Tutorial-2

Internal forced convection

5th-6th Feb 2020

Exercise 1. Hot air flows with a mass rate of $\dot{m} = 0.05$ kg/s through an uninsulated sheet metal duct of diameter $D = 0.15$ m. The hot air enters the duct at 103 °C and after a distance of 5 m cools to 77 °C. The heat transfer coefficient of the outer surface is 6 W/m^2 K and the temperature of the outside air far from the pipe is 0 °C. Find:

- The rate of heat loss for the entire length of the pipe
- The heat flux and surface temperature at $x = 5$ m.

Exercise 2. Engine oil is heated by flowing through a circular tube of diameter D= 50 mm and length L = 25 m. Before entering the 25 m heating section, the fluid passes through 1 m of unheated length. The surface of the tube is maintained at 150 °C. If the flow rate and inlet temperature of the oil are 0.5 kg/s and 20 °C, what is the outlet temperature $T_{m,o}$? What is the total rate of heat transfer for the entire tube?

Exercise 3. An annulus consists of the region between two concentric tubes having diameter of 4 cm and 5 cm. Ethylene glycol flows in this space at a velocity of 6.9 m/s. The entrance temperature is 20 °C and the exit temperature is 40 °C. Only the inner tube is the heating surface and it is maintained at 80 °C. Calculate the length of annulus necessary for the required heat transfer.

Exercise 4. Water at 0.4 Kg/s is to be cooled from 71° C to 32° C. Which would result in less pressure drop, to run the water through a tube of 12.5 mm diameter or through a tube of 15. mm diameter? Wall temperature of 12.5 mm diameter pipe is 4 °C and 15 mm diameter pipe is 27 °C.

Table 1: Heat Transfer Correlations for pipe flow

Condition	**Correlation**
Laminar, constant wall flux, thermally and hydrodynamically fully developed	$$Nu_D = \frac{hD}{k} = 4.36$$
Laminar, constant wall temperature,thermally and hydrodynamically fully developed	$$Nu_D = \frac{hD}{k} = 3.66$$
Laminar flow, constant surface temperature, thermal entry length problem. All Prandtl number.	$$\overline{Nu_D} = 3.66 + \frac{0.068Gz}{1 + 0.04Gz^{2/3}}$$
Laminar flow, constant surface temperature, combined entry length problem. $Pr \gtrapprox 5$	$$\overline{Nu_D} = 3.66 + \frac{0.068Gz}{1 + 0.04Gz^{2/3}}$$
Dittus Boelter equation	$$Nu_D = 0.023Re^{0.8}Pr^n$$

TABLE A.5 Thermophysical Properties of Saturated Fluids[a]

Saturated Liquids

T (K)	ρ (kg/m^3)	c_p (kJ/kg·K)	$\mu \cdot 10^2$ (N·s/m^2)	$\nu \cdot 10^6$ (m^2/s)	$k \cdot 10^3$ (W/m·K)	$\alpha \cdot 10^7$ (m^2/s)	Pr	$\beta \cdot 10^3$ (K^{-1})
Engine Oil (Unused)								
273	899.1	1.796	385	4280	147	0.910	47,000	0.70
280	895.3	1.827	217	2430	144	0.880	27,500	0.70
290	890.0	1.868	99.9	1120	145	0.872	12,900	0.70
300	884.1	1.909	48.6	550	145	0.859	6400	0.70
310	877.9	1.951	25.3	288	145	0.847	3400	0.70
320	871.8	1.993	14.1	161	143	0.823	1965	0.70
330	865.8	2.035	8.36	96.6	141	0.800	1205	0.70
340	859.9	2.076	5.31	61.7	139	0.779	793	0.70
350	853.9	2.118	3.56	41.7	138	0.763	546	0.70
360	847.8	2.161	2.52	29.7	138	0.753	395	0.70
370	841.8	2.206	1.86	22.0	137	0.738	300	0.70
380	836.0	2.250	1.41	16.9	136	0.723	233	0.70
390	830.6	2.294	1.10	13.3	135	0.709	187	0.70
400	825.1	2.337	0.874	10.6	134	0.695	152	0.70
410	818.9	2.381	0.698	8.52	133	0.682	125	0.70
420	812.1	2.427	0.564	6.94	133	0.675	103	0.70
430	806.5	2.471	0.470	5.83	132	0.662	88	0.70

Ethylene Glycol [$C_2H_4(OH)_2$]

273	1130.8	2.294	6.51	57.6	242	0.933	617	0.65
280	1125.8	2.323	4.20	37.3	244	0.933	400	0.65
290	1118.8	2.368	2.47	22.1	248	0.936	236	0.65
300	1114.4	2.415	1.57	14.1	252	0.939	151	0.65
310	1103.7	2.460	1.07	9.65	255	0.939	103	0.65
320	1096.2	2.505	0.757	6.91	258	0.940	73.5	0.65
330	1089.5	2.549	0.561	5.15	260	0.936	55.0	0.65
340	1083.8	2.592	0.431	3.98	261	0.929	42.8	0.65
350	1079.0	2.637	0.342	3.17	261	0.917	34.6	0.65
360	1074.0	2.682	0.278	2.59	261	0.906	28.6	0.65
370	1066.7	2.728	0.228	2.14	262	0.900	23.7	0.65
373	1058.5	2.742	0.215	2.03	263	0.906	22.4	0.65

TABLE A.6 Thermophysical Properties of Saturated Water[a]

Temperature, T (K)	Pressure, p (bars)[b]	Specic Volume (m³/kg)		Heat of Vaporization, h_{g} (kJ/kg)	Specic Heat (kJ/kg · K)		Viscosity (N · s/m²)		Thermal Conductivity (W/m · K)		Prandtl Number		Surface Tension, $\sigma \cdot 10^3$ (N/m)	Expansion Coefficient, $\beta \cdot 10^6$ (K⁻¹)	Temperature, T (K)
		$v \cdot 10^3$	v_g		$c_{p,f}$	$c_{p,g}$	$\mu \cdot 10^6$	$\mu_g \cdot 10^6$	$k \cdot 10^3$	$k_g \cdot 10^3$	Pr	Pr_g			
273.15	0.00611	1.000	206.3	2502	4.217	1.854	1750	8.02	569	18.2	12.99	0.815	75.5	−68.05	273.15
275	0.00697	1.000	181.7	2497	4.211	1.855	1652	8.09	574	18.3	12.22	0.817	75.3	−32.74	275
280	0.00990	1.000	130.4	2485	4.198	1.858	1422	8.29	582	18.6	10.26	0.825	74.8	46.04	280
285	0.01387	1.000	99.4	2473	4.189	1.861	1225	8.49	590	18.9	8.81	0.833	74.3	114.1	285
290	0.01917	1.001	69.7	2461	4.184	1.864	1080	8.69	598	19.3	7.56	0.841	73.7	174.0	290
295	0.02617	1.002	51.94	2449	4.181	1.868	959	8.89	606	19.5	6.62	0.849	72.7	227.5	295
300	0.03531	1.003	39.13	2438	4.179	1.872	855	9.09	613	19.6	5.83	0.857	71.7	276.1	300
305	0.04712	1.005	29.74	2426	4.178	1.877	769	9.29	620	20.1	5.20	0.865	70.9	320.6	305
310	0.06221	1.007	22.93	2414	4.178	1.882	695	9.49	628	20.4	4.62	0.873	70.0	361.9	310
315	0.08132	1.009	17.82	2402	4.179	1.888	631	9.69	634	20.7	4.16	0.883	69.2	400.4	315
320	0.1053	1.011	13.98	2390	4.180	1.895	577	9.89	640	21.0	3.77	0.894	68.3	436.7	320
325	0.1351	1.013	11.06	2378	4.182	1.903	528	10.09	645	21.3	3.42	0.901	67.5	471.2	325
330	0.1719	1.016	8.82	2366	4.184	1.911	489	10.29	650	21.7	3.15	0.908	66.6	504.0	330
335	0.2167	1.018	7.09	2354	4.186	1.920	453	10.49	656	22.0	2.88	0.916	65.8	535.5	335
340	0.2713	1.021	5.74	2342	4.188	1.930	420	10.69	660	22.3	2.66	0.925	64.9	566.0	340
345	0.3372	1.024	4.683	2329	4.191	1.941	389	10.89	664	22.6	2.45	0.933	64.1	595.4	345
350	0.4163	1.027	3.846	2317	4.195	1.954	365	11.09	668	23.0	2.29	0.942	63.2	624.2	350
355	0.5100	1.030	3.180	2304	4.199	1.968	343	11.29	671	23.3	2.14	0.951	62.3	652.3	355
360	0.6209	1.034	2.645	2291	4.203	1.983	324	11.49	674	23.7	2.02	0.960	61.4	697.9	360
365	0.7514	1.038	2.212	2278	4.209	1.999	306	11.69	677	24.1	1.91	0.969	60.5	707.1	365