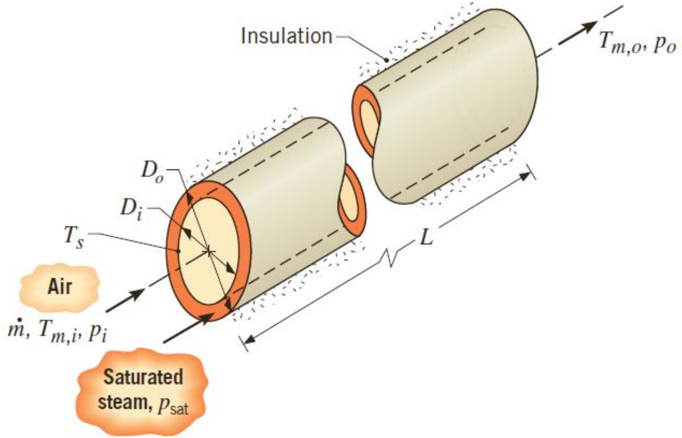
7.15 Water at 24°C flows at 0.8 m/s in a smooth, 1.5 cm I.D. tube that is kept at 27°C. The system is extremely clean and quiet, and the flow stays laminar until a noisy air compressor is turned on in the laboratory. Then it suddenly goes turbulent. Calculate the ratio of the turbulent h to the laminar h. [$h_{turb} = 4429$ W/m^{2}K.]

7.37 Water flows at 4 m/s, at a temperature of 100°C, in a 6 cm I.D. thin-walled tube with a 2 cm layer of 85% magnesia insulation on it. The outside heat transfer coefficient is 6 W/m^{2}K, and the outside temperature is 20°C. Find: (a) U based on the inside area, (b) Q W/m, and (c) the temperature on either side of the insulation.

7.17 Air at 200 psia flows at 12 m/s in an 11 cm I.D. duct. Its bulk temperature is 40°C and the pipe wall is at 268°C. Evaluate h if $\varepsilon/D = 0.00006$.

8.38 An air heater for an industrial application consists of an insulated, concentric tube annulus, for which air flows through a thin-walled inner tube. Saturated steam flows through the outer annulus, and condensation of the steam maintains a uniform temperature T_s on the tube surface.



Consider conditions for which air enters a 50-mm-diameter tube at a pressure of 5 atm, a temperature of $T_{m,i} = 17$°C, and a flow rate of $m = 0.03$ kg/s, while saturated steam at 2.455 bars condenses on the outer surface of the tube. If the length of the annulus is $L = 5$ m, what are the outlet temperature $T_{m,o}$ and pressure p_o of the air? What is the mass rate at which condensate leaves the annulus?

7.15 Water at 24°C flows at 0.8 m/s in a smooth, 1.5 cm I.D. tube that is kept at 27°C. The system is extremely clean and quiet, and the flow stays laminar until a noisy air compressor is turned on in the laboratory. Then it suddenly goes turbulent. Calculate the ratio of the turbulent h to the laminar h. [$h_{\text{turb}} = 4429$ W/m^{2}K.]

Table A.3: saturated liquids...*continued*

Temperature K	°C	ρ (kg/m^3)	c_p (J/kg·K)	k (W/m·K)	α (m^2/s)	ν (m^2/s)	Pr	β (K^{-1})
				Water				
300	27	996.5	4181	0.6103	1.465×10^{-7}	8.568×10^{-7}	5.85	0.000275

Re = 1.4006e+04

In the case of laminar flow

$$Nu_D = 3.657,$$

h = Nu*k/D = 148.79 W/m^{2}K

$h_{turbulent}/h_{laminar}$ = 27.5

Re = 1.4006e+04

In the case of turbulent flow

$$Nu_D = \frac{(f/8)(Re_D - 1000)\,Pr}{1 + 12.7\sqrt{f/8}\left(Pr^{2/3} - 1\right)}$$

for $2300 \leq Re_D \leq 5 \times 10^6$.

$$f = (0.790 \ln Re_D - 1.64)^{-2}$$

f = 0.028705

Nu = 100.77

h = Nu*k/D = 4099.9 W/m^{2}K

7.37 Water flows at 4 m/s, at a temperature of 100°C, in a 6 cm I.D. thin-walled tube with a 2 cm layer of 85% magnesia insulation on it. The outside heat transfer coefficient is 6 W/m^2K, and the outside temperature is 20°C. Find: (a) U based on the inside area, (b) Q W/m, and (c) the temperature on either side of the insulation.

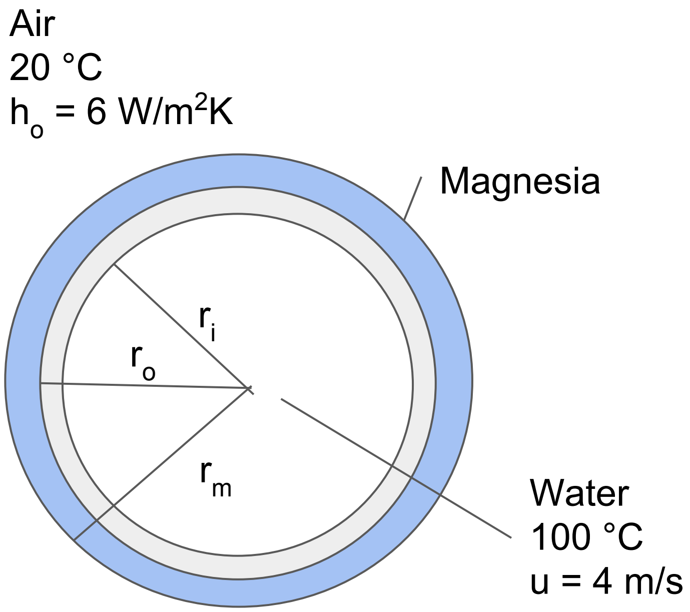
Table A.3: saturated liquids...*continued*

Temperature K	°C	ρ (kg/m^3)	c_p (J/kg·K)	k (W/m·K)	α (m^2/s)	ν (m^2/s)	Pr	β (K^{-1})
Water								
373.15	100.0	958.3	4216	0.6791	1.681×10^{-7}	2.940×10^{-7}	1.75	0.000751

Table A.2...*continued.*

Material	*Temperature Range* (°C)	*Density* ρ (kg/m^3)	*Specific Heat* c_p (J/kg·K)	*Thermal Conductivity* k (W/m·K)	*Thermal Diffusivity* α (m^2/s)
Magnesia, 85% (insulation)	38	≈200		0.067	
	93			0.071	
	150			0.074	
	204			0.08	

Re_{water} = 8.1633e+05 (turbulent)



In the case of turbulent flow

$$Nu_D = \frac{(f/8)(Re_D - 1000)\,Pr}{1 + 12.7\sqrt{f/8}\,(Pr^{2/3} - 1)}$$

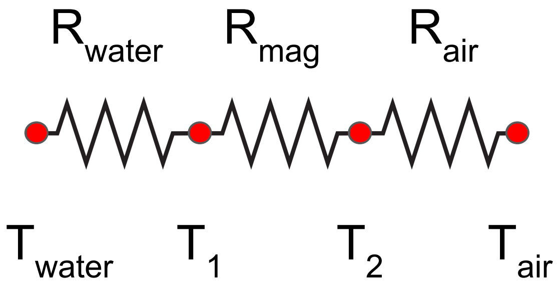
for $2300 \le Re_D \le 5 \times 10^6$.

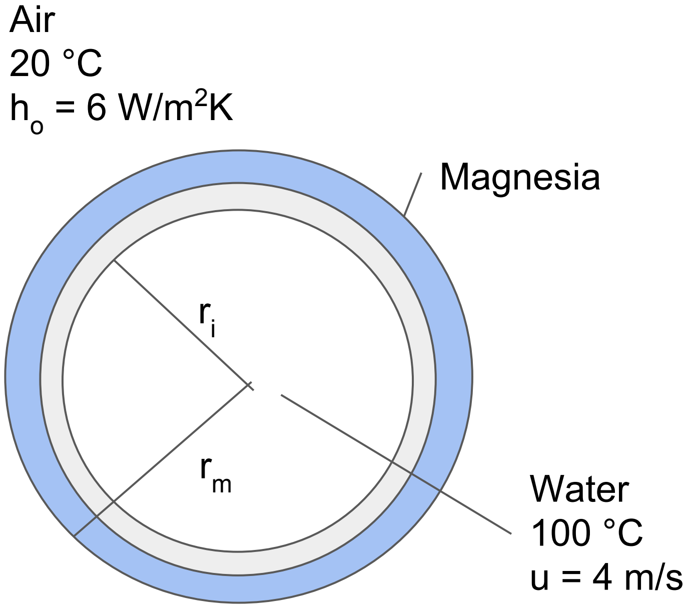
$$f = (0.790 \ln Re_D - 1.64)^{-2}$$

f = 0.012039

Nu = 1756.0

h = Nu*k/D = 1.9875e+04 W/m^2K





$$R_{t_{\mathrm{cyl}}} = \frac{\ln(r_o/r_i)}{2\pi l k}$$

$$R_{t_{\mathrm{conv}}} = \frac{1}{\bar{h}A}$$

$R_{water} = 1/(2\pi r_i h_{water})$ = **2.6693e-04** K/W

$R_{mag} = \ln(r_m/r_i)/(2\pi k_{mag})$ = **1.1451** K/W

$R_{air} = 1/(2\pi r_m h_{air})$ = **0.53052** K/W

$R_{total} = R_{water} + R_{mag} + R_{air}$ = **1.6759** K/W

$Q = \Delta T/R_{total}$ = **47.737** W/m

$U = Q/(A*\Delta T) = 1/(A_i*R_{total})$ = **3.1656** W/m^{2}K

$T_2 = T_{air} + R_{air}*Q$ = **45.325** °C

$T_1 = T_{water} + R_{water}*Q$ = **99.987** °C

7.17 Air at 200 psia flows at 12 m/s in an 11 cm I.D. duct. Its bulk temperature is 40°C and the pipe wall is at 268°C. Evaluate h if $\varepsilon/D = 0.00006$.

DATA

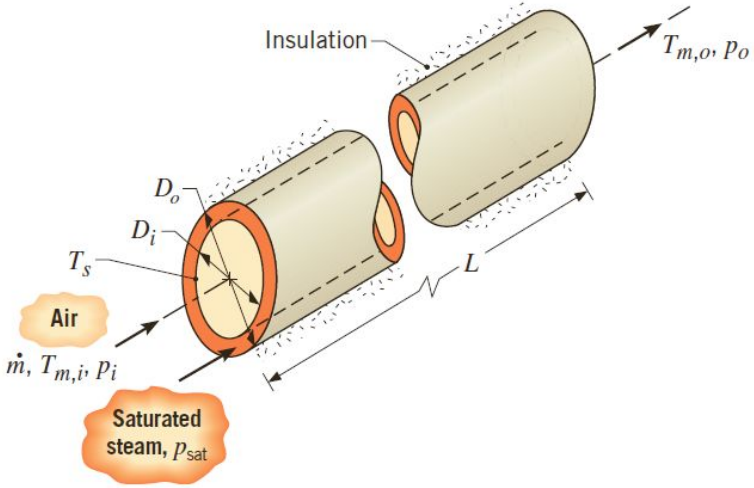
T=154; [°C]
rho=11.207; [kg/m3]
cp=1.0264; [kJ/kgK]
k=0.03555; [W/mK]
Pr=0.703; [-]
mu=24.338e-6; [Pa*s]

$$Nu_D = \frac{(f/8)\,(Re_D - 1000)\,Pr}{1 + 12.7\sqrt{f/8}\left(Pr^{2/3} - 1\right)}$$

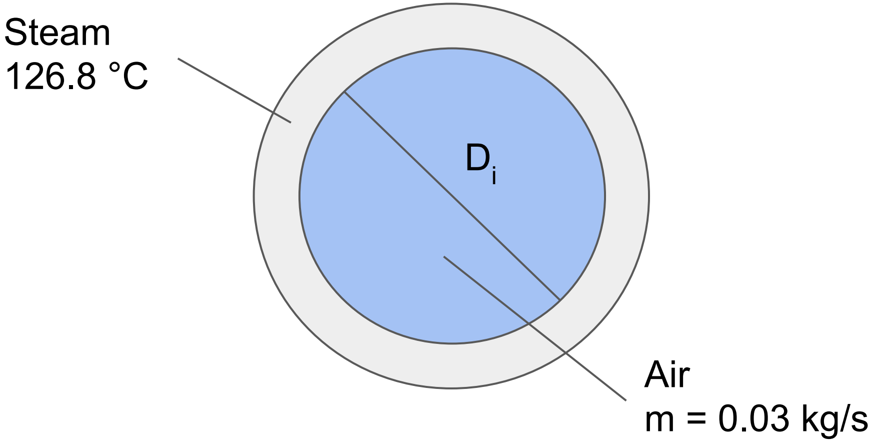
f = 0.013602
f_smooth = 0.012679

Nu = 814.64
h = 263.28 W/m2K
Nu_smooth = 756.14
h_smooth = 244.37 W/m2K

8.38 An air heater for an industrial application consists of an insulated, concentric tube annulus, for which air flows through a thin-walled inner tube. Saturated steam flows through the outer annulus, and condensation of the steam maintains a uniform temperature T_s on the tube surface.



Consider conditions for which air enters a 50-mm-diameter tube at a pressure of 5 atm, a temperature of $T_{m,i} = 17°C$, and a flow rate of $m = 0.03$ kg/s, while saturated steam at 2.455 bars condenses on the outer surface of the tube. If the length of the annulus is $L = 5$ m, what are the outlet temperature $T_{m,o}$ and pressure p_o of the air? What is the mass rate at which condensate leaves the annulus?



DATA

T_wall=126.8; [°C]

T_mean=71.9; [°C]

rho=5.12; [kg/m3]
cp=1.01; [kJ/kgK]
k=0.029764; [W/mK]
Pr=0.705; [-]
mu=20.697e-6; [Pa*s]

Appendix A: Some thermophysical properties of selected materials

Table A.5: saturated vapors (p =

T (K)	p (MPa)	ρ (kg/m^3)	c_p (J/kg·K)	k (W/m·K)	μ (kg/m·s)
Water vapor					
273.16	0.0006177	0.004855	1884	0.01707	0.9216×10^{-5}
275.0	0.0006985	0.005507	1886	0.01717	0.9260
280.0	0.0009918	0.007681	1891	0.01744	0.9382
285.0	0.001389	0.01057	1897	0.01773	0.9509
290.0	0.001920	0.01436	1902	0.01803	0.9641
295.0	0.002621	0.01928	1908	0.01835	0.9778
300.0	0.003537	0.02559	1914	0.01867	0.9920
305.0	0.004719	0.03360	1920	0.01901	1.006
310.0	0.006231	0.04366	1927	0.01937	1.021
320.0	0.01055	0.07166	1942	0.02012	1.052
340.0	0.02719	0.1744	1979	0.02178	1.116
360.0	0.06219	0.3786	2033	0.02369	1.182
373.15	0.1014	0.5982	2080	0.02510	1.227
380.0	0.1289	0.7483	2110	0.02587	1.250
400.0	0.2458	1.369	2218	0.02835	1.319
420.0	0.4373	2.352	2367	0.03113	1.388

Table A.4 Some latent heats of vaporization, h_{fg} (kJ/kg), with temperatures at triple point, T_{tp} (K), and critical point, T_c (K).

T(K)	Water	Ammonia	CO_2	HCFC-22	HFC-134a	Mercury	Methanol	Nitrogen	Oxygen
60									238.4
70								208.1	230.5
80								195.7	222.3
90								180.5	213.2
100								161.0	202.6
110								134.3	189.7
120				300.4				92.0	173.7
130				294.0					153.1
140				287.9					125.2
150				281.8					79.2
160				275.9					
180				264.3	257.4				
200		1474		252.9	245.7		1310		
220		1424	344.9	241.3	233.9		1269		
230		1397	328.0	235.2	227.8		1258		
240		1369	309.6	228.9	221.5		1247		
250		1339	289.3	222.2	215.0		1235		
260		1307	266.5	215.1	208.2		1222		
270		1273	240.1	207.5	201.0		1209		
273	2501	1263	230.9	205.0	198.6	306.8	1205		
280	2485	1237	208.6	199.4	193.3	306.6	1196		
290	2462	1199	168.1	190.5	185.0	306.2	1181		
300	2438	1158	103.7	180.9	176.1	305.8	1166		
310	2414	1114		170.2	166.3	305.5	1168		
320	2390	1066		158.3	155.5	305.1	1150		
330	2365	1015		144.7	143.3	304.8	1116		
340	2341	957.9		128.7	129.3	304.4	1096		
350	2315	895.2		109.0	112.5	304.1	1078		
360	2290	824.8		81.8	91.0	303.8	1054		
373	2257	717.0				303.3	1022		
400	2183	346.9				302.4	945		
500	1828					299.2	391		
600	1173					295.9			
700						292.3			
T_{tp}	273.16	195.5	216.6	115.7	169.9	234.2	175.5	63.2	54.3
T_c	647.1	405.4	304.3	369.3	374.2		512.5	126.2	154.6

Calculation of the friction coefficient and pressure drop

Re = 3.6911e+04

Turbulent

$$f = (0.790 \ln Re_D - 1.64)^{-2} \qquad 3000 \lesssim Re_D \lesssim 5 \times 10^6$$

f = 0.022492

$$f \equiv \frac{\text{head loss}}{\left(\dfrac{\text{pipe length}}{D}\,\dfrac{u_{av}^2}{2}\right)} = \frac{\Delta p}{\left(\dfrac{L}{D}\,\dfrac{\rho u_{av}^2}{2}\right)}$$

P_in = 5.066 [bar]
Dp = 51.276 [Pa]
P_out = 5.0655 [bar]

Energy Balance on the air side

$$\mathrm{Nu}_D = \frac{(f/8)\,(\mathrm{Re}_D - 1000)\,\mathrm{Pr}}{1 + 12.7\sqrt{f/8}\,\left(\mathrm{Pr}^{2/3} - 1\right)}$$

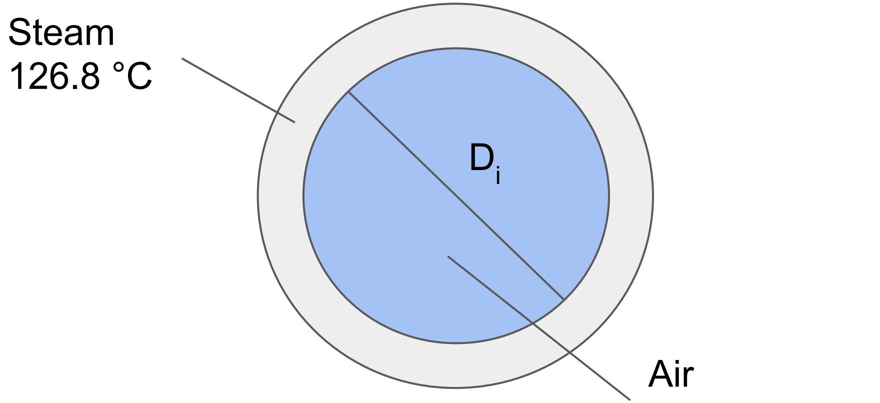
for $2300 \le \mathrm{Re}_D \le 5 \times 10^6$.

Nu = 82.765
h = 49.268 [W/m2K]

$$\frac{T_{b_{out}} - T_{b_{in}}}{T_w - T_{b_{in}}} = 1 - \exp\left(-\frac{\bar{h}PL}{\dot{m}c_p}\right)$$

T_out = 96.182 [°C]

Energy Balance on the whole heat exchanger



h_lv=2182.9; [kJ/kg]

Q_air = Q_cond

m_air*cp*(T_out-T_in) = m_cond*h_lv

m_cond = m_air*(cp*1e3)*(T_out-T_in)/(h_lv*1e3)

m_cond = 0.0010991 kg/s