열교환기 설계 예제

참고도서: 공기조화 및 냉동, Prentice Hall, 김무환, 강희찬 외

예제 11.1

93.3°C에서 75.6°C로 변화하는 고온수에 의해 습공기가 21.1°C에서 65.6°C로 가열되고 있다. 만약 열교환기의 형태가 다음과 같을 때 실제 평균온도차를 구하시오. (a) 순수 대향류, (b) 1열 관을 갖는 순수 교차류, (c) 4열 관을 가진 순수 교차류, (d) 2열의 관 경로를 가진 대향류

풀이

Symbol	Unit	Value	Equation	Note
$t_{h.i}$	°C	93.3		Inlet temperature of hot fluid
$t_{h.o}$	°C	75.6		Outlet temperature of hot fluid
$t_{c.i}$	°C	21.1		Inlet temperature of cold fluid
$t_{c.o}$	°C	65.6		Outlet temperature of cold fluid
Δt_1	°C	54.5	$\Delta t_1 = t_{h,o} - t_{c,i}$	Temperature difference 1
Δt_2	°C	27.7	$\Delta t_2 = t_{h,i} - t_{c,o}$	Temperature difference 2
(a)				
Δt_{mcf}	°C	39.6	$\Delta t_{m,cf} = \frac{\Delta t_1 - \Delta t_2}{\ln(\Delta t_1/\Delta t_2)}$	Mean temperature difference
F	-	1.00		Temperature correction factor for counter flow
(b)				
R	-	0.40	$R = \frac{t_{h,i} - t_{h,o}}{t_{c,o} - t_{c,i}}$	Parameter
P	-	0.62	$P = \frac{t_{c,o} - t_{c,i}}{t_{h,i} - t_{c,i}}$	Parameter

F_{CF}	-	0.92	$F=\dfrac{\ln\left[\dfrac{1-P}{1-RP}\right]}{(R-1)\ln\left[\dfrac{R}{R+\ln(1-RP)}\right]}$	Temperature correction factor for cross-flow
$\Delta t_{m,CF}$	^{o}C	36.2		Mean temperature difference

예제 11.1의 해설

Case	Method of solution	F	Δt_m
(a) 순수 대향류	Eq. (11.1)	1.00	39.6
(b) 1열 관을 갖는 순수 교차류	Fig. 11.5	0.92	36.2
(c) 4열 관을 가진 순수 교차류	Fig. 11.6	0.94	37.2
(d) 2열의 관 경로를 가진 대향류	Fig. 11.7	0.99	39.2

예제 11.2

건구온도 10^{o}C 인 습포화증기는 교차류 열교환기에서 고온수에 의하여 가열되며, 물은 혼합되고 공기는 비혼합이라고 가정한다. 물은 60^{o}C에서 20 L/s의 유량으로 들어오고 있다. 공기의 체적유량은 30 m^3/s 이다. 만약 열교환기의 U_oA_o=100 kW/^{o}C 인 경우 공기와 물의 출구온도를 구하여라.

풀이

Symbol	Unit	Value	Equation	Note
V_a	m^3/s	30.0		Volume flow rate of air
v_s	m^3/kg	0.8116		Specific volume of air
W	kg$_w$/kg$_a$	0.007661	예제 8.4 참조	Humidity ratio
c_{pa}	kJ/kg.K	1.00		Specific heat of air
c_{pw}	kJ/kg.K	1.86		Specific heat of vapor
m_ac_{pa}	kW/^{o}C	37.5	$m_ac_{pa}=\dfrac{V_a(c_{pa}+c_{pw}W)}{v_s}$	Heat capacity of air
V_w	m^3/s	0.02		Volume flow rate of water

v_w	m^3/kg	0.001017		Specific volume of water
c_{pl}	kJ/kg.K	4.187		Specific heat of liquid
$m_w c_{pw,f}$	kW/^oC	82.3	$m_w c_{pw,f} = \frac{V_w c_{pw,f}}{v_w}$	Heat capacity of water

$c_{\min}$	kW/^oC	37.5		Minimum heat capacity
$c_{\max}$	kW/^oC	82.3		Maximum heat capacity
c_r	-	0.455	$c_r = \frac{c_{\max}}{c_{\min}}$	Ratio of C

$U_o A_o$	kW/^oC	100.0		U times A
NTU	-	2.67	$\mathrm{NTU} = \frac{U_o A_o}{c_{\min}}$	Number of heat Transfer Unit

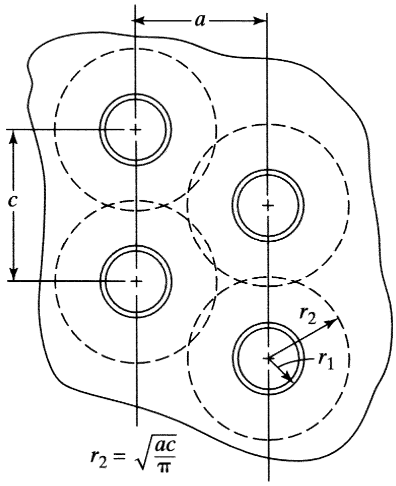
ε	-	0.759	$\varepsilon = \frac{1}{c_r}\left[1 - \exp\left(-c_r\left[1 - \exp\left[-\mathrm{NTU}\right]\right]\right)\right]$	Thermal effectiveness

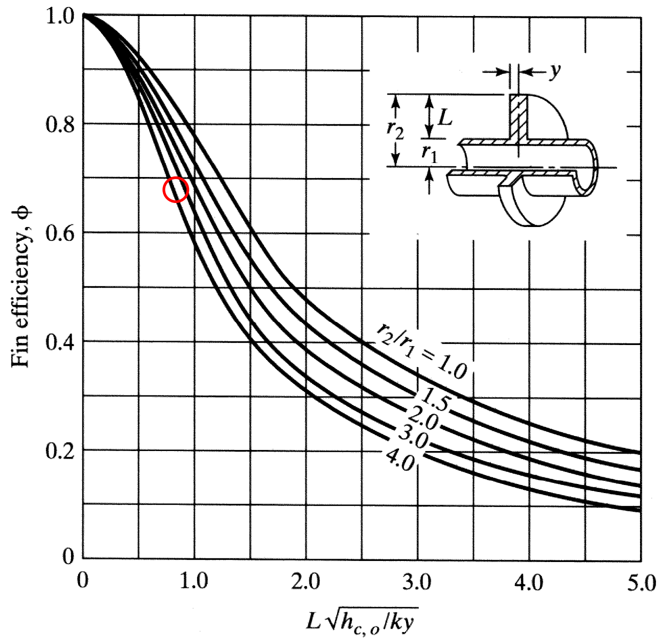
$t_{h,i}$	^oC	60.0		Inlet temperature of water
$t_{c,i}$	^oC	10.0		Inlet temperature of air
$t_{c,o}$	^oC	47.9	$\varepsilon = \frac{t_{c,o} - t_{c,i}}{t_{h,i} - t_{c,i}}$	Outlet temperature of air
$t_{h,o}$	^oC	42.7	$m_a c_{pa}\left(t_{c,o} - t_{c,i}\right) = m_w c_{pw,f}\left(t_{h,i} - t_{h,o}\right)$	Outlet temperature of water

예제 11.3

공기 가열코일은 구리 관에 사각형 휜을 부착하여 만들어 졌다. 관은 여러 열로 배열되어 있다. 물리적 자료는 다음과 같다. a = 0.043 m, c = 0.0381 m, x_p = 0.71 mm, r_1 = 6.34 mm, 2y = 0.254 mm, P_f = 3.175 mm, $A_{p,i}$ = 0.0354 m^2/m, $A_{p,o}$ = 0.0368 m^2/m, $A_{p,m}$ = 0.0375 m^2/m, A_F = 0.948 m^2/m, 그리고 A_o = 0.985 m^2/m. (a) 만약 $h_{c,o}$ = 56.8 W/m^2·K, h_i = 3407 W/m^2·K 그리고 휜 재질이 알루미늄인 경우 각각의 열저항과 총괄열전달계수를 구하시오. (b) 휜의 재질이 구리인 경우 (a)를 다시 계산하시오. (c) $h_{c,o}$ = 28.4 W/m^2·K 일

때 (a)를 다시 계산하시오. (d) h_i = 6814 W/m^2·K 일 때 (a)를 다시 계산하시오.





풀이

Symbol	Unit	(a)	(b)	(c)	(d)	Note	Equation
a	m	0.0430	0.0430	0.0430	0.0430	Row pitch	
c	m	0.0381	0.0381	0.0381	0.0381	Tube pitch	
r_1	m	0.00634	0.00634	0.00634	0.00634	Radius of tube	
r_2	m	0.0228	0.0228	0.0228	0.0228	Radius of fin	$r_2 = \sqrt{ac/\pi}$
L	m	0.0165	0.0165	0.0165	0.0165	Fin height	
x_p	m	0.00071	0.00071	0.00071	0.00071	Tube wall thickness	
y	m	0.000127	0.000127	0.000127	0.000127	Fin thickness	
r_2/r_1	-	3.60	3.60	3.60	3.60		

k_p	W/m·K	207.7	385.9	207.7	207.7	Conductivity of fin	
$h_{c,o}$	W/m·K	56.8	56.8	28.4	56.8	Tube outside h	
h_i	W/m·K	3407	3407	3407	6814	Tube inside h	

mL	-	0.765	0.562	0.541	0.765		$mL = L\sqrt{h_{c,o}/ky}$
ϕ	-	0.73	0.83	0.84	0.73	Fin efficiency	Fig. 11.11

$A_{p,i}$	m^2/m	0.0354	0.0354	0.0354	0.0354	Tube inside area	
$A_{p,o}$	m^2/m	0.0368	0.0368	0.0368	0.0368	Tube outside area	
$A_{p,m}$	m^2/m	0.0375	0.0375	0.0375	0.0375	Tube average area	
A_F	m^2/m	0.948	0.948	0.948	0.948	Fin area	
A_o	m^2/m	0.985	0.985	0.985	0.985	Outside area	
$A_{p,o}/A_F$	-	0.0388	0.0388	0.0388	0.0388	Area ratio	

R_i	$m^2 \cdot K/W$	0.00817	0.00817	0.00817	0.00408	Resistance of tube Inside	$R_i = A_o / A_{p,i} h_i$
R_p	$m^2 \cdot K/W$	0.000090	0.000048	0.000090	0.000090	Resistance of Pipe wall	$R_p = A_o x_p / A_{p,m} k_p$
R_F	$m^2 \cdot K/W$	0.00618	0.00344	0.00641	0.00618	Resistance of Fin	$R_F = \frac{1}{h_{c,o}} \left(\frac{1-\phi}{\phi + A_{p,o}/A_F} \right)$
R_o	$m^2 \cdot K/W$	0.0176	0.0176	0.0352	0.0176	Resistance of tube Outside	$R_o = 1/h_{c,o}$
R_t	$m^2 \cdot K/W$	0.0320	0.0293	0.0499	0.0280	Total resistance	$R_t = \sum R$

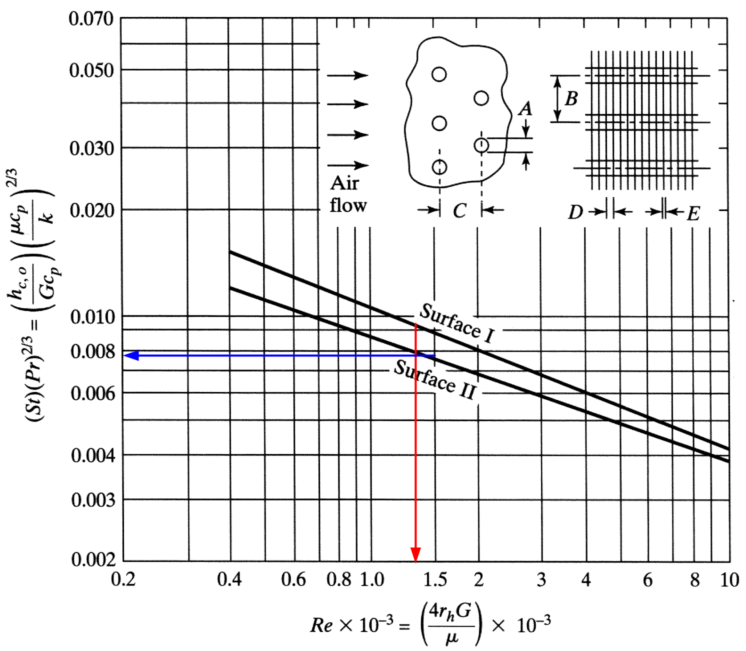
$\%R_i$	-	25.5%	27.9%	16.4%	14.6%	% of R_i in R_t	
$\%R_p$	-	0.28%	0.17%	0.18%	0.32%	% of R_P in R_t	
$\%R_F$	-	19.3%	11.8%	12.9%	22.1%	% of R_F in R_t	
$\%R_o$	-	54.9%	60.2%	70.6%	63.0%	% of R_o in R_t	

U_o	W/m·K	31.2	34.2	20.0	35.8	Overall h	$U_o = 1/R_t$

예제 11.4

-6.7 °C의 포화공기가 5.66 m^3/s 로 통과하여 최종온도 65.5°C 가 되도록 열교환기를 설치하고자 한다. 가열매체는 34483 Pa에서 응축하는 건조-포화증기 이다. 대기압은 96552 Pa 이다. 표 11.5의 유형 II 표면에 구리 관과 알루미늄 휜을 사용한다. 공기의 입구 면속도는 2.54 m/s 이다. (a) 요구되는 코일의 전면적을 구하시오. (b) 요구되는 총 외부면적을 구하시오. (c) 요구되는 관의 열수를 구하시오. (d) 증기 응축액의 포화액 상태로 코일에서 유출된다고 할 때 요구되는 증기의 질량유량을 구하시오.

풀이



Symbol	Unit	SI value	Note	Equation
A	m	0.0172	tube outside diameter	
B	m	0.0381	tube spacing across face	
C	m	0.04450	tube spacing between rows	
D	m	0.00382	spacing of fins	
E	m	0.0004	thickness of aluminum fins	
D_h	m	0.00032	flow passage hydraulic diameter	$4r_h$
$A_{o,1}$	-	22.86	external surface/face area	
$A_o/A_{p,i}$	-	19.31	external surface/internal surface	
A_c/A_{fr}	-	0.497	minimum flow area/face area	
A_F/A_o	-	0.905	fin surface/external surface	

$A_{p,o}/A_F$	-	0.105	fin surface/external surface	
(a)				
A_{fr}	m^2	2.23	face area	$A_{fr} = \dot{V}/u_{fr}$
(b)				
$t_{h,i}$	^oC	107.3	inlet temperature of hot vapor	
$t_{c,i}$	^oC	-6.67	inlet temperature of cold air	
$t_{h,o}$	^oC	107.3	outlet temperature of hot vapor	
$t_{c,o}$	^oC	65.6	outlet temperature of cold air	
Δt_1	^oC	41.8	inlet temperature difference	$\Delta t_1 = t_{h,i} - t_{c,o}$
Δt_2	^oC	114.0	outlet temperature difference	$\Delta t_2 = t_{h,o} - t_{c,i}$
Δt_m	^oC	71.9	mean temperature difference	$\frac{\Delta t_1 - \Delta t_2}{\ln(\Delta t_1/\Delta t_2)}$
F	-	1.0	temperature correction factor	cross flow @ $\varepsilon = 1$

$\dot{V}$	m^3/s	5.66	volume flow rate	
P_o	Pa	96552	ambient pressure	
$P_{sat,g}$	Pa	34483	gauge pressure	
P	Pa	131034	steam pressure	
u_{fr}	m/s	2.54	frontal velocity	
h_i	$W/m^2 \cdot K$	6814	tube inside h	Eq. (2.63)
$h_{d,i}$	$W/m^2 \cdot K$	11357	tube inside h	Table 2.3

t_m	^oC	35.4	mean temperature of air for air properties	$t_m = t_{h,i} - \Delta t_m$
μ	Pa·s	0.0000189	viscosity of air	
c_p	J/kg·K	1009	specific heat of air	
Pr	-	0.706	Prandtl number of air	
W_1	kg_w/kg_a	0.00225	specific humidity of air	예제 11.2 참조
v_1	m^3/kg_a	0.795	specific volume of dry air	
ρ_1	kg_a/m^3	1.26	density of air	$\rho_1 = \frac{1+W_1}{v_1}$

$\dot{m}_a$	kg/s	7.14	mass flow rate of air	$\dot{m} = \rho_1 \dot{V}$
G	kg/s·m^2	6.44	mass velocity of air	$G = \frac{\dot{m}_a}{A_c}$
Re	-	1318	Reynolds number of air	$\frac{GD_h}{\mu}$
j	-	0.0078	j factor	Fig. 11.15
$h_{c,o}$	W/m^2·K	64	tube inside h	$\mathrm{j} = \frac{h_{c,o}\,\mathrm{Pr}^{2/3}}{Gc_p}$
r_1	m	0.00860	radius of tube	$A/2$
r_2	m	0.0232	radius of fin	
r_2/r_1	-	2.70	radius ratio	
k_{fin}	W/m·K	207.7	conductivity of fin	
y	m	0.00021	half of fin thickness	$E/2$
L	m	0.0146	fin height	$L = r_2 - r_1$
mL	-	0.567	parameter for fin	$mL = L\sqrt{h_{c,o}/ky}$
ϕ	-	0.86	fin efficiency	Fig. 11.11
U_o	W/m^2·K	44.5	overall heat transfer coefficient	Eq. (11.40)
Q	W	520153	heat transfer rate	$\dot{m}_a c_{pa}\left(t_{c,o} - t_{c,i}\right)$
A_o	m^2	162	external surface area	$\frac{Q}{U_o \Delta t_m}$
(c)				
N_{row}	#	3.2	number of row	
(d)				
$h_{fg,s}$	J/kg	2.23E+06	latent heat of steam	
$m_{dot,s}$	kg/s	0.23	mass flow rate of steam	$\frac{Q}{h_{fg,s}}$

$$U_o = \frac{1}{\dfrac{A_o}{A_{p,i} h_i} + \dfrac{A_o}{A_{p,i} h_{d,i}} + \dfrac{1-\phi}{h_{c,o}(A_{p,o}/A_F + \phi)} + \dfrac{1}{h_{c,o}}}$$

예제 11.5

예제 11.4와 동일한 문제로 가정하되 가열매체로 고온수를 이용한다. 물은 93.3 ^oC로 코일에 들어가 82.2 ^oC로 나온다고 가정한다. 그림 11.3(b)의 대향교차류 배열과 유사하다고 가정한다. 전면적이 2.23 m^2 이므로 코일의 높이는 1.22 m 이고 길이는 1.83 m 로 가정한다. 요구되는 물의 유량을 구하시오. (b) 요구되는 외부표면적을 구하시오. (c) 요구되는 관의 길이를 구하시오.

풀이

Symbol	Unit	SI value	Note	Equation
Geometry				
A	m	0.0172	tube outside diameter	
B	m	0.0381	tube spacing across face	
C	m	0.04450	tube spacing between rows	
D	m	0.00382	spacing of fins	
E	m	0.0004	thickness of aluminum fins	
D_h	m	0.00032	flow passage hydraulic diameter	$4r_h$
H_{HEX}	m	1.22	height of tube	
L_{HEX}	m	1.83	length of tube	
$A_{o,1}$	-	22.86	external surface/face area	
$A_o/A_{p,i}$	-	19.31	external surface/internal surface	
A_c/A_{fr}	-	0.497	minimum flow area/face area	
A_F/A_o	-	0.905	fin surface/external surface	
$A_{p,o}/A_F$	-	0.105	fin surface/external surface	
A_{face}	m^2	2.23	face area	
(a)				
$t_{h,i}$	^oC	93.3	inlet temperature of hot water	
$t_{c,i}$	^oC	-6.67	inlet temperature of cold air	
$t_{h,o}$	^oC	82.2	outlet temperature of hot water	
$t_{c,o}$	^oC	65.6	outlet temperature of cold air	
Δt_1	^oC	27.8	inlet temperature difference	$\Delta t_1 = t_{h,i} - t_{c,o}$

Δt_2	^oC	88.9	outlet temperature difference	$\Delta t_2 = t_{h,o} - t_{c,i}$
Δt_m	^oC	52.5	mean temperature difference	$\frac{\Delta t_1 - \Delta t_2}{\ln(\Delta t_1 / \Delta t_2)}$
Water				
Q	W	520633	heat transfer rate	
$c_{p,wa}$	J/kg.K	4187	specific heat of water	
$m_{dot,wa}$	kg/s	11.2	mass flow rate of water	
ρ_{wa}	kg_{wa}/m^3	968	density of water	
c_{wa}	W/K	46857	heat flow capacity of water	
$V_{dot,wa}$	m^3/s	0.0116	volume flow rate of water	
Air				
$V_{dot,a}$	m^3/s	5.66	volume flow rate of air	
ρ_a	kg_a/m^3	1.26	specific volume of air	$\rho_a = \frac{1+W_1}{v_1}$
$c_{p,a}$	J/kg.K	1009	specific heat of air	
$m_{dot,a}$	kg/s	7.14	mass flow rate of air	$\dot{m} = \rho_1 \dot{V}$
c_a	W/K	7202	heat flow capacity of air	

c_r	-	0.154	ratio of C	$c_r = c_{\min} / c_{\max}$
ε	-	0.723	thermal effectiveness	$\varepsilon = Q / Q_{\max}$
NTU	-	1.377	number of heat transfer unit	$\mathrm{NTU} = \frac{\ln\left(\frac{1-c_r\varepsilon}{1-\varepsilon}\right)}{1-c_r}$

N_{tube}	#/row	32	number of tube	$N_{tube} = H_{HEX} / B$
d_i	m	0.014	tube inner diameter	$d_i = \frac{A_{o,1} A_{face}}{A_o \pi L_{HEX} N_{tube} / A_{pi}}$
A_w	m^2/row	0.00518	inner cross area	$A_w = \frac{\pi d_i^2 N_{tube}}{4}$

V_{wa}	m/s	2.23	velocity of water	$V_{wa}=\frac{V_{dot,wa}}{A_w}$
k_{wa}	W/m.K	0.675	conductivity of water	
μ_{wa}	Pa.s	0.000313	viscosity of water	
Re_{wa}	-	99226	Reynolds number of water	$\mathrm{Re}_{wa}=\frac{\rho_{wa}V_{wa}d_i}{\mu_{wa}}$
Pr_{wa}	-	1.94	Prandtl number of water	
Nu_{wa}	-	279	Prandtl number of water	$\mathrm{Nu}_{wa}=0.023\mathrm{Re}_{wa}^{0.8}\mathrm{Pr}_{wa}^{0.3}$
$h_{c,i}$	$\mathrm{W/m^2.K}$	13104	tube inside h	$h_{c,i}=\frac{\mathrm{Nu}_{wa}k_{wa}}{d_i}$
Fouling				
$h_{d,i}$	$\mathrm{W/m^2.K}$	11357	tube inside h	
Air				
V	m/s	2.54	frontal velocity	
t_m	^{o}C	40.8	mean temperature of air	$t_m=t_{h,i}-\Delta t_m$
μ	Pa.s	0.0000189	viscosity of air	
Pr	-	0.706	Prandtl number of air	
W_1	$\mathrm{kg_w/kg_a}$	0.00225	specific humidity of air	예제 11.2 참조
v_1	$\mathrm{m^3/kg_a}$	0.795	specific volume of air	
G	$\mathrm{kg/s.m^2}$	6.44	mass velocity of air	$G=\frac{\dot{m}_a}{A_c}$
Re	-	1318	Reynolds number of air	$\frac{GD_h}{\mu}$
j	-	0.0078	j factor	Fig. 11.15
$h_{c,o}$	$\mathrm{W/m^2.K}$	64	tube inside h	$\mathrm{j}=\frac{h_{c,o}\mathrm{Pr}^{2/3}}{Gc_p}$
r_1	m	0.00860	radius of tube	$A/2$
r_2	m	0.0232	radius of fin	
r_2/r_1	-	2.70	radius ratio	
k_{fin}	W/m.K	207.7	conductivity of fin	
y	m	0.00021	half of fin thickness	$E/2$

L	m	0.0146	fin height	$L = r_2 - r_1$
mL	-	0.567	parameter for fin	$L = r_2 - r_1$
ϕ	-	0.86	fin efficiency	Fig. 11.11
Over all				
U_o	W/m^2.K	47.4	overall heat transfer coefficient	Eq. (11.40)
Q	W	520153	heat transfer rate	$\dot{m}_a c_{pa}\left(t_{c,o} - t_{c,i}\right)$
A_o	m^2	209	external surface area	$\dfrac{Q}{U_o \Delta t_m}$
(c)				
N$_{\text{row}}$	#	4.1	number of row	$\text{N}_{row} = \dfrac{A_o}{A_{o,i} A_{face}}$

$$U_o = \frac{1}{\dfrac{A_o}{A_{p,i} h_i} + \dfrac{A_o}{A_{p,i} h_{d,i}} + \dfrac{1-\phi}{h_{c,o}(A_{p,o}/A_F + \phi)} + \dfrac{1}{h_{c,o}}}$$

예제 11.6

예제 11.3과 동일한 열전달 표면은 습공기를 냉각하고 제습하는데 사용된다. 공기상태는 건구온도 26.7 ^{o}C, 열역학적 습구온도 20.0 ^{o}C, 대기압 101325 Pa 이다. 냉매온도는 7.2 ^{o}C 이다. 외부표면을 덮고 있는 수막의 평균두께는 0.000127 m로 가정한다. (a) 만약 $h_{c,o}$ = 56.8 W/m^2·K, h_i = 3407 W/m^2·K, 휜 재질은 알루미늄 이며 k_F = 207.7 W/m·K 일 때 각각 열저항과 총괄열전달계수를 구하시오. (b) 구리 휜에서 k_F = 385.9 W/m·K 이고 나머지는 (a)와 동일하다. (c) $h_{c,o}$ = 28.4 W/m^2·K 이고 나머지는 (a)와 동일하다. (d) h_i = 6814 W/m^2·K 이고 나머지는 (a)와 동일하다.

풀이

Symbol	Unit	(a)	(b)	(c)	(d)	Note	참고사항
a	m	0.0430	0.0430	0.0430	0.0430	row pitch	
c	m	0.0381	0.0381	0.0381	0.0381	tube pitch	
r_1	m	0.00634	0.00634	0.00634	0.00634	radius of tube	
r_2	m	0.0228	0.0228	0.0228	0.0228	radius of fin	

L	m	0.0165	0.0165	0.0165	0.0165	fin height	
x_p	m	0.00071	0.00071	0.00071	0.00071	tube wall thickness	
y	m	0.000127	0.000127	0.000127	0.000127	fin thickness	
r_2/r_1	-	3.60	3.60	3.60	3.60		
y_w	m	0.000127	0.000127	0.000127	0.000127	film thickness	

t_p	^oC	12.8	12.8	12.8	12.8	pipe temperature	가정
t_R	^oC	7.2	7.2	7.2	7.2	refrigerant temperature	
$h_{s,P}$	kJ/kg	36.2	36.2	36.2	36.2	h_s of saturated air at t_P	
$h_{s,R}$	kJ/kg	23.1	23.1	23.1	23.1	h_s of saturated air at t_R	
b_R'	kJ/kg^{o}C	2.36	2.36	2.36	2.36	dh/dt	

$t_{w,m}$	^oC	15.6	15.6	15.6	15.6	assume fin temperature	가정
$b_{w,m}$	kJ/kg^{o}C	2.87	2.87	2.87	2.87	dh/dt	
W	kg_w/kg_a	0.01	0.01	0.01	0.01	assume W	
c_{pa}	J/kg_a.K	1.02	1.02	1.02	1.02	specific heat of air	
k_w	W/m.K	0.592	0.592	0.592	0.592	conductivity of water	
k_{fin}	W/m.K	207.7	385.9	207.7	207.7	conductivity of fin	
$h_{c,o}$	W/m^2.K	56.8	56.8	28.4	56.8	tube outside h	
$h_{o,w}$	W/m^2.K	154.5	154.5	78.6	154.5	tube outside h	
h_i	W/m^2.K	3407	3407	3407	6814	tube inside h	
mL	-	1.26	0.93	0.90	1.26		
mr_iF	-	1.83	1.34	1.30	1.83		
ϕ_w	-	0.52	0.65	0.66	0.52	fin efficiency	$\phi_w = \frac{\tanh(mr_1\psi)}{mr_1\psi}$
h	kJ/kg	57.02	57.02	57.02	57.02	h at inlet	
t_p	^oC	12.4	13.1	11.0	10.4	pipe temperature	
$h_{s,w,m}$	kJ/kg	46.1	44.4	40.7	43.7	h_s at $t_{w,m}$	
$t_{w,m}$	^oC	16.4	15.8	14.5	15.6	confirm of fin temperature	가정 확인

$A_{p,i}$	m^2/m	0.0354	0.0354	0.0354	0.0354	tube inside area	
$A_{p,o}$	m^2/m	0.0368	0.0368	0.0368	0.0368	tube outside area	
$A_{p,m}$	m^2/m	0.0375	0.0375	0.0375	0.0375	tube average area	
A_F	m^2/m	0.948	0.948	0.948	0.948	fin area	
A_o	m^2/m	0.985	0.985	0.985	0.985	outside area	
$A_{p,o}/A_F$	-	0.0388	0.0388	0.0388	0.0388	area ratio	

$R_{i,w}$	m^2.kJ/W.kg	0.01923	0.01923	0.01923	0.00962	resistance of tube Inside	
$R_{F,w}$	m^2.K/W	0.01598	0.00943	0.01763	0.01598	resistance of fin	
$R_{o,w}$	m^2.K/W	0.0186	0.0186	0.0365	0.0186	resistance of tube outside	
$R_{t,w}$	m^2.K/W	0.0538	0.0472	0.0734	0.0441	total resistance	

$\%R_{i,w}$	-	35.8%	40.7%	26.2%	21.8%	% of R_i in R_t	백분율
$\%R_{F,w}$	-	29.7%	20.0%	24.0%	36.2%	% of R_F in R_t	백분율
$\%R_{o,w}$	-	34.5%	39.3%	49.7%	42.0%	% of R_o in R_t	백분율

$U_{o,w}$	W/m^2.K	18.6	21.2	13.6	22.7	overall h	

$$\psi = (r_2/r_1 - 1)[1 + 0.35\ln(r_2/r_1)]$$

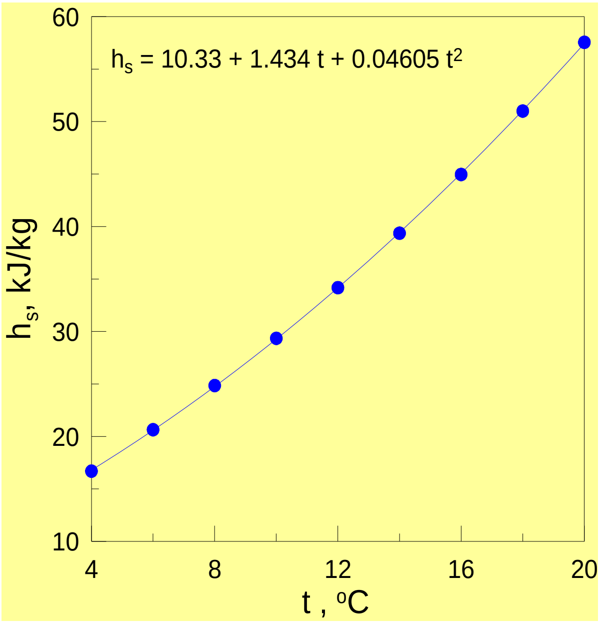


Fig. 1. 온도와 포화습공기의 엔탈피의 관계

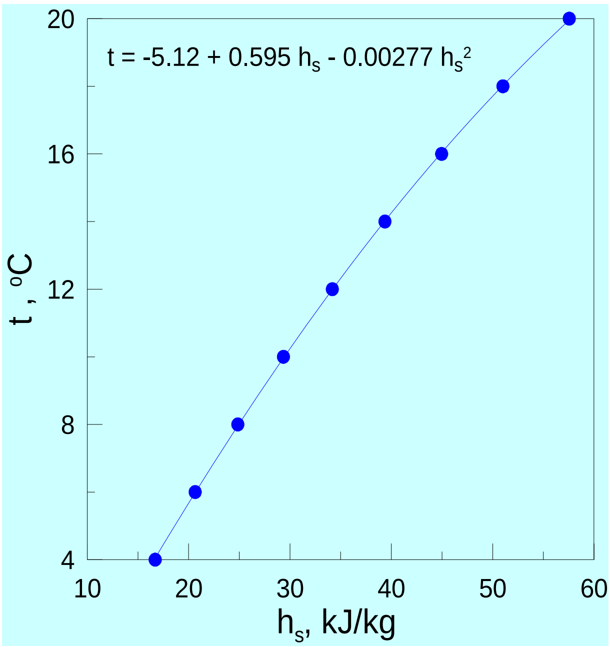


Fig. 2. 포화습공기의 엔탈피와 온도와 관계

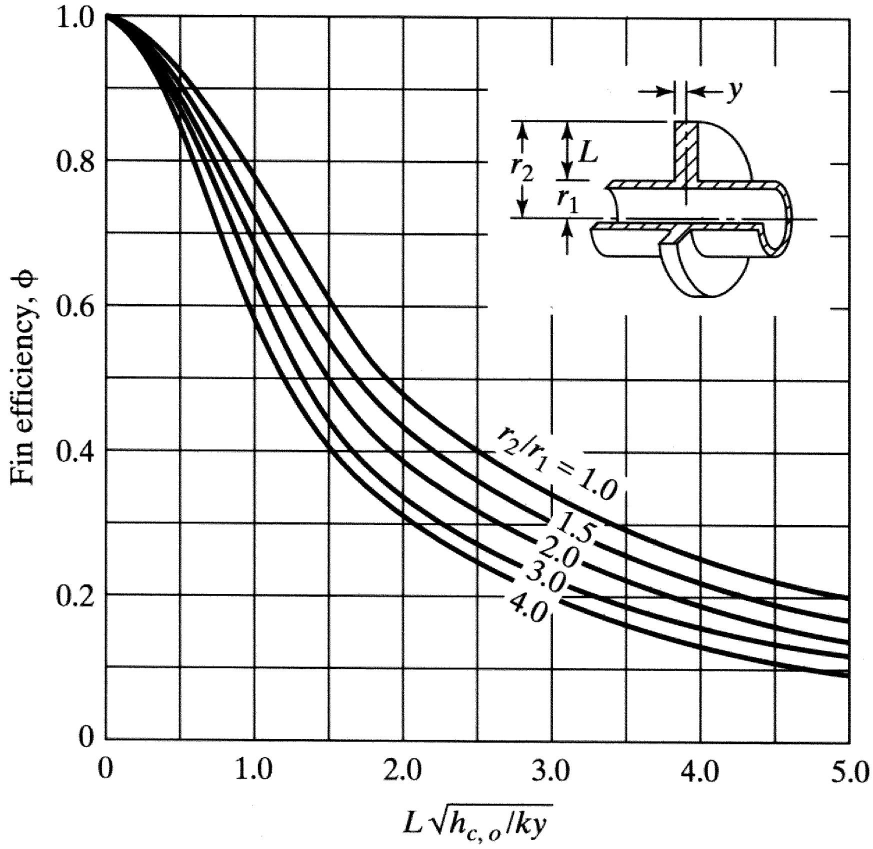


Fig. 11.11. 원형휜의 휜효율