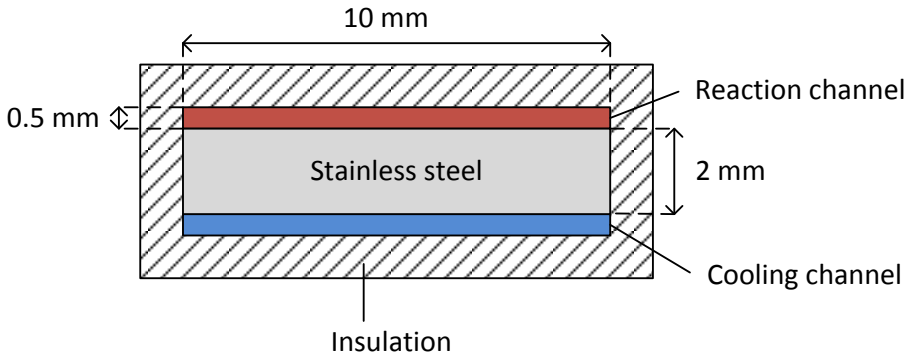
Exercise 21

Estimate the overall heat transfer coefficient (*U*) for an insulated stainless steel micro-structured reactor with rectangular reaction and cooling channels. The reaction is carried out using toluene as a solvent and water is used as a cooling fluid.

Data



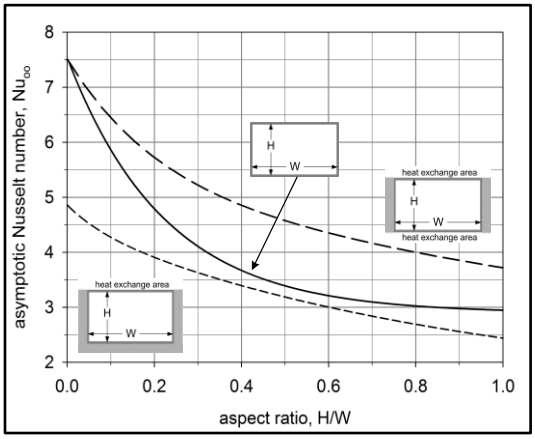
- Heat conductivity of stainless steel: $\lambda_{wall} = 21\ W\ K^{-1}\ m^{-1}$
- Length of reaction and cooling channels: $L_c = 0.2\ m$
- Height of reaction and cooling channels: $H = 0.5\ mm$
- Width of reaction and cooling channels: $W = 10\ mm$
- Thickness of stainless steel layer between cooling and heating channels: $e = 2\ mm$

	water	**toluene**
$\boldsymbol{\rho(kg\ m^{-3})}$	1000	867
$\boldsymbol{c_p(J\ kg^{-1}K^{-1})}$	4200	1720
$\boldsymbol{\lambda\ (W\ K^{-1}\ m^{-1})}$	0.600	0.141
$\boldsymbol{\mu\ (Pa \cdot s)}$	$1.0\ 10^{-3}$	$5.8\ 10^{-4}$
$\boldsymbol{Q(l\ h^{-1})}$	9	0.36

Solution

$$d_h = 2\frac{HW}{(H+W)}$$

$\frac{H}{W} = 0.05 \rightarrow Nu_\infty = 4.5$ (chart)



<u>For each channel j ($j = r$: reaction and $j = c$: cooling), calculate:</u>

$$u_j = \frac{Q_j}{H\ W}$$

$$Re_j = \frac{u_j\ d_h}{\nu_j}$$

$$Pr_j = \frac{\mu_j c_{p,j}}{\lambda_j}$$

If $\left(Re_j \cdot Pr_j \cdot \frac{d_h}{L_c}\right) < 20 \rightarrow Nu_{m,j} = Nu_\infty$

$$Nu_{2,j} = 1.615 \left(Re_j \cdot Pr_j \cdot \frac{d_h}{L_c}\right)^{1/3}$$

$$Nu_{3,j} = \left(\frac{2}{1 + 22\ Pr_j}\right)^{1/6} \left(Re_j \cdot Pr_j \cdot \frac{d_h}{L_c}\right)^{1/2}$$

$$Nu_{m,j} = \left[Nu_\infty^3 + 0.7^3 + \left(Nu_{2,j} - 0.7\right)^3 Nu_{3,j}^3\right]^{1/3}$$

$$h_j = \frac{Nu_{m,j}\ \lambda_j}{d_h}$$

$$U = \frac{1}{\frac{1}{h_r} + \frac{e}{\lambda_{wall}} + \frac{1}{h_c}}$$

$$\frac{A}{V} = \frac{W\ L_c}{H\ W\ L_c} = \frac{1}{H}$$

$$U_V = U\frac{A}{V} = \frac{U}{H}$$

dh	9.52E-04	m
H/W	5.00E-02	
Nu inf	4.5	chart
lambda/e	10500	W/m^2 K

	Cooling	**reaction**	
u	5.00E-01	2.00E-02	m/s
Re	476	28	
Pr	7.0	7.08	
Re Pr dh/Lc	15.9	1.0	
Nu2	4.1	1.6	
Nu3	1.9	0.5	
Num	7.1	4.5	
h	4497	667	W/m^2 K

U	**551**	W/m^2 K
A	2.00E-03	m^2
V	1.00E-06	m^3
A/V	2000	m-1
Uv	**1.10E+06**	W/m^3 K