UNIT III – TOPIC 3

Drying and Dehydration: Understanding the Process

Drying and dehydration are crucial unit operations in many industries, from food processing to pharmaceuticals and chemical manufacturing. These processes involve removing moisture from materials while preserving their essential qualities. Let's explore the drying rate and the changes that occur during drying.

Drying Rate

The drying rate describes how quickly moisture is removed from a material over time. This process typically follows a characteristic pattern that can be divided into several distinct periods:

1. Initial Adjustment Period

When a wet material is first exposed to drying conditions, there's a brief adjustment period where the material's temperature equilibrates with the surrounding environment. During this short phase, the drying rate increases as the material warms up to the wet-bulb temperature of the air.

2. Constant Rate Period

This is perhaps the most well-understood phase of drying. During the constant rate period:

- The surface of the material remains saturated with moisture
- Water evaporates from the surface at a steady rate
- The drying rate remains relatively constant
- Heat transfer to the material equals the rate of evaporation
- The material's temperature stays close to the wet-bulb temperature of the air

The constant rate period is governed primarily by external conditions rather than material properties. Factors like air velocity, temperature, humidity, and the available surface area for evaporation determine the drying rate.

Mathematically, we can express the constant rate drying as:

$N^c = h(T^g - T^w)/\lambda$

Where:

- N^c is the constant drying rate
- h is the heat transfer coefficient
- T^g is the dry-bulb temperature of the air
- T^w is the wet-bulb temperature of the air
- λ is the latent heat of vaporization of water

3. Falling Rate Period

As drying progresses, eventually there isn't enough moisture near the surface to maintain saturation. This point is called the critical moisture content. Beyond this point, the drying rate begins to decrease, and we enter the falling rate period.

The falling rate period can be further divided into two zones:

First Falling Rate Period:

- The surface is no longer fully saturated
- Some dry spots appear on the surface
- The drying front recedes into the material
- The rate of moisture movement from the interior to the surface becomes limiting
- Temperature of the material begins to rise above the wet-bulb temperature

Second Falling Rate Period:

- The surface is completely dry
- All evaporation occurs from within the material
- Moisture must diffuse through the material as vapor
- Internal diffusion becomes the limiting factor
- The material temperature approaches the dry-bulb temperature of the air

The falling rate period is heavily influenced by the material's properties such as porosity, permeability, thickness, and moisture diffusivity.

Changes During Drying

Several significant changes occur in materials as they dry:

Physical Changes

1. **Shrinkage**: Most materials contract as moisture is removed. This shrinkage can be uniform or non-uniform, potentially causing warping, cracking, or case hardening.
2. **Structural Changes**: Internal structures may collapse or rearrange as water is removed. In foods, this might mean changes in cell walls or protein structures.
3. **Surface Characteristics**: The surface may become harder, glossier, or develop a crust (case hardening). This happens when the surface dries much faster than the interior, forming a barrier that slows further drying.
4. **Porosity Changes**: The material's porosity typically decreases as it dries, though some materials may develop a more porous structure as water channels are replaced by air.
5. **Rehydration Capacity**: Dried materials often cannot absorb water to the same degree as their original state. This is particularly important in food processing where rehydration behavior matters.

Chemical Changes

1. **Browning Reactions**: In foods, Maillard reactions and caramelization can occur during drying, especially at higher temperatures.
2. **Oxidation**: Many materials become more susceptible to oxidation during drying.
3. **Enzymatic Activity**: Initially, enzymes may become more concentrated and active as water is removed, but eventually, most enzymatic activity ceases at very low moisture levels.
4. **Protein Denaturation**: Proteins may unfold and lose their native structure, affecting functionality and nutritional value.
5. **Crystallization**: Dissolved solids may crystallize as their concentration increases during water removal.

Nutritional Changes (for Food Materials)

1. **Vitamin Loss**: Heat-sensitive vitamins like vitamin C and some B vitamins can be degraded during thermal drying.
2. **Protein Digestibility**: Protein structure changes can affect digestibility.
3. **Bioavailability**: The bioavailability of minerals and other nutrients may change.

Microbiological Changes

1. **Microbial Inactivation**: As water activity decreases below certain thresholds, different types of microorganisms become unable to grow.
2. **Preservation Effect**: Reducing moisture content to sufficiently low levels prevents microbial growth, extending shelf life.

Critical Moisture Content and Equilibrium Moisture Content

Two important concepts in drying are:

1. **Critical Moisture Content (CMC)**: This is the point at which the constant rate period ends and the falling rate period begins. It represents the moisture content at which the surface is no longer fully saturated.
2. **Equilibrium Moisture Content (EMC)**: This is the moisture content at which the material neither gains nor loses moisture when exposed to air at a specific temperature and humidity. It represents the theoretical endpoint of drying.

The EMC depends on both the material properties and environmental conditions (temperature and relative humidity). It's typically represented by moisture sorption isotherms, which show the relationship between equilibrium moisture content and relative humidity at constant temperature.

Practical Implications

Understanding drying rates and the changes that occur during drying helps engineers:

- Design more efficient drying equipment
- Predict drying times for different materials

- Control product quality by managing the drying process
- Minimize energy consumption
- Prevent quality defects like cracking, case hardening, or excessive shrinkage
- Optimize rehydration properties in the final product

The key to effective drying is balancing the rate of moisture removal with the material's ability to withstand the physical stresses of drying without damage to its structure or desired properties.