UNIT III – TOPIC 2

Sedimentation

Sedimentation is a physical process where suspended particles settle out of a fluid due to gravity. It's one of the oldest and most fundamental separation techniques used across numerous industries.

At its core, sedimentation works because particles denser than the surrounding fluid tend to sink. The rate at which particles settle depends on several factors that we can understand through Stokes' Law:

The settling velocity of a particle increases with:

- Larger particle size (specifically, with the square of the diameter)
- Greater density difference between the particle and the fluid
- Lower fluid viscosity

Imagine dropping sand into a glass of water. The larger, heavier sand grains quickly fall to the bottom, while finer particles take longer to settle. This simple observation illustrates the principle that engineers harness in industrial sedimentation.

In water treatment plants, sedimentation tanks (also called clarifiers) are large, shallow basins where water flows slowly enough to allow suspended solids to settle to the bottom. As the water moves horizontally through the tank, progressively smaller particles have time to sink, creating a zone of clear water near the surface that can be collected.

Primary sedimentation removes larger particles like sand and grit, while secondary sedimentation might capture biological flocs after biological treatment processes. The settled material (sludge) is periodically removed from the bottom of these tanks.

In environmental analysis, a device called an Imhoff cone is used to measure "settleable solids" in wastewater—a standardized way to determine how much material will settle out naturally over a specific time period.

Different sedimentation tank designs exist:

- Horizontal flow tanks (rectangular)
- Circular tanks with central feed
- Inclined plate or tube settlers that increase effective settling area

The ideal sedimentation process allows sufficient residence time for particles to settle while maintaining a steady, non-turbulent flow that won't re-suspend settled particles.

Filtration

Filtration is a mechanical separation process that uses a porous medium (filter) to separate solids from fluids by allowing the fluid to pass while retaining the solids.

When we think about filtration, we can envision it happening at different scales:

At a macroscopic level, like coffee filters trapping coffee grounds while letting brewed coffee through, filtration works as a simple physical barrier. Particles larger than the pores in the filter medium are caught, while the fluid and smaller particles pass through.

At a microscopic level, additional mechanisms come into play:

- Direct interception: Particles following fluid streamlines contact filter material
- Inertial impaction: Particles with momentum deviate from fluid streamlines to hit the filter
- Diffusion: Small particles move randomly (Brownian motion) and collide with the filter
- Electrostatic attraction: Charged particles adhere to oppositely charged filter surfaces

Filtration systems range from simple to complex:

- Gravity filters rely on hydrostatic pressure to force fluid through the filter medium
- Pressure filters use pumps to create positive pressure on the upstream side
- Vacuum filters use suction to create negative pressure on the downstream side

The filter medium can be made from various materials depending on the application:

- Paper, cloth, or synthetic fibers for general-purpose filtration
- Ceramic or sintered metal for high-temperature applications
- Membrane filters with precisely controlled pore sizes for ultrafiltration
- Deep bed filters (like sand filters) that capture particles throughout their depth

An important consideration in filtration is filter cake formation—as solids build up on the filter surface, they create an additional barrier that can enhance filtration quality but also reduce flow rate. Engineers must decide between batch processes (where filtration stops for cake removal) and continuous processes (where cake is continuously removed during operation).

Filter aids like diatomaceous earth are sometimes added to improve filtration by creating a more permeable filter cake structure or providing additional surface area for particle capture.

Centrifugation

Centrifugation harnesses centrifugal force to separate materials of different densities more rapidly and effectively than gravity alone can achieve.

To understand centrifugation, imagine swinging a bucket of muddy water in a circle around yourself. The outward force pushes denser particles toward the outside of the path, creating a separation effect. This is essentially what happens in a centrifuge, but in a controlled, mechanical manner.

The principles behind centrifugation involve centrifugal acceleration, which can be thousands of times stronger than gravity. This acceleration is determined by:

- Rotational speed (measured in revolutions per minute or RPM)
- Radius of rotation

The equation $F = m\omega^2 r$ helps us understand that the separating force increases with the mass of the particle (m), the square of the angular velocity (ω), and the radius (r).

Centrifuges come in many forms:

- Tubular centrifuges operate at extremely high speeds for separating fine particles
- Disc-stack centrifuges use a series of conical discs to increase separation surface area
- Basket centrifuges spin a perforated basket to filter and separate simultaneously
- Decanter centrifuges use a horizontal design with a screw conveyor to continuously remove solids

Applications of centrifugation are incredibly diverse:

- Laboratory analysis for separating blood components or isolating microorganisms
- Dairy industry for separating cream from milk
- Wastewater treatment for dewatering sludge
- Uranium enrichment using gas centrifuges
- Sugar refining to separate sugar crystals from molasses

The efficiency of centrifugation depends on factors like particle size distribution, density difference between phases, viscosity of the continuous phase, and residence time in the centrifugal field.

Engineers must balance separation effectiveness against practical concerns like energy consumption, material handling, and equipment wear when designing centrifugation processes.

These three separation techniques—sedimentation, filtration, and centrifugation—represent a progression of increasingly intensive methods for separating materials. While sedimentation relies on natural gravitational forces, filtration adds a physical barrier, and centrifugation amplifies the separating force through mechanical means. Each has its place in the engineer's toolkit depending on the specific separation challenge at hand.