Vacuum Freeze-Dryer Selection Guide

From eutectic point testing to mass-production models • For factories and R&D

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1. How Freeze-Drying Happens

Freeze-drying (vacuum freeze-drying) is divided into three steps, and the sequence cannot be changed:

1. **Pre-freezing**: All moisture in the material freezes into ice. The temperature at which all moisture inside the material is completely frozen is called the eutectic point, and the pre-freezing temperature must be 5–10°C below the eutectic point.
2. **Sublimation drying (primary drying)**: Vacuum is drawn to below 15Pa, and the ice directly turns into water vapor, which is condensed and trapped by the cold trap (water catcher). This step removes about 90% of the moisture in the material.

3. **Desorption drying (secondary drying)**: The shelf temperature is raised to carry away the remaining bound water, reducing the final moisture content to the target value.

Key point: **During the sublimation stage, enough heat must be supplied, but not too much**. If too little is supplied, freeze-drying is slow and the cycle is long; if too much is supplied, the material partially melts and collapses, and the entire batch is scrapped. Therefore, the shelf temperature is designed around the eutectic point.

II. First Measure the Eutectic Point, Then Define the Curve

1. Without measuring the eutectic point, the curve is just guesswork

- Eutectic point = the temperature at which all water in the material freezes
- Pre-freezing temperature = eutectic point − 5~10°C
- Upper limit of shelf temperature in the sublimation stage, not higher than the eutectic point (operate with a safety margin)

2. A Set of Real Data (Papain Concentrate)

Item	Parameter
Batch size	1000 kg/batch
Material moisture content	80%
Pre-freezing	20°C → −30°C, completed in 4 hours
Water removed by sublimation	798 kg
Heat absorbed per kg of water sublimated	2,830 kJ
Cold trap peak load	52~65 kW
Vacuum level during sublimation	Below 15 Pa
Full batch cycle	24 hours
Refrigeration configuration	Two-stage screw compressor, lower limit −65°C
Vacuum configuration	Three-stage pump set (to ensure pumping speed during sublimation)
Unit energy consumption	Approx. 4.4 kWh/kg (measured basis for this batch)

In one sentence: **batch size × moisture content × 2,830 kJ is the heat that must be removed during sublimation**, and the displacement of the cold trap and compressor is derived backward

from this figure.

III. Selecting Area by Batch Size: Three Production Models

Model	Shelf Area	Typical Material	Batch	Cycle	Cold Trap Temperature	Vacuum Level	Pump Set
CVD-1000	10 m²	Fruit	100 kg/batch	25 h	−40℃	15 Pa	Rotary Vane Pump + Roots Pump
CVD-5000	50 m²	Tea Powder	500 kg/batch	—	—	—	—
CVD-10000	100 m²	Concentrated Liquid	1000 kg/batch	24 h	—	≤15 Pa	Three-Stage Pump Set

CVD-5000 supporting parameters: cooling capacity 80.8 kW, chamber 22.6 m³, double doors, evaporative condenser.

Selection sequence: first determine batch size and material, then work backward to shelf area. Reversing the sequence (selecting equipment by site area) is a common source of rework.

IV. R&D and Household: HFD Series

For small-scale trials, formulation validation, and teaching/R&D scenarios, use the HFD series (shelf area 0.25–5.0 m²):

Model range	Area	Single-compressor cold trap ≤ −60°C	Dual-compressor cold trap ≤ −75°C
HFD-1 ~ HFD-10	0.25 ~ 1.0 m²	✓	—
HFD-15 ~ HFD-50	1.5 ~ 5.0 m²	—	✓

- HFD-1: 0.25 m², approximately 2–3 kg per batch
- HFD-5: 0.50 m², approximately 6–7 kg per batch
- HFD-50: 5.0 m², approximately 50–60 kg per batch

The value of R&D models lies in first establishing a proven cycle (pre-freezing rate, shelf temperature, sublimation time), then scaling up to production models. Cycle scale-up is the stage

most prone to problems in freeze-drying projects.

V. How to Determine the Supporting Systems

1. Vacuum System

- Target vacuum level ≤15Pa: Roots pump + rotary vane pump is required; large-scale units use a three-stage pump set
- The Roots pump requires a backing pump to first reduce pressure to approximately 1kPa before it can start; the sequence of piping and valves shall follow the plan
- Insufficient pumping speed during the sublimation phase causes pressure to rise and ice surface temperature to increase → collapse. Pumping speed shall be matched to the sublimation load, not to the chamber volume

2. Cold Trap and Water Vapor Condenser

- The cold trap temperature determines how much water vapor can be condensed: −40°C for conventional mass production, down to −65°C for biopharmaceutical-grade systems equipped with a two-stage screw compressor.
- The cold trap surface area is designed based on the peak sublimation water vapor load (peak of 52~65 kW in the example above).
- When the cold trap and shelves share a single refrigeration system, the cooling capacity is sized for the most unfavorable operating condition (mid-sublimation).

3. Heating and Temperature Control

Shelf temperature, heating rate, and vacuum level operate in coordination. The value of the control system lies in reproducing the curve consistently, rather than providing a few fixed programs.

VI. Common Pitfalls in Model Selection

1. **Selecting equipment by floor area**: Shelf area should be back-calculated from batch size and material
2. **Scale-up without measuring the eutectic point**: If the pre-freezing temperature is guessed, the risk of losing an entire batch is yours to bear
3. **Looking only at shelf area without considering moisture content**: At the same 10 m², materials with 80% moisture and 40% moisture have completely different cycle times

4. **Sizing pumping speed by chamber volume**: It should be sized by sublimation load, otherwise pressure will rise again in the mid-stage
5. **Comparing energy consumption with hot-air drying**: Freeze-drying is a dehydration + preservation process; product quality, rehydration, and shelf life are not on the same benchmark as hot-air drying
6. **Scaling up before the R&D model curve is proven**: Lab scale → pilot scale → mass production; stepwise scale-up is the most reliable
7. **Overlooking cold trap defrosting and switching**: Continuous production requires either dual cold trap switching or shutdown defrosting, which affects shift output
8. **Overlooking pre-treatment**: Material shape, loading thickness, and tray material directly affect the drying cycle

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VII. Applicable Scope of Freeze-Dried Products

Based on actual project experience, the freeze-drying process is commonly used for:

- **Food category**: fruit slices/cubes, vegetables, tea powder, coffee, soup bases, pet food, seafood, seasonings
- **Biological and fine chemical category**: enzyme preparations, protein concentrates, microbial strains, biological products
- **Agricultural product processing**: specialty fruits and vegetables, edible fungi, Chinese medicinal materials

Whether a product is suitable for freeze-drying depends on its positioning (rehydration properties, flavor retention, shelf-life requirements) and cost tolerance, and must be evaluated on a product-by-product basis.

VIII. Contact Us

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Freeze-drying solutions need to be based on the material, batch size, moisture content, and site conditions. The eutectic point and curve are subject to actual measurement.