Table 15-5 Thermal conductivities and viscosities of saturated refrigerant liquid and vapor

Refrigerant	t, °C	Viscosity, Pa • s		Conductivity, W/m • K	
		Liquid	Vapor	Liquid	Vapor
11	-40	0.000922		0.106	
	-20	0.000694		0.100	
	0	0.000546		0.0943	
	20	0.000441	0.0000103	0.0890	
	40	0.000367	0.0000119	0.0832	0.00841
	60	0.000312	0.0000127	0.0777	0.0093
12	-40	0.000409		0.0931	
	-20	0.000325	0.0000108	0.0857	0.00734
	0	0.000267	0.0000118	0.0784	0.00838
	20	0.000225	0.0000126	0.0711	0.00938
	40	0.000194	0.0000135	0.0637	0.0105
	60	0.000169	0.0000148	0.0564	0.0118
22	-40	0.000330	0.0000101	0.120	0.0069
	-20	0.000275	0.0000110	0.110	0.00817
	0	0.000237	0.0000120	0.100	0.00942
	20	0.000206	0.0000130	0.090	0.0107
	40	0.000182	0.0000144	0.0805	0.0119
	60	0.000162	0.0000160	0.0704	0.0133
502	-40	0.000356	0.0000100	0.0898	0.00796
	-20	0.000284	0.0000111	0.0820	0.00907
	0	0.000233	0.0000120	0.0742	0.0102
	20	0.000193	0.0000132	0.0665	0.0114
	40	0.000153	0.0000146	0.0585	0.0124
	60	0.000117	0.0000161	0.0486	0.0144
717	-40			0.632	
	-20	0.000236	0.0000097	0.585	0.0204
	0	0.000190	0.0000104	0.540	0.0218
	20	0.000152	0.0000112	0.493	0.0267
	40	0.000122	0.0000120	0.447	0.0318
	60	0.000098	0.0000129	0.400	0.0381

Problem. 1: An air-cooled condenser is to reject 70 kw of heat from a condensing refrigerant to air. The condenser has an air-side area of 210 m^2 and a U value based on this area is 0.037 $kW/m^2.K$; it is supplied with 6.6 m^3/s of air, which has a density of 1.15 kg/m^3. If the condensing temperature is to be limited to 55 C, what is the maximum allowable temperature of inlet air?

Solution: $A_o = 210\ m^2$

$U_o = 0.037\ kW/m^2.K$

$q = 70$ kw

$\rho = 1.15\ kg/m^3$

Condensing Temperature = 55 C

$w = (6.6\ m^3/s) / (1.15\ kg/m^3) = 5.739\ kg/s$

$c_p = 1.0\ kJ/kg.K$

$$LMTD = \frac{(t_c - t_i) - (t_c - t_o)}{\ln\left[\frac{(t_c - t_i)}{(t_c - t_o)}\right]}$$

$q = U_o A_o LMTD$

$$LMTD = \frac{q}{U_o A_o} = \frac{70}{(0.037)(210)} = 9.009\ K$$

But $q = wc_p(t_o - t_i)$

$$t_o - t_i = \frac{q}{wc_p} = \frac{70}{(5.739)(11)} = 12.197\ K$$

$$LMTD = \frac{(t_c - t_i) - (t_c - t_o)}{\ln\left[\frac{(t_c - t_i)}{(t_c - t_o)}\right]}$$

$$9.009 = \frac{12.197}{\ln\left[\frac{(55 - t_i)}{(55 - t_o)}\right]}$$

$$\frac{55 - t_i}{55 - t_o} = 3.8724$$

$55 - t_i = 3.8724(55 - 12.197 - t_i)$

$t_i = 38.6$ C - - - Ans.

Problem. 2: An air-cooled condenser has an expected U value of 30 $W/m^2.K$ based on the air-side area. The condenser is to transfer 60 kW with an airflow rate of 15 kg/s entering at 35 C. If the condenser temperature is to be 48 C, what is the required air-side area?
Note;

Solution:

$$q = U_o A_o LMTD$$

$$q = wc_p(t_o - t_i)$$

w = 15 kg/s

c_p = 1.0 kJ/kg.K

$$t_o = t_i + \frac{q}{wc_p}$$

$$t_o = 35 + \frac{60}{(15)(1)}$$

t_o = 39 C

$$LMTD = \frac{(t_o - t_i)}{\ln\left[(t_c - t_i)/(t_c - t_o)\right]}$$

$$LMTD = \frac{(39 - 35)}{\ln\left[(48 - 35)/(48 - 39)\right]} = 10.878\ K$$

$$q = U_o A_o LMTD$$

60 kw = (30 / 1000)(A_o)(10.878)

A_o = 184 m^2 - - - Ans.

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Problem. 3: A shell-and-tube condenser has a U value of 800 W/m^2.K based on the water-side are and a water pressure drop of 50 kPa. Under this operating condition 40 percent of the heat-transfer resistance is on the water side. If the water-flow rate is doubled, what will the new U value and the new pressure drop be?

U_1 = 800 W/m2.K

h_1 = Water-side coefficient

$$h_1 = \frac{1}{(0.40)\left(\frac{1}{800}\right)} = 2{,}000$$

Eq. 12-13, replace 0.6 by 0.8 for condenser.

Water-side coefficient = (const)(flow rate)$^{0.8}$

For $w_2 / w_1 = 2$

$$\frac{h_2}{h_1} = \left(\frac{w_2}{w_1}\right)^{0.8}$$

$h_2 = (2000)(2)^{0.8} = 3482.2$ W/m^2.K

Remaining resistance = (0.60)(1 / 800) = 0.00075

New U-Value:

$$\frac{1}{U_2} = \frac{1}{3482.2} + 0.00075$$

U_2 = 964 W/m^2.K - - - Ans.

New Pressure Drop:

$$\Delta p_2 = \Delta p_1 \left(\frac{w_2}{w_1}\right)^2$$

$$\Delta p_2 = (50)(2)^2$$

Δp_2 = 200 kPa - - - Ans.

Problem. 4: What is the UA value of a direct-expansion finned coil evaporator having the following areas: refrigerant side, 15 m^2; air-side prime, 13.5 m^2, and air-side extended, 144 m^2? The refrigerant-side heat-transfer coefficient is 1300 W/m^2.K, and the air-side coefficient is 48 W/m^2.K. The fin effectiveness is 0.64.

Solution: $\eta = 0.64$

$A_i = 15\ m^2$

$h_i = 1300\ W/m^2.K$

$h_f = 48\ W/m^2.K$

$A_p = 13.5\ m^2$

$A_e = 144\ m^2$

Eq. 12-20 neglect tube resistance.

$$\frac{1}{U_o A_o} = \frac{1}{h_f\left(A_p + \eta A_e\right)} + \frac{1}{h_i A_i}$$

$$\frac{1}{U_o A_o} = \frac{1}{(48)(13.5 + 0.64(144))} + \frac{1}{(1300)(15)}$$

$U_o A_o$ = 4,025 W/K - - - Ans.

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Problem. 5: A refrigerant 22 system having a refrigerating capacity of 55 kW operates with an evaporating temperature of 5 C and rejects heat to a water-cooled condenser. The compressor is hermetically sealed. The condenser has a U value of 450 W/m2.K and a heat-transfer area of 18 m2 and receives a flow rate of cooling water of3.2 kg/s at a temperature of 30 C. What is the condensing temperature?

$$H.R.R. = \frac{Q_c}{Q_E}$$

$$Q_c = U A \, LMTD$$

$$LMTD = \frac{(T_c - T_i) - (T_c - T_o)}{\ln \frac{T_c - T_i}{T_c - T_o}}$$

$$H.R.R. = \frac{Q_c}{Q_E}$$

H.R.R. based upon figure 12-12; We can assume H.R.R. at $T_{evap} = 5\ ^\circ C$ within the range [1.25–1.3]

let us assume H.R.R. = 1.27

$$\therefore H.R.R. = \frac{Q_c}{Q_E} \Rightarrow 1.27 = \frac{Q_c}{55}$$

$$\therefore Q_c = 69.85 \text{ kW}$$

Since; $Q_c = U A \, LMTD$ where $U = 450\ W/m^2 K$

Then; $69850 = 450 * 18 * LMTD$

$$\therefore LMTD = 8.62345679\ K$$

According to the Conservation of Energy:

(Heat lost by Condenser) = (Heat absorbed by Water)

$$Q_{cond} = Q_{water} \Rightarrow Q_{cond} = \dot{m} C_w (T_o - T_i)$$

$$69850 = 3.2 * 4200 * (T_o - 30)$$

$$\therefore T_o = 35.19717262\ ^\circ C$$

If $C_w = 4.18$ kJ/kg K, then "T_o" will be $T_o = 35.22203947\ ^\circ C$

Finally;

$$LMTD = \frac{(T_c - T_i) - (T_c - T_o)}{\ln \frac{T_c - T_i}{T_c - T_o}}$$

$$8.6234 = \frac{(T_c - 30) - (T_c - 35.2220)}{\ln \frac{(T_c - 30)}{(T_c - 35.2220)}}$$

$$\Rightarrow T_c = 41.22\ ^\circ C$$

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Problem. 6: Calculate the mean condensing heat-transfer coefficient when refrigerant 12 condenses on the outside of the horizontal tubes in a shell-and-tube condenser. The outside diameter of the tubes is 19 mm, and in the vertical rows of tubes there are respectively, two, three, four, three, and two tubes. The refrigerant is condensing at a temperature of 52 C and the temperature of the tubes is 44 C.

Solution:

Condensing Coefficient: Eq. 12-24.

$$h_{cond} = 0.725\left(\frac{g\rho^2 h_{fg} k^3}{\mu \Delta t N D}\right)^{1/4}$$

Table A-5 at 52 C.

h_{fg} = 370.997 - 251.004 kJ/kg = 119.993 kJ/kg

h_{fg} = 199,993 J/kg

ρ = 1 / (0.83179 L/kg) = 1202 kg/m^3

Table 15-5, Liquid Refrigerant 12

μ = 0.000179 PA.s

k = 0.05932 W/m.K

N = (2 + 3 + 4 + 3 +2) / 5 = 2.8

Δt = 52 C - 44 C = 8 K

g = 9.81 m/s^2

D = 19 mm = 0.019 m

$$h_{cond} = 0.725\left(\frac{(9.81)(1202)^2(119{,}993)(0.05932)^3}{(0.000174)(8)(2.8)(0.019)}\right)^{1/4}$$

h_{cond} = 1065 W/m^2.K - - - Ans.

Problem. 7: A condenser manufacturer guarantees the U value under operating conditions to be 990 W /m^2 • K based on the water-side area. In order to allow for fouling of the tubes, what is the U value required when the condenser leaves the factory?

$$\left(\frac{1}{U_i A_i} = \frac{1}{h_o A_s} + \frac{x}{k A_m} + \frac{1}{h_i A_i} + \frac{1}{h_{ff} \cdot A_i}\right) * A_i$$

$$\frac{1}{U_i} = \boxed{\frac{1}{h_o}\frac{A_i}{A_o} + \frac{x}{k}\frac{A_i}{A_m} + \frac{1}{h_i}} + \frac{1}{h_{ff}} \qquad \boxed{\;} \rightarrow \frac{1}{U_{i\,new}}$$

$$\frac{1}{U_i)_{old}} = \frac{1}{U_i)_{new}} + \frac{1}{h_{ff}}$$

$$\frac{1}{990} = \frac{1}{U_i)_{new}} + 0.000176$$

$$\Rightarrow U_i)_{new} = 1198.895563 \ W/m^2 \cdot K$$