ME444 ENGINEERING PIPING SYSTEM DESIGN

CHAPTER 10A : INDUSTRIAL HOT AND CHILLED WATER UTILITY SYSTEM

CONTENT

1. INTRODUCTION
2. GENERATION PLANTS
3. DISTRIBUTION SYSTEM
4. INSULATION

1. INTRODUCTION

APPLICATIONS (OPEN LOOP SYSTEM)

DOMESTIC USE

INDUSTRIAL USE

- PROCESS SUPPLY
- CLEANING

CONSIDERATION

GENERATION

STORAGE

CIRCULATION

INSULATION

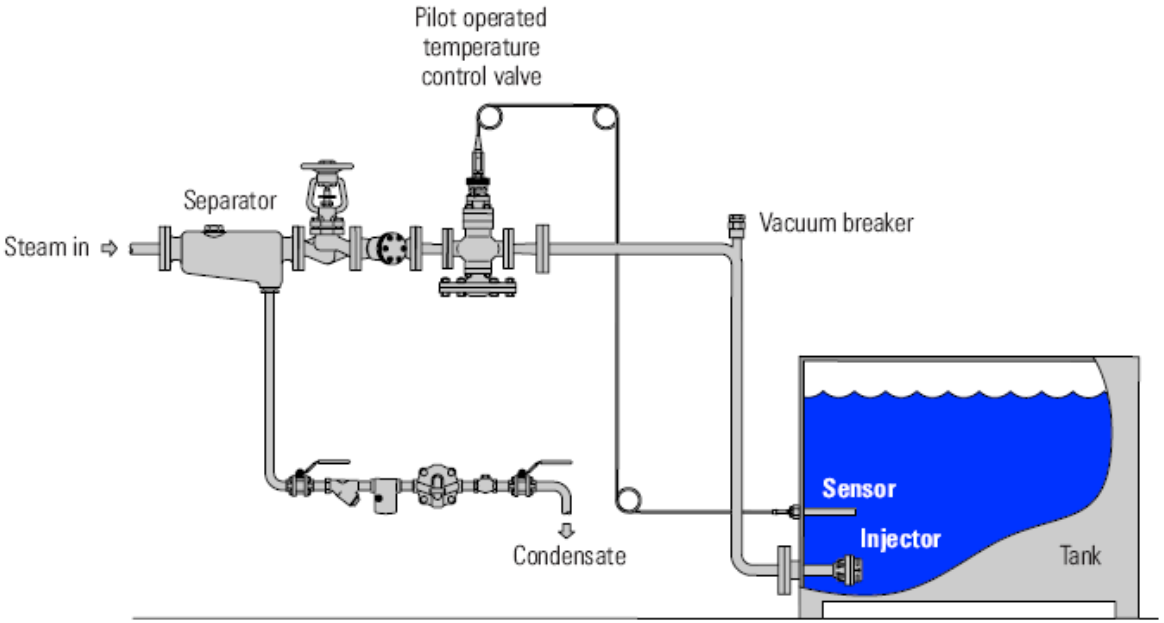
2. GENERATION PLANTS

STEAM INJECTION

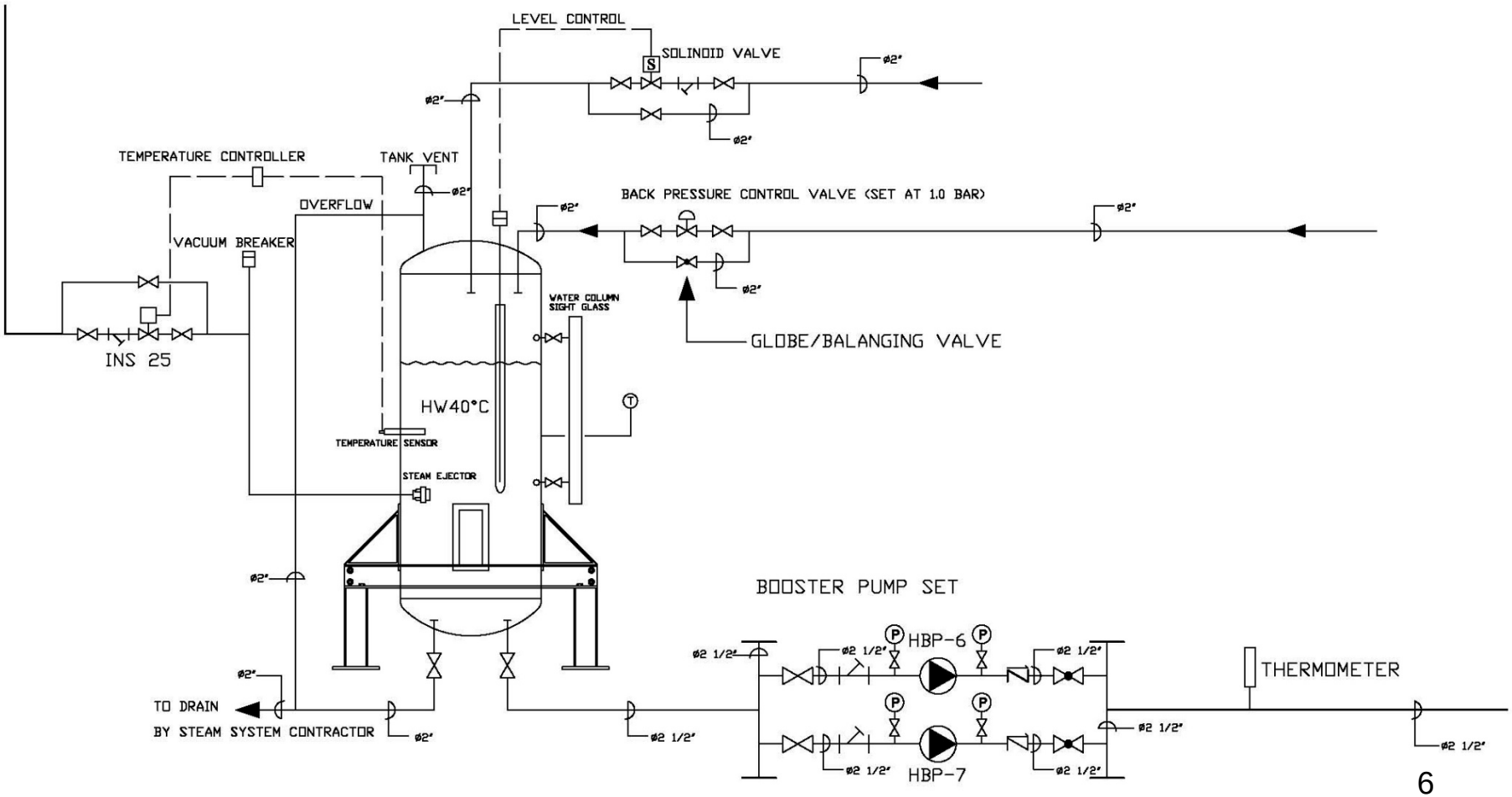
STEAM COIL

ELECTRIC HEATER

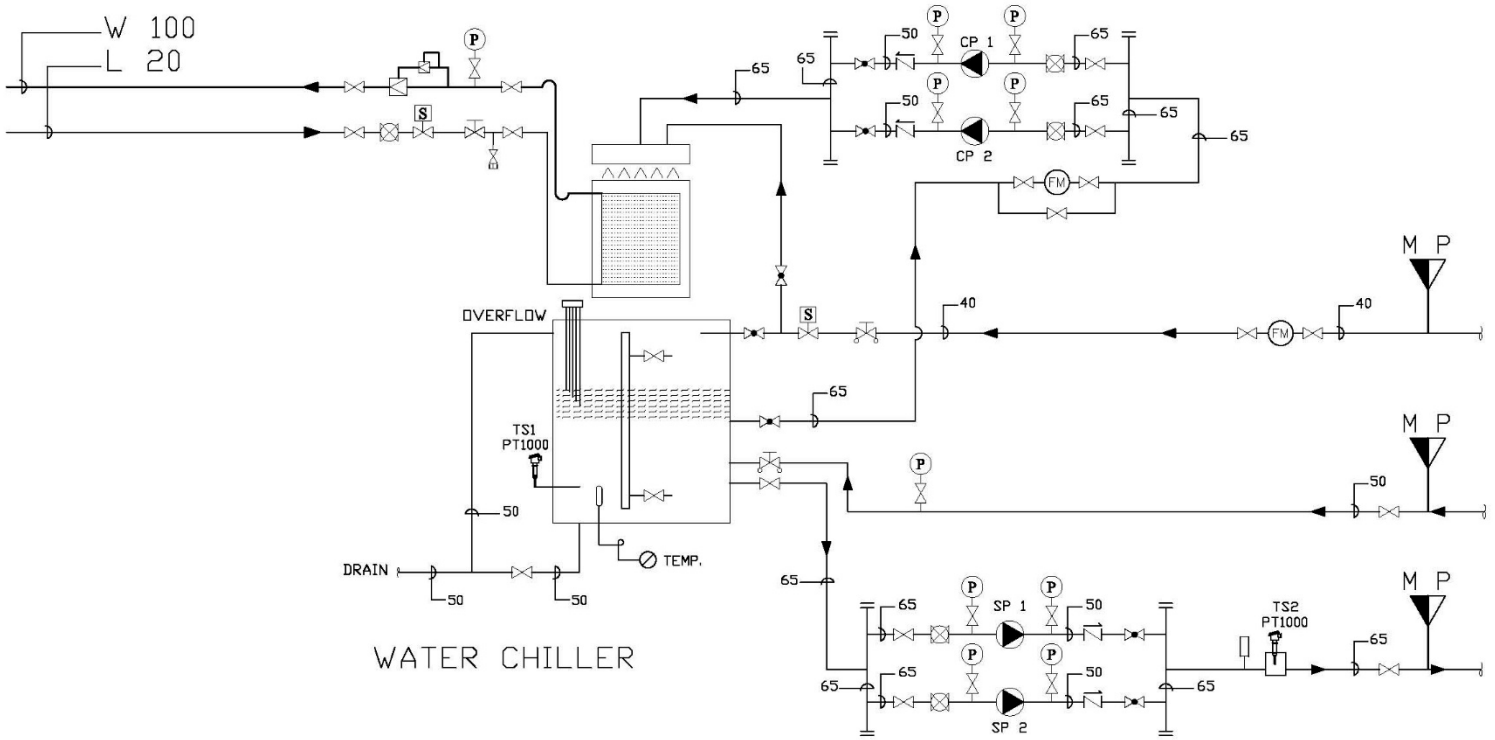
GAS BURNER



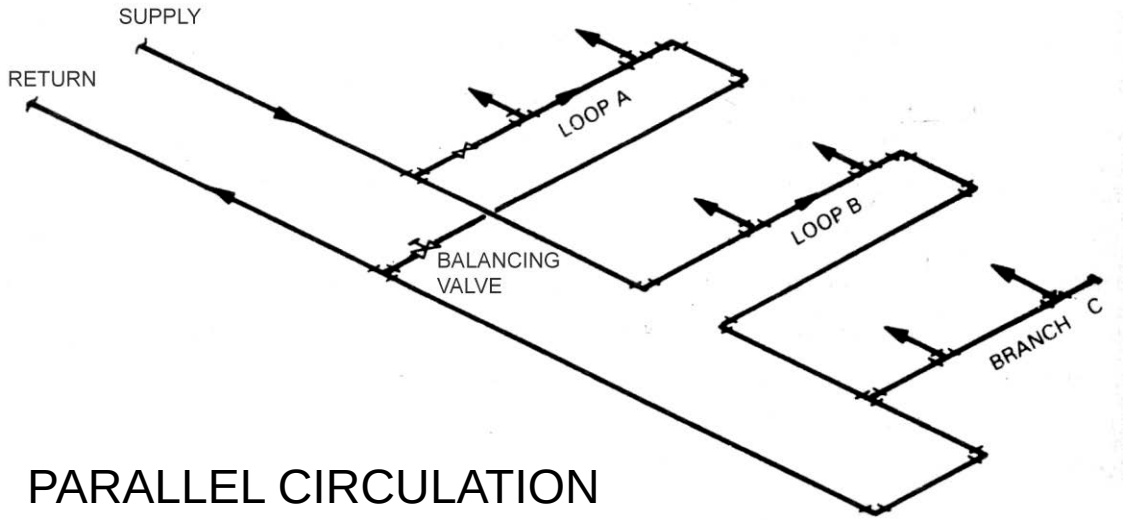
HOT WATER PLANT



CHILLED WATER PLANT



3. DISTRIBUTION SYSTEM

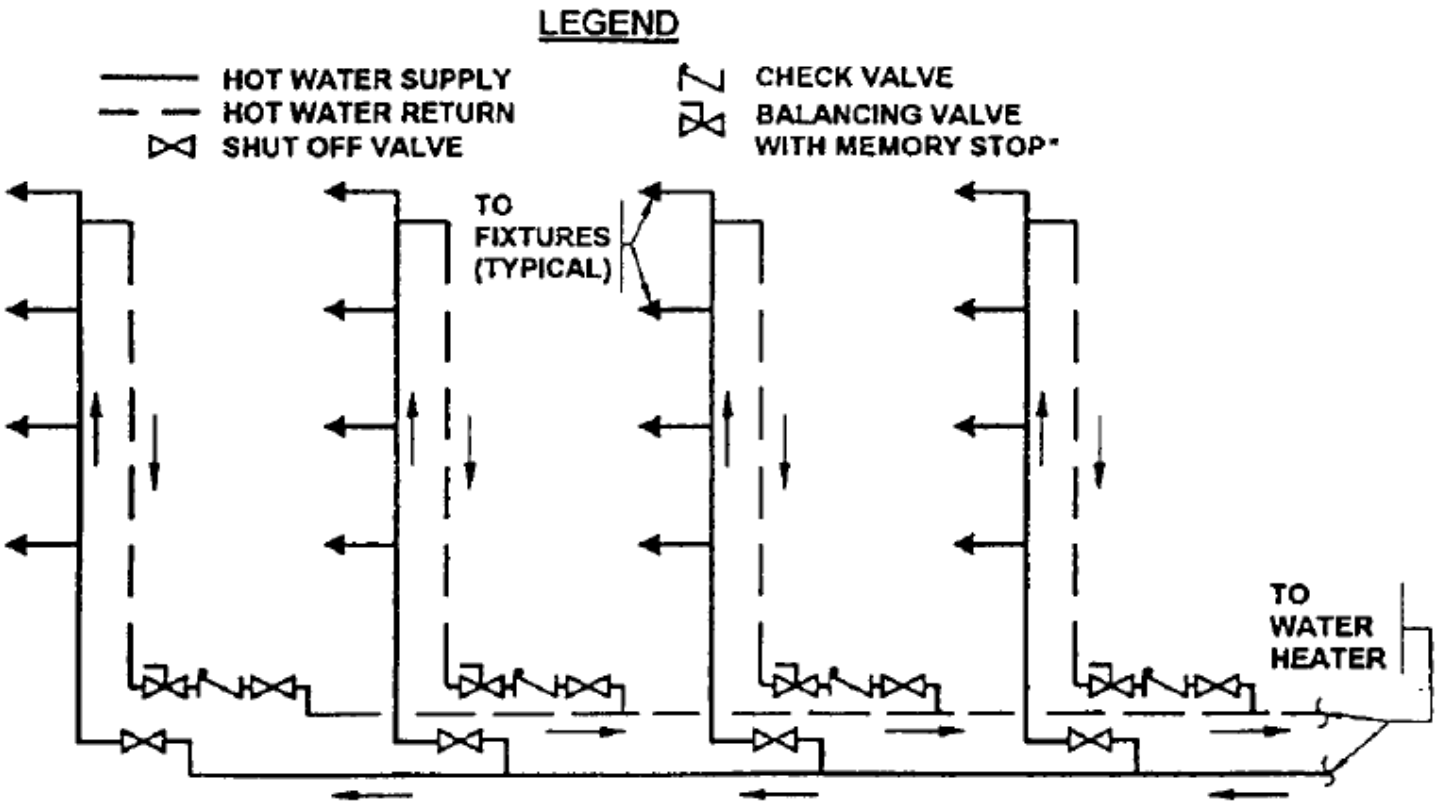


LOOP A = PARALLEL CIRCULATION

LOOP B = SERIAL CIRCULATION

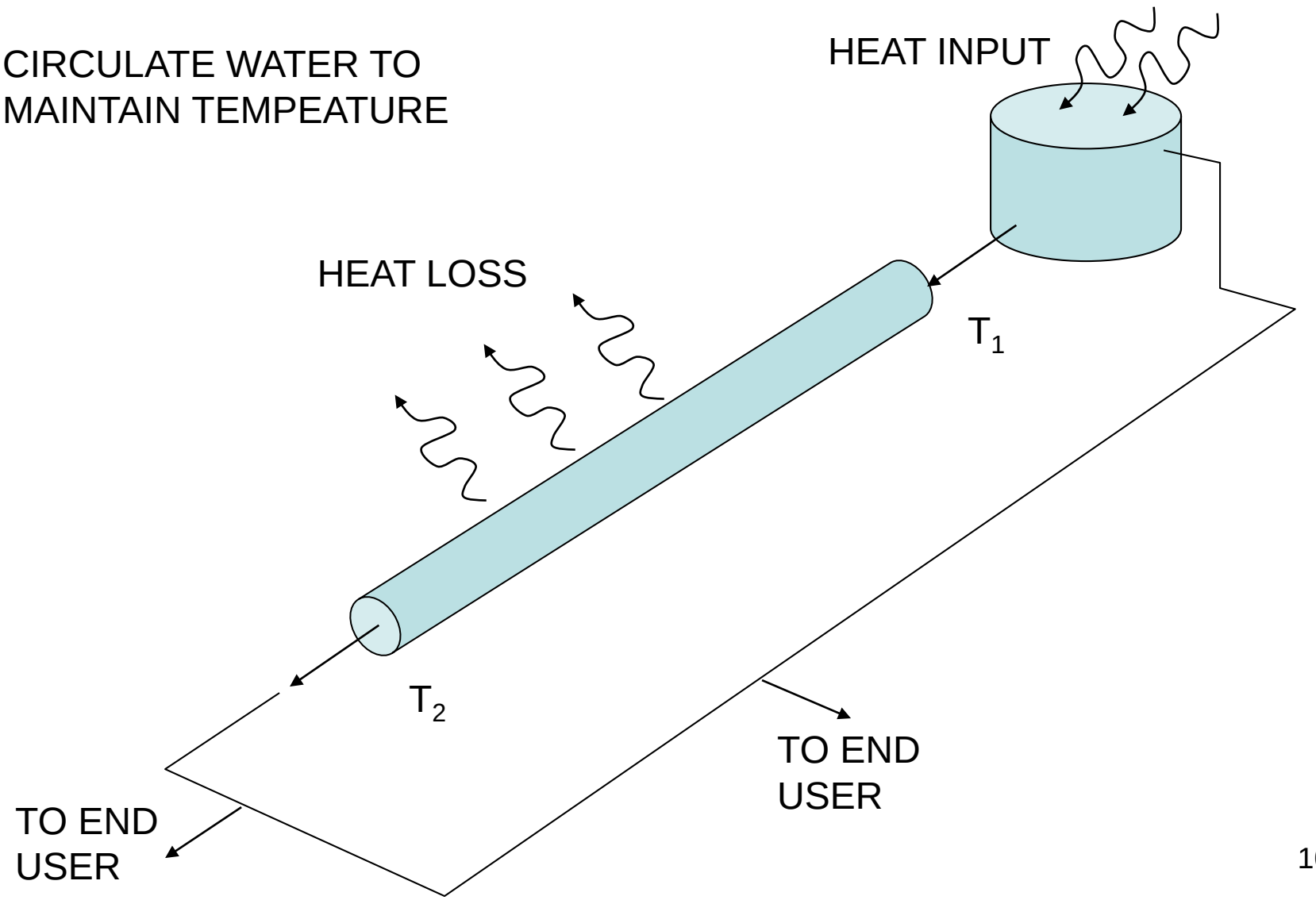
BRANCH C = NON-CIRCULATED BRANCH
(NOT TO BE LONGER THAN 10 METERS)

TYPICAL DISTRIBUTION SYSTEM



CIRCULATION

CIRCULATE WATER TO
MAINTAIN TEMPEATURE



CIRCULATION RATE

- COMPUTE TOTAL VOLUME OF WATER IN PIPE (V)
- COMPUTE TOTAL HEAT LOSS RATE
- SPECIFY ALLOWABLE TEMPERATURE DROP
- COMPUTE TIME REQUIRED FOR TEMPERATURE TO DROP (t)
- CIRCULATION RATE > V / t

EXAMPLE

COMPUTE CIRCULATION RATE FOR:

- 3” PIPE 200 M. LENGTH
- *HEAT LOSS 25 WATT/M*
- TEMPERATURE DROP < 2 CELCIUS

VOLUME OF WATER (V) = $\frac{\pi \times (3 \times 0.0254)^2}{4} \times 200$

= 3.65 CU.M.

HEAT LOSS RATE = 25*200 = 5000 WATT = 5 kW

HEAT LOSS FOR 2 CELCIUS DROP

= 3.65m^3 x 1000kg/m^3 x 4.2kj/kg *2 C = 30660 kj

TIME REQUIRED = 30660/5 = 6132 sec = 1.7 hours

MIN. CIRCULATION RATE = 3.65/1.7 = 2.15 m^3/hr = 9.45 GPM

PIPE SIZING

SUPPLY PIPE
DESIGN TO MEET THE DEMAND PLUS MARGIN

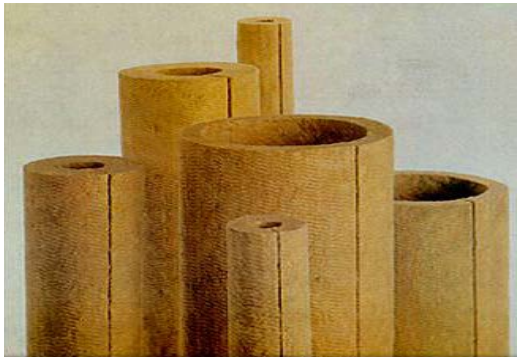
RETURN PIPE
DESIGN TO MEET THE MINIMUM CIRCULATION RATE PLUS SOME MARGIN

NORMALLY RETURN PIPES ARE ONE STEP DOWN FROM THE SUPPLY PIPE

KEEP POSITIVE PRESSURE WITH A BACK PRESSURE CONTROL VALVE

LARGE PIPE = HIGH INITIAL COST
SMALL PIPE = HIGH OPERATING COST

4. INSULATION



ROCK WOOL

FIBRE GLASS

ELASTOMIC

	Cellular Glass	Flexible Elastomeric	Closed-Cell Phenolic	Polyisocyanurate	Polystyrene
Standard that specifies material and temperature requirements	ASTM C552	ASTM C534	ASTM C1126	ASTM C591	ASTM C578
Suitable temp. range, °C	−270 to 430	−30 to 104	−180 to 120	−183 to 150	−55 to 75
Flame spread rating[a]	5	25	25	25	25
Smoke developed rating[a]	0	50	50	50	115
Water vapor permeability[b], ng/(s·m·Pa)	0.007	0.15	3.0	6.5	2.2
Thermal conductivity[c], W/(m·K)					
At −20°C mean temperature	0.039	0.036	—	0.027	—
At +25°C mean temperature	0.045	0.039	0.019	0.027	0.035
At +50°C mean temperature	0.048	0.042	0.022	0.030	0.037

[a]Tested in accordance with ASTM E84 for 25 mm thick insulation.
[b]Tested in accordance with ASTM E96, Procedure A. Cellular glass tested with ASTM E96, Procedure B.
[c]Tested at 180 days of age in accordance with ASTM C177 or C518.

TYPE OF INSULATION

GLASS FOAM AND CELLULOSE FOAM	-270C TO 100C
CALCIUM SELICATE	100C TO 500C
CERAMIC FIBRE	500C UP

THERMAL CONDUCTIVITY OF HOT INSULATION

Mean Temperature °C	Calcium Silicate	Resin bonded Mineral wool	Ceramic Fiber Blankets
100	-	0.04	-
200	0.07	0.06	0.06
300	0.08	0.08	0.07
400	0.08	0.11	0.09
700	-	-	0.17
1000	-	-	0.26
Specific heat(kJ/kg/°C)	0.96	0.921	1.07
	(at 40°C)	(at 20°C)	(at 980°C)
Service temp, (°C).	950	700	1425
Density kg/m^3	260	48 to144	64 to 128

THERMAL CONDUCTIVITY OF COLD INSULATION

MATERIALS	Thermal Conductivity W/m-°C
Mineral Or Glass Fiber Blanket	0.039
Board or Slab	
Cellular Glass	0.058
Cork Board	0.043
Glass Fiber	0.036
Expanded Polystyrene (smooth) - Thermocole	0.029
Expanded Polystyrene (Cut Cell) - Thermocole	0.036
Expanded Polyurethane	0.017
Phenotherm (Trade Name)	0.018
Loose Fill	
Paper or Wood Pulp	0.039
Sawdust or Shavings	0.065
Minerals Wool (Rock, Glass, Slag)	0.039
Wood Fiber (Soft)	0.043

INSULATION THICKNESS

CONSIDERATION
THICK INSULATION – TOO COSTLY
THIN INSULATION – ENERGY LOSS
OPTIMUM POINT EXISTS

OTHER CONSTRAINTS
HOT PIPE INSULATION
-KEEP THE SURFACE TEMPERATURE BELOW 48 C FOR HUMAN SAFETY
-KEEP WATER FROM FREEZING (IN COLD WEATHER)

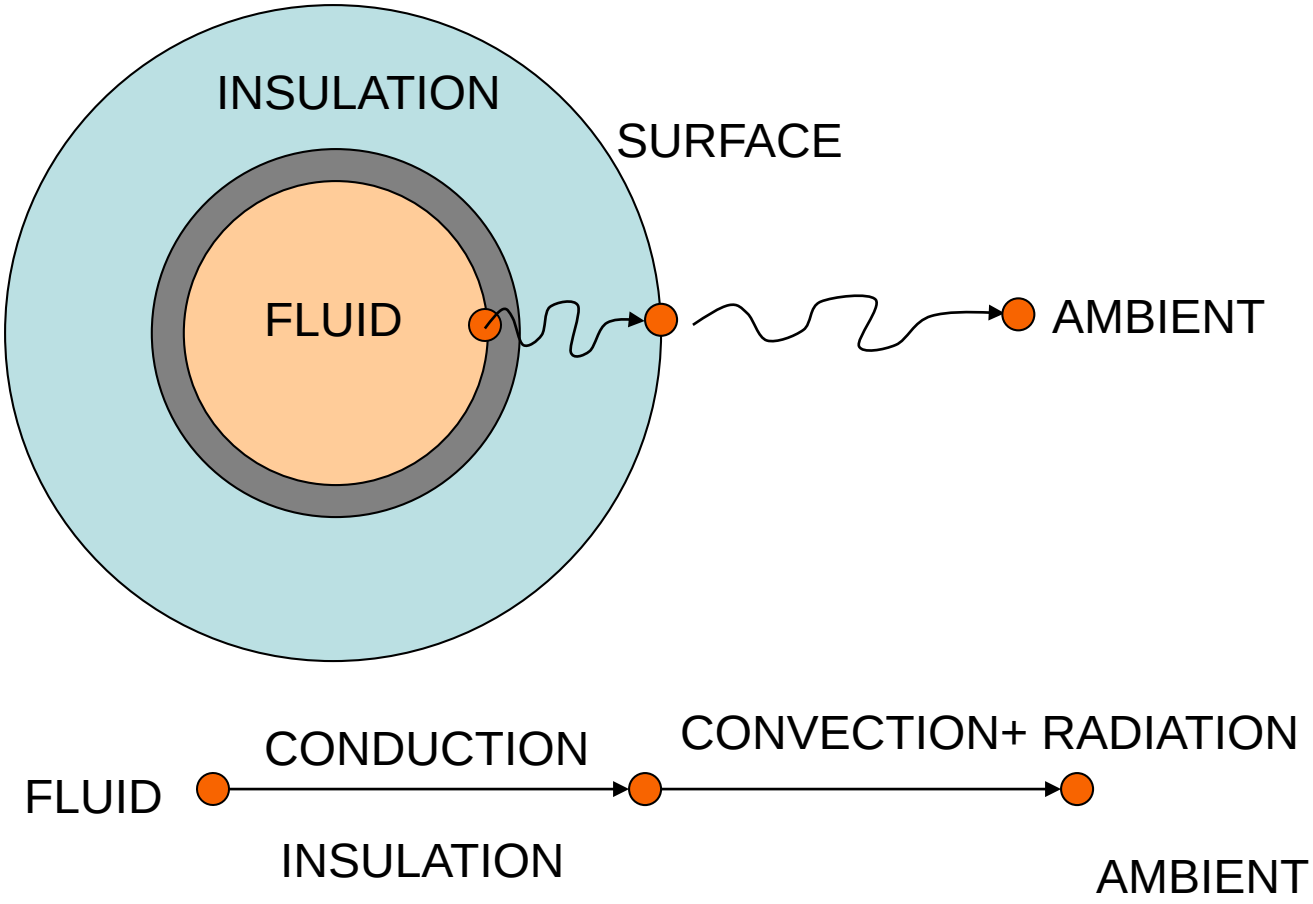
COLD PIPE INSULATION
-PREVENT CONDENSATION
-ASHRAE RECOMMEND THE THICKNESS FOR 25 W/SQ.M HEAT GAIN

RECOMMENDED HOT PIPE INSULATION THICKNESS

FIBRE GLASS INSULATION

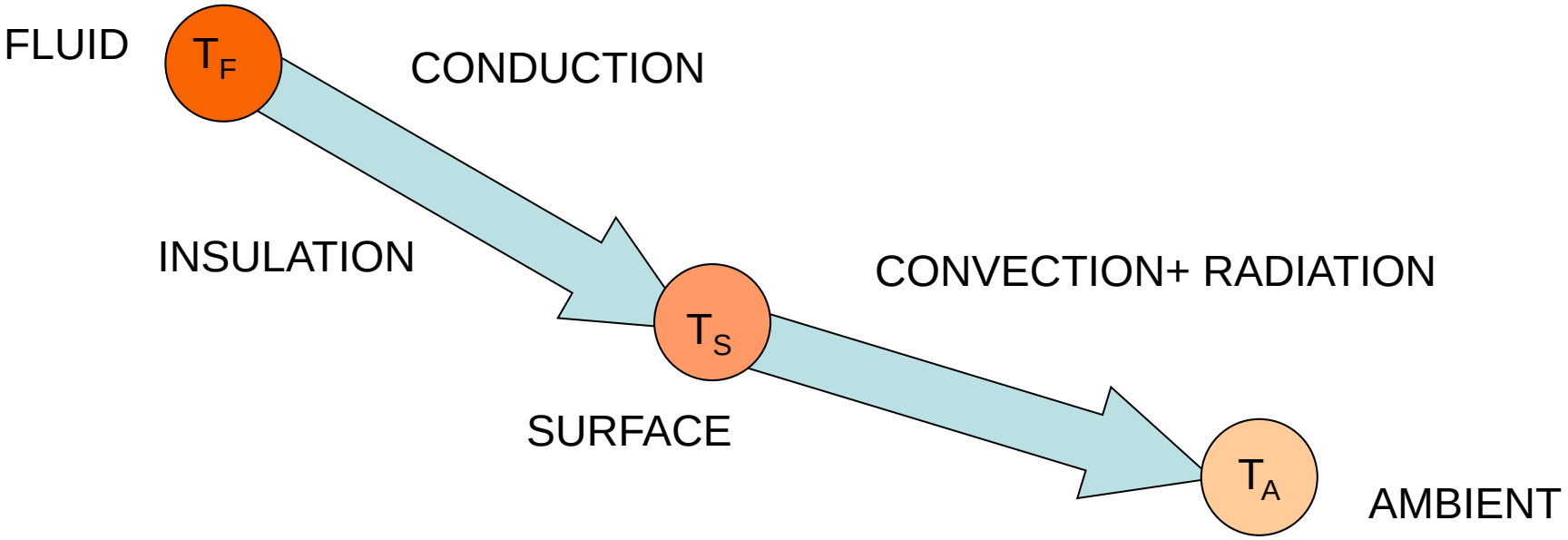
Fluid temp. >	120C			150C			250C		
Pipe size (inch)	THK (inch)	LOSS (w/m)	Ts (C)	THK (inch)	LOSS (w/m)	Ts (C)	THK (inch)	LOSS (w/m)	Ts (C)
0.5	0.5	14.9	42.8	1	11.7	40.0	1	18.8	47.8
0.75	0.5	12.0	40.0	0.5	19.9	48.9	1.5	12.6	41.7
1	0.5	16.1	44.4	1	11.7	40.6	1	19.3	48.9
1.25	0.5	14.4	42.8	1	14.9	44.4	1.5	12.3	41.7
1.5	0.5	17.9	47.2	1	13.5	42.8	1.5	13.8	43.3
2	0.5	16.1	45.6	1	13.8	43.3	1.5	14.1	43.9
2.5	0.5	16.4	46.1	1.5	7.6	36.1	1.5	12.0	41.7
3	0.5	18.8	48.9	1	15.2	45.6	1.5	15.5	46.1
3.5	1	7.3	35.6	1	12.0	41.7	1.5	13.5	43.9
4	0.5	17.9	48.3	1	15.2	45.6	1.5	16.4	47.2
5	1	9.7	38.9	1	16.1	47.2	1.5	17.3	48.9
6	1	10.3	39.4	1	16.7	48.3	2	12.9	43.3
8	1	9.7	39.4	1	16.1	47.8	2	13.2	44.4
10	1	10.5	40.6	1.5	10.8	41.1	2	13.2	44.4
12	1	9.4	39.4	1	15.8	47.8	2	13.5	45.0

HEAT LOSS


INSULATION
SURFACE
FLUID
AMBIENT
CONDUCTION
CONVECTION+ RADIATION
FLUID
INSULATION
AMBIENT

HEAT TRANSFER

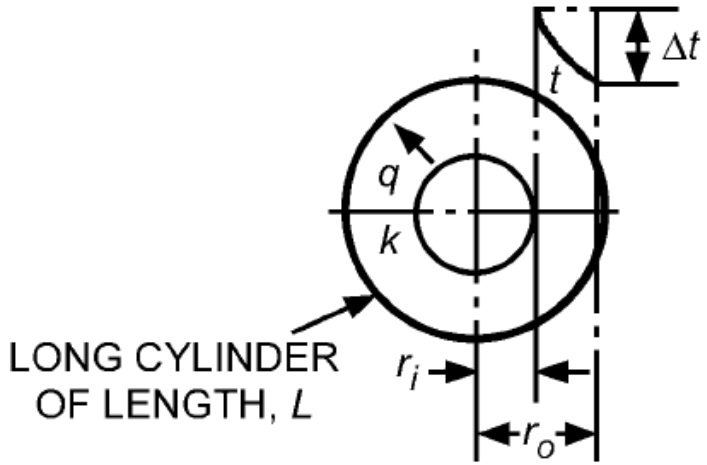
$$Q_{COND} = Q_{CONV+RAD}$$



CONDUCTION

$$q = k\left(\frac{A_m}{L_m}\right)\Delta t = \frac{\Delta t}{R}$$

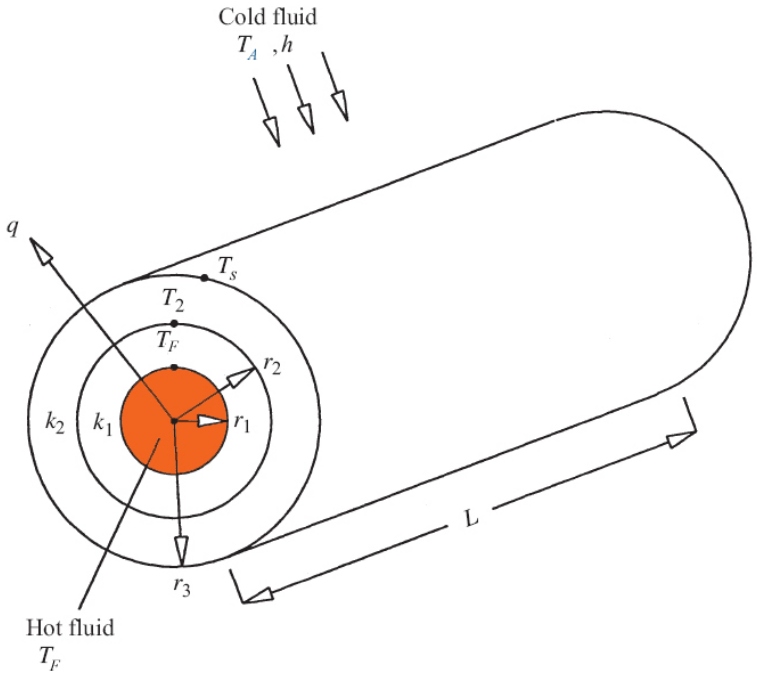
Radial flow through a
right circular cylinder

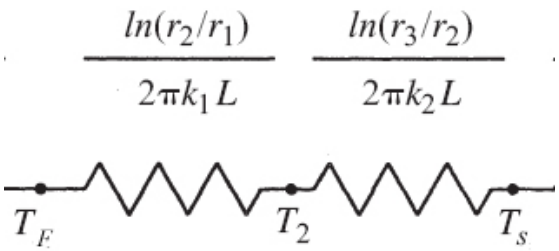


$$R = \frac{\ln(r_o/r_i)}{2\pi kL}$$

CONDUCTION IN COMPOSITE CYLINDER

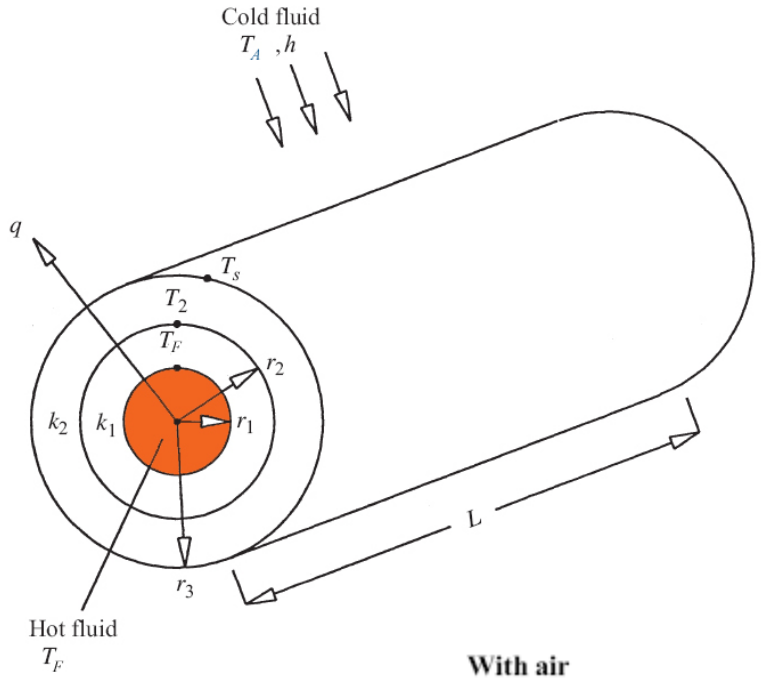
Assumption: inside pipe temperature is close to fluid temperature.





$$Q_{cond} = \frac{T_F - T_S}{\ln(r_2/r_1)/2\pi k_1 L + \ln(r_3/r_2)/2\pi k_2 L}$$

CONVECTION



$$Q_{CONV} = \bar{h} A (T_S - T_A)$$

With air

$\text{Gr Pr} = 1.6 \times 10^6 L^3 \Delta t$ (at 21 °C, L in m, Δt in K)

(a) Horizontal cylinders

Small cylinder, laminar range $h = 1.32(\Delta t/L)^{0.25}$

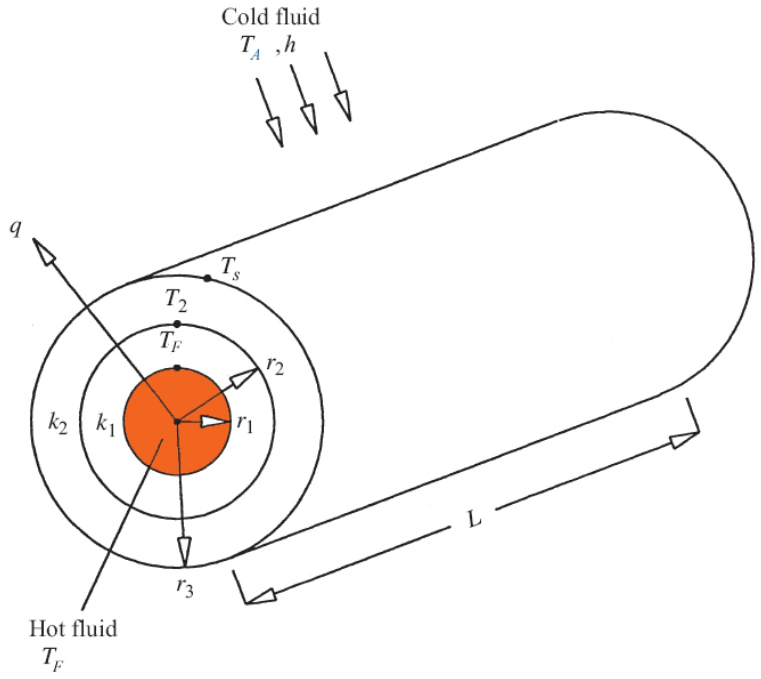
Large cylinder, turbulent range $h = 1.24(\Delta t)^{0.33}$

(b) Vertical plates

Small plates, laminar range $h = 1.42(\Delta t/L)^{0.25}$

Large plates, turbulent range $h = 1.31(\Delta t)^{0.33}$

RADIATION



$$Q_{RAD} = \varepsilon\sigma\left(T_S^4 - T_A^4\right)$$

$$\sigma = 5.670 \times 10^{-8}\ \mathrm{W/m^2 \cdot K^4}$$

CALCULATION OF HEAT LOSS

KNOW T_F AND T_A

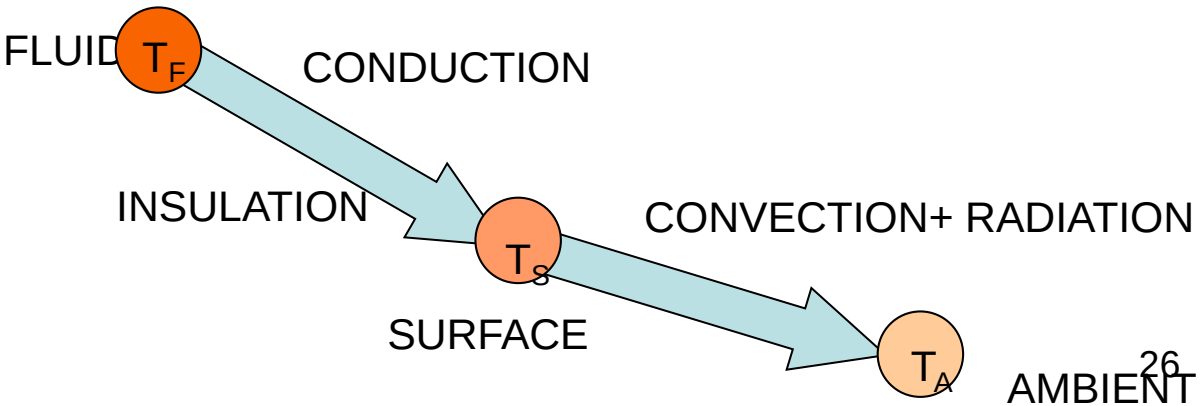
KNOW PIPE SIZE, PIPE THICKNESS AND INSULATION THICKNESS

SET

$$Q_{COND} = Q_{CONV+RAD}$$

$$\frac{T_F - T_S}{\ln(r_2/r_1)/2\pi k_1 L + \ln(r_3/r_2)/2\pi k_2 L} = \bar{h}A(T_S - T_A) + \varepsilon\sigma\left(T_S^4 - T_A^4\right)$$

SOLVE FOR T_s



CALCULATION SHEET

Pipe Heat Loss							
		3.48499					
Convection and Radiation							
Convection coefficient	h=	4.979309	w/m2 (10-20)		Qconvection	40.53	w/m
Stafan-Boltzman coefficient	sigma=	5.67E-08	w/m2.k4		Qradiation	22.99	w/m
Emissivity	eps=	0.4					
					k/h	0.008434906	m
Conduction							
	Nominal Dia	Thickness	OD	k	ri	ro	1/R
	(inch)	(inch)	(inch)	(w/m.K)	(m)	(m)	
Pipe	2	0.154	2.375	50	0.026	0.030	0.00278
Insulation		1	4.375	0.042	0.030	0.056	14.54545
Cladding		0.039	4.454	50	0.056	0.057	0.00036
						Sum	14.54859
Fluid temperaure	200	C	Qconv+rad	**64**	watt/m		
Ambient Temperature	30	C	Qconduction	**64**	watt/m		
Surface Temperature	52.90546182	C	Residual	0.0%			

HEAT LOSS TABLE

(SEE THE FULL TABLE IN THE BOOK)

Heat loss from metal pipe insulated with glass fiber (ASTM C547) located outdoor under 32 km/hr wind (watt/m)

Insulation thickness	dT (C)	Nominal Pipe Size												
		1/2	3/4	1	1-1/4	1-1/2	2	2-1/2	3	4	5	6	7	8
1/2"	5	1.3	1.6	1.9	2.1	2.4	3.0	3.5	4.0	4.8	6.9	8.8	11.0	12.8
	10	2.7	3.2	3.8	4.4	5.0	5.9	7.0	8.2	10.0	14.3	18.1	22.4	26.2
	20	5.4	6.2	7.5	8.8	10.2	11.8	14.0	16.5	20.5	28.9	36.8	45.2	53.1
	30	8.1	9.4	11.3	13.3	15.5	17.8	21.1	24.9	31.1	43.7	55.7	68.3	80.4
	50	13.9	16.3	19.3	23.0	26.5	30.7	36.1	42.5	53.2	75.1	95.7	117.1	137.9
	80	23.1	27.1	32.0	38.2	44.2	51.1	59.9	70.8	88.2	125.0	159.0	194.7	229.0
	100	29.7	34.8	41.1	49.1	56.8	65.6	76.9	91.0	113.3	160.3	204.1	249.8	293.8
	120	36.6	42.9	50.7	60.5	70.0	80.8	94.9	112.2	139.8	197.7	251.7	307.9	362.1
1"	5	0.8	1.1	1.1	1.3	1.6	1.6	1.9	2.1	2.7	3.7	4.8	5.9	6.9
	10	1.7	2.1	2.3	2.7	3.2	3.3	3.9	4.5	5.6	7.8	9.9	12.0	14.2
	20	3.4	4.1	4.7	5.4	6.2	6.8	7.9	9.4	11.5	15.8	20.1	24.4	28.7
	30	5.2	6.1	7.1	8.1	9.4	10.4	12.0	14.2	17.5	24.0	30.4	37.0	43.4
	50	9.1	10.4	12.0	13.9	15.8	18.1	20.8	24.3	29.9	41.4	52.1	63.6	74.3
	80	15.1	17.4	20.0	23.4	26.5	30.0	34.8	40.5	49.7	68.8	86.8	105.6	123.6
	100	19.6	22.3	25.7	30.0	34.0	38.7	44.6	52.0	63.7	88.5	111.4	135.8	158.9
	120	24.2	27.5	31.7	37.0	41.9	47.7	55.1	64.2	78.6	109.4	137.6	167.7	196.1