Transient Heating or Cooling: Lumped Capacitance

Time for a small body to heat or cool to a temperature in a fluid, or its temperature after a time, with the Biot number check, by the lumped capacitance method.

Method: Incropera; DeWitt; ...

Input parameters

Unit system: SI

Parameter	Value	Unit
Initial temperature of the body	600.00	°C
Fluid temperature	30.000	°C
Temperature wanted (for the time)	100.00	°C
Time (for the temperature)	600.00	s
Convection coefficient	50.000	W/(m²·K)
Volume of the body	1.0000e-04	m³
Surface area	0.012000	m²
Density	7,850.0	kg/m³
Specific heat	0.49000	kJ/(kg·K)
Conductivity of the body (for the Biot number)	45.000	W/(m·K)

Calculated results

Parameter	Value	Unit
Biot number h L_c / k, L_c = V/A	0.009259	
Time constant ρ V c_p/(h A)	641.08	s
Time to reach the temperature wanted	1,344.4	s
Temperature after the time given	253.57	°C

Formula and method

$$\frac{T-T_\infty}{T_i-T_\infty}=e^{-t/\tau},\quad \tau=\frac{\rho V c_p}{hA_s},\quad Bi=\frac{hV/A_s}{k}$$

Variables

T_i	Initial temperature of the body	K
T_∞	Fluid temperature	K
T	Temperature wanted (for the time)	K
t	Time (for the temperature)	s
h	Convection coefficient	W/(m²·K)
V	Volume of the body	m³
A_s	Surface area	m²
ρ	Density	kg/m³
c_p	Specific heat	J/(kg·K)
k	Conductivity of the body (for the Biot number)	W/(m·K)
Bi	Biot number h L_c / k, L_c = V/A	-
$\mathcal{T}$	Time constant ρ V c_p/(h A)	s
t_T	Time to reach the temperature wanted	s
T_t	Temperature after the time given	K

Method and standards

Energy balance on a uniform-temperature body.

Assumptions and limits

- Uniform body temperature, constant h. Results are still given when Bi > 0.1 (with a note), but they are then approximate.
- h must include radiation where it matters: for a hot body in air (for example steel at several hundred °C) radiation dominates, so add $h_r = \varepsilon\sigma(T_s^2 + T_\infty^2)(T_s + T_\infty)$ to the convective h.

References

- Incropera
- DeWitt
- Bergman and Lavine
- Fundamentals of Heat and Mass Transfer
- ch. 5 (lumped capacitance)

Report details

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Release checks	3 reference cases of this calculator, computed independently, are checked on every release

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

This calculator online

https://calc.firecad.com/mechanical/heat-transfer/lumped-capacitance-cooling

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Reopens the calculator with the inputs of this report.