# Assignment 1(Report)

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1. **Derivation of the Overall Heat Transfer Coefficient (Uo)**

   This analysis considers a straight double-pipe heat exchanger. The derivation is based on a thermal resistance network for heat transfer from the hot fluid (inside) to the cold fluid (outside).

   Assumptions:
   i) Steady-state heat transfer.
   ii) One-dimensional radial conduction through the cylindrical wall.
   iii) Constant properties for fluids and wall (i.e., hi, ho, k_wall are constant).
   iv) Negligible axial conduction and heat loss to the surroundings.

   The total thermal resistance (R_total) for the heat path (based on an arbitrary length L) is the sum of four resistances in series: inner convection (R_conv,i), wall conduction (R_wall), outer convection (R_conv,o), and outer fouling (R_fouling,o).

   R_total = R_conv,i + R_wall + R_conv,o + R_fouling,o

The individual resistances for a cylindrical system of length L are:

R_conv,i = 1/(hi* Ai) = 1/(hi *pi* Di* L)
R_wall = ln(Do/Di)/2*pi*k_wall*L
R_conv,o = 1/(ho* Ao) = 1/(ho *pi* Do* L)
R_fouling = Rf/Ao = Rf/(pi* Do* L)

Expression for 1/Uo

The overall heat transfer coefficient based on the outer surface area (Ao) is related to the total resistance by:

1/Uo = Ao * R_total

Substituting the individual resistances and Ao = pi*Do*L

$$\frac{1}{U_o} = (\pi D_o L)\left(\frac{1}{h_i \pi D_i L} + \frac{\ln(D_o/D_i)}{2\pi k_{wall} L} + \frac{1}{h_o \pi D_o L} + \frac{R_f}{\pi D_o L}\right)$$

$$\frac{1}{U_o} = \frac{D_o}{D_i h_i} + \frac{D_o \ln(D_o/D_i)}{2k_{wall}} + \frac{1}{h_o} + R_f$$

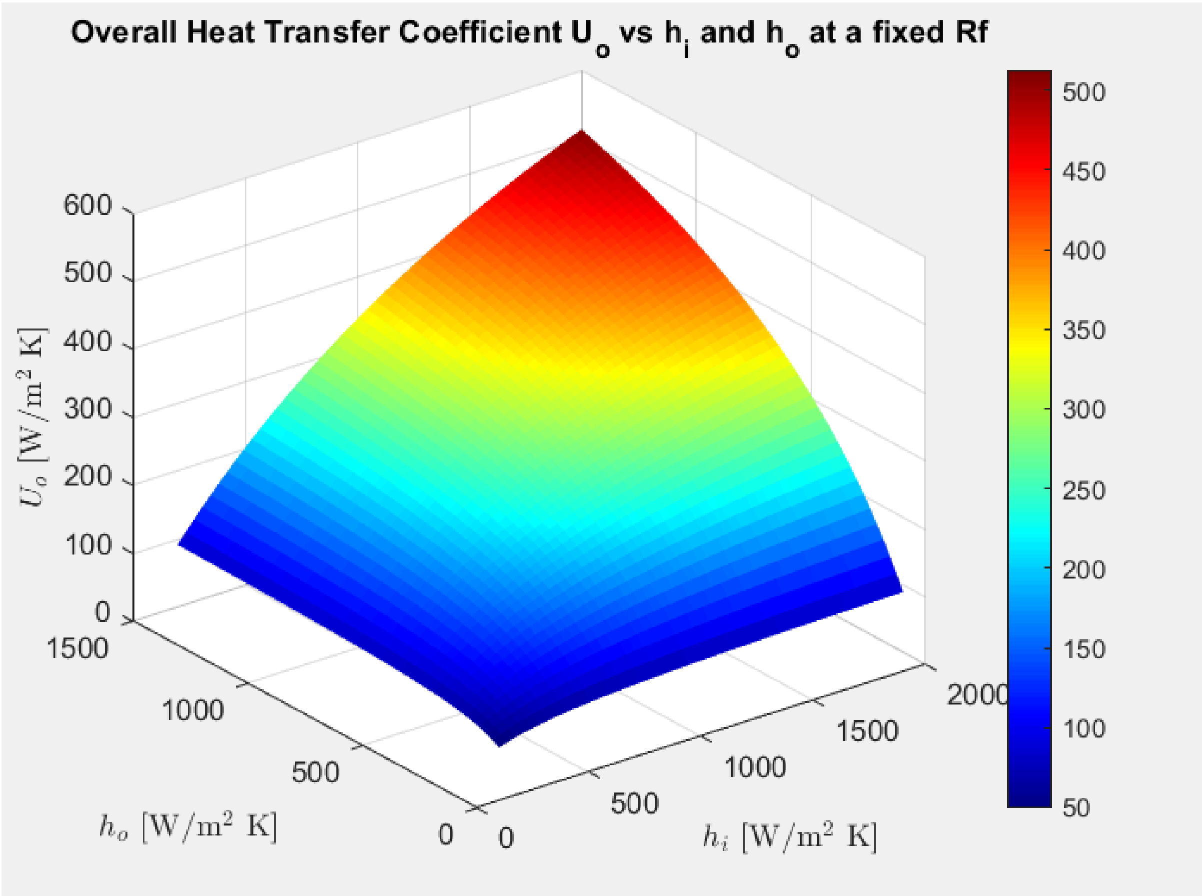
This is the final general expression for 1/Uo

## 2. MATLAB Analysis and Plots

The following plots were generated using MATLAB based on the derived expression and the given parameters (Di = 0.020 m, Do = 0.040 m, k_wall =385 W/m K)

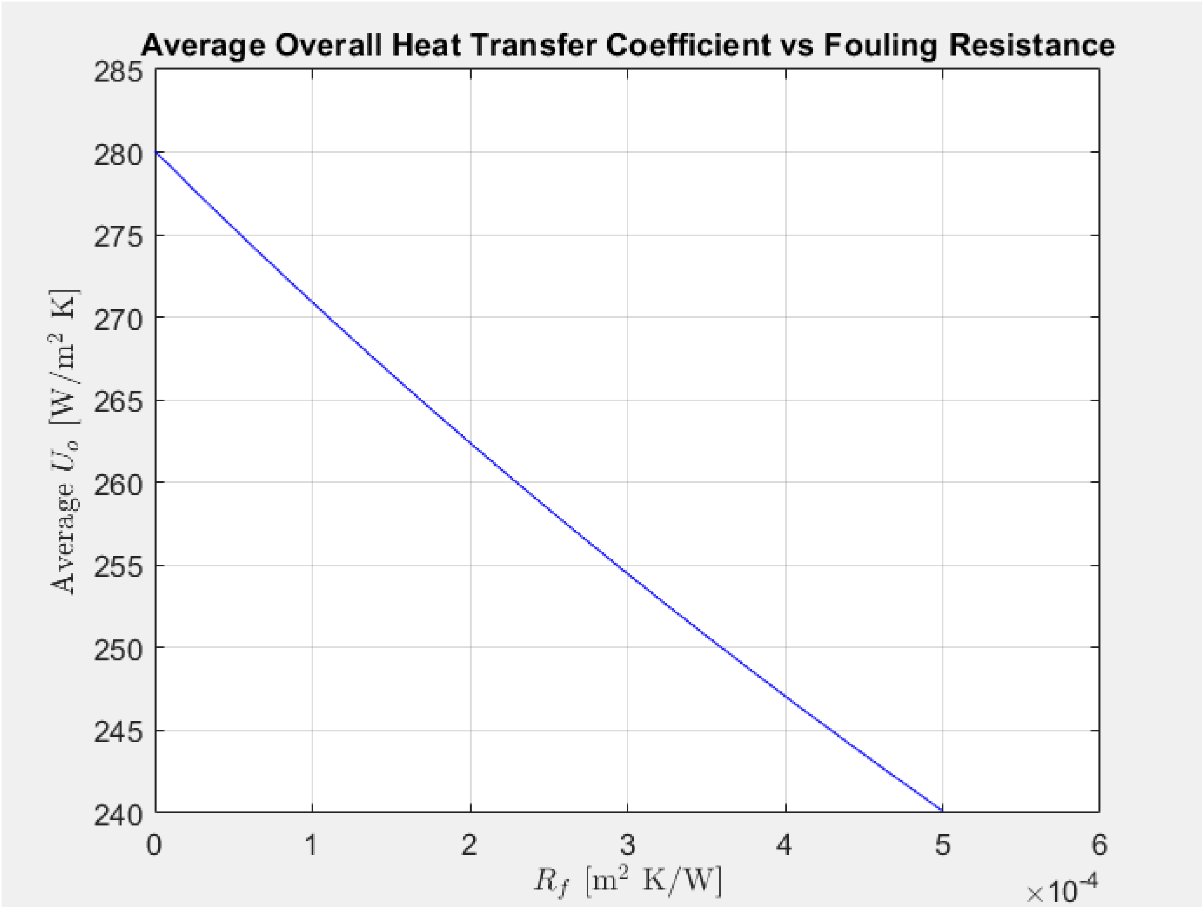
**Plot 1: 3D Surface Plot (Uo vs hi and ho)**

## Figure 1: Heat Transfer Coefficient Uo vs hi and ho (Fixed Rf = 2.5e-4 m^2 K/W)




**Plot 2: 2D Plot (Average Uo vs Rf)**

## Figure 2: Average Overall Heat Transfer Coefficient vs Fouling Resistance




## Answers to Conceptual Problems ➖

1. For the given geometry (Do/Di = 2), the **inner convective coefficient (hi) has a stronger influence** on the overall heat transfer coefficient (Uo). This is because the inner convection resistance term (1/hi) is multiplied by the area ratio (Do/Di) when based on the outer area, effectively doubling its contribution to the total resistance compared to the outer term (1/ho). If Do and Di were much more different (i.e., Do/Di >> 1), the influence of hi would be amplified further.

2. The wall thermal conductivity (k_wall) is inversely proportional to the wall conduction resistance. A higher k_wall (like copper, k ~ 385 W/m K ) results in a negligible

wall resistance and a higher Uo. Conversely, switching to a material with low k (like stainless steel, k ~ 16 W/m K ) significantly increases the wall resistance, thereby **decreasing Uo**. Since the required heat transfer area is inversely proportional to Uo, a lower k means a **larger heat exchanger** is necessary to achieve the same heat duty.

3. Heat transfer can be dominated by: 1) **Internal Convection** (low hi, often due to viscous fluid), necessitating an increase in internal fluid velocity. 2) **Wall Conduction** (low k_wall), requiring the use of a higher conductivity material. 3) **Fouling** (high Rf), which requires strict maintenance and cleaning schedules. The regime of dominance indicates where design and operational efforts should be focused to maximize efficiency.

4. The overall heat transfer coefficient (Uo) is **most sensitive to small increases in fouling resistance (Rf) when the exchanger is clean** (Rf is near zero). The rate of performance drop slows down as Rf increases. A typical cleaning criterion involves determining the Rf value at which Uo drops to an unacceptable level , often **75% to 80% of its clean value**, to balance maintenance costs against the economic penalty of reduced performance.

**Keys insights :-**

The analysis highlights that the **inner convective heat transfer coefficient (hi) has a stronger influence on Uo** than ho because the inner resistance term is amplified by the area ratio (Do/Di) when calculating Uo based on the outer area Ao. This is a critical design insight, suggesting that increasing flow velocity or turbulence inside the inner tube yields the most significant performance gains (Figure 1). Furthermore, while a high-conductivity wall material like copper makes the wall resistance negligible, a low-conductivity material drastically reduces Uo, necessitating a much larger required heat transfer area. Operationally, the **fouling resistance (Rf) causes a performance decay** where Uo is most sensitive to small increases in Rf when the exchanger is clean. Therefore, an effective maintenance strategy must be based on a clear efficiency threshold (e.g., cleaning when Uo drops to 75% of its clean value) to balance maintenance costs against energy efficiency losses (Figure 2).