

## 1.1 Walking speed



The first step in tackling the sub problems is defining the expression for the rate of heat loss. Afterwards, the unknown parameters within these expression can be determined and filled in, which will result in the final answer.

- a) Determine the rate of heat loss from an average person walking in air at 15 °C by convection in the case of walking in still air with a velocity of 1 m/s.

### 1) Defining the rate of heat loss:

The rate of heat loss due to convection can be described by:

$$\rightarrow \dot{Q} = \alpha A_s (T_s - T_\infty) \quad (1.1)$$

### 2) Determining the heat transfer coefficient:

The relative velocity in the given problem is 1 m/s and heat transfer coefficient equals:

$$\rightarrow \alpha = 8.2V^{0.49} = 8.2 \cdot 1^{0.49} = 8.6 \text{ [W/m}^2\text{K}] \quad (1.2)$$

### 3) Filling in:

$$\dot{Q} = \alpha A_s (T_s - T_\infty) = 8.2 \text{ [W/m}^2\text{K}] \cdot 1.8 \text{ [m]} \cdot (30 - 15) \text{ [K]} \quad (1.3)$$

$$\rightarrow \dot{Q} = 221.4 \text{ [W]} \quad (1.4)$$

- b) Determine the rate of heat loss from an average person walking in air at 15 °C by convection in the case of standing still, while the wind blowing at a velocity of 1.5 m/s.

### 1) Defining the rate of heat loss:

The rate of heat loss due to convection can be described by:

$$\rightarrow \dot{Q} = \alpha A_s (T_s - T_\infty) \quad (1.5)$$

### 2) Determining the heat transfer coefficient:

The relative velocity in the given problem is 1.5 m/s and heat transfer coefficient equals:

$$\rightarrow \alpha = 8.2V^{0.49} = 8.2 \cdot 1.5^{0.49} = 10.0 \text{ [W/m}^2\text{K}] \quad (1.6)$$

**3) Filling in:**

$$\dot{Q} = \alpha A_s (T_s - T_\infty) = 10.0 \text{ [W/m}^2\text{K}] \cdot 1.8 \text{ [m]} \cdot (30 - 15) \text{ [K]} \quad (1.7)$$

$$\rightarrow \dot{Q} = 270.1 \text{ [W]} \quad (1.8)$$

c) Determine the rate of heat loss from an average person walking in air at 15 °C by convection in the case of walking in the opposite direction of the flow of the wind with a velocity of 2 m/s, while the wind blowing at a velocity of 1.5 m/s.

**1) Defining the rate of heat loss:**

The rate of heat loss due to convection can be described by:

$$\rightarrow \dot{Q} = \alpha A_s (T_s - T_\infty) \quad (1.9)$$

**2) Determining the heat transfer coefficient:**

The relative velocity in the given problem is 0.5 m/s and heat transfer coefficient equals:

$$\rightarrow \alpha = 8.2V^{0.49} = 8.2 \cdot 0.5^{0.49} = 5.8 \text{ [W/m}^2\text{K]} \quad (1.10)$$

**3) Filling in:**

$$\dot{Q} = \alpha A_s (T_s - T_\infty) = 5.8 \text{ [W/m}^2\text{K}] \cdot 1.8 \text{ [m]} \cdot (30 - 15) \text{ [K]} \quad (1.11)$$

$$\rightarrow \dot{Q} = 157.6 \text{ [W]} \quad (1.12)$$

## 1.2 Flat plate in a wind tunnel

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The Reynolds number is used to determine whether the fluid flow is laminar or turbulent. In both questions some information is given or is asked about the type of flow. With the definition of the Reynolds number both questions can be answered.

- a) *What type of flow regime will the airflow experience in the boundary layer at 0.25 m from the leading edge?*

### 1) Setting up the definition of the Reynolds number:

The general expression for the Reynolds number at a specified location  $x$  is:

$$\rightarrow \text{Re}_x = \frac{U \cdot x}{\nu} \quad (1.13)$$

### 2) Defining the characteristics:

The velocity  $U$  as well as the kinematic viscosity  $\nu$  of the flow are given. Furthermore, the position  $x$  is specified in the task, which is 0.25 m.

### 3) Inserting and rewriting:

Inserting numerical values yields:

$$\rightarrow \text{Re}_{x=0.25 \text{ m}} = \frac{50 \text{ [m/s]} \cdot 0.25 \text{ [m]}}{15.35 \cdot 10^6 \text{ [m}^2/\text{s]}} = 8.14 \cdot 10^5 \quad (1.14)$$

It is therefore found that  $\text{Re}_{x=0.25 \text{ m}} > \text{Re}_{\text{crit}}$ , which implies that at position  $x$  the flow has transited into a turbulent flow.

- b) *Determine the position of the plate where the flow starts its transition from laminar to turbulent flow.*

### 1) Setting up the definition of the Reynolds number:

The general expression for the Reynolds number at a specified location  $x$  is:

$$\rightarrow \text{Re}_x = \frac{U \cdot x}{\nu} \quad (1.15)$$

### 2) Defining the characteristics:

The velocity  $U$  as well as the kinematic viscosity  $\nu$  of the flow are given. Furthermore, position  $x$  should be determined where the flow transits from laminar flow to

turbulent flow. This is the case where  $\text{Re}_x = \text{Re}_{\text{crit}}$ .

### 3) Inserting and rewriting:

Inserting  $\text{Re}_x = \text{Re}_{\text{crit}}$  yields:

$$\text{Re}_{\text{crit}} = \frac{U \cdot x_{\text{crit}}}{\nu} \quad (1.16)$$

Rewriting:

$$x_{\text{crit}} = \frac{\text{Re}_{\text{crit}} \cdot \nu}{U} \quad (1.17)$$

Inserting numerical values:

$$\rightarrow x_{\text{crit}} = \frac{5 \cdot 10^5 \cdot 15.35 \cdot 10^6 \text{ [m}^2/\text{s]}}{50 \text{ [m/s]}} = 0.15 \text{ [m]} \quad (1.18)$$

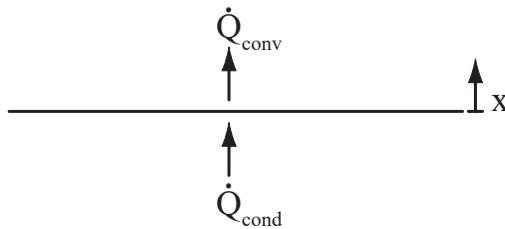
## 1.3 Thick solid plate



The heat transfer coefficient should be determined. This can be derived from the fact that at the interface the rate of heat transfer by conduction is equal to the rate of heat transfer by convection. When having determined the heat transfer coefficient, this can be rewritten in terms of the temperature gradient at the interface.

- a) *Determine the convection heat transfer coefficient in terms of the given variables.*  
 First step to see that the conductive heat flux and the convective heat flux are equal to each other can be seen from deriving an energy balance.

### 1) Setting up an energy balance:



Where it can be seen that:

$$\frac{\partial U}{\partial t}^0 = \sum \dot{Q}_{in} - \sum \dot{Q}_{out} \quad (1.19)$$

$$\rightarrow 0 = \dot{Q}_{cond} - \dot{Q}_{conv} \quad (1.20)$$

### 2) Defining the fluxes:

The rate of heat transfer by conduction can be described by use of Fourier's law:

$$\rightarrow \dot{Q}_{cond} = -\lambda_p \cdot A_c \cdot \frac{dT}{dx} = \lambda_p \cdot A_c \cdot \frac{T_L - T_U}{t} \quad (1.21)$$

$$\rightarrow \dot{Q}_{conv} = \alpha \cdot A_s \cdot (T_U - T_\infty) \quad (1.22)$$

### 3) Inserting and rewriting:

Inserting into the energy balance yields:

$$0 = \dot{Q}_{cond} - \dot{Q}_{conv} \quad (1.23)$$

$$0 = \lambda_p \cdot A_c \cdot \frac{T_L - T_U}{t} - \alpha \cdot A_s \cdot (T_U - T_\infty) \quad (1.24)$$

Note that  $A_s = A_c$ , therefore rewriting yields:

$$\rightarrow \alpha = \frac{\lambda_p}{t} \cdot \frac{T_L - T_U}{T_U - T_\infty} \quad (1.25)$$

b) Determine the temperature gradient inside the water at the interface in terms of the given variables. The heat transfer coefficient is defined as:

$$\alpha = \frac{-\left(\lambda_w \frac{dT}{dx}\right|_{water,w})}{T_U - T_\infty} \quad (1.26)$$

Equaling this expression to the found expression for  $\alpha$  in task a) yields:

$$\frac{-\left(\lambda_w \frac{dT}{dx}\right|_{water,w})}{T_U - T_\infty} = \frac{\lambda_p}{t} \cdot \frac{T_L - T_U}{T_U - T_\infty} \quad (1.27)$$

And therefore rewriting gives us:

$$\rightarrow \frac{dT}{dx}|_{water,w} = -\frac{\lambda_p}{\lambda_w \cdot t} \cdot (T_L - T_U) \quad (1.28)$$