Specific Heat of Materials

Thermal Capacitance in Heat Transfer
Analysis – Lesson 2

Discussion of Governing Equation

The difference between steady-state heat transfer and transient heat transfer is the existence of the transient term with **density, specific heat** and the **time derivative of temperature** on the right side of the governing equation.

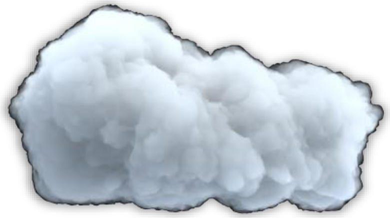
- Density and specific heat are materials properties.
- The time derivative of the temperature indicates that the governing equation solves a problem that changes with time.

$$k\nabla^2 T + q = \underset{\text{Density}}{\rho}\,\underset{\text{Specific Heat}}{c}\,\frac{\partial T}{\partial t}$$

Density

The density of a material is its mass per unit volume:

$$k\nabla^2 T + q = \rho c \frac{\partial T}{\partial t}$$

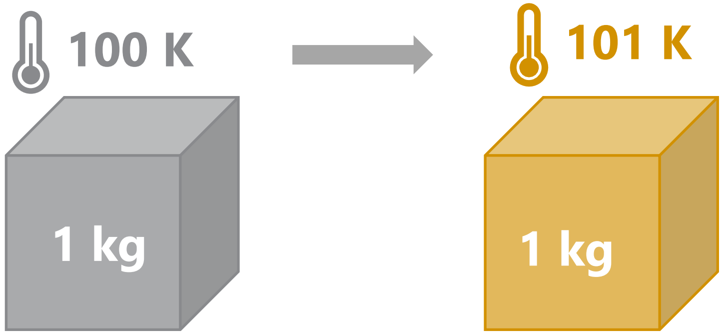


- For the same volume, materials with different densities have different masses.
- Mass should be differentiated from weight. Weight changes with the location of the object, mass doesn't.

Specific Heat

Specific heat describes how much energy is required to raise the temperature by 1 unit for a unit mass of material.

$$k\nabla^2 T + q = \rho c \frac{\partial T}{\partial t}$$



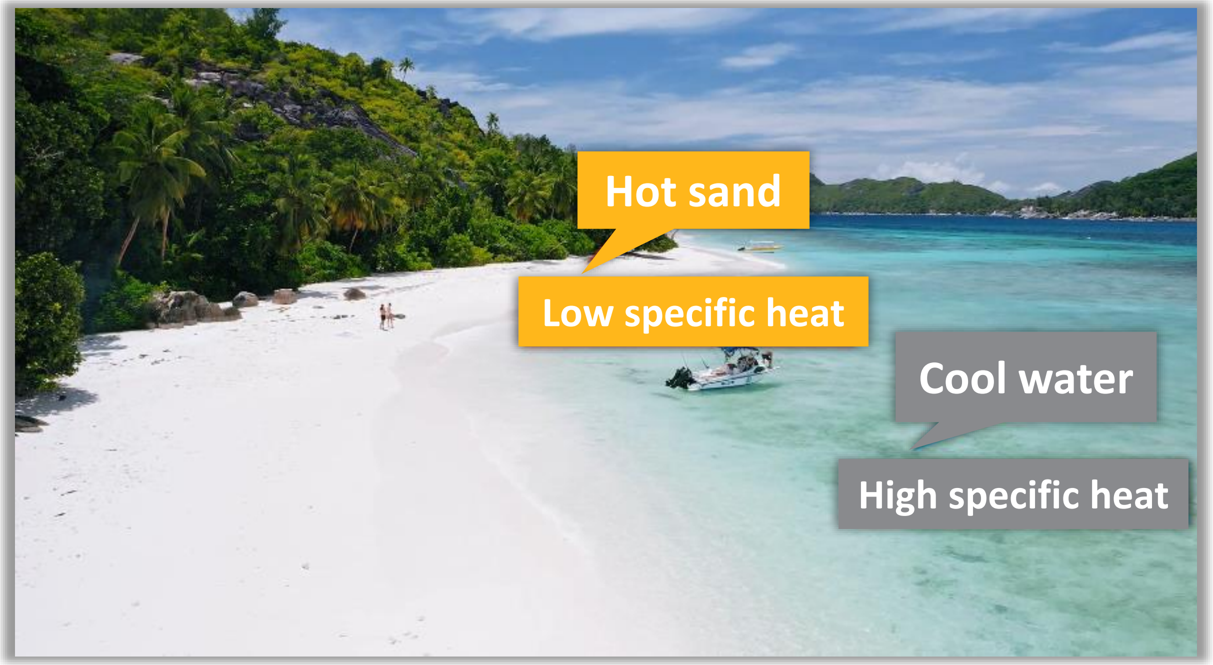
How much heat is needed?

- SI unit: energy (J) per unit temperature (K) per unit mass (kg) → J/kg·K
- Since one temperature increment in Kelvin equals one temperature increment on the Celsius scale, the unit of specific heat can also be written as J/kg·°C

Specific Heat

A material with **high specific heat** can absorb a lot of heat before a temperature change. Less heat is needed to increase the temperature of a material with **low specific heat.**

- Water is a typical material with very high specific heat. Oceans store huge amounts of heat on the earth without changing much in temperature.



Material	Specific Heat (J/kg· K)
Water	4180
Sand	830

Thermal Capacitance/Thermal Mass

While specific heat is a useful quantity, in engineering applications people often use the product of the specific heat and volume to describe a material's capacity to store heat energy. We call this thermal capacitance.

$$k\nabla^2 T + q = \rho c \frac{\partial T}{\partial t}$$

Thermal capacitance/thermal mass $\rho V c = mc$

Thermal capacitance for unit volume ρc

Thermal Capacitance/Thermal Mass

Examples of thermal capacitance for a unit volume of various materials:

Material	ρ $(\mathrm{kg/m^3})$	c $\mathrm{J/kg\cdot\ K)}$	ρc $(\mathrm{J/m^3\cdot K})$
Air	1.2	**1000**	1200
Styrofoam	32	**1100**	35200
Wood	350	**1800**	630000
Plywood	400	**1200**	480000
Polyethylene	900	**2300**	2070000
Aluminum	2690	**920**	2474800
Stainless steel	7500	**450**	3375000
Mercury	13600	**150**	2040000

An interesting observation. For many materials, if the density of a material is high, the specific heat of the material is comparatively low. Therefore, in engineering applications, you might find that the term ρc does not differ drastically between different materials. This rule does not apply to all materials.

Specific Heat and Conductivity

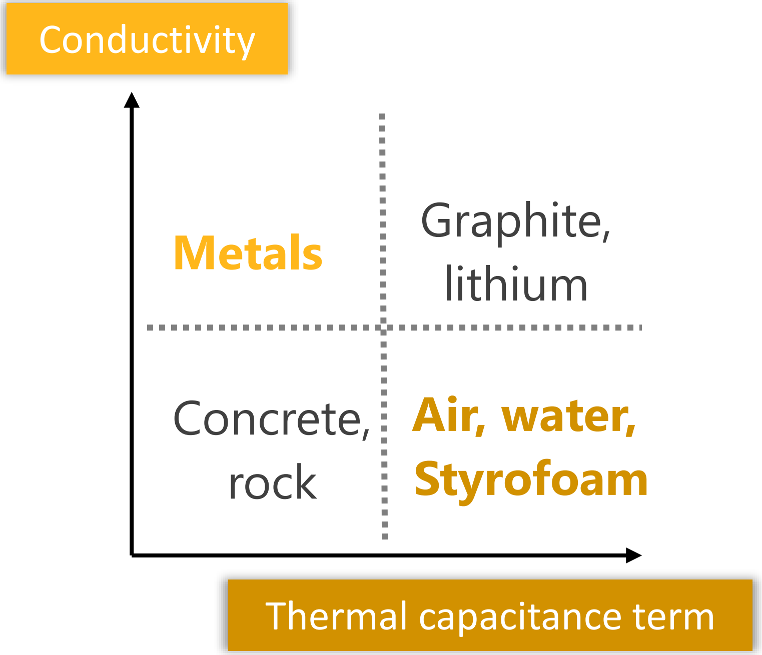
What’s the difference between conductivity and specific heat? They are two thermal properties of a material. In most cases, we need to consider them together to choose an appropriate material for product design.

- Specific heat: capability to store heat in **time**

$$\rho c \frac{\partial T}{\partial t}$$

- Conductivity: capability to transfer heat in **space**

$$k \frac{\partial T}{\partial x}$$



Conductivity

Metals

Graphite, lithium

Concrete, rock

Air, water, Styrofoam

Thermal capacitance term

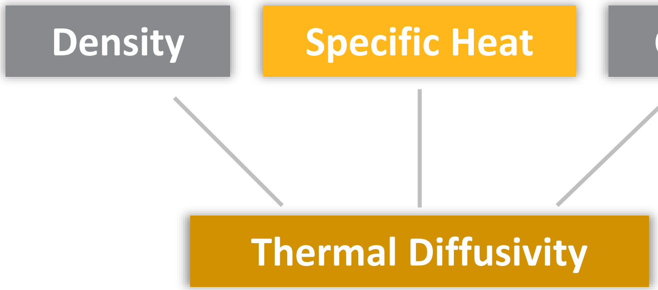
Air and Styrofoam are bad at conduction, while they are good at storing heat energy. Therefore, they are ideal materials for insulators.

Metals are good at heat conduction, so they are ideal materials for cookware.

Thermal Diffusivity

We have learned about the density, conductivity and specific heat of a material. Thermal diffusivity combines these three properties in one: It is the thermal conductivity divided by the density and the specific heat at constant pressure.

- Materials with high thermal diffusivity conduct heat rapidly.
- Thermal diffusivity describes how fast heat spreads in an area. Unit of thermal diffusivity is (m^2/s).



Density

Specific Heat

Conductivity

Thermal Diffusivity

$$\alpha = \frac{k}{\rho c}$$

Material	Thermal Diffusivity (m²/s)
Styrofoam	5.68182E-08
Polyethylene	9.66184E-08
Water	1.43541E-07
Plywood	4.16667E-07
Stainless steel	4.47407E-06
Silicon	9.61538E-05

Thermal Diffusivity

Which bench will you choose to sit on during a hot summer afternoon?

Based on life experiences, the wood bench seems to be the choice, buy why? Let’s have a look at the thermal properties of the two benches.

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