MEC E 371 Formula Sheet

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8. Internal Forced Convection

8.1. General Procedure

1. Find fluid properties from Appendix 1 at bulk mean temperature $T_b = (T_i + T_e)/2$
   - ρ, μ, k, c_p, Pr, ν
2. Determine mean velocity V_{avg}
3. Determine the type of flow (laminar or turbulent)
   - Laminar: $Re < 2300$
   - Turbulent: $Re > 4000$
4. Determine the Nusselt number Nu using the appropriate correlation
5. Determine the heat transfer coefficient h using Nu, k, and A_s

8.2. Variable Definitions

- Nu: Nusselt number
- Re: Reynolds number
- Pr: Prandtl number
- μ: Dynamic viscosity
- ν: Kinematic viscosity
- k: Thermal conductivity
- h: Convection heat transfer coefficient
- D_h: Hydraulic diameter
- A_s: Surface area
- A_c: Cross-sectional area
- V_{avg}: Average velocity
- T_b: Bulk mean temperature
- T_i: Inlet temperature
- T_e: Exit temperature
- $\dot{m}$: Mass flow rate
- $\dot{q}$: Heat flux
- ΔT_{lm}: Log mean temperature difference

8.3. Formulas

$$
\begin{aligned}
\dot{m} &= \rho V_{\text{avg}} A_c \\
\text{Re} &= \frac{\rho V_{\text{avg}} D}{\mu} = \frac{V_{\text{avg}} D}{\nu} \\
D_h &= \frac{4A_c}{\text{Perimeter}} = D|_{\text{circular}} = a|_{\text{square}} \\
&= \left.\frac{2ab}{a+b}\right|_{\text{rectangular}} = \left.\frac{4ab}{a+b}\right|_{\text{channel}} \\
\text{Nu} &= \frac{hD_h}{k} \\
A_s &= \pi DL|_{\text{circular}} = 4ab|_{\text{rectangular}} \\
A_c &= \pi \frac{D^2}{4}|_{\text{circular}} = ab|_{\text{rectangular}} \\
l_{h,\text{laminar}} &= 0.05\text{Re}D_h \\
l_{t,\text{laminar}} &= 0.05\text{Re}\text{Pr}D_h = 0.05\text{Pr}l_{h,\text{laminar}} \\
l_{h,\text{turbulent}} &\approx l_{t,\text{turbulent}} = 10D_h
\end{aligned}
$$

Constant $\dot{q}$:

$$T_e = T_i + \frac{\dot{q}}{\dot{m}C_p}$$

Constant T_s:

$$
\begin{aligned}
T_e &= T_s - (T_s - T_i)\exp\left(-\frac{\dot{m}C_p}{hA_s}\right) \\
T_s &= \frac{T_e - T_i \exp\left(-\frac{\dot{m}C_p}{hA_s}\right)}{1 - \exp\left(-\frac{\dot{m}C_p}{hA_s}\right)} \dot{Q} \qquad = hA_s \Delta T_{\text{lm}} \\
T_{\text{lm}} &= \frac{T_i - T_e}{\ln[(T_s - T_e)/(T_s - T_i)]}
\end{aligned}
$$

Pressure drop:[1]

$$
\begin{aligned}
\Delta P_L &= f\frac{L}{D_h}\frac{\rho V_{\text{avg}}^2}{2} \\
h_L &= \frac{\Delta P_L}{\rho g} = f\frac{L}{D_h}\frac{V_{\text{avg}}^2}{2g} \\
f|_{\text{laminar}} &= \frac{64}{\text{Re}} \\
V_{\text{avg}} &= \frac{\Delta P D^2}{32\mu L}
\end{aligned}
$$

[1] Check if D_h should be used for D in V_{avg}