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Appendix A

CALIBRATION DATA

Part I Calibration of Orifice Meters

1. Calibration of hot water orifice meter

Manometer reading (Δ h) cm.Hg	Amount of water kgs/min
6.0	15.53
5.0	14.84
4.0	13.71
3.0	11.87
2.0	9.59
1.0	6.26

2. Calibration of cold water orifice meter

Manometer reading (Δ h) cm.Hg	Amount of water kgs/min
4.0	14.83
3.5	13.82
3.0	13.16
2.5	11.66
2.0	10.51
1.0	7.23

Part 2 Calibration of Cu-Constantan Thermocouple

References junction at $0^{\circ}C$

Temperature $^{\circ}C$ (ΔT)	Emf (mv)
0	0
10	0.389
20	0.787
30	01.194
40	1.610
50	2.035
60	2.467
70	2.908
80	3.357
90	3.813
100	4.277
110	4.749
120	5.227

Appendix B

EXPERIMENTAL DATA

Part I Effect of Cycle Time on Heat Transfer Coefficients

a) Inlet hot water temperature 82°C

Fraction open	cycle time (seconds)	t_{c_1} °C	t_{h_1} °C	t_{c_2} °C	t_{h_2} °C
1.0	-	23.0	78.0	39.5	83.0
0.7	6.1	23.0	60.5	39.0	82.0
	10.0	25.0	62.5	33.5	82.0
	13.0	26.5	61.5	38.0	82.0
0.6	6.1	23.0	61.5	42.0	83.0
	10.0	25.5	65.0	40.0	83.0
	13.0	28.5	67.5	48.0	83.0
0.5	6.1	23.5	66.0	41.0	82.0
	10.0	26.0	65.0	44.0	83.0
	13.0	28.0	60.0	42.0	83.0

where t_{c_1} = inlet temperature of cold water

t_{c_2} = outlet temperature of cold water

t_{h_1} = Outlet temperature of hot water

t_{h_2} = inlet temperature of hot water

b) Inlet hot water temperature 72°C

Fraction Open	cycle time (seconds)	t_{c_1} °C	t_{h_1} °C	t_{c_2} °C	t_{h_2} °C
1.0	-	23.0	66.5	33.0	71.0
0.7	6.1	23.5	61.5	34.5	72.0
	10.0	25.5	58.0	36.0	72.0
	13.0	26.5	62.5	40.0	73.0
0.6	6.1	23.5	60.5	36.5	72.0
	10.0	25.5	58.5	33.0	73.0
	13.0	27.0	64.0	41.0	72.0
0.5	6.1	22.5	60.0	36.0	72.0
	10.0	26.0	61.0	39.5	73.0
	13.0	28.0	63.0	40.0	72.0

Part II Effect of Reynolds Number Upon Heat Transfer Coefficients

a) Inlet hot water temperature 82°C

Fraction open 0.5

i) cycle time 6.1 seconds

Cold water Reynolds No.	Hot water Reynolds No.	t_{c_1} °C	t_{h_1} °C	t_{c_2} °C	t_{h_2} °C
1173.0	3789	25.5	68.0	41.0	82.0
	3620	23.5	67.0	40.5	82.0
	3344	23.5	66.0	39.0	82.0
	2896	23.0	64.5	37.0	82.0
1041.0	3789	23.5	68.0	42.0	82.0
	3620	23.5	66.0	41.0	82.0
	3344	23.0	67.0	41.0	82.0
	2896	23.0	66.0	40.0	82.0
922.0	3789	23.5	68.0	42.0	82.0
	3620	23.5	66.0	40.0	82.0
	3344	23.0	65.0	40.0	82.0
	2896	23.0	65.5	38.0	82.0

ii) cycle time 10.0 seconds

Cold water Reynolds No.	Hot water Reynolds No.	t_{c_1} °C	t_{h_1} °C	t_{c_2} °C	t_{h_2} °C
1173	3789	26.0	68.0	46.0	82.0
	3620	26.0	65.0	44.0	83.0
	3344	26.0	66.0	42.0	83.0
	2896	26.0	62.0	39.0	83.0
1041	3789	26.0	69.0	49.5	83.0
	3620	26.0	66.0	47.0	83.0
	3344	26.0	65.5	45.5	82.0
	2896	26.0	65.0	44.5	83.0
922	3789	26.0	68.5	44.5	83.0
	3620	26.0	64.0	41.0	83.0
	3344	26.0	60.5	40.0	83.0
	2896	26.0	62.0	38.0	83.0

iii) cycle time 13 seconds

Cold water Reynolds No.	Hot water Reynolds No.	t_{c_1} °C	t_{h_1} °C	t_{c_2} °C	t_{h_2} °C
1173	3789	28.0	61.0	43.0	83.0
	3620	28.0	60.0	42.0	83.0
	3344	28.0	62.0	42.0	82.0
	2896	28.0	62.5	41.0	82.0
1041	3789	28.0	71.0	47.0	82.0
	3620	28.0	59.0	39.0	83.0
	3344	28.0	55.0	39.0	83.0
	2896	28.0	56.0	38.0	83.0
922	3789	28.0	68.5	41.0	82.0
	3620	28.0	59.0	41.0	83.0
	3344	28.0	58.0	36.0	83.0
	2896	28.0	58.0	35.0	83.0

b) Inlet hot water temperature 72°C,

Fraction open 0.7

i) cycle time 6.1 seconds

Cold water Reynolds No.	Hot water Reynolds No.	t_{c_1} °C	t_{h_1} °C	t_{c_2} °C	t_{h_2} °C
1457	5133	23.5	62.0	35.0	73.0
	4904	23.5	63.0	35.0	73.0
	4531	23.5	60.0	33.0	73.0
	3924	23.5	56.5	39.0	73.0
1535	5133	23.5	63.5	39.0	73.0
	4904	23.5	62.5	39.0	73.0
	4531	23.5	62.0	36.0	73.0
	3924	23.5	65.0	37.0	73.0
1642	5133	23.5	61.5	34.5	72.0
	4904	23.5	63.5	34.5	73.0
	4531	23.5	59.0	33.0	73.0
	3924	23.5	63.5	28.0	72.0

ii) cycle time 10 seconds

Cold water Reynolds No.	Hot water Reynolds No.	t_{c_1} °C	t_{h_1} °C	t_{c_2} °C	t_{h_2} °C
1457	5133	25.5	56.5	39.5	73.0
	4904	25.5	52.5	32.0	73.0
	5431	25.5	55.0	35.0	73.0
	3924	25.5	46.0	34.0	73.0
1535	5133	25.5	53.0	38.0	73.0
	4904	25.5	55.0	39.0	73.0
	4531	25.5	47.0	36.0	73.0
	3924	25.5	53.0	35.0	73.0
1642	5133	25.5	58.0	43.0	73.0
	4904	25.5	56.5	46.5	73.0
	4531	25.5	58.0	31.0	73.0
	3924	25.5	46.0	35.0	73.0

iii) cycle time 13 seconds

Cold water Reynolds No.	Hot water Reynolds No.	t_{c_1} °C	t_{h_1} °C	t_{c_2} °C	t_{h_2} °C
1457	5133	26.5	62.5	40.0	73.0
	4904	26.5	59.0	36.0	72.0
	4531	26.5	56.0	35.0	73.0
	3924	26.5	56.0	33.0	72.0
1535	5133	26.5	59.0	38.0	72.0
	4904	26.5	58.0	37.0	73.0
	4531	26.5	56.0	37.0	73.0
	3924	26.5	56.0	36.0	73.0
1642	5133	26.5	59.0	38.0	73.0
	4904	26.5	59.5	38.0	73.0
	4531	26.5	55.0	35.0	72.0
	3924	26.5	53.0	33.0	72.0

Part III Effect of Fraction Open Upon Heat Transfer Coefficients

a) Inlet hot water temperature 82°C

cycle time (seconds)	fraction open	t_{c_1} °C	t_{h_1} °C	t_{c_2} °C	t_{h_2} °C
6.1	0.5	23.5	70.5	50.0	82.0
		23.5	70.0	49.0	83.0
		23.0	68.0	45.0	82.0
		23.0	68.0	45.0	83.0
6.1	0.7	23.0	71.5	47.0	83.0
		23.0	70.0	46.5	82.0
		23.0	72.0	45.0	83.0
		23.0	70.0	43.0	83.0
10.0	0.5	26.0	68.5	51.0	83.0
		26.0	68.0	50.0	83.0
		26.0	65.0	47.0	83.0
		26.0	61.0	41.5	82.0
10.0	0.7	25.0	65.0	49.0	83.0
		25.0	63.0	48.0	82.0
		25.0	61.0	41.0	83.0
		25.0	64.0	42.0	82.0
-	1.0	23.0	74.5	44.0	86.0
		23.0	76.5	41.2	82.5
		23.0	75.5	40.5	82.0
		23.0	76.5	44.1	83.0

b) Inlet hot water temperature 72°C

cycle time (seconds)	fraction open	t_{c_1} °C	t_{h_1} °C	t_{c_2} °C	t_{h_2} °C
10.0	0.5	26.0 26.0 26.0 26.0	26.0 55.0 54.0 57.0	41.0 38.0 37.0 37.0	37.0 73.0 72.0 73.0
10.0	0.7	25.5 25.5 25.5 25.5	56.5 52.5 55.0 46.0	39.5 32.0 35.0 34.0	73.0 73.0 73.0 73.0
13.0	0.5	22.5 22.5 22.5 22.5	61.0 60.5 59.5 56.0	37.0 38.0 36.0 34.0	72.0 72.0 71.0 73.0
13.0	0.7	26.5 26.5 26.5 26.5	59.0 58.0 55.0 53.0	38.0 37.0 35.0 33.0	73.0 73.0 72.0 72.0
-	1.0	23.0 23.5 23.5 23.0	66.5 66.5 67.5 67.0	33.0 33.1 33.0 33.0	71.0 71.5 72.0 72.0

Appendix C

SAMPLE CALCULATIONS

1. Calculation of Reynolds Number

Re = Reynolds number

$$= \frac{\rho V D_{eq}}{\mu}$$

(For hot water in annulus)

where μ = viscosity of hot water at average temperature

= 0.682×10^{-2} poise (g/cm sec)(Perry)

= $0.682 \times 6.72 \times 10^{-4}$ lb/ft sec

ρ = density of hot water

= 62.0 lb/cu.ft.

D_{eq} = equivalent diameter, ft

$$= 4 \frac{\text{(annular area)}}{\text{wetted perimeter}} = \frac{4S}{P}$$

The inner diameter of outer pipe $= \frac{1.610}{12} = 0.1341$ ft

The outer diameter of inner pipe $= \frac{1.050}{12} = 0.0875$ ft

$\therefore$ annular area, $S = \frac{\pi}{4} \left[(.1341)^2 - (.0875)^2 \right]$

$= \frac{\pi}{4} (.2216)(.0466)$

$= .008113 \text{ ft}^2$

Wetted perimeter, P $= \pi\{(.1341)+(.0875)\}$

$= .6964$ ft

Therefore, Deq $= \dfrac{(4)\ (.008113)}{(.6964)}$

$= .04659$ ft

So the velocity of hot water,

$$U = \frac{(15.53)\ (2.2)(\text{lb/min})\ (\text{min})}{(62.0)\ \text{lb/cu.ft.}(.008113)\ \text{ft}^2\ (60)\text{sec}}$$

$= 1.132$ ft/sec

Therefore, Re $= \dfrac{(.04659)(1.132)(62.0)}{(.682)(6.72)(10^{-4})}$

$= 7149.24$

2. Calculation of Logarithmic Mean Temperature

Data

cycle time = 6.1 sec fraction open = 0.5

(^{o}C)	t_{c_1}	t_{h_1}	t_{c_2}	t_{h_2}
	23.5	70.5	50.0	82.0

Logarithmic mean temperature difference, ΔT_{ln} was calculated by using the equation

$$\Delta T_{ln} = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}}$$

where $\Delta T_1 = T_{h_1} - T_{c_1}$

$\Delta T_2 = T_{h_2} - C_{c_2}$

Therefore, $\Delta T_{ln} = \frac{(70.5-23.5)-(82.0-50.0)}{\ln \frac{(70.5-23.5)}{(82.0-50.0)}}$

$= 39.0625$

3. Calculation of Overall Heat Transfer Coefficient

From the equation...

$$Q = U_o A_o \Delta T_{ln} \qquad .....(3\text{-}1)$$

where Q is the heat transfer rate, Btu/hr

U_o is the over all heat transfer coefficient, BTU/hr ^oF ft^2

A_o is the total heating surface area based on outside diameter

$$A_o = \pi D_o L$$

$$= (\frac{22}{7})(.0875)(10)$$

$$= 2.7499 \quad ft^2$$

So $$Q = wC_p \Delta T = U_o A_o \Delta T_{ln}$$

$$U_o = \frac{wC_p \Delta T}{A_o \Delta T_{ln}}$$

where T = Temperature difference (^oF)

w = flow rate of hot water (lb/hr)

Therefore, the over all heat transfer coefficient is

$$U_o = \frac{(15.53)(2.2)(0.53)(60)(1.0)(82.0-70.5)(1.8)}{(2.7499)(39.0625)}$$

$$= 209.88 = 209.9 \quad Btu/hr\ ft^2\ ^oF$$

VITA

Miss Kanchana Ratchatasuwan received her Bachelor Degree of Science in the field of Chemical Engineering from Faculty of Science, Chulalongkorn University in 1974

She has been joining the teaching staff in the Department of Chemical Engineering, Faculty of Engineering, King Mongkut Institute of Technology. The subjects which she had taught are: Material and Energy Balances, Unit Processes, Physical Chemistry, Inroganic Chemistry, Chemical Engineering Laboratory and Mechanical Laboratory.

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