Product Cooling and Freezing Load

Heat to remove when a product is cooled, frozen and sub-cooled (sensible, latent of its water, sensible below freezing) and the load over the pull-down time.

Method: Mass and energy balances (definitions); latent heat of fusion of ice 333.55 kJ/kg

Input parameters

Unit system: SI

Parameter	Value	Unit
Product	10,000	kg
Specific heat above freezing	3.6000	kJ/(kg·K)
Specific heat below freezing	1.8000	kJ/(kg·K)
Water that freezes (share of mass)	70.000	%
Initial temperature	20.000	°C
Initial freezing point	-2.0000	°C
Final temperature	-18.000	°C
Pull-down time	24.000	h

Calculated results

Parameter	Value	Unit
Sensible heat above freezing	792.00	MJ
Latent heat	2,334.9	MJ
Sensible heat below freezing	288.00	MJ
Total	3,414.8	MJ
Average refrigeration load	39.524	kW

Notes for this case

- The load is the average over the pull-down; the peak at the start is higher.
- Add packaging, respiration (fresh produce), infiltration and fan heat for the room load.

Formula and method

$$Q_1 = Mc_u \max\left[T_1 - \max(T_f, T_2), 0\right], \quad Q_2 = Mw_f\lambda_f \ (T_2 < T_f), \quad Q_3 = Mc_f \max\left[\min(T_f, T_1) - T_2, 0\right]$$

$$Q = Q_1 + Q_2 + Q_3, \quad \dot{Q} = \frac{Q}{t}$$

Variables

M	Product	kg
c_u	Specific heat above freezing	J/(kg·K)
c_f	Specific heat below freezing	J/(kg·K)
w_f	Water that freezes (share of mass)	-
T_1	Initial temperature	K
T_f	Initial freezing point	K
T_2	Final temperature	K
t	Pull-down time	s
Q_1	Sensible heat above freezing	J
Q_2	Latent heat	J
Q_3	Sensible heat below freezing	J

Q	Total	J
$\dot{Q}$	Average refrigeration load	W
λ_f	Latent heat of fusion of ice, 333 550	J/kg

Method and standards

Sensible and latent heat balance.

Assumptions and limits

- Freezing at one temperature.
- A product entered at or below its freezing point is taken as unfrozen (supercooled) and the full latent heat is counted; for product already frozen, Q is high by M w_f λ_f.
- The load is an average over the pull-down time; the peak at the start is higher.

References

- Mass and energy balances (definitions); latent heat of fusion of ice 333.55 kJ/kg

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/food-dairy/product-freezing-load

Open this case on calc.firecad.com →

Reopens the calculator with the inputs of this report.