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Broadcasting and Television School
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AGRICULTURAL PRODUCT DRYING TECHNOLOGY AND ITS APPLICATION

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PART.03

Principles, Methods and Applications of Various Drying Equipment

1. Hot Air Drying (1st Generation)

Principles

- Based on heat and mass transfer.
- Employs flowing hot air to heat and dehydrate material.

Typical Drying Process

- Carried out in dryers or drying ovens.
- Equipped with conveyor belts.

Core Equipment Components

- Heater.
- Hot-air system.
- Dryer.
- Drying chamber.
- Relatively simple structure.

1. Hot Air Drying (1st Generation)

Advantages

- **Low investment.**
- **Low operating cost.**
- **Simple operation.**
- Widely used in **small and medium sized food enterprises.**

Disadvantages

- **Higher drying temperature.**
- **Longer processing time.**
- Results in **firmer tissue.**
- Leads to **poorer texture and relatively lower product quality.**

2. Tunnel Dryer

Core Structure

- Drying chamber: a **narrow tunnel-shaped structure** with **rails** on the ground.

Material Flow

- Materials are conveyed through the tunnel by **rail-mounted carriers** and complete drying along the passage.

Classified by feeding direction or material-airflow relationship

- Counter-Current Dryers
- Concurrent Dryers
- Mixed-Flow Dryers

2. Tunnel Dryer

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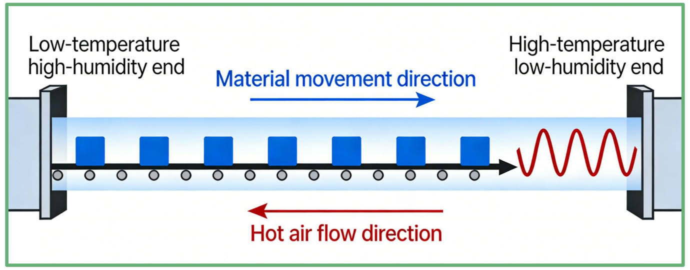
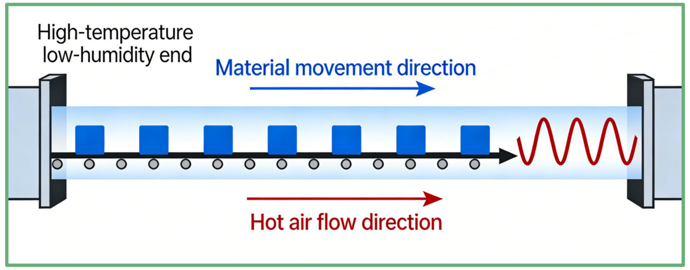
Classified by feeding direction or material-airflow relationship

Counter-Current Dryers



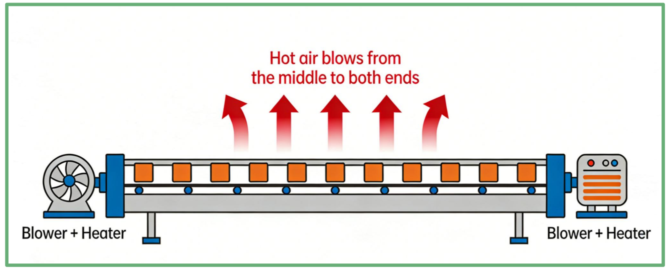
- Carrier moves **opposite** to hot-air flow.
- Raw material enters from **low-temperature, high-humidity** end.
- Dried product exits from **high-temperature, low-humidity** end.

Concurrent Dryers



- Carrier moves in the **same direction** as hot-air flow.
- Raw material enters from the **high-temperature, low-humidity** end.

Mixed-Flow Dryers



- Also called **central exhaust dryers**.
- Two blowers + two heaters installed at both ends of the track.
- Hot air is **blown from the center toward both ends**.

2. Tunnel Dryer

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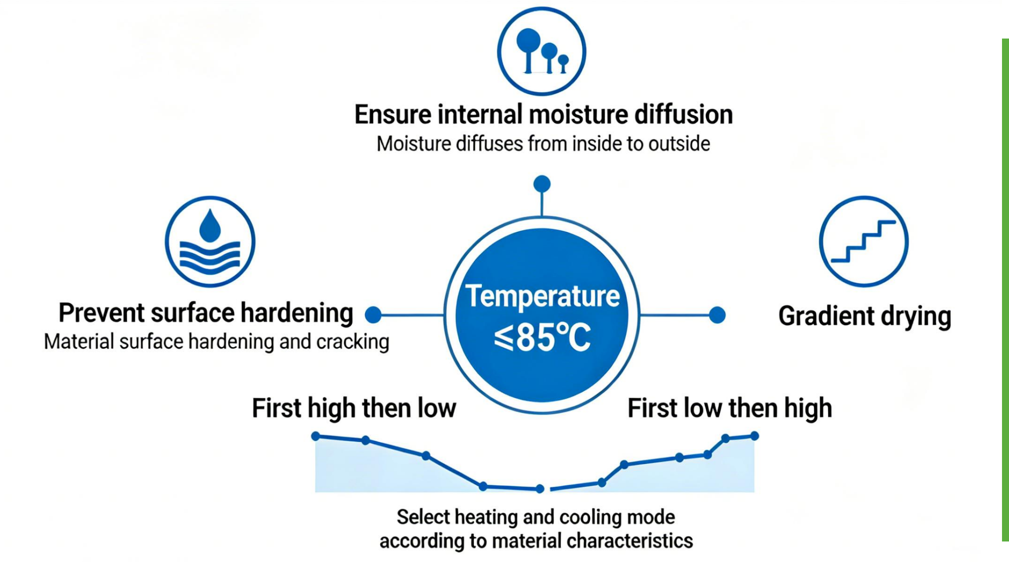
■ Temperature Requirement

- Drying temperature must **≤ 85° C**.
- Excessively high temperatures → **rapid surface hardening** → hinders internal moisture diffusion.

■ Gradient Approach

- Temperature sequences such as **high-low** or **low-high** are applied according to material properties.
- Ensures **optimal drying results**.



3. Belt Dryer

Core Features

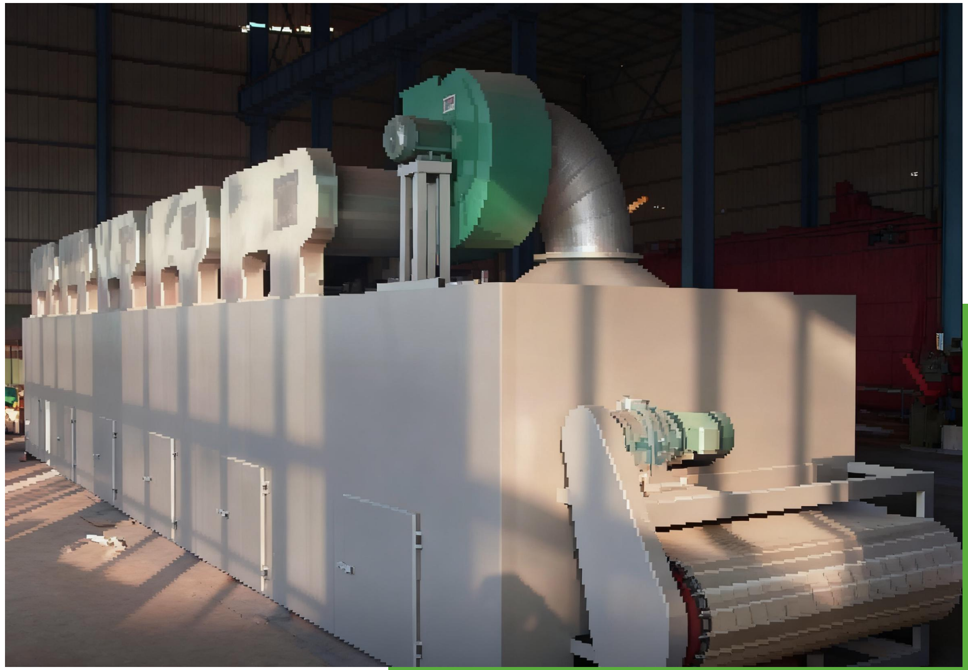
- Large-scale operation; integrable into production lines.

Operation of the Belt Dryer

- Raw materials **placed on a moving conveyor belt**.
- Belt materials include **canvas, rubber, coated**, and **steel** belts.
- Raw materials are **spread evenly** on the belt.
- Belt is driven forward by a **mechanical transmission device**.

Suitable Materials

- Particularly suitable for **staple crops**.
- Suitable for **high-yield**, **seasonal products**.



4. Heat Pump Drying (1st generation)

Core Advantages

- Although a **first-generation heating method**, **heat pump drying** ranks **highest in cost-effectiveness** and **overall performance**.

Principle & Working Process

- **Absorbs heat from low-temperature sources** and releases **usable thermal energy** at higher temperatures.
- Heat pump **removes moisture** from humid air inside the drying chamber → **reheat dehumidified air** → reused in drying fruits and vegetables.

Operating Characteristics

- Operates at **relatively low temperatures**.
- Achieves **efficient dehydration**.
- Utilizes **low-grade heat sources**.
- **High energy efficiency**.

Application Scope

- Widely applied to drying **heat-sensitive fruits** and **vegetables**.

4. Heat Pump Drying (1st generation)

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System Components

- System consists of a **heat pump + drying unit**.
- Four main components:

Compression	Condensation
Throttling	Evaporation

Limitations

- **Reduced drying rates + lower throughput** due to low operating temperature.
- **Potential microbial growth risks** associated with slow drying.

Operating Advantages

- Enables **cold air drying**.
- Operating temperature often controllable at **about 30° C**, sufficient to complete drying of agricultural products.
- **Relatively short drying cycle** (around **4 hours**, varying with material).
- **Air recirculation → high efficiency + energy savings + lower CO_2 emissions** → combines economic and environmental benefits.

4. Heat Pump Drying (1st generation)

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Application Scope

- Applied to a wide range of materials:

tobacco, chili peppers, shiitake mushrooms, goji berries, honeysuckle, chrysanthemum, apricots, jujubes, maize.

Product Quality

- Products such as **tobacco leaves, honeysuckle, chrysanthemum, goji berries, chili peppers, jujubes** retain **bright and appealing color**.

Nutrient Retention

- **Good preservation of nutrients and bioactive compounds**, second only to **freeze-drying**.

4. Heat Pump Drying (1st generation)

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Recommended Application

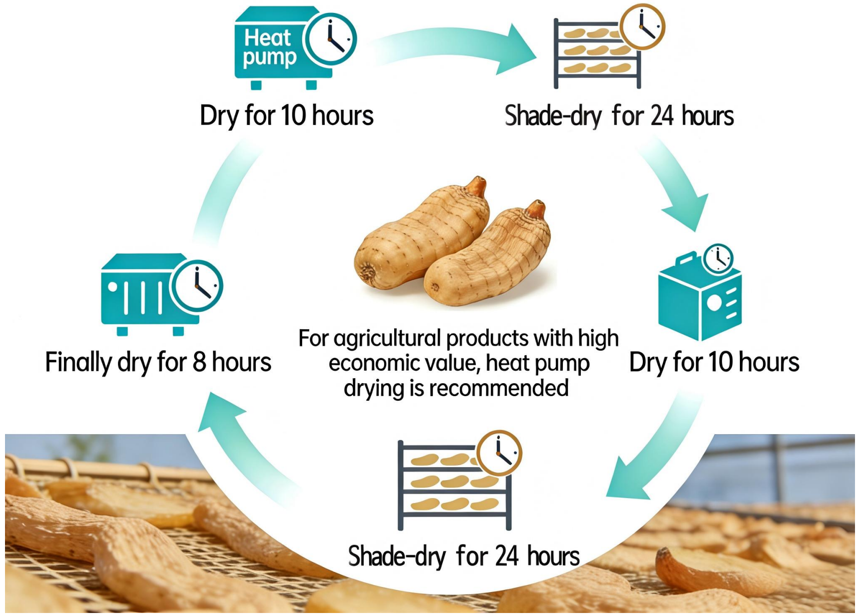
- **High-value agricultural products:** heat pump drying is strongly recommended.

Example: Gastrodia elata

- Due to difficulty in removing internal moisture, heat pump drying delivers **excellent results** → preserves **color, aroma and flavor**.

Staged Drying Process

- **Initial drying**: 10 hours → **Shade drying**: 24 hours → **Second drying**: 10 hours → **Shade drying**: 24 hours → **Final drying**: 8 hours.



Shade Drying Purpose

- Each shade-drying **interval allows internal moisture** to migrate to the surface.
- Facilitates subsequent dehydration and achieves **optimal drying outcomes**.

5. Spray Drying (2nd Generation)

Principle of Spray Drying

- Atomizing devices (sprayers) **disperse suspensions/viscous liquids into fine droplets**.
- Droplets **rapidly dried** by **high-temperature, high-velocity airflow**:

  simultaneous heat + mass transfer with hot air.

Suitable Materials

- Particularly suited for **milk powder**, **fruit powders**, **yeast, certain antibiotics**.

5. Spray Drying (2nd Generation)

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Advantages

- Produces powders with **uniform particle size** and **excellent solubility**.

  For example: milk powder readily dissolves in water, avoids agglomeration and poor dispersion.

Suitability

- **Relatively low drying temperature** → suitable for **heat-sensitive** or **high-value materials** (e.g., fruit and vegetable powders).

5. Spray Drying (2nd Generation)

Key Limitations

- Not suitable for **highly viscous materials**: tend to adhesion to inner wall → cleaning difficulty + reduced efficiency.

Additional Drawbacks

- Difficult to maintain **stable moisture content** in final products.
- **High equipment costs**.

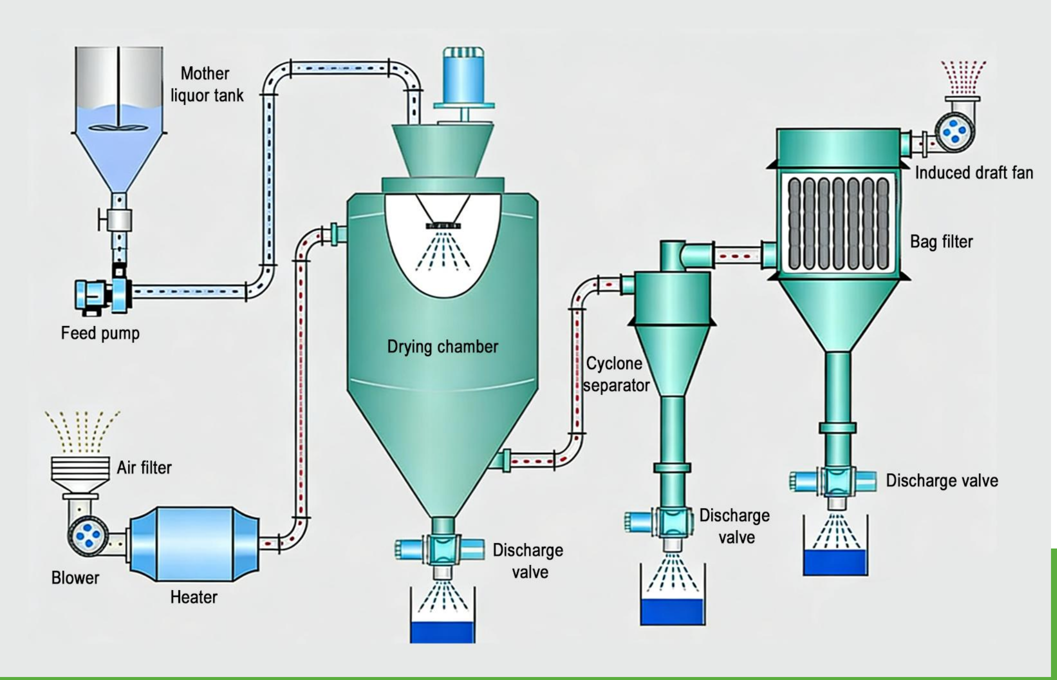
Flavor Loss Risk

- Requires **homogenization before atomization** + exposure to **high temperatures** → significant losses of **volatile flavor compounds**.

5. Spray Drying (2nd Generation)

Equipment Components

- **Atomization system**.
- **Air heating system**.
- **Drying chamber**.
- **Air powder separation unit**.
- **Blower**.
- **Sprayer + drying chamber** = core components.



Applications in China

- Widely for **fruit and vegetable powders**:

  jujube, **carrot**, **pumpkin**, **strawberry, kiwifruit**, **mango powders**.

6. Drum Drying (2nd Generation)

Drum Drying Process

- A continuous **rotary drying technique**.
- Viscous slurries **applied/sprayed onto heated drum surfaces**.
- Drying via **conductive heat transfer**.

Drum Dryer Structure

- **One or two hollow metal cylinders**.
- **Rotate around a horizontal axis**.
- Heated internally by **steam**, **hot gases**, or **other heating media**.

6. Drum Drying (2nd Generation)

Advantages

- **Relatively low energy consumption**.
- **Lower operating costs**.
- **High thermal efficiency**.
- **Greater evaporation intensity** compared with spray drying.
- Enables **faster drying rates**.
- Supports **stable product quality**.

Disadvantages

- High tendency for **scorching, browning**, or **caramelization** due to **direct contact** with the heated drum surface.
- **Prolonged contact** and **adhesion** to the drum surface → undesirable changes in **color** and **quality**.

6. Drum Drying (2nd Generation)

Applications

- Applied in processing foods such as **applesauce**, **tomato paste**, **mashed potatoes**, **pumpkin purée**, **mashed bananas**, **sweet potato paste**, and **pregelatinized starch**.

7. Vacuum Freeze-drying (3rd generation)

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Principle of Vacuum Freeze-Drying

- Material **frozen under low temperature** → forms **ice crystals**.
- **Sublimations under vacuum** (solid ice → vapor, no liquid phase).

Key Outcome

- Moisture removed while **preserving material's structure**.

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7. Vacuum Freeze-drying (3rd generation)

Advantages

- **Effectively retains nutrients.**
- Produces **superior-quality products**.
- Suitable for **heat-sensitive materials**.

Disadvantages

- **High equipment costs.**
- **Considerable energy consumption.**

Applications

- Due to cost constraints, used mainly for **high-value products**.
- Especially for **fruit and vegetable dehydrated products** such as:

  mango, banana, strawberry, yellow peach, lychee, and other tropical fruits.

8. Vacuum Frying Drying Equipment

Principle of Vacuum Frying Drying

- Under **reduced pressure**, hot oil provides **conductive heat transfer** → **vaporizes + continuously evaporates** moisture.
- **Intense boiling** + **vaporization** → significant **internal pressure** → **cellular expansion** → rapid dehydration in a short time.

Key Parameters

- **Degree of vacuum.**
- **Oil temperature.**
- **Frying duration.**
- **Pre-treatment method.**

Typical Operational Conditions

- A pressure range **of 92–98 MPa** .
- Oil temperature < **100° C**.

8. Vacuum Frying Drying Equipment

Advantages

- **Relatively low processing temperatures** → reduced nutrient losses.
- **Rapid evaporation + short processing time**.
- **Excellent rehydration capacity**.
- **Stable color**.
- Desirable flavor from **Maillard reactions** among lipids, sugars, amino acids, and proteins → rich aroma and taste.
- Suitable for **fruit processing**, combining sweetness and aroma → important for developing novel products.

Disadvantages

- **Residual oil content > 10%**.
- **Relatively short shelf life**.
- Potential **health risks** with long-term consumption.

Current Application

- Widely used to produce sweet and fragrant fruit snacks.

9. Puffing Drying

Types of Puffing Drying

- Two forms:
  - **Low temperature vacuum frying drying**.
  - **Variable-temperature pressure-difference puffing drying**.

Low-temperature Vacuum Frying Drying

- **Combined drying technique** under **reduced temperature** + **vacuum**.
- **Low-temperature** + **frying** processes.
- **Higher oil content**.

Variable-temperature Pressure-difference Puffing Drying

- **Non-frying puffing technique**.
- Principle: **rapid temperature/pressure fluctuations → pressure differentials → sudden vaporization of internal moisture → formation of porous structure**.
- Enables **simultaneous drying + puffing**.
- Advantages: **relatively low equipment cost + reduced energy consumption**.

low-temperature vacuum frying drying

variable-temperature pressure-difference puffing drying

10. Osmosis Drying

Principle of Osmotic Dehydration

- A commonly applied **drying method**.
- Water-rich materials **immersed in hypertonic aqueous solutions** containing edible solutes (e.g., **sugar, salt**).
- **Osmotic pressure** → a significant amount of **water removed**.

Examples and Applications

- Fresh fruits or vegetables **cut** + **immersed** with salt/sugar → **substantial water migrates outward** quickly.
- Widely used in **traditional processing and preservation** of pickled vegetables.

11. Dielectric Drying (4th generation)

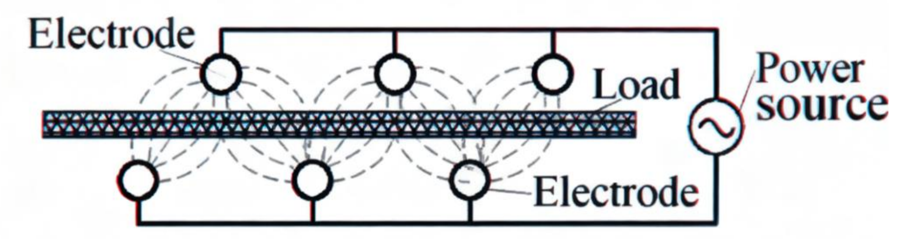
(1) Radiofrequency (RF) Drying

Conventional vs RF Drying Mechanisms

- Conventional drying: heat transferred from **surface to interior**.
- RF drying operates under the action of a **high-frequency electromagnetic field**.
- Material absorbs **electromagnetic energy → converts into internal thermal energy → used to evaporate moisture**.

Benefits of RF Drying

- **Rapidly reduces moisture content.**
- **Significantly shortens drying time.**
- **Lowers energy consumption.**



Schematic buildup of RF applicators

11. Dielectric Drying (4th generation)

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(2) Far Infrared Drying

Infrared Heating Mechanism

- Transfers heat via **radiation**.
- **Molecules** irradiated with **infrared of specific frequencies** → **energy spectrum** of the radiation source **resonates** with **heated molecules** → **resonate absorption**.
- Accelerates **internal thermal motion** of molecules → achieves **heating**.

Advantages

- Rapid drying rate.
- High production efficiency.
- Good product quality.
- Energy savings.
- Compact equipment scale.
- Relatively low construction cost.

Drawbacks

- Irradiation blind zones.
- Non-uniform temperature distribution.
- Tendency to cause product expansion or rupture.

11. Dielectric Drying (4th generation)

(3) Microwave Drying

Drying Efficiency

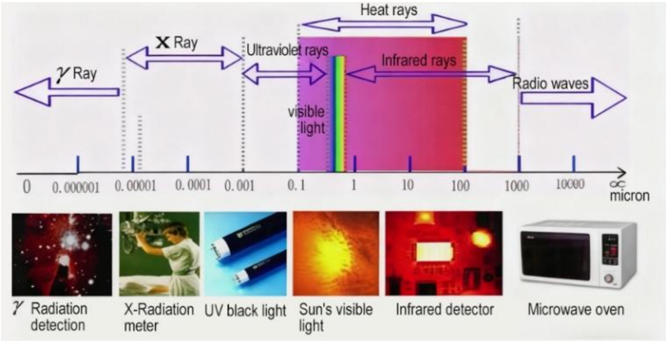
- **Microwave drying** (e.g., roast chicken/duck) achieves excellent color, aroma, and flavor in **15–20 min** < conventional heating **30–60 min.**

Mechanism

- Microwaves have a wavelength of **1–1,000 mm**; RF occupies **3×10^{8}–3×10^{11} Hz**.
- Both generate **high-frequency electromagnetic fields**.
- Electromagnetic fields have **strong penetrability** and **specific interactions** with matter.

Applications

- In food processing, microwaves are widely applied in **heating**, **drying**, **sterilization, and extraction**.



11. Dielectric Drying (4th generation)

(3) Microwave Drying

Radiation Types

- **Gamma rays and X-rays**: extremely strong penetration, very short wavelengths.
- **Ultraviolet**: 0.01–0.1 μm; may induce melanin formation and skin burns.
- **Visible light** → **infrared** → **microwaves** 1,000–100,000 μm; relatively long wavelengths.

Microwave Frequencies

- Household microwave ovens: **2,450 MHz**.
- Higher microwave frequencies used in **food processing**.

11. Dielectric Drying (4th generation)

(3) Microwave Drying

■ **Electromagnetic Interaction**

- The electromagnetic field undergoes **hundreds of millions of periodic changes per second**, penetrating material and interacting with **polar molecules** (e.g., water molecules).
- Polar molecules absorb **microwave energy** and undergo **polarization changes** and → oscillate synchronously with the field.

■ **Heat Generation and Drying**

- Intense motion of polar molecules produces **frictional heat** → raises **bulk temperature** + induces **water evaporation** → achieving drying.

11. Dielectric Drying (4th generation)

(3) Microwave Drying

Microwave Characteristics

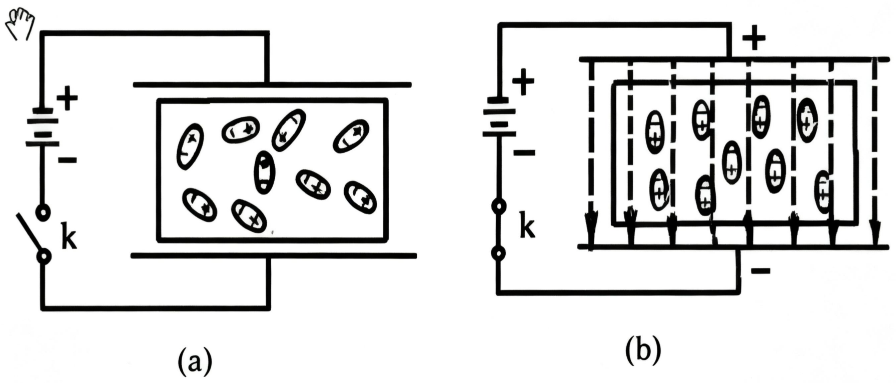
- **Electromagnetic energy** → alters **ionic migration direction and dynamic state** but does **not** change molecular structure → represent **non-ionizing radiation**.
- Materials that absorb microwaves are called **dielectrics**.

Heating Mechanisms

- Two microwave mechanisms may coexist.
- Applying an **external magnetic field** → state and motion of material altered → **more uniform heating**, favourable for drying.

Drying Principle

- Microwave field **penetrates into the material interior** → internal water molecules **move and absorb heat**.
- Drying **begins from within**, with moisture **diffuses outward**.



Dipole Alignment in Dielectric

(a) Without Electric Field (b) With DC Electric Field

11. Dielectric Drying (4th generation)

(3) Microwave Drying

Main Applications

- Widely applied to **dried fruits, crisps, and powders**, including:
  - **lychee, mango, longan, apple, banana, preserved fruits, fruit & vegetable crisps, fruit & vegetable powders, potatoes**.

Moisture Content Requirement

- Most suitable for **fruit and vegetable materials with moisture content below 30%**.

For Moisture > 30%

- Requires **hot-air drying combined with microwave drying** (i.e., microwave-assisted drying).

11. Dielectric Drying (4th generation)

(3) Microwave Drying

Safety

- Microwave wavelengths are the **longest** among the above bands.
- **Low frequency + long wavelength → harmless to human health**.
- Household microwave ovens are **safe for daily use**.

Shared Features with Infrared

- Both belong to **dielectric heating**.
- Shared common features:

Rapid heating rate.	**High energy efficiency.**
Uniform heating.	**Possibility of selective heating.**

11. Dielectric Drying (4th generation)

Conventional Drying Mechanism

- Water **evaporates first from the surface**, with internal moisture gradually diffusing outward.
- Heat is **conducted from outside to inside**.
- Driving force for mass transfer is **temperature gradient**.
- **High external temperatures** are required to establish a gradient that promotes moisture diffusion.

11. Dielectric Drying (4th generation)

Dielectric Drying Mechanism

- Heat is **generated internally**.
- Driving force for mass transfer: **pressure gradient** (from rapid internal steam buildup).
- High initial moisture → **internal pressure rises markedly + liquid water** forced out under this gradient.
- Higher initial moisture → **greater "pumping" effect** of this pressure gradient (liquid water + vapor driven outward).
- Results in an **extremely fast drying rate**.

12. Combined Drying Technologies

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- **Purpose**
  - **Energy conservation & environmental protection** → combined drying technologies are increasingly promoted.
- **Complementary Drying Effects**
  - **Integrates different drying methods → complementary effects → superior drying performance**.

12. Combined Drying Technologies

(1) Microwave-hot Air Combined Drying

Concept of Microwave-Hot Air Combined Drying

- A hybrid drying process = **hot air drying** + **microwave drying** → applied in stages according to the **properties of the raw materials**.

Objectives

- Shorten drying time.
- Reduce energy consumption.
- Enhance product quality.

12. Combined Drying Technologies

(1) Microwave-hot Air Combined Drying

Heat & Moisture Transfer Differences

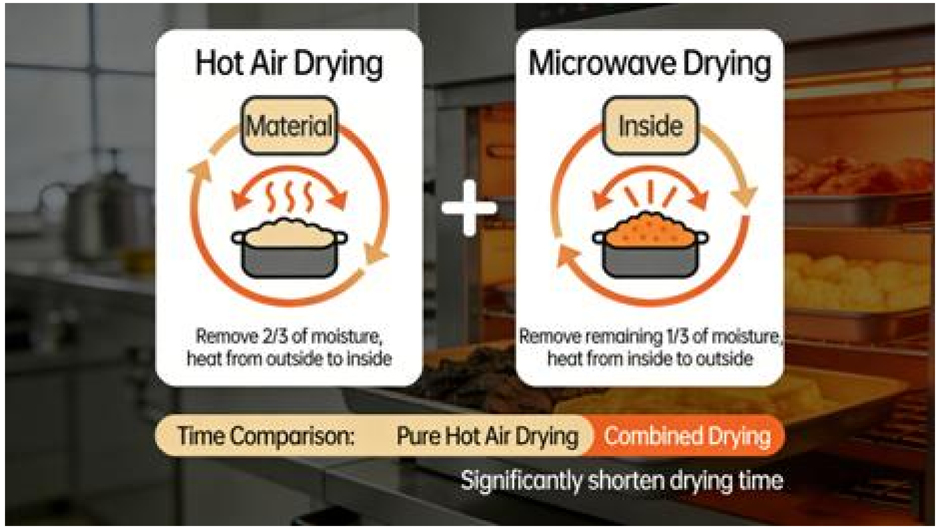
- **Hot air drying** transfers heat **from the outside to the inside,** pushing moisture **from the inside to the surface**.
- **Microwave drying** generates heat **from the inside to the outside**, creating a heat flow **directly opposite to hot air drying**.

Drying Sequence

- **Hot air drying → removes two-thirds** of the water content.
- **Microwave drying → removes the remaining one-third** and meets the final drying requirements.

Effect on Drying Time

- **Significantly reduces drying time**.



12. Combined Drying Technologies

(1) Microwave-hot Air Combined Drying

Practical Example

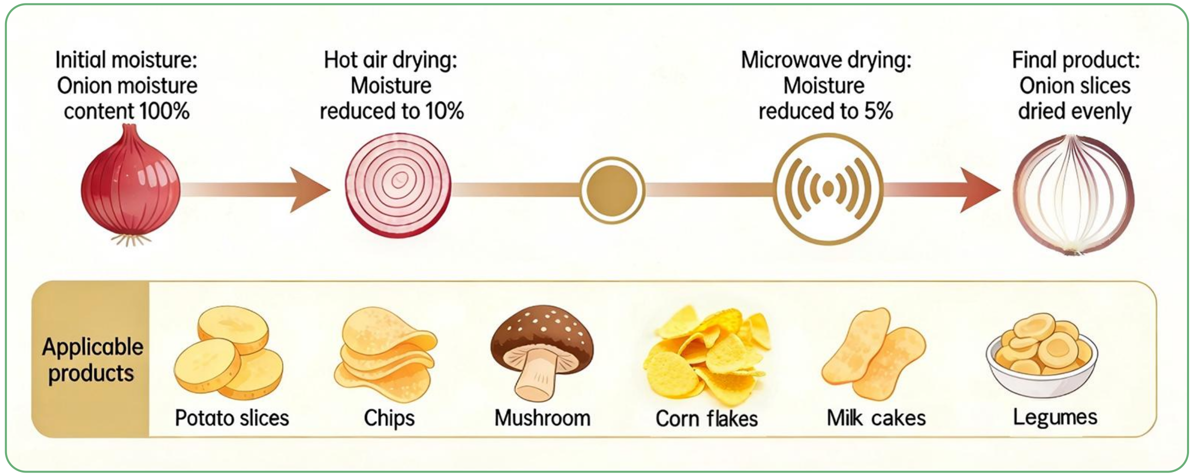
- **Onion drying**: **hot air drying** first reduces moisture content to **10%**, then **microwave drying** removes an additional **5%**.

Key Effects of the Hot Air Drying Stage

- Saves approximately **30%** of energy consumption.
- Eliminates **90%** of bacteria.

Applicable Products

- Suitable for processing potato slices, chips, shiitake mushrooms, corn flakes, milk cakes, legumes, etc.



12. Combined Drying Technologies

(1) Microwave-hot Air Combined Drying

Industrial Applications of Tunnel-type Microwave-hot Air Drying

- Can be applied in the final dehumidification stage of:
  - Macaroni
  - Biscuits
  - Fried potato chips
  - Other similar products.

Effects

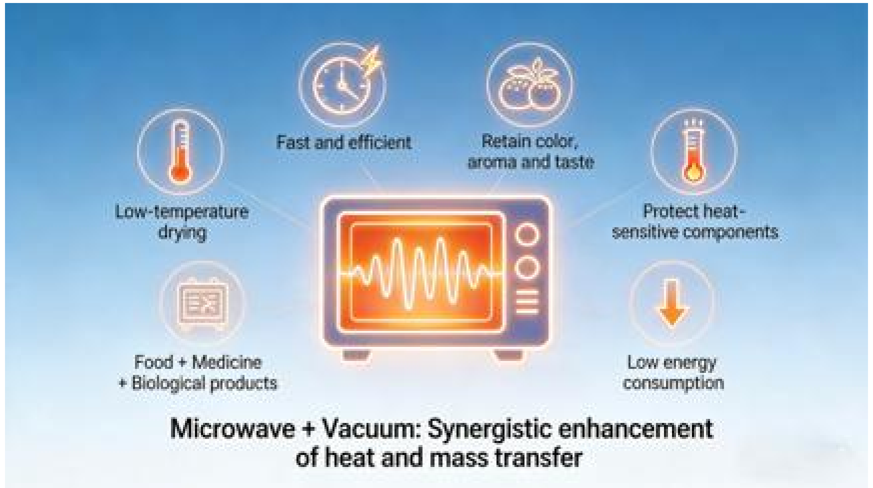
- Significantly shortens drying time.
- Improves the structural and cooking characteristics of macaroni.

12. Combined Drying Technologies

(2) Microwave-vacuum Drying Technology

Principle of Microwave-Vacuum Drying

- Combines the advantages of **microwave drying** and **vacuum drying**.
- Heat and mass transfer mechanisms similar to **dielectric drying**.
- Vacuum conditions **decrease the boiling point of water**, enabling faster moisture evaporation.



Key Advantages

- **Lowers** drying **temperature** and **accelerates** drying **rate**, realizing **rapid**, **efficient** and **low-temperature drying**.

12. Combined Drying Technologies

(2) Microwave-vacuum Drying Technology

Benefits for Product Quality

- Preserves original color, aroma, flavor, and nutrients.
- Avoids degradation of heat-sensitive constituents or bioactive compounds during drying.

Application Suitability & Cost Advantages

- Suitable for heat-sensitive foods, pharmaceuticals, and bioproducts.
- Relatively low equipment and operating costs.
- Applicable to process diverse products such as:

Fruit and vegetable powders. | Egg yolk powder. | Dehydrat.

12. Combined Drying Technologies

(2) Microwave-vacuum Drying Technology

Equipment Scope & Core Structure

- Available in both **small scale** and **industrial models**, featuring a **sealed chamber** as the **core structure**.

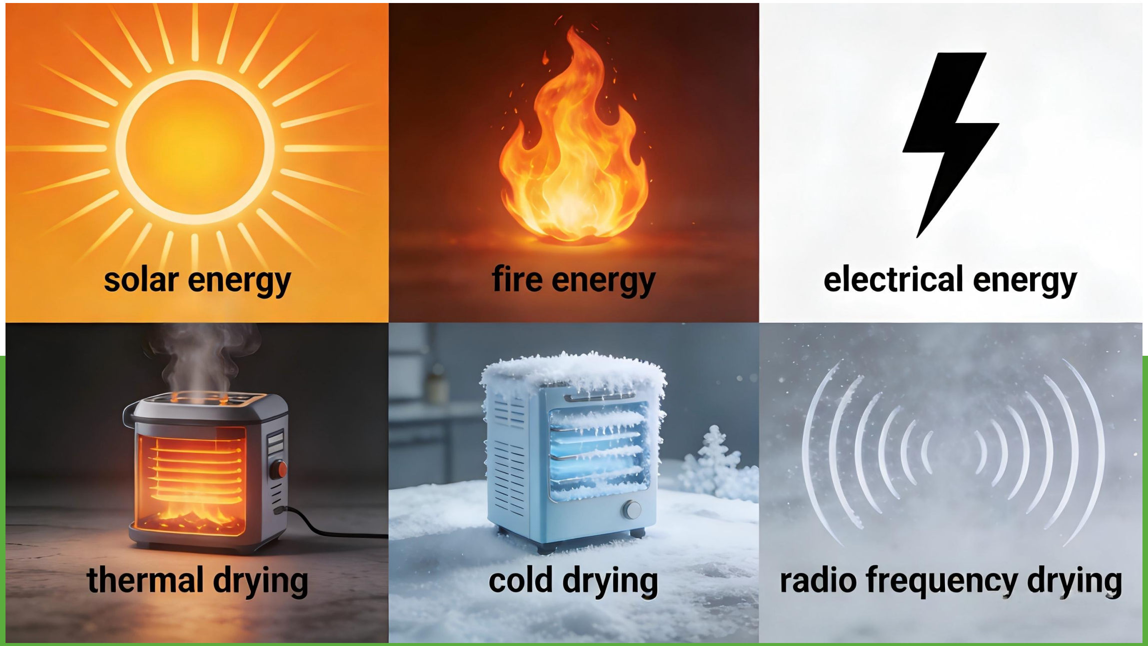
Key Characteristics

- **Low drying temperatures and oxygen isolation** minimize damage to heat-sensitive and oxidation-prone substances, preserving nutritional quality and color.
- **Greater retention of original food flavor**, with good product uniformity and superior color, flavor, texture, and rehydration compared with hot-air drying.
- **Simultaneous heating of surface and interior** → synchronous moisture heating ⇒ faster drying + shorter processing time ⇒ reduce energy use + higher energy efficiency.
- **Compact equipment footprint** with relatively low cost and operating expenses.
- **Sealed design** that prevents release of harmful substances or waste by-products.

13. Principles for Drying Technology Selection

Classification of Drying Methods

- Energy sources: Natural solar energy, combustion heat, electrical energy.
- Drying types: Thermal drying, cold drying, radio frequency drying.



Key Principles for Method Selection

- Based on intrinsic properties of the material.
- Apply a suitable drying technique accordingly.
- Use corresponding drying equipment.

13. Principles for Drying Technology Selection

Core Principles for Drying Method Selection

- **Evaluate material properties**: physical state, dispersion degree, viscosity, moisture content, heat sensitivity, surface tension, water binding state, and key changes during drying.
- **Consider dried product quality requirements**: protection of heat-sensitive constituents and retention of flavor compounds.
- **Weigh drying cost and investment**: prioritize methods with **lower cost** and **higher return on investment**.

Selection Goal

- Select the optimal drying process.
- Achieve superior product quality.
- Control heat and energy consumption.
- Balance economic efficiency and product quality.

Conclusion: Toward Efficient and High-Quality Drying

Technology Developmental Trajectory

- Agricultural product drying technologies evolve from **natural drying** → **traditional drying** → **novel drying** → **combined drying**.

Technology Unique Attributes

- Each technology has distinct **drying mechanism, technical features, equipment configuration, operating conditions** and **applicable scope.**

Selection Basis

- Selection relies on **processing requirements.**

Core Goal

- The core goal is to **produce high-quality products** in a **short time** at **low cost**.