Freeze-Drying (Lyophilisation) Primary Drying Time

Sublimation rate and primary drying time of a vial in a freeze dryer from the shelf and product temperatures, the vial heat transfer coefficient and the ice mass.

Method: Steady-state heat-transfer model of primary drying (vial heat transfer coefficient)

Input parameters

Unit system: SI

Parameter	Value	Unit
Fill volume per vial	3.0000	mL
Solids share of the fill	5.0000	%
Density of the solution	1,030.0	kg/m³
Vial bottom area (outer)	3.8000	cm²
Vial heat transfer coefficient	20.000	W/(m²·K)
Shelf temperature	-10.000	°C
Product temperature at the sublimation front	-30.000	°C
Heat of sublimation of ice	2,838.0	kJ/kg

Calculated results

Parameter	Value	Unit
Ice per vial	2.9355	g
Heat flow to the vial	152.00	mW
Sublimation rate per vial	1.9281e-04	kg/h
Primary drying time	15.225	h

Notes for this case

• During primary drying the heat that reaches the vial from the shelf, K_v A_v (T_s − T_p), is used to sublime ice, so the sublimation rate is that heat over the heat of sublimation and the drying time is the ice mass over the rate. The product temperature must stay below its collapse (or eutectic) temperature, which limits how warm the shelf can be; K_v depends on the vial and the chamber pressure (about 10–30 W/(m²·K) for glass tubing vials at 10–20 Pa). The dry layer's resistance, ignored here, sets the product temperature: confirm with a cycle run.

Formula and method

$$\dot{m} = \frac{K_v A_v (T_s - T_p)}{\Delta H_s}, \quad t = \frac{m_{ice}}{\dot{m}}$$

Variables

V_f	Fill volume per vial	m³
x_s	Solids share of the fill	-
ρ	Density of the solution	kg/m³
A_v	Vial bottom area (outer)	m²
K_v	Vial heat transfer coefficient	W/(m²·K)
T_s	Shelf temperature	K
T_p	Product temperature at the sublimation front	K
ΔH_s	Heat of sublimation of ice	J/kg
m_{ice}	Ice per vial	kg
$\dot{Q}$	Heat flow to the vial	W

$\dot{m}$	Sublimation rate per vial	kg/s
t	Primary drying time	s

Method and standards

Primary drying.

Assumptions and limits

- Heat-transfer-limited drying; uniform vials; constant temperatures.

References

Steady-state heat-transfer model of primary drying (vial heat transfer coefficient)

Report details

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Results are for engineering estimation. Verify critical designs against the referenced standards and your own data.

This calculator online

https://calc.firecad.com/chemical/bioprocess/freeze-drying-primary-time

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Reopens the calculator with the inputs of this report.