10.3 Convection

Name: _____ Class: _____ Date: _____ **Total: 14 marks**

KEY WORDS Nusselt number • Prandtl number

Objective

Find a convection coefficient from a correlation: work out the Reynolds number, choose the correlation that fits the flow, find the Nusselt number and turn it into h and a heat flow.

1 Key knowledge and worked examples

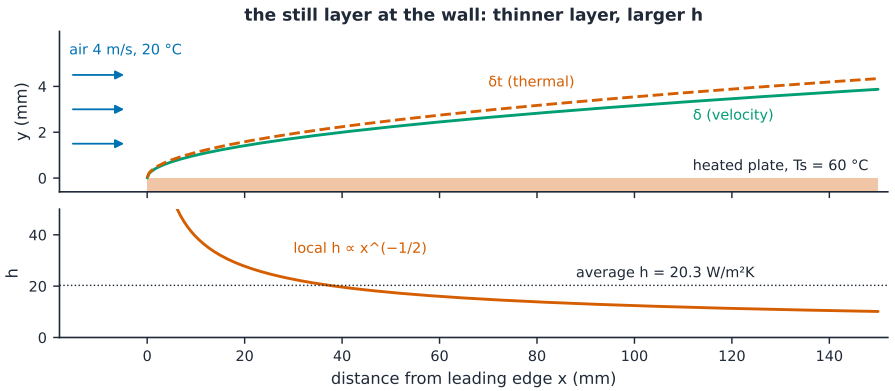
From Reynolds to h

- **Nusselt number** $Nu = hL/k_f$: the dimensionless wall temperature gradient. **Prandtl number** $Pr = \nu/\alpha$.
- Flat plate, laminar ($Re_L < 5\times10^5$), average: $Nu = 0.664 Re_L^{1/2} Pr^{1/3}$.
- Tube, turbulent ($Re > 10^4$), fluid heated (Dittus–Boelter): $Nu = 0.023 Re^{0.8} Pr^{0.4}$.
- Then $h = Nu\,k_f/L$ and $q = hA\,\Delta T$.

Worked example. Air over a plate

Air 4 m/s, 20 °C ($\nu = 1.6\times10^{-5}$ m^2/s, $k = 0.0265$, $Pr = 0.71$), plate 150 mm long.

- $Re_L = VL/\nu = 4\times0.15/(1.6\times10^{-5}) = \mathbf{37\,500}$: laminar.
- $Nu = 0.664 Re_L^{1/2} Pr^{1/3} = \mathbf{114.7}$.
- $h = Nu\,k/L = 114.7\times0.0265/0.15 = \mathbf{20.3}$ W/(m$^2\cdot$K).



2 Practice

Air: $\nu = 1.6\times10^{-5}$ m^2/s, $k = 0.0265$ W/(m$\cdot$K), $Pr = 0.71$. Water at 40 °C: $\nu = 0.658\times10^{-6}$ m^2/s, $k = 0.631$ W/(m$\cdot$K), $Pr = 4.32$.

2.1 Air flows at 5 m/s along a plate 0.2 m long. Find Re_L and say whether the flow is laminar. [2]

2.2 Find the average Nusselt number (one decimal) and h (one decimal, W/(m$^2\cdot$K)). [3]

2.3 The plate is 0.3 m wide and 40 K above the air. Find the heat loss from one face (one decimal, W). [2]

3 Exam-style questions

3.1 Water at 40 °C flows at 1.5 m/s in a 25 mm tube and is heated by the wall. Find Re, justify Dittus–Boelter, and find Nu (one decimal), h (nearest W/(m^2 · K)) and the heat gained per metre of tube when the wall is 20 K above the water (two decimals, kW/m). Compare h with the air value of 2.2. [7]

Solutions

2.1

- $Re_L = VL/\nu = 5 \times 0.2/(1.6 \times 10^{-5}) = \mathbf{62\,500}$.
- Below 5×10^5, so laminar over the whole plate.

2.2

- $Nu = 0.664 Re_L^{1/2} Pr^{1/3} = 0.664 \times 250 \times 0.892 = \mathbf{148.1}$.
- $h = Nu\,k/L = 148.1 \times 0.0265/0.2 = \mathbf{19.6}$ W/(m^2 · K).

2.3

- $q = hA\,\Delta T = 19.6 \times (0.2 \times 0.3) \times 40 = \mathbf{47.1}$ W.

3.1

- $Re = VD/\nu = 1.5 \times 0.025/(0.658 \times 10^{-6}) = \mathbf{56\,990}$.
- Turbulent ($Re > 10^4$), $Pr = 4.32$ inside 0.6 to 160, fluid heated: Dittus–Boelter with $Pr^{0.4}$ applies.
- $Nu = 0.023 Re^{0.8} Pr^{0.4} = \mathbf{263.4}$.
- $h = Nu\,k/D = 263.4 \times 0.631/0.025 = \mathbf{6647}$ W/(m^2 · K).
- $q' = h\pi D\,\Delta T = 6647 \times \pi \times 0.025 \times 20 = \mathbf{10.44}$ kW/m.
- About 340 times the air value: water's conductivity and the thin turbulent wall layer make liquid-side resistances small.