

CoolingBasics Check-up

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Thermal Expansion

linear expansion

$$\Delta l = \alpha \cdot l_1 \cdot (T_2 - T_1) = \alpha \cdot l_1 \cdot (t_2 - t_1)$$

$$\Delta l = l_2 - l_1$$

$$l_2 = l_1 \cdot [1 + \alpha \cdot (T_2 - T_1)] = l_1 \cdot [1 + \alpha \cdot (t_2 - t_1)]$$

volumetric expansion

$$\Delta V = V_2 - V_1$$

$$\Delta V = V_2 - V_1$$

$$V_2 = V_1 \cdot [1 + \gamma \cdot (T_2 - T_1)] = V_1 \cdot [1 + \gamma \cdot (t_2 - t_1)] \quad \gamma = 3 \alpha$$

l_1 initial length [m]

l_2 final length [m]

α coefficient of linear expansion [1/K]

V_1 initial volume [m³]

V_2 final volume [m³]

γ coefficient of volumetric expansion [1/K]

Ideal Gas Law

Boyle-Mariotte

$$p \cdot V = \text{const.} \quad T = \text{const.}$$

$$p \cdot v = \text{const.}$$

$$p_1 \cdot V_1 = p_2 \cdot V_2$$

p	absolute pressure [Pa]
V	volume [m ³]
v	specific volume [m ³ /kg]
T	thermodynamic temperature [K]

Gay-Lussac

$$\frac{V}{T} = \text{const.} \quad p = \text{const.}$$

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

Amontons

$$\frac{p}{T} = \text{const.} \quad V = \text{const.}$$

$$\frac{p_1}{p_2} = \frac{T_1}{T_2}$$

Ideal Gas Law

combined gas law

$$\frac{p \cdot V}{T} = \text{const.}$$

$$\frac{p_1 \cdot V_1}{T_1} = \frac{p_2 \cdot V_2}{T_2}$$

ideal gas law

$$p \cdot V = m \cdot R_i \cdot T$$

R_i individual gas constant [J/(kg·K)]

M molar mass [kmol/kg]

R universal gas constant

individual gas constant

$$R_i = \frac{p \cdot v}{T}$$

$$R_i = \frac{R}{M}$$

$$R_i = c_p - c_v$$

c_p heat capacity, if $p = \text{const.}$

c_v heat capacity, if $V = \text{const.}$

$R = 8,314 \text{ kJ/(kmol·K)}$

Heat Flow

quantity of heat

$$Q = m \cdot c \cdot \Delta t$$

heat flow / thermal rating / refrigeration capacity

$$\dot{Q} = \frac{Q}{\tau}$$

$$\dot{Q} = \dot{m} \cdot \Delta h = \dot{m} \cdot (h_2 - h_1)$$

$$\dot{Q} = \dot{m} \cdot c \cdot \Delta t$$

$$\dot{Q} = k \cdot A \cdot \Delta t$$

Q heat [kJ]

$\dot{Q}$ heat flow [kW]

m mass [kg]

$\dot{m}$ mass flow [kg/s]

Δh enthalpy differential [kJ/kg]

c heat capacity [kJ/(kg K)]

U heat transmission coefficient [W/(m²·K)]

A heat transfer surface [m²]

Heat Flow

freeze

$$Q = Q_{\text{cooling}} + Q_{\text{solidification}} + Q_{\text{aftercooling}}$$

$$\dot{Q} = \dot{Q}_{\text{cooling}} + \dot{Q}_{\text{solidification}} + \dot{Q}_{\text{aftercooling}}$$

$$Q_{\text{cooling}} = m \cdot c_v \cdot \Delta t_v$$

$$Q_{\text{solidification}} = m \cdot \Delta h_f$$

$$Q_{\text{aftercooling}} = m \cdot c_n \cdot \Delta t_n$$

$$\Delta t_v = t_1 - t_s$$

unfreeze

$$Q = Q_{\text{heating}} + Q_{\text{melting}} + Q_{\text{heating2}}$$

$$\dot{Q} = \dot{Q}_{\text{heating}} + \dot{Q}_{\text{melting}} + \dot{Q}_{\text{heating2}}$$

$$Q_{\text{heating}} = m \cdot c_n \cdot \Delta t_n$$

$$Q_{\text{melting}} = m \cdot \Delta h_f$$

$$Q_{\text{heating2}} = m \cdot c_v \cdot \Delta t_v$$

$$\Delta t_n = t_s - t_2$$

Q_{cooling} heat to be dissipated before solidification

$Q_{\text{aftercooling}}$ heat to be dissipated after solidification

Q_{heating} loaded heat before melting

Q_{heating2} loaded heat after melting

Δh_f heat of fusion [kJ/kg]

$\Delta h_f = 335 \text{ kJ/kg}$ water

$t_s = 0 \text{ }^\circ\text{C}$ water

Heat Transfer

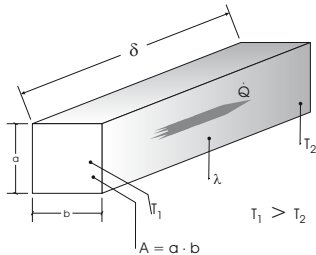
heat conduction

$$\dot{Q} = \frac{\lambda}{\delta} \cdot A \cdot \Delta T$$

$$\dot{Q} = \frac{\lambda}{\delta} \cdot A \cdot \Delta t$$

$$q = \frac{\dot{Q}}{A} = \frac{\lambda}{\delta} \cdot \Delta t$$

$$\Delta T = T_1 - T_2$$



heat transfer

$$\dot{Q} = \alpha \cdot A \cdot \Delta T$$

$$\dot{Q} = \alpha \cdot A \cdot \Delta t$$

$$q = \frac{\dot{Q}}{A} = \alpha \cdot \Delta t$$

λ thermal conductance [W/(m·K)]

δ layer thickness [m]

α heat transfer coefficient [W/(m² K)]

A heat transfer surface area [m²]

q specific heat flow [W/m²]

heat transmission and thermal transmittance coefficient

$$\dot{Q} = U \cdot A \cdot \Delta T$$

$$\dot{Q} = U \cdot A \cdot \Delta t$$

$$q = \frac{\dot{Q}}{A} = U \cdot \Delta t$$

$$\frac{1}{U} = \frac{1}{\alpha_a} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \dots + \frac{\delta_n}{\lambda_n} + \frac{1}{\alpha_i}$$

$$t_1 = t_a - \Delta t = t_a - \frac{\dot{Q}}{\alpha \cdot A} \quad \text{surface temperature}$$

$$t_{11} = t_1 - \Delta t = t_1 - \frac{\delta_1 \cdot \dot{Q}}{\lambda_1 \cdot A} \quad \text{interface temperature}$$

