab generates 20 L of mixed solvent waste and some broken glass vials. How should each be segregated and handled? *(Solvents → hazardous liquid waste container for solvent recovery or authorised disposal; broken glass → separate sharps/glass bin, not mixed with general waste.)*
3. A stainless-steel purified-water pipeline shows tiny deep holes though the surface looks shiny. Identify the corrosion type, its likely cause, and one corrective action. *(Pitting corrosion; likely high chloride in water breaking the passive film; corrective — reduce chlorides / improve water quality, passivate the steel, inspect regularly.)*

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22. References

- Banker, G. S. Pharmaceutical Engineering (preferably latest edition)
- Sambamurthy, K. Introduction to Pharmaceutical Engineering (preferably latest edition)
- Kennedy, T. F. Good Design Practices for GMP Pharmaceutical Facilities (preferably latest edition)
- Cole, G. C. Pharmaceutical Facilities: Design, Layouts and Validation (preferably latest edition)
- Bertch, F. J. Fundamentals of Modern Pharmaceutical Process Engineering (preferably latest edition)
- Chase, A. G. Environmental Management in the Pharmaceutical Industry (preferably latest edition)
- Bunn, G. Pharmaceutical Production Facilities: Design and Applications (preferably latest edition)
