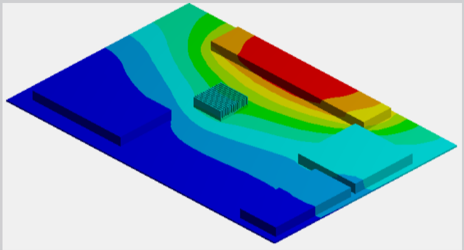
Film Coefficient

Thermal Convection in Heat Transfer – Lesson 2

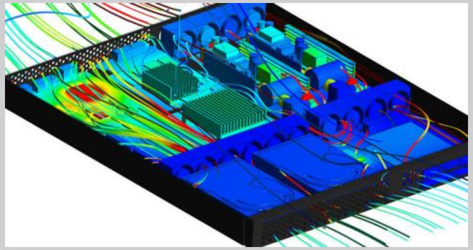
Modeling Convection: Solvers

Heat Transfer Simulation



Conduction-based Solver

- Simulates heat transfer in solids with convection as a boundary condition
- Is computationally less expensive
- Convection is reduced to two parameters – **film coefficient and bulk temperature**



Computational Fluid Dynamics (CFD) Solver

- Solves for fluid flow and energy equation in the fluid, as well as in solids
- Is computationally expensive
- Directly solves heat transfer between fluid and solid
- Does not use film coefficient as for conduction-based solver

A conduction-based solver is used in this course

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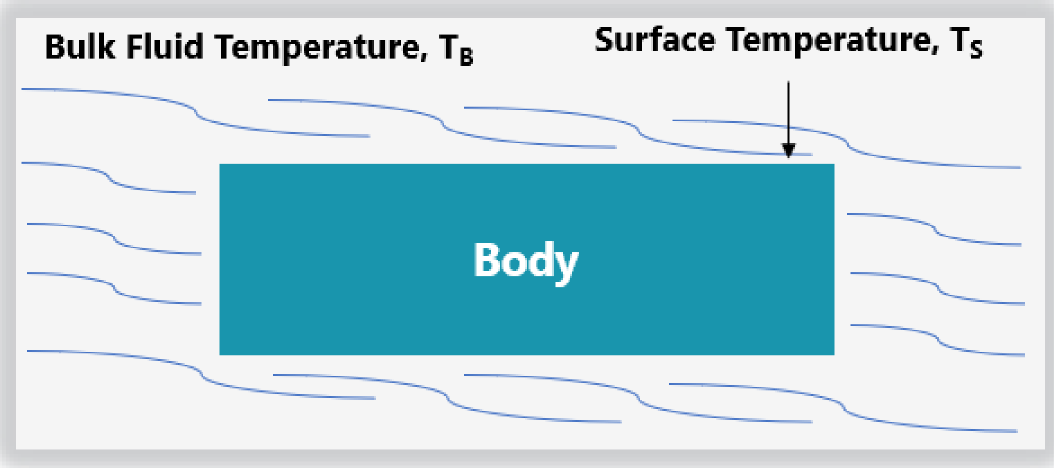
Convective Heat Transfer Rate

Convection is a complex process (a combination of advection and diffusion) where heat energy is transferred between a body and a surrounding fluid.

- The following equation gives the convective heat transfer rate:

$$\boldsymbol{Q = h \cdot A(T_s - T_B)}$$



Where:

Q = Heat transfer rate

h = Film coefficient

A= Area of body in contact with fluid

T_s = Surface temperature

T_B = Bulk fluid temperature

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Film Coefficient (Heat Transfer Coefficient)

- Rewriting the convection equation in terms of the **convective heat flux rate, q_c** :

$$q_c = Q/A = h \cdot (T_s - T_B) = h \cdot dT$$

where **dT** = temperature difference between the solid surface and the fluid.

- ***The film coefficient h*** may be thought of as the amount of heat flux (W/m^2) needed to cause a unit difference in temperature between surface and bulk temperature.
- Film coefficients may be obtained by:

- Analytical methods that involve solving the mass, momentum and energy equations; however, analytical solutions are available only for very simple situations.

- Through careful experiments — the equations suggested for convective heat transfer coefficients are mostly empirical.

- Using CFD analysis and extrapolation for laminar and turbulent flow.

- The S.I. unit of ***h*** is $W/m^2.K$. In Imperial units, the film coefficient ***h*** is expressed in $BTU/h.ft^2.°F$, where BTU stands for British Thermal Unit and h in the denominator represents hour.

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Factors Affecting the Film Coefficient

The heat transfer coefficient is a function of the physical variables expressed below:

***h* = *f* (fluid properties, velocity field, geometry, surface roughness, temperature, etc.)**

From the table below, it can be seen that the value of ***h*** depends upon:

- Fluid properties: The higher the viscosity, the higher the ***h*** value. For example – $h_{water} > h_{air}$. Between cold water and cold air, water feels colder immediately.
- Fluid velocity: Forced convection has higher ***h*** than natural convection. For example – $h_{forced\ air} > h_{free\ air}$. When a fan is switched on, the air removes more heat from the object compared to when the fan is switched off.

Convection Process	**Film Coefficient (W/m²·K)**				
	Air	Water	Gas	Oil	Molten Metals
Free/ Natural	10-100	50-3000	5-37	50-350	-
Forced	10-1000	50-10000	10-350	300-1700	2000-45000

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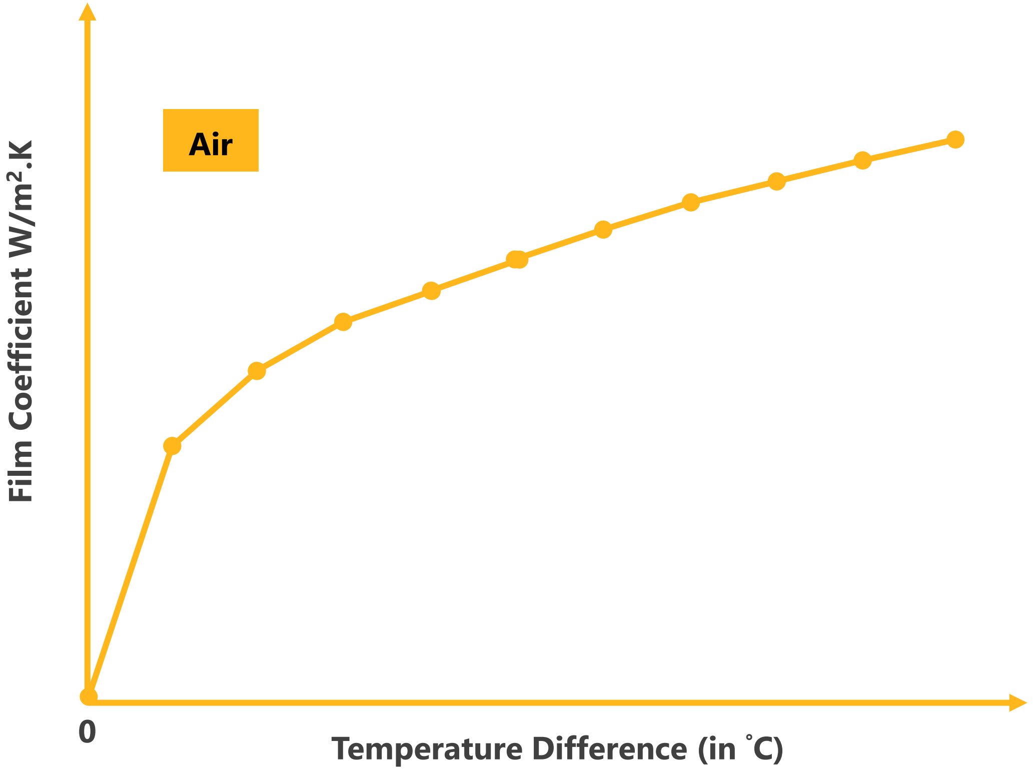
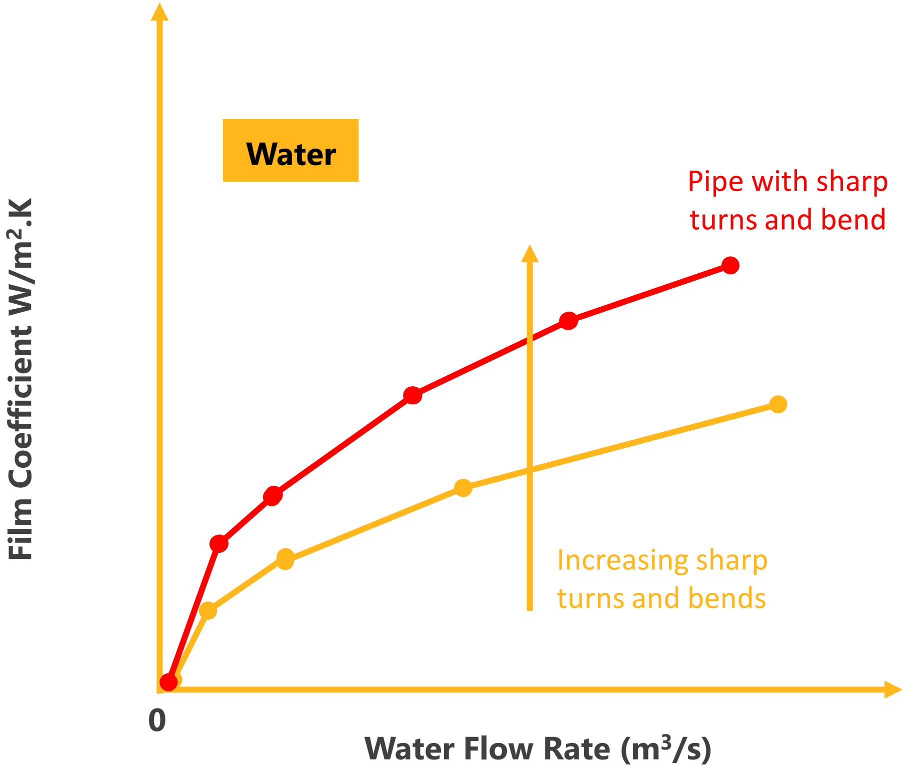
Factors Affecting the Film Coefficient (cont.)

From the graph below it can be seen that the value of ***h*** depends upon:

- Temperature: The higher the temperature difference between surface and fluid, the higher the ***h*** value.
- Geometry: ***h*** value increases with sharp turns and bends in a pipe.





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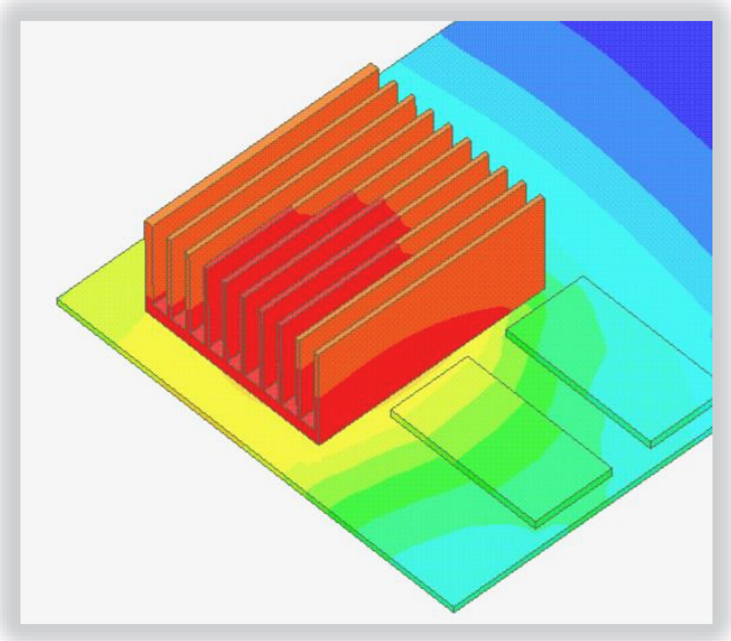
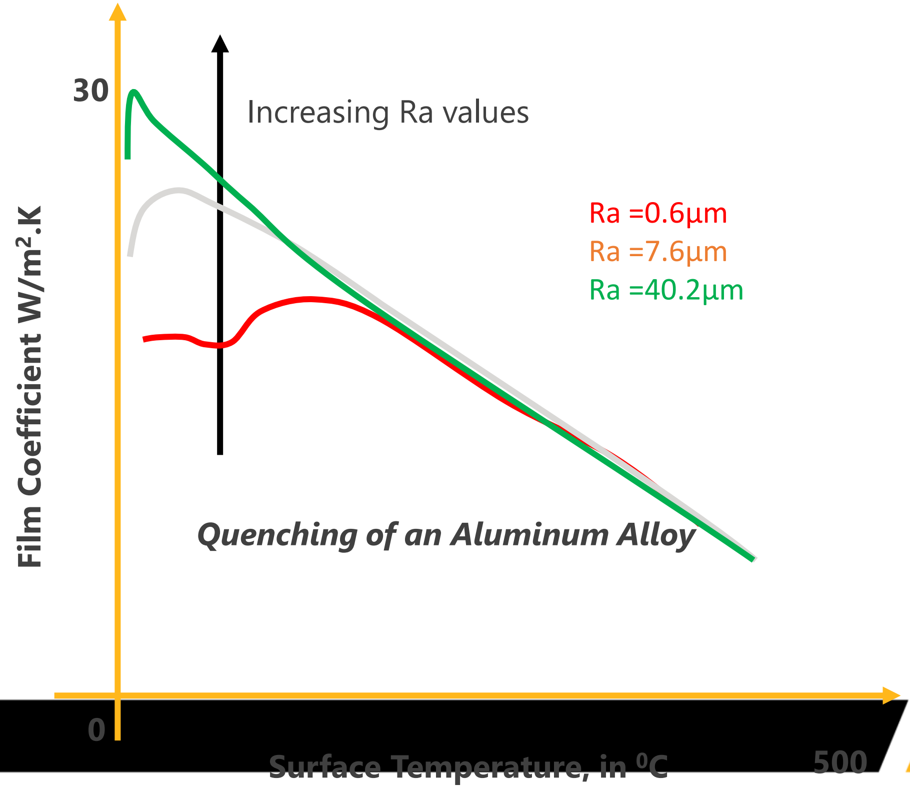
Factors Affecting the Film Coefficient (cont.)

From the image/graph below it can be seen that the value of ***h*** depends upon:

- Geometry: Due to buoyancy effects a vertical plate has higher ***h*** compared to a horizontal plate. That is why heat sinks have vertical fins/pins.
- Surface roughness (Ra): At a given surface temperature, a higher value of **Ra** higher increases the turbulence and hence increases ***h***.





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Bulk Temperature (Fluid Ambient Temperature)

As seen in a previous slide, the second input required to solve the equation below is ***the bulk temperature, T_B***.

$$Q = h \cdot A(T_s - T_B)$$

- This temperature represents the temperature of the bulk or average temperature of the fluid and is also called the ***fluid ambient temperature***.
- If $\mathbf{T_B > T_S}$ heat flows from the fluid into the surface and vice-versa.
- $\mathbf{T_B}$ can be a direct input or a part of a fluid network.

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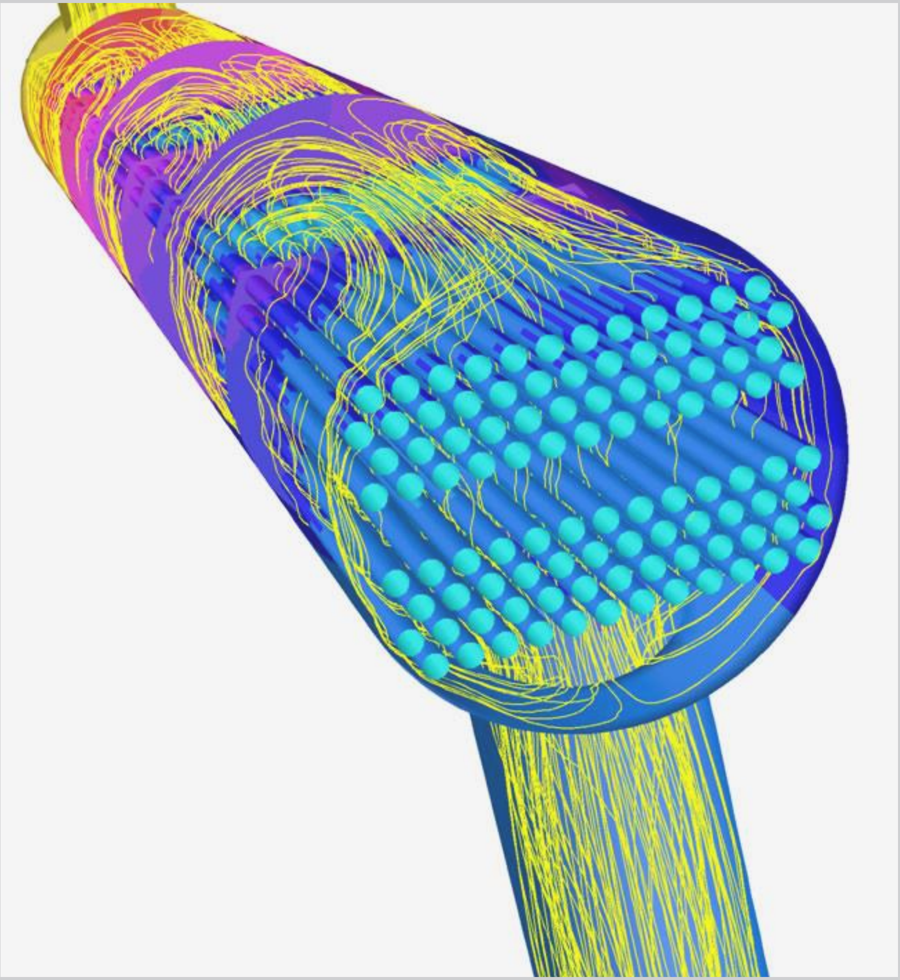
Conjugate Heat Transfer Problem

- In fluid dynamics analysis ***h*** is not used; instead, a conjugate heat transfer problem is solved.
- A conjugate heat transfer problem deals with heat transfer in solids (conduction dominates) and fluids (convection dominates). Also, a fluid will have motion–energy transport, fluid viscosity and change in fluid density. Solving such a problem is complex and time-consuming.
- Hence, using a conduction-based solver having a convection boundary condition is quite useful (faster, easy to solve and time-saving) because it models convection without the fluid flow. Some examples are heat exchangers and heat sinks.



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A Few Important Points

- When applying the convection boundary condition, ***h*** and $\boldsymbol{T_B}$ should be defined appropriately by the analyst, as fluid flow is not being modeled.
- We indicated earlier that ***h*** is function of temperature and if we write **h=f(T)** then the convection equation becomes nonlinear.
- Even if the value of ***h*** changes, solutions are relatively quick (compared with CFD).
- Design studies can easily be performed to study the relationship of temperature with variation of ***h*** or $\boldsymbol{T_B}$. This is useful because we are simplifying a conjugate heat transfer problem with two parameters (***h*** and $\boldsymbol{T_B}$) and can perform parametric studies to provide upper and lower bounds for the problem. Hence, ***h*** and $\boldsymbol{T_B}$ can be used with some conservatism.

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