Heat Transfer: Learning Path Convection

Nomenclature

Subscript:

∞	Environment specific
W	Wall
F	Liquid
V	Volume specific
H	Hydraulic
Q	Cross-section specific
Th	Thermal
St	Material property specific
crit	Critical

Superscript:

''	Area-related
'''	Volume-related
$\dot{}$	Time derivative (heat flux, mass flow, enthalpy flow etc.)

Symbol:

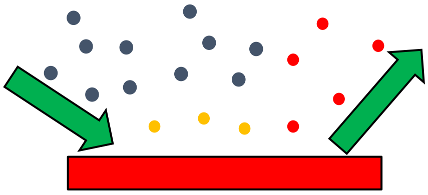
α or h	Heat transfer coefficient	$[\mathrm{W/m^2\,K}]$
λ or k	Thermal conductivity	$[\mathrm{W/m\,K}]$
a	Thermal diffusivity	$[\mathrm{m^2/s}]$
c_p	Specific heat capacity	$[\mathrm{J/kg\,K}]$
T	Temperature	$[\mathrm{K}]$
A	Area	$[\mathrm{m^2}]$
δ_u	Viscous boundary layer thickness	$[\mathrm{m}]$
δ_T	Thermal boundary layer thickness	$[\mathrm{m}]$
L_th	Thermal entry length	$[\mathrm{m}]$
$\dot{\mathrm{Q}}$	Heat flux	$[\mathrm{W}]$
$\dot{q}''$	Heat flux density	$[\mathrm{W/m^2}]$
n	Amount of substance	$[\mathrm{mol}]$
$\dot{h}$	Enthalpy flow	$[\mathrm{W}]$
u	Velocity in x-direction	$[\mathrm{m/s}]$
v	Velocity in y-direction	$[\mathrm{m/s}]$
w	Velocity in z-direction	$[\mathrm{m/s}]$
τ	Shear stress	$[\mathrm{N/m^2}]$
ρ	Density	$[\mathrm{kg/m^3}]$
ν	Dynamic viscosity	$[\mathrm{m^2/s}]$
P	Pressure	$[\mathrm{N/m^2}]$
$\dot{\Phi}$	Heat source	$[\mathrm{W}]$
R	Universal gas constant	$[\mathrm{Kg/mol\,K}]$
ψ	Stream function	$[\mathrm{m^2/K}]$
β	Volume expansion coefficient	$[\mathrm{1/K}]$
D	Diameter	$[\mathrm{m}]$

Dimensionless numbers:

Re	Reynolds number	Ratio of the inertia forces to viscous forces.	[-]
Pr	Prandtl number	Ratio of the diffusive momentum transport to the diffusive heat transport.	[-]
Nu	Nusselt number	Dimensionless heat transfer coefficient.	[-]
Gr	Grashof number	Ratio of the buoyance forces to the viscous forces.	[-]
Pe	Péclet number	Ratio of the advective heat flow to the diffusive heat flow.	[-]
Ar	Archimedes number	Ratio of the buoyance forces to the friction forces.	[-]
f	Dimensionless stream function		[-]

L01: Introduction to Convection and the Conservation Equations

Learning goals:



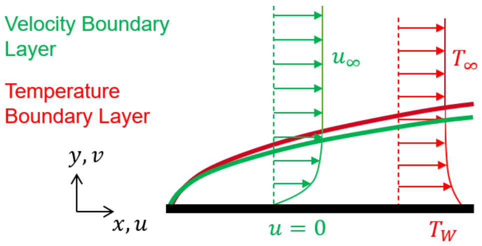
- Understanding convection and the distinction from advection
- Convection as the interaction of heat conduction and advection
- Classification of convection problems
- Derive the conservation equations for mass, momentum and energy
- Understand the similarity between momentum and energy transport

Comprehension questions:

- ☐ What is meant by a heat transfer coefficient and what does it describe?
- ☐ Why does Fourier's law of heat conduction also apply on the fluid side in the immediate vicinity of the wall?
- ☐ What does the dimensionless Nusselt number mean?
- ☐ What is the difference between natural and forced convection?

L02: Boundary Layer Equation – Forced Convection

Learning goals:



- Understanding the boundary layer concept on a flat plate in a constant laminar flow.
- Similarity of velocity and temperature profiles in the boundary layer, and the resulting relation between the heat transfer coefficient and sher stress for this case.

Comprehension questions:

- ☐ What is the difference between the Nusselt and Biot numbers?
- ☐ What is the relevance of the Prandtl number for the Boundary Layer theory?
- ☐ If there is an identity between the thickness of the Flow Boundary Layer and the Temperature Boundary Layer ($\delta_\mathrm{u} = \delta_\mathrm{T}$), what is the relationship for the Nusselt number? (Not relevant for the exam)

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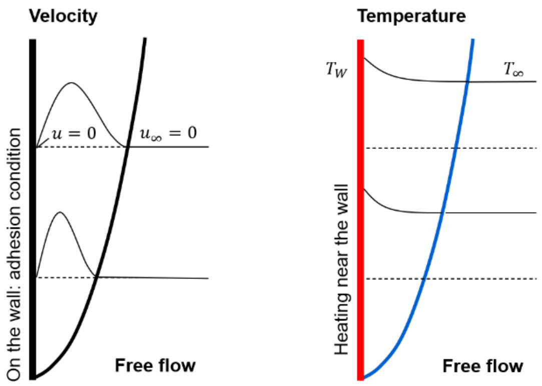
L03: Boundary Layer Equations – Natural Convection

Learning goals:



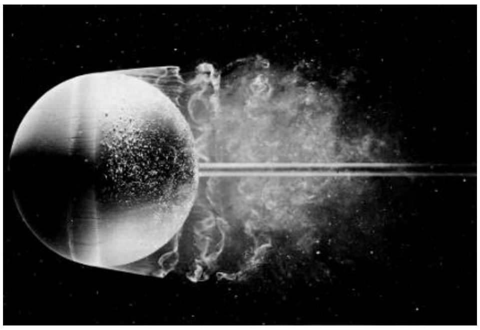
- ➢ Understanding the boundary layer profile (temperature and velocity) on a flat plate with natural (free) convection.
- ➢ Derivation and meaning of the Grashof number.
- ➢ Knowledge of the difference between the boundary layer profiles for forced and free convection.

Comprehension questions:

- ☐ What is the driving potential of natural convection?
- ☐ Why are buoyancy forces negligible in forced convection?

L04: Turbulent Flow

Learning goals:



- ➢ Occurrence of turbulent flow
- ➢ Understanding the macroscopic effect of turbulent fluctuations on mass and heat transport.

Comprehension questions:

- ☐ How does turbulence affect heat transfer?

L05: Application of Dimension Analysis

Learning goals:

- ➢ Basic understanding of dimensional analysis.
- ➢ Understand the physical meanings of relevant dimensionless numbers that can describe a convection problem.
- ➢ Ability to distinguish different convective heat transfer problems in terms of flow and boundary conditions.

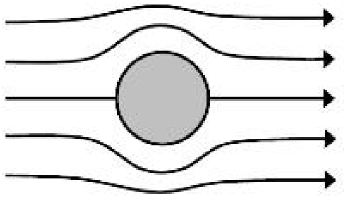
$$Nu = Nu(Re, Gr, Pr)$$

Comprehension questions:

- ☐ What does the dimensional analysis say and what must be taken into account so that the solutions of two different problems are identical?
- ☐ Which dimensionless numbers are essential for the empirically found heat transfer laws?

L06: Heat Transfer Laws for the Forced Convection in External Flow

Learning goals:



- ➢ Knowledge and understanding of the dimensionless numbers.
- ➢ Overview of different application cases and associated correlations.

Comprehension questions:

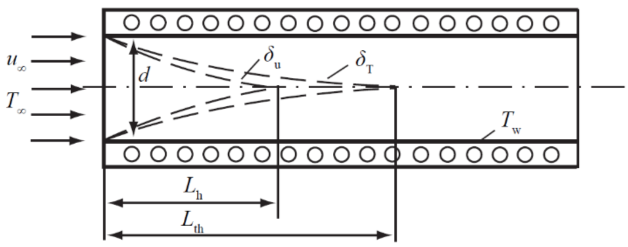
- ☐ Which dimensionless numbers have to be considered in forced convection?

  How is the applicability of a correlation checked?
- ☐ At what temperature are the material properties occurring in the dimensionless numbers to be determined?
- ☐ What is the difference between local and average heat transfer in a flat plate with heating or cooling?

L07: Forced Convection in Internal Flow – Developing versus Fully Developed Flows and the Caloric Mean Temperature

Learning goals:

- ➢ Knowledge of the essential differences between external and internal flows.
- ➢ Understanding of the hydrodynamic and thermal inlet behavior.
- ➢ Ability to calculate the caloric mean temperature.
- ➢ Ability to calculate the local temperatures and heat fluxes as well as the average heat transfer coefficient.



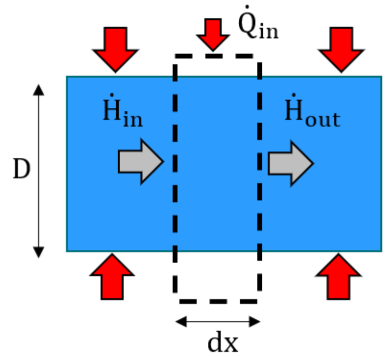
Comprehension questions:

- ☐ Which coefficient can be used to characterize the transition point from a laminar to a turbulent pipe flow?
- ☐ Is the local heat transfer coefficient always lower than the averaged heat transfer coefficient?
- ☐ What influence does the inlet length have on the temperature profile?
- ☐ When do the different boundary layers of a pipe flow converge?

L08: Forced Convection in Internal Flow and the LMTD

Learning goals:

- Knowledge of the meaning of the logarithmic mean temperature difference (LMTD).
- Ability to apply and calculate the LMTD.



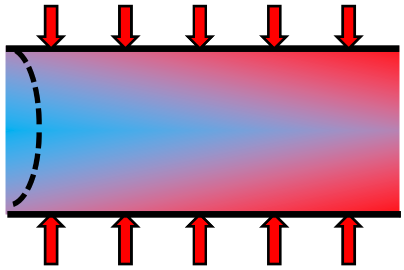
Comprehension questions:

- ☐ What is the meaning of the logarithmic mean temperature difference, and when do we need to apply this?

L09: Forced Convection in Internal Flows – HTC in Laminar Fully Developed Flows

Learning goals:

- Ability to calculate the heat transfer coefficient in laminar flows under fully developed conditions.
- Ability to distinguish between different flow configurations and to choose the proper correlation for the HTC.



Comprehension questions:

- ☐ Why is the HTC constant in fully developed flow region of an internal flow?
- ☐ What are the major steps to calculate the HTC in the fully developed region?
- ☐ What can result in a loss of self-similarity of the heat transfer behavior?
- ☐ Proof that the Nusselt number for a laminar flow between two parallel plates with a constant heat flux boundary condition is Nu = 8.235.
- ☐ Think about another geometry/flow configuration for which you can determine a laminar velocity profile analytically and calculate the Nusselt number.

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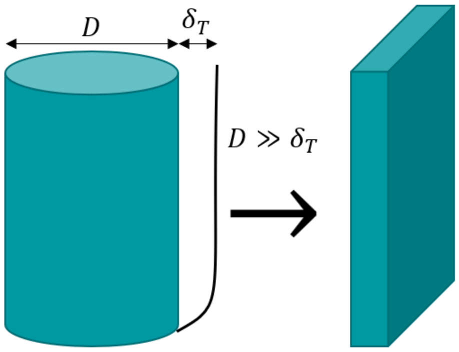
L10: Natural Convection in External Flow



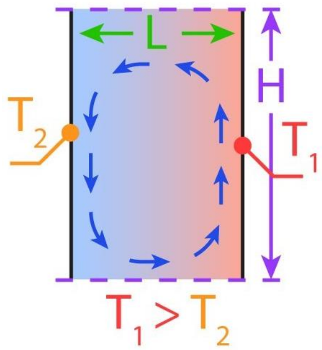
Learning goals:

- ➢ Knowledge of the correlations given in the reader and on the formula sheet for cases of natural convection.

Comprehension questions:

- ☐ Which dimensionless numbers must be taken into account when applying the heat transfer laws?
- ☐ What is the driving potential in natural convection?
- ☐ Which are the two different cases for horizontal plates and how do they differ from vertical plates?

L11: Natural Convection in Enclosed Spaces



Learning goals:

- ➢ Understanding the influence of heated and cooled surfaces in enclosed spaces.
- ➢ Decision-making competence for vertical and horizontal arrangements.
- ➢ Gain an overview of different applications.

Comprehension questions:

- ☐ Why is heat generally transferred between two horizontal surfaces in a fluid layer only by conduction when the upper plate is heated?
- ☐ Which exception exists to the rule stated in the question above?
