Heat Conduction: Learning Path Heat Conduction

Nomenklatur

Subskript:

L	Thermal conductivity specific
$\mathrm{c/conv.}$	Convection specific
i	Number of layers
u	Ambient
U	Perimeter
R	Fin-specific
Q	Cross section area specific
F	Foot of the fin
V	Volume specific

Superskript:

$''$	Area-related / area-based
$'''$	Volume-related/ volume-based
$\cdot$	Time derivated (heat flux, mass flux, enthalpy flow etc.)

Stationary heat conduction:

λ	Thermal conductivity	$[\mathrm{W/m\ K}]$
δ	Wall thickness	$[\mathrm{m}]$
n	Total number of layers	$[-]$
T	Temperature	$[\mathrm{K}]$
A	Area	$[\mathrm{m}^2]$
L	Length	$[\mathrm{m}]$
k	Heat transfer coefficient	$[\mathrm{W/m^2K}]$
$\dot{Q}$	Heat Flux	$[\mathrm{W}]$
$\dot{q}''$	Heat flux density	$[\mathrm{W/m^2}]$
η	Efficiency	$[-]$
R	Thermal resistance	$[\mathrm{W/K}]$
m	Fin parameters	$[1/\mathrm{m}]$
θ	Dimensionless temperature	$[-]$

Heat transfer with sources:

$\dot{\Phi}$	Heat source	$[\mathrm{W}]$

Unsteady heat transfer:

U	Inner energy	$[\mathrm{J}]$
C	Specific heat capacity	$[\mathrm{J/kg\ K}]$
θ^*	dimensionless temperature	$[\mathrm{K}]$
Bi	Biot-Zahl	$[-]$

Convection:

α	Convective heat transfer coefficient	$[\mathrm{W/m^2\ K}]$

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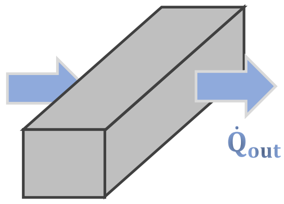
L 01: Introduction to the topic of heat conduction

Learning Goals:

- Steady state and transient heat conduction
- Heat conduction with heat source and sink
- Calculation of heat flow inside an object
- Temperature distribution inside an object



Comprehension questions:

- ☐ What is the driving potential of heat conduction?
- ☐ Which three influencing variables determine a heat flow transferred by heat conduction according to Fourier's law?
- ☐ Why must the temperature gradient in a positive coordinate system have a negative sign?
- ☐ Which material property is decisive for heat conduction?

HQ 02: Fourier-Law

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Learning objectives:

- Develop a good feeling for the heat conduction inside solid bodies
- Relation between temperature gradient and heat flux (Fourier 's law)
- Ability to draw the temperature distribution inside solid bodies

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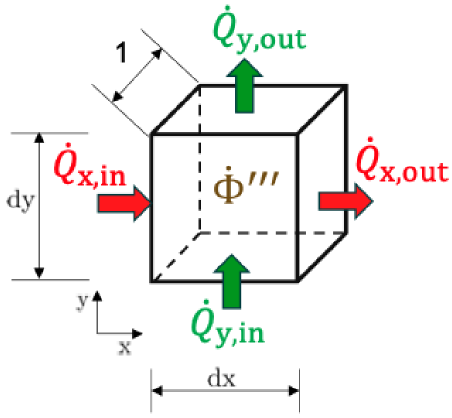
L 02: Derivation of the steady state energy conservation equations

Learning Goals:

- Setting up energy balances for different cases
- Development of a differential equation from the energy balance using Taylor series expansion
- Establishment of necessary boundary conditions



Comprehension questions:

- ☐ What is the steady-state temperature profile for a homogeneous, one-dimensional, flat wall without heat sources?
- ☐ Under which conditions does Poisson's equation become Laplace's equation (heat conduction)?

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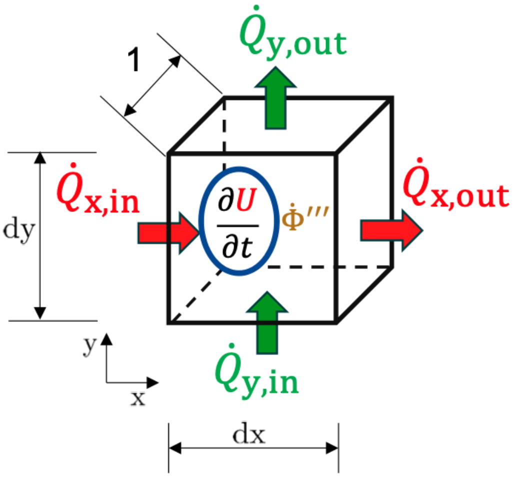
L 03: Derivation of the unsteady energy conservation equations

Learning Goals:



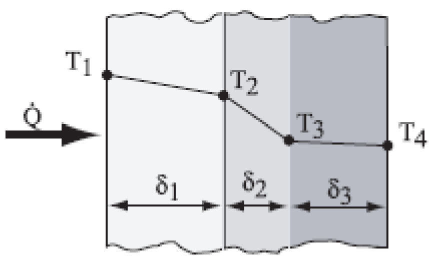
- Understand the concept of internal energy and the difference to kinetic and potential energy
- Difference between the specific heat at constant temperature and constant pressure
- Setting up energy balances for different cases
- Development of a differential equation from the energy balance using Taylor series expansion
- Establish necessary boundary conditions
- Solving the differential equation for simple cases

Comprehension questions:

- ☐ What is the steady state temperature profile for a homogeneous, one-dimensional, flat wall without heat sources?
- ☐ Under which conditions does Poisson's equation become Laplace's equation (heat conduction)?

L 04: Heat conduction in a multilayer plane wall

Learning Goals:



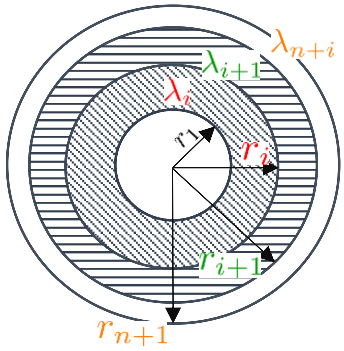
- Consideration of temperature profile of a multilayer wall under steady state conditions
- Combining the thermal resistors connected in series to define the total resistance

Comprehension questions:

- ☐ What is the course of the temperature profile in a flat wall without heat sources and sinks in steady state?
- ☐ Under what conditions can it be assumed that the heat flow remains constant in all layers?

  How is the thermal resistance of a plane wall defined? How can the thermal resistance be calculated for a wall of n layers?

L 05: Heat conduction in cylindrical coordinate system



Learning Goals:

- Schematic curves for temperature, cross section and heat
- Derivation of the differential equation via energy balances
- Mathematical solution of the differential equation
- Expand the equation to several resistors
- Simplification of the problem (engineering approach)

Comprehension questions:

- ☐ What is the course of the temperature profile for cylindrical bodies?
- ☐ How does the temperature profile of a cylindrical body differ from the temperature profile in a plane wall? What is the reason for this?
- ☐ Under which conditions can the curvature of the cylinder and thus the change of the area inside the cylinder wall be neglected??

HQ 03: Multi-layer systems

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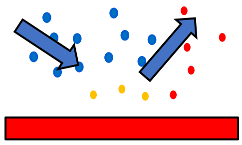
Learning objectives:

- Temperature kink at the crossover of different materials
- Direction of slope change at the temperature kink

L 06: Introduction to the topic of convection and advective heat transfer

Learning Goals:

- What is convection?
- How are advection, conduction and convection related to each other?
- What is a heat transfer coefficient (HTC) and what does it relate to?



Comprehension questions:

- ☐ What is convection and how can it be described empirically?
- ☐ What is the shape of the temperature profile close to the wall on the fluid side due to convection?
- ☐ What is the meaning of the heat transfer coefficient (HTC)?

L 06: Heat conduction in a multilayer plane wall with convection

Learning Goals:

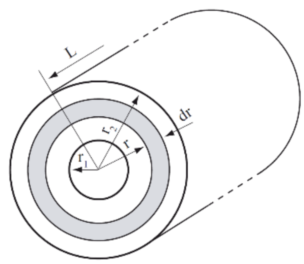
- ➢ What is the temperature profile in a multilayer plane wall considering convection resistances?
- ➢ What is the total resistance in a multilayer plane wall with convection?
- ➢ How to calculate the heat flow in a multilayer plane wall with convection?

Comprehension questions:

- ☐ What is the curvature of the temperature profile on the fluid side due to convection?
- ☐ What influence does the additional consideration of convection have on the total heat transfer?

L 07: Heat conduction in a multilayer pipe wall with convective resistances

Learning Goals:



- ➢ How does the surface area change in a multilayer pipe wall?
- ➢ How is the temperature profile in a multilayer pipe wall?
- ➢ How is calculated the total thermal resistance in a multilayer pipe wall?
- ➢ How is calculated the heat flow in a multilayer pipe wall?

Comprehension questions:

- ☐ How does the curved surface of a pipe affect the temperature gradient at constant heat flow and constant thermal conductivity?
- ☐ What reference area and reference diameter must be considered when calculating the total heat transfer coefficient k for a pipe wall problem?

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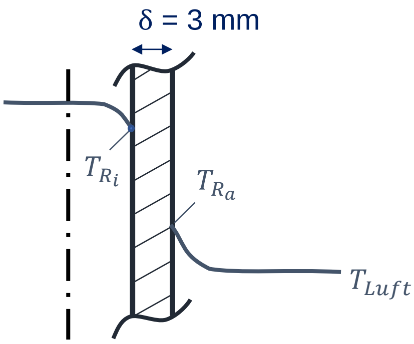
L 08 : Example: Pipe in the heating system

Learning Goals:

- Learning the procedure for calculating thermal resistances and heat flows in a pipe wall



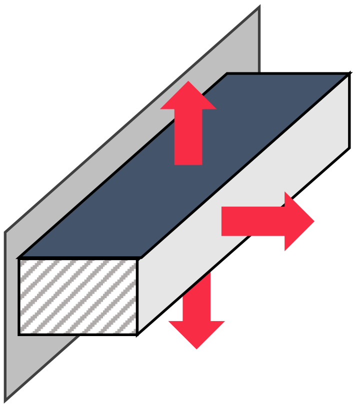
Comprehension questions:

- ☐ Which simplifying assumption can be made when calculating the heat flow through a pipe wall?
- ☐ Which resistance determines the heat transfer (coefficient) ?

L 09: Introduction to the topic of fins

Learning Goals:

- What are fins?
- Which heat transfer processes are of relevance?
- How does the temperature profile in a fin look like?
- Establishment of the energy balance for fins
- Derivation of the differential equation for fins



Comprehension questions:

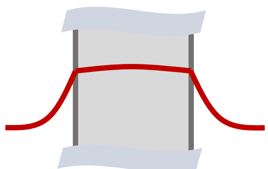
- ☐ What are fins and what are they used for?
- ☐ Which heat flow are considered in the derivation of the fin differential equation?
- ☐ What is the temperature profile in a fin (from physical consideration)?

L 10: Biot-Number

Learning Goals:

- Characterization of the dominant thermal resistances by using the relevant dimensionless number.
- Simplify complex multidimensional heat conduction problems based on the problem-defining thermal resistances.

Comprehension questions:



- ☐ What information does the Biot number provide?
- ☐ Which assumptions may be made for $\boldsymbol{Bi} \ll \mathbf{1}$?
- ☐ For a classical fin problem, is the Biot number high or low?

L 11: Solving the differential equation for fin

Learning Goals:

- Homogenization of the differential equation for fin
- General solution of the dfferential equation
- Interpretation of the fin parameter m for different fin geometries
- Recognize and implement different constraints for the fin problem

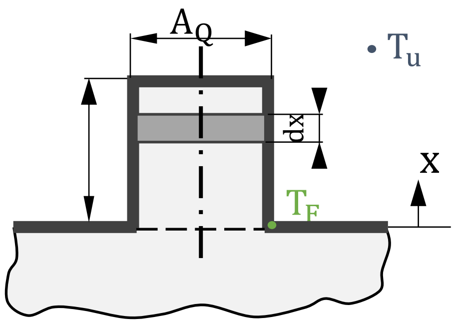
Comprehension questions:

- ☐ Which approach can be used to solve the inhomogeneous differential equation for fins
- ☐ Which parameters effect the fin parameter m?
- ☐ Which common boundary conditions can be used to solve the temperature profile in the fin ?

L 12: Efficiency coefficient of the fin

Learning Goals:

- Fin material
- Fin geometry
- Interpretation of the fin-efficiency coefficient



Comprehension questions:

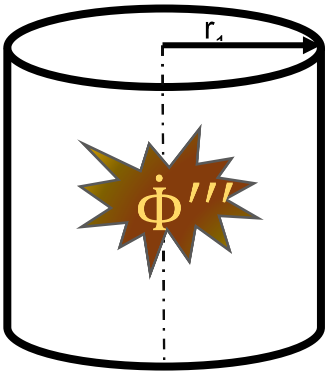
- ☐ Which relation describes the fin efficiency coeffitient?
- ☐ What is the assumption for the theoretical maximum transmittable heat of a fin ?
- ☐ How can the fin efficiency be increased ?

HQ 04: Fins

Learning objectives:

- Purpose of fins
- Temperature profile in fin-like structures
- Importance of resistances (Biot number)

L 13: Steady state heat conduction with heat source



Learning Goals:

- How is a heat source/sink considered?
- Derivation of the differential equation via energy balances
- Definition of boundary conditions
- Solving the differential equation by inserting the boundary conditions
- Final differential equation
- Calculation of the maximum and minimum temperature in a body

Comprehension questions:

- ☐ Which temperature profile is obtained for cylindrical bodies with heat source ?
- ☐ Which different boundary conditions can exist on the cylinder surface?
- ☐ How is the generated heat dissipated over the surface of the cylinder ?
- ☐ How can minimum and maximum temperatures be determined?

HQ 05: Heat sources and sinks

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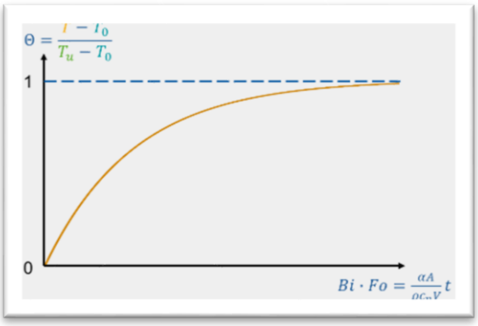
Learning objectives:

- Temperature profile in bodies with heat sources and heat sinks
- Influence of symmetry boundary conditions
- Meaning of adiabatic walls

L 14: Introduction to unsteady heat conduction

Learning Goals:

- Comprehension and abstraction of the problem
- Reducing the problem and determining an appropriate strategy for solving the problem
- De-dimensioning the problem
- Dimensionless numbers
- Solving the differential equation mathematically



Comprehension questions:

- ☐ Under which condition is the temperature within a body to be assumed as homogeneous? Which dimensionless number can be used for this purpose?
- ☐ What describes the Fourier number?

L 15: Example Fewer

Learning Goals:

- ➢ Use case for objects with very high thermal conductivity
- ➢ Practical approach

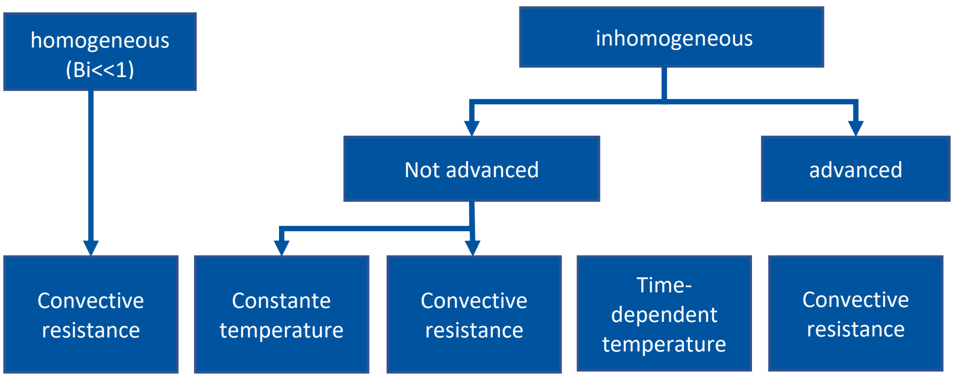
Comprehension questions:

- ☐ For safety reasons, quicksilver thermometers are no longer offered in the markets. Thermometers filled with alcohol are also hardly used anymore. Why? What are the disadvantages of these measuring instruments?
- ☐ The standard devices currently in use are digital thermometers. How is the body temperature determined with it?

L 16: Semi-Infinite Plates

Learning Goals:

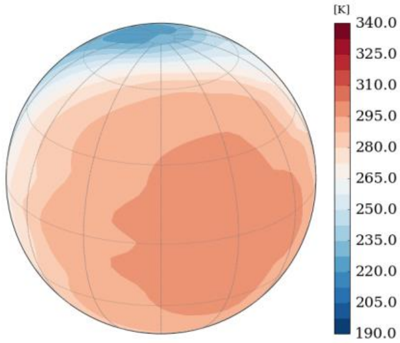
- ➢ Comprehension of the applied boundary conditions in semi-infinite body with impacted wall temperature
- ➢ Solving the problem using tabular of error function
- ➢ Comprehension of the applied boundary conditions in semi-infinite body with non-negligible heat transfer resistance.



Comprehension questions:

- ☐ What is meant by a semi-infinite body and how is it defined?
- ☐ Which two dimensionless numbers describe the unsteady temperature course within a (semi-infinite) body with relevant convective resistance?
- ☐ What is meant by thermal penetration depth?

L 16: Semi-infinite plates



Learning Goals:

- Periodic problems with periodic change of boundary condition

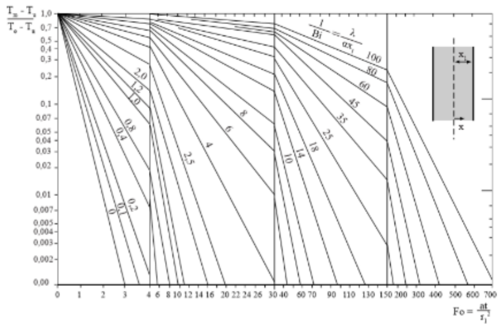
Comprehension questions:

- ☐ How does the amplitude of the temperature oscillation change within the wall?
- ☐ How can the phase shift of the temperature oscillation be explained?

L 17: Dimensionless numbers and Heisler diagrams

Learning Goals:

- Importance of dimensionless numbers, especially Fourier and Biot numbers for unsteady heat transport.
- Understanding of Heisler diagrams for determining core body temperature, local temperature profile, and heat flow.
- Application of the Heisler diagrams.



Comprehension questions:

- ☐ Which two dimensionsless numbers describe the unsteady heat transfer problem of a body with additional external thermal resistance?
- ☐ What tool allows determination of the temperature profile or the amount of heat transferred for extended plates, long cylinders, or spheres?

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