PROBLEM 1:

In a shell-and-tube feedwater heater, cold water at 15°C flowing at a rate of 180 kg/h is preheated to 90°C by flue gases entering at 150°C and flowing at a rate of 900 kg/h. The water flows inside copper tubes ($d_i = 25$ mm, $d_o = 32$ mm)having a thermal conductivity of $k_w = 381$ W/mK.

The heat transfer coefficients on the gas and water sides are 120 W/m²·K and 1200 W/m²·K, respectively. The fouling factor on the water side is 0.002 m²·K/W.

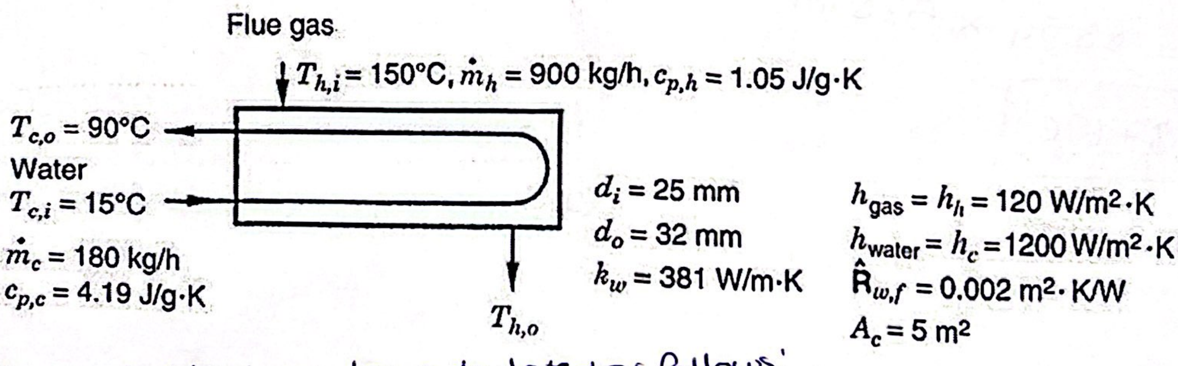
Determine:

1. The flue gas outlet temperature,
2. The overall heat transfer coefficient based on the outside tube diameter, and
3. The true mean temperature difference for heat transfer.

Assume the specific heats (c_p) are:

- For flue gases: $c_{p,g} = 1.05$ J/gK $= 1050$ J/kgK
- For water: $c_{p,w} = 4.19$ J/gK $= 4190$ J/kgK

The total outside surface area of the tubes is 5 m². There are no fins inside or outside the tubes, and there is no fouling on the gas side.



→ The required heat can be calculated as follows:

$$\dot{Q} = \dot{m}_c . c_{p,c} . (T_{c,o} - T_{c,i}) \rightarrow \left[\frac{180 \text{ kg/h}}{3600 \text{ s/h}}\right] . \left(4190 \frac{\text{J}}{\text{kgK}}\right) [90 - 15]$$

$$\dot{Q} = 15713 \text{ kW}$$

$$\dot{Q} = \dot{m}_h . c_{p,h} . (T_{h,i} - T_{h,o})$$

$$15713 = \left[\frac{900 \text{ kg/h}}{3600 \text{ s/h}}\right] (1050) . [150 - T_{h,o}] \rightarrow \boxed{T_{h,o} = 90{,}1 \text{ °C}}$$

Overall Heat Transfer Coefficient:

First way: $\Rightarrow$ $A = A_h = \pi . d_o . L . N_{tube}$

$$\frac{1}{U_o} = \frac{1}{h_o} + \frac{1}{h_{o,f}} + \frac{d_o . \ln(d_o/d_i)}{2k_w} + \frac{d_o}{h_{fi} . d_i} + \frac{d_o}{h_i . d_i}$$

Second way $\Rightarrow$ $$\frac{1}{U_i} = \frac{d_i}{h_o . d_o} + \frac{d_i}{h_{of} \, d_o} + \frac{d_i . \ln(d_o/d_i)}{2k_w} + \frac{1}{h_{fi}} + \frac{1}{h_i}$$

Hot fluid flows in outer side.

$$\frac{1}{U_h} = \frac{1}{h_h} + \cancel{\frac{1}{h_{h,f}}}_{0} + \frac{d_o . \ln(d_o/d_i)}{2k_w} + \frac{d_o}{\underbrace{h_{C,f}}_{} . d_i} + \frac{d_o}{h_c . d_i}$$

R_{fi}

$$\frac{1}{U_h} = \frac{1}{120} + \frac{0.032 . \ln(32/25)}{2 \times 381} + \frac{0.002 \times 0.032}{0.025} + \frac{0.032}{1200 \times 0.025}$$

$$\frac{1}{U_h} = 0.01137 \rightarrow \boxed{U_h = 83.54 \ W/m^2K}$$

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mean Temperature Difference:

$$\dot{Q} = U_h . A_h . \Delta T_m$$

$$15713 = 83.54 \times 5 \times \Delta T_m$$

$$\boxed{\Delta T_m = 37.6°C}$$

PROBLEM 2:

An air blast cooler with a surface area for a heat transfer of 600 m^2 and an overall heat transfer coefficient of U = 60 W/m^2·K is fed with the following streams: air: m_c = 15 kg/s, $c_{p,c}$ = 1050 J/(kg·K), $T_{c,in}$ = 25°C; oil: m_h = 5 kg/s, $c_{p,h}$ = 2000 J/(kg·K), $T_{h,in}$ = 90°C. Calculate the stream exit temperatures, the F-factor, and the effectiveness for a <u>two-shell-pass and four-tube pass</u> exchanger.

$A = 600 m^2$; $U = 60 W/m^2K$

(Cold) Air ⇒ $\dot{m}_c = 15 kg/s$; $c_{p,c} = 1050 \frac{J}{kgK}$; $T_{c,in} = 25°C$

(Hot) Oil ⇒ $\dot{m}_h = 5 kg/s$; $c_{p,h} = 2000 \frac{J}{kgK}$; $T_{h,in} = 90°C$

$T_{c,out} = ?$; $T_{h,out} = ?$; $F = ?$; $\mathcal{E} = ?$

⇒ $c^* = \frac{C_h}{C_c}$ ⇒ $C_c = \dot{m}_c . c_{p,c} = 15 \times 1050 = 15750$ W/K ; $C_h = \dot{m}_h . c_{p,h} = 5 \times 2000 = 10000$ W/K ; $C_{min} = C_h$, $C_{max} = C_c$

$c^* = \frac{C_h}{C_c} = \frac{10000}{15750}$ → $\boxed{c^* = 0.635}$

(Figure 2.15 son ecbel)

$\boxed{\mathcal{E} = 0.83}$

→ $NTU = \frac{A.U}{C_{min}}$ ⇒ $\frac{600 \times 60}{10000}$ ⇒ $\boxed{NTU = 3.6}$

→ $\mathcal{E} = \frac{C_h (T_{h1} - T_{h2})}{C_{min}(T_{h1} - T_{c1})} = \frac{C_c (T_{c2} - T_{c1})}{C_{min}(T_{h1} - T_{c1})}$

↓

$\mathcal{E} = \frac{\cancel{C_h}}{\cancel{C_{min}}} \left[\frac{T_{h1} - T_{h2}}{T_{h1} - T_{c1}} \right]$ → $\mathcal{E} = \frac{T_{h1} - T_{h2}}{T_{h1} - T_{c1}}$ = $0.83 = \frac{90 - T_{h2}}{90 - 25}$

$\boxed{T_{h2} = 36.05°C}$

→ To calculate outlet temp of cooling fluid)

① First way ⇒ $\dot{Q} = \underbrace{\dot{m}_h . c_{p,h}}_{C_h} (T_{h,in} - T_{h,out}) = \underbrace{\dot{m}_c . c_{p,c}}_{C_c} (T_{c,o} - T_{c,i})$

$10000 (90 - 36.05) = 15750 (T_{co} - 25)$ → $\boxed{T_{co} = 59.25°C}$

② Second way ⇒ $R = \frac{\dot{m}_c . c_{p,c}}{\dot{m}_h . c_{p,h}} = \frac{15750}{10000} = 1.575$

$R = \frac{T_{h1} - T_{h2}}{T_{c2} - T_{c1}}$ → $1.575 = \frac{90 - 36.05}{T_{c,o} - 25}$ → $\boxed{T_{c,o} = 59.25°C}$

- To determine correction factor F_S R and P will be find

$R = 1,575$

$$P = \frac{T_{c2} - T_{c1}}{T_{h1} - T_{c1}} = \frac{59,25 - 25}{90 - 25} \Rightarrow P = 0,53$$

From figure 2.8 $\rightarrow$ $\boxed{F = 0,67}$

PROBLEM 3:

A shell-and-tube heat exchanger is designed to heat water from 40°C to 60°C with a mass flow rate of 20,000 kg/hr. Water at 180°C flows through tubes with a mass flow rate of 10,000 kg/hr. The tubes have an inner diameter of $d_i = 20$ mm, the Reynolds number is $Re = 10{,}000$. The overall heat transfer coefficient-based outside heat transfer surface area is estimated to be $U = 450\ \text{W/m}^2\text{K}$.

a-) Calculate the heat transfer rate Q of the heat exchanger and the exit temperature of the hot fluid.

b-) If the heat exchanger is counterflow with one tube and one shell pass; determine (by the use of LMTD method):

b-1. the outer heat transfer area ;
b-2. the velocity of the fluid through the tubes

$$(\rho = 906.23 \frac{kg}{m^3}\ ;\ \mu = 1.6804x10^{-4} Pa \cdot s);$$

b-3. the cross-sectional area of the tubes;
b-4. the number of the tubes and the length of the heat exchanger.

Assume the specific heats (c_p) are:

- For cold fluid: $c_{p,c} = 4181$ J/kgK
- For hot fluid: $c_{p,h} = 4407$ J/kgK

→ Counter flow , one tube and one shell pass:

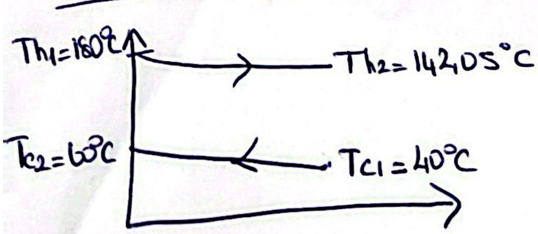
Cold Fluid:	Hot Fluid:	
$T_{c1} = 40°C$	$T_{h1} = 180°C$	$Re = 10000$
$T_{c2} = 60°C$	$\dot{m}_h = 10000\ kg$	$d_i = 20mm$
$\dot{m}_c = 20000 \frac{kg}{h}$		$U_o = 450\ W/m^2K$

a-) $\dot{Q} = \dot{m}_c \cdot c_{p,c} (T_{c2} - T_{c1}) = \dot{m}_h \cdot c_{p,h} \cdot (T_{h1} - T_{h2})$

$$\dot{Q} = \left[20000 \frac{kg}{h} \cdot \frac{1h}{3600s}\right] 4181 \frac{J}{kgK} (60-40) \rightarrow \boxed{\dot{Q} = 464556\,W}$$

$$T_{h2} = T_{h1} - \frac{\dot{Q}}{\dot{m}_h c_{p,h}} = 180 - \frac{464556}{\frac{10000}{3600} \cdot 4407} \rightarrow \boxed{T_{h2} = 142{,}05°C}$$

LMTD Method



$\Delta T_2 = 180 - 60 = 120°C$
$\Delta T_1 = 142{,}05 - 40 = 102{,}05°C$

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln\left(\frac{\Delta T_2}{\Delta T_1}\right)} \Rightarrow \boxed{\Delta T_{lm} = 110{,}78°C}$$

Heat Transfer Area $\Rightarrow$ $\dot{Q} = U.A.\Delta T_{lm}$

$$A = \frac{\dot{Q}}{U.\Delta T_{lm}} = \frac{464556}{450 \times 110.78} \rightarrow \boxed{A = 9{,}319\ m^2}$$

Velocity (U_m) $\Rightarrow$ $Re = \frac{\rho.U_m.d_i}{\mu}$ $\Rightarrow$ $10000 = \frac{806.23.U_m.0.02}{1.6804 \times 10^{-4}}$

$$\boxed{U_m = 0.0827\ m/s}$$

Mass Flow Rate of Hot $\Rightarrow$ $\dot{m}_h = \rho.A_c.U_m$

$$A_c = \frac{\dot{m}_h}{\rho.U_m} = \frac{2{,}7778}{806.23 \times 0.0827} \rightarrow \boxed{A_c = 0.033\ m^2}$$

Number of Tubes $\Rightarrow$ $N_t = \frac{A_c}{\frac{\pi.d_i^2}{4}} \Rightarrow \frac{0{,}033}{\frac{\pi.0.02^2}{4}} \rightarrow \boxed{N_T = 105{,}04 \cong 106}$

Length $\Rightarrow$ $A = \pi.d_i.N_T.L$

$9.319 = \pi.0.02.106 \rightarrow \boxed{L = 1.4\ m}$

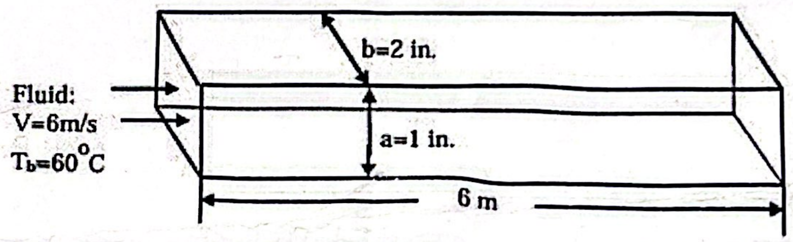
PROBLEM 4

A fluid flows steadily with a velocity of 6 m/s through a commercial iron rectangular duct whose sides are 1 in. by 2 in. and the length of the duct is 6 m. The average temperature of the fluid is 60°C. The fluid completely fills the duct. Calculate the surface heat transfer coefficient if the fluid is

a. Water; (ρ=983.1 kg/m^3, c_p=4184 J/(kg.K), μ=4.66×10^{-4} kg/m-s, Pr=3, k=0.651 W/m.K).

b. Air at atmospheric pressure; (ρ=1.0595 kg/m^3, c_p=1009 J/(kg.K), μ=2×10^{-5} kg/m-s, Pr=0.709, k=0.0285 W/m.K).

c. Engine oil (ρ=864 kg/m^3, c_p=2047 J/(kg.K), υ=0.0839×10^{-3} m^2/s, Pr=1050, k=0.140 W/m.K).



Hydraulic diameter is given by;

$$D_h = \frac{4\times A_c}{P_w} = \frac{4\times(2\times 1)}{6} = \frac{4}{3}\text{ in} = 0.0339\text{ m}$$

a) $$Re = \frac{\rho . u_m . D_h}{\mu} = \frac{983.1 . 6 . 0.0339}{4.66\times10^{-4}} = 429104 > 2300 \text{ Turbulent}$$

Using Gnielinski's correlation:

$$Nu_b = \frac{(f/2)(Re_b - 1000)Pr_b}{1.07 + 12.7(f/2)^{1/2} . [Pr_b^{2/3} - 1]}$$

$$f = (1.58 \times \ln[429104] - 3.28)^{-2} \Rightarrow f = 0.003376$$

$$Nu_b = \frac{(0.003376/2)[429104 - 1000] . 3}{1.07 + 12.7(0.003376/2)^{1/2} . [3^{2/3} - 1]} \rightarrow Nu_b = 1330.1$$

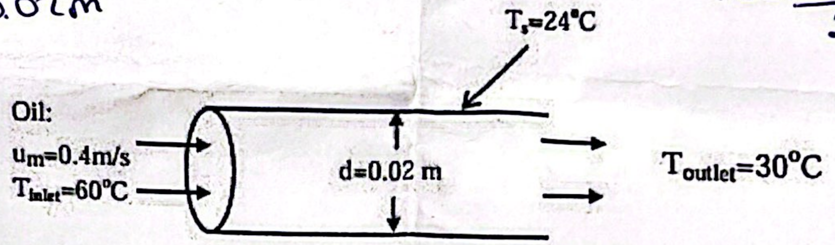
$$h = Nu_b . \frac{k}{D_h} = 1330.1 \times \frac{0.651}{0.0339} = 25542.6 \text{ W/m}^2\text{K}$$

PROBLEM 5:

An oil with k=0.120 W/m.K, c_p=2000 J/kg.K, ρ=895 kg/m³, μ=0.0041 kg/m.s flows through a 2-cm diameter tube which is 2-m long. The oil is cooled from 60°C to 30°C. The mean flow velocity is 0.4 m/s, and the tube wall temperature is maintained at 24°C (μ_w=0.021 kg/m.s). Calculate the heat transfer rate.

$d_i = 2cm = 0.02m$

$$T_b = \frac{60+30}{2} = 45°C$$



$$Re = \frac{\rho . u_m . d_i}{\mu} = \frac{895 \times 0.4 \times 0.02}{0.0041} = Re = 1746.34 < 2300$$

$\underbrace{\phantom{Re = 1746.34 < 2300}}_{(Laminar)}$

$$Pr = \frac{\nu}{\alpha} = \frac{\mu . c_p}{K} = \frac{0.0041 \times 2000}{0.12} = Pr = 68.3$$

$$Pe = Re.Pr \Rightarrow Pe = 1746.34 \times 68.3 \Rightarrow Pe = 119\,275$$

$$\frac{d_i}{L} = \frac{0.02}{2} = 0.01$$

$$\left(Pe.\frac{d_i}{L}\right)^{1/3} . \left(\frac{\mu_b}{\mu_w}\right)^{0.14} = \left[119275 \times 0.01\right]^{1/3} . \left(\frac{0.0041}{0.021}\right)^{0.14}$$

$$= 8.44 > 2 \checkmark$$

Using Sieder and Tate correlation:

$$Nu_b = 1.86 \left(Pe.\frac{d_i}{L}\right)^{1/3} . \left(\frac{\mu_b}{\mu_w}\right)^{0.14} = 1.86 . (8.44) \Rightarrow \boxed{Nu_b = 15.7}$$

Heat transfer coeff.

$$h = \frac{Nu\,k}{d_i} = \frac{15.7 \times 0.12}{0.02} \rightarrow \boxed{h = 94.2\ W/m^2K}$$

→ Heat transfer rate:

$$Q = A.h.(T_b - T_w) \Rightarrow \pi . d_i . L . h\,(T_b - T_w) = \pi . 0.02 \times 2 \times 94.2\,(\overset{T_b \uparrow}{45} - 24)$$

$\boxed{Q\ [illegible]}$