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Design of Heat Recovery System in a Sheet Rock Plant

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ABSTRCT

This report is about the design of heat recovery system in a sheet rock plant. A sheet rock is basically a gypsum board which is mainly used as finish for walls, ceilings in households and commercial buildings. According to the given problem, during summer months the city water supplies to the manufacturing plant at a higher temperature of 90^0 F but during other months the temperature of water supply as 45^0 F. The demand of water temperature is 85^o F for the process so the city water is heated by natural gas burners when it's in a storage tank. During the final stage of sheet rock production heated air is used in a closed oven with sheet rock for the drying process. The air gets exhausted from aluminium stacks. This waste heat energy is being recovered it in the form of energy with the help of specially selected heat exchanger. The energy recovered will be minimising the need of natural gas burner which is to heat the city water receiving at a temperature of 45^0 F. This would reduce the need of natural gas to use as the main source of heating the city water for production of sheet rock. The heat recovery system would be compatible to work for 24 hr in a 6 days week frame till 8 months. The report will include the type of heat exchanger selected, pump for heat recovery and piping system with fittings and routing for heat recovery. This would also include the cost involved in the whole additional process as installation, operational and maintenance cost with a calculated payback period of time for investment.

Nomenclature

- Density — ρ
- Specific Heat of water — Cp_w
- Specific Heat of flue gas — Cp_f
- Heat Energy (Flue gas) — q_f
- Heat Energy (Water) — q_w
- Effectiveness — E
- Mass flow rate (Flue gas) — m_f
- Mass flow rate (Water) — m_w
- Heat Capacity (Flue gas) — C_F
- Heat Capacity (Water) — C_W
- Capacity Ratio — C_r
- Temperature Inlet (Flue gas) — T_i
- Temperature Inlet (Water) — t_i
- Temperature Outlet (Flue gas) — T_O
- Temperature Outlet (Water) — t_o

- Log Mean Temperature Difference ΔT_{lm}
- Pressure p
- Volume V
- Length L
- Diameter (Pipe) D
- Area A
- Flow rate Q
- Velocity of Flow V
- Overall Heat Transfer Coefficient U

Contents

INTRODUCTION

A heat recovery is a mechanical process in which heat is recovered from different sources of a plant to gain the potential of enhancing the energy of the system. The heat recovery system starts from a specially constructed heating surface through rectangular ducts into a cross flow heat exchanger to gain the energy for heating purposes. This hot flue gas, when passed through large no. of tubes in the heat exchanger, will exchange a lot of energy to the crossed flowing water in the tubes. The flowing water is coming at a temperature of 45^0F (7.22^0C) from the city water supply lines provided by the district water supply unit. The water has headers at both the ends of a heat exchanger device and through pipes, in a half circular pattern, the water will flow to gain heat for the system. The efficiency of hot flue gas transferred into energy form is not 100% due to heat losses at certain junctions and duct fittings. The amount of heat left in the system is moved further towards the stack at a dimension of 34 feet and 50 feet from the ground level. To let the gas exhaust through the stacks at each cross-section, manual dampers are installed in both the stacks as well as heat recovery system inlet and out of the ducting arrangement which would open the surface free for the exhaust when the flue gas was allowed to pass through heat recovery system and mean time both stacks dampers are in closed condition so that total flue gas can be passed through heat recovery system.

As the medium is flue gas and low temperature water hence the heat exchanger has been selected – crossed flow Economiser heat exchanger system which consists tubing arrangement with both end water heaters. The inlet water of 45^oF entered in the Economiser header and passed through tubes and return to the heat exchanger out let header and carried away heat energy from the passing cross flow flue gas of 230^o F. Assuming the dew point of flue gas 140^oF we have calculated the heating surface area of heat exchanger and 140oF flue gas exhausted out of the stack and the heat energy utilised during the process.

After the heat transfer to the water tubes, the water temperature rises from given city water temperature of 45^0F (7.22^0C) to a temperature of 62.4 ^{0}F (16.77^0C). The heated water will travel through the MS C class piping of 100 NB length 295 feet towards the water holding tank. The water holding tank has two incoming water inlets. The first one is city water 45^oF and another one is heated water of 62.4^oF coming through the heat recovery process. This heated water contains an enormous amount of energy to partially fulfil the demand of heat provided by the natural gas burners. Natural gas would now be used partially as a major source of heating for the system of manufacturing a sheet rock in a plant. The total profit from this heat recovery system has been calculated with a consideration of working days 8 months, 6 working days in a week and 24 hours of working.

Benefits of Waste Heat Recovery

Benefits of ‘waste heat recovery’ can be broadly classified into two categories:

Direct Benefits

Recovery of waste heat energy has a direct effect on the saving of natural gas which is being used to heat the process water from 45^{o}F to 62.4 ^{o}F forr 8 months resulting to decrease the operation cost of the process which is reflected in process costing.

Indirect Benefits

a) **Reduction in pollution**: By installing heat recovery system the natural gas consumption has reduced which is directly polluting the atmospherere due to higher emission level ie reduced the pollution level.

b) **Reduction in equipment sizes:**Waste heat recovery reduces the fuel consumption, which leads to reduction in natural gas consumption causing reduction in equipment sizes of all natural gas handling equipments like burners, storage of natural gas and piping etc.

c) **Auxiliary energy consumption**: Reduction in equipment sizes attracts additional benefits in the form of a reduction in auxiliary energy consumption.

Information

Given: The given information to design a project are:

1. City water Temperature during 8 months (^{0}F): 45^0F = 7.22^0C
2. Availability of city water for summer (4 months) 90^0F = 32.22^0C
3. Process Water requirement: 85^oF
4. Flow rate of City water: 70 GPM = 19093.9 Kg/Hr (1 GPM = 272.77 Kg/Hr)
5. City water line pressure (psig): 55 psig = 3.79 Kg/CM^2 (1 kg/cm^2= 14.53 Psig)
6. Total Flow rate of Flue Gas through both Chimney (CFM): 2*14000 = 28000 CFM = 16520 m^3/hr (1 CFM= 0.59 M3/Hour)
7. ID of Chimney: 3.6 Ft
8. Temperature of Flue Gas at outlet of each stack (F): 230^0F = 110^0C
9. Height of 1st Chimney: 50 Ft (From ground surface)
10. Height of 2nd Chimney: 34 Ft (From ground surface)
11. Distance from water tank to drying oven: 300 Ft
12. Specific heat of water as per table A-6 (Incropera 6th edition) = 4184 J/Kg.k
13. Specific heat of Flue gas as per table = 1068 J/Kg.K (At 110^0C)
14. Density of Flue gas as per table = 0.94 Kg/m^3

ASSUMPTIONS

The values which are assumed based on the requirements of the heat recovery system project are:

1) Dew point temperature of Flue gas in each chimney: $140^0F = (60^0C)$
2) Assuming overall heat transfer coefficient as per table C-2
   a. Flue Gas (U_f) = 45 $W/m^2.\ ^0C$
   b. Water (U_w) = 625 $W/m^2.\ ^0C$
3) Assuming dimension's for flue gas in Heat Exchanger:

   Tubes ID: 0.0050 m, Metal thickness: 1.5 mm; Pitch: 20 mm; Length: 12 m
4) Assuming width of Heat Exchanger: 4 m
5) Assumed GCV (Gross Calorific Value) of Natural Gas: 9600 Kcal/Kg
6) Assumed Rate of Natural Gas: CAD $ 0.13/kg

Heat Exchanger

Heat exchanger design is a multi-step, iterative process made up of the following steps:

1. First start with a selection of heat exchanger based on the given mediums i.e air, water, gas.
2. Design ways to connect the heat producing surface with the heat exchanger.
3. Calculating the log mean temperature difference between the mediums.
4. Assuming the overall heat transfer coefficient given for the mediums of flow in a heat exchanger.
5. Calculate the area of effectiveness for the incoming heat in the heat exchanger.
6. Calculating the heat transfer rate of incoming heat from the heating surfaces to the heat exchanger.
7. Calculating the mass flow rate of the heat.
8. Calculate the heat capacity ratio of different mediums for analysing the efficiency of the heat exchanger.
9. Calculating the effectiveness through NTU method.
10. Calculating the no. of tubes of the heat exchanger for the medium to pass through the heat exchanger.
11. Calculating the size and width of the heat exchanger.

Heat Exchanger Selection

Cross Flow Heat Exchanger: The economiser cross flow heat exchanger is the type of heat exchanger process which has been selected for designing the heat recovery system in a sheet rock plant. In this process, fluid as city water would flow through the tubes in a circular pattern from inlet header to outlet header and the heat energy coming from the drying oven as a flue gas would entered from the duct cross sectional area below and above the heat exchanger area in a cross flow pattern. The arrangement of heat exchanger would be one medium flowing in unmixed matter inside the tubes and another one is cross flowing in a mixed manner outside the tubes in the ducting cross sectional area.

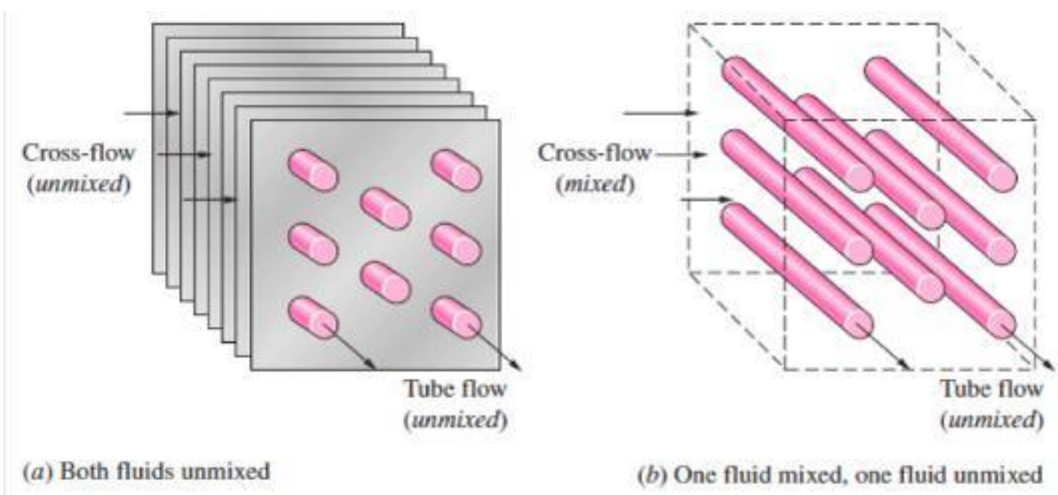


Fig-Cross Flow Heat Exchanger

Size of Heat Exchanger

The design of Heat Exchanger Calculations

Heat Exchanger Calculations		
Description	**UOM**	**Values**
Given		
Water flow rate	GPM	70
Water flow rate in Kg/Hour (1GPM =272.77 Kg/Hour)	Kg/hour	19093.9
Temperature reqd to be heated up to	oF	85
	oC	29.44
Temperature of city water is being received for 8 months	oF	45
Temperature of city water is being received for 8 months	oC	7.22
Chimney flue gas flow of one chimney	CFM	14000
Chimney flue gas flow of another chimney	CFM	14000
Total Gas flow	CFM	28000
Gas flow (1CFM=0.59 M3/hour)	M3/hour	16520.00
Chimney Temperature at outlet be(Ti)	oF	230
Hence Temperature at outlet of flue gas will be (Ti)	oC	110
Assuming Due point temperature of flue gas (To)	oC	60
Density of flue gas as per table	kg/m3	0.94
Specific heat of flue gas as per table	kcal/Kg/oC	0.255

Useful heat energy from flue gas (qf)		Kcal/hour	m x CPf X(Ti-To) x ρ
Useful heat energy from flue gas (qf)		Kcal/hour	197992
Heat energy Utilised from chimney flue gas (qf)		Kcal/hour	197992
Mass flow rate of water mCPw		Kg/hour	m x CPw
(assumed specific heat of water =1Kcal/kg/oC)		Kg/hour	19093.9
We know that heat energy from flue gas (qf) = Heat energy of water (qw)			
hence qf=qw = mCPw x (to-ti)			
ie qf = mCPw x (to-ti)			
Hence Temperature rise of water (to-ti)		oC	qf/mCPw
Hence Temperature rise of water (to-ti)		oC	10.37
We know that inlet temperature of water is - ti (as given)		oC	7.22
hence the out let temperature of water will be -to		oC	17.59
Ti		oC	110
to		oC	17.59
To		oC	60
ti		oC	7.22

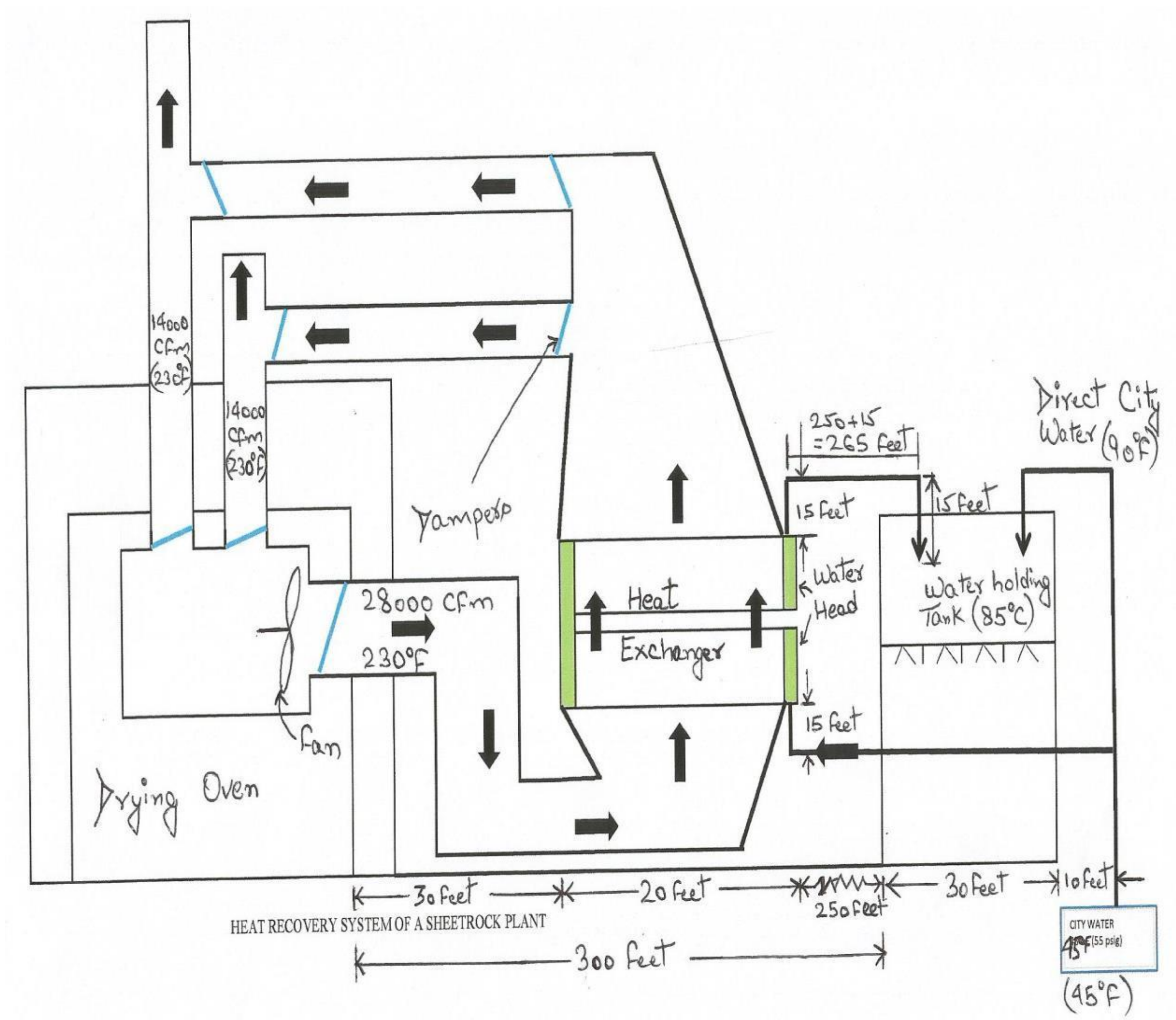
Mass flow rate of water as given (Mc)		Kg/sec	5.30	
Specific heat of water (CPw) as per table A-6		J/kg/k	4184	
Heat capacity of cooling water Cc = Mc x CPc	W/K	J/sec/K	22191	
Mass flow rate of flue gas (Mf)		Kg/Sec	4.31	
Specific heat of Flue gas as per table A -6		J/kg/k	1068.00	
Heat Capacity of flue gas (Cf) = Mf x CPf	W/K	J/sec/K	4606.88	Cf Max
Heat capacity of Flue gas Cf = Mfx CPf= Heat Capacity of Water Cc x (to-ti)/Ti-To		W/K	4601.23	Cf min
We know that Heat Transfer q max = Cf min x (Ti-ti)		Watt	472904.44	
Actual heat transfer rate is q = Cc x (to-ti)		Watt	230061.62	
We know that Effectiveness E = Heat transfer actual (q)/ Heat Transfer Max (qMax)			0.49	
NTU = -Log (1- E(1+CR))/(1+CR) as per graph 11.14 (INCROPERA 6 th edition)			1.00	
CR = Cmin/Cmax calculated			1.00	

Assuming Uf - 45 W/M2oC and Uw - 625 W/M2oC as per table C 2		
We know that NTU = Uf x Af /Cmin		
Hence Flue gas heat transfer Area Af = NTU * C min/Uf	m2	E64*E56/45
	m2	102.25
Assuming Tube id 0.0050 M and metal thickness 1.5 mm , Pitch -20 mm nd and length 12 M of Flue gas heat exchanger		
Hence No of Tubes (N) = A/∏ x D x L	Nos	E72/(3.14*0.005*12)
	Nos	543
No of coils	Nos	E75/2
	Nos	271
Width of Economizer Heat Exchanger will be	m	E76*(0.0053+0.002)
	m	3.96
Say width of Heat Excahnger	m	4
Hence the Size of Economizer Heat Exchanger will be L X W - 6 x 4 M		
MOC - Carbon steel		
Tube Size - 50 MM , Thickness -1.5mm		
Inlet and outlet water header size --- 200 mm		

Location of Heat Exchanger

Location of Heat Exchanger -			
volume of chimney exhaust gast		CFM	28000
mass flow rate (1CFM =0.59 M3/Hour, 1 hour = 3600 Sec)		m3/sec	E89*0.59/3600
		m3/sec	4.589
density		kg/m3	0.940
mass flow rate		Kg/sec	E91/E92
		Kg/sec	4.882
ID of chimney		Ft	3.6
Inside area of Chimney		Ft2	∏*D2/4
		Ft2	10.17
Velocity of gas flow V= Q/A		FPM	E89/2/E97
		FPM	1376
Hence the velocity of gas flow will be		FPM	1376
		m/s	E100/3.28/60
		m/s	6.99
Duct sizing area for Economizer heat exchanger		Ft2	Q/V
Duct sizing area for Economizer heat exchanger		Ft2	E89/E100
		Ft2	20.35
Hence the size of duct would be			**4.51x 4.51 feet**
Hence the location of Heat Exchanger will be away from drying oven		**Ft**	**30**
Length of Heat Exchanger is taken		**Ft**	**20**
Hence remaining distance from Heat exchanger to Water storage tank		**Ft**	**250**

Design Layout of the System



HEAT RECOVERY SYSTEM OF A SHEETROCK PLANT

Construction Material

The construction material used for the cross flow heat exchanger is Medium Carbon Steel. The Carbon steel is a steel alloy which consists of iron and carbon as the main constituent's material. Several other elements such as Manganese, Silicon, and Copper were allowed in carbon steel as low maximum percentages as follows: Manganese (1.65% max), Silicon (0.60% max), Copper (0.60% max). Other elements could be present in the steel in small quantities which won't affect the properties of carbon steel.

There are four types of carbon steel based on the amount of carbon in the alloy as follows:

1. **Low Carbon Steel:** Carbon content (0.05-0.25%), Manganese (0.4%) also known as mild steel. Its properties as- Low cost material, easy to shape.

2. **Medium Carbon Steel:** Carbon content (0.29-0.54%), Manganese (0.60-1.65%). Its properties as ductile and strong with good wear properties.

3. **High Carbon Steel:** Carbon content (0.55-0.95%), Manganese (0.30-0.90%). Its properties as strong and holds shape memory very well ideally for springs and wire.

4. **Very High Carbon Steel:** Carbon content (0.96-2.1%). Its high carbon content makes it the extremely strong material, brittle and requires special handling.

Pump

Pump Calculations			
City water Pressure given		psig	55
Converted (1Kg/cm2= 14.53 psig)		Kg/cm2	3.79
Pressure drop across the Heat Exchanger			
e		mm	0.000150
L		m	12
D		m	0.0050
ρ		Kg/m3	999.70
V		m/sec	1.2
Diameter of Tube for Heat Exchanger (D)		m	0.0050
µ Viscosity		N sec/m2	0.00130
Re= ρ x V x D /µ (For Turbulent flow)			4614
F (Friction Factor)			0.038
F=1/SQRT(F) +2*LOG(e/(3.7*D) + 2.51/(Re*SQRT(F)))			
Pressure drop across Heat Exchanger ΔP = ρx F x L /D X V2/2		Kg/m/sec2 (Pascal	1.87
Frictional loss across Heat Exchanger h= FX(L/D)xV2/2		m2/sec2	66
Head loss across heat exchanger = ΔP /ρ x g +h/g		**m**	**7**

Total Suction Head = Net Positive suction head - Head Loss		**m**	**375**
Frictional losses in Pipe line (200 Feet) h= FX(L/D)xV2/2		m2/sec2	17
Pressure drop across Suction pipe line ΔP = ρx F x L /D X V2/2		Kg/m Sec2 (Pascal	16798
Head Loss in suction pipe line (200 Feet) = ΔP /ρ x g +h/g		**m**	**3.43**
Total Discharge head = Static Discharge lift + Discharge head loss + Head Loss across Heat Exchanger		**m**	**214**
Static Discharge lift		m	200
Pressure Drop across Heat Exchanger		m	7
Discharge head loss across pipe line		m	7
Head Loss in Discharge pipe line (405 Feet) = ΔP /ρ x g +h/g		m2/sec2	7
Frictional losses in Pipe line h= FX(L/D+3Le/D)xV2 /2		m2/sec2	35
Pressure drop in discharge pipe line (405 Feet) ΔP = ρx F x L /D X V2/2		Kg/m/sec2 (Pascal	34017
for positive suction Total Dynamic head = Total Discharge Head - Total Suction Head		m	-162
Positive suction Head		Kg/cm2	-1.62
Hence New pump is not required due to available pressure of City water			

Piping System

Pipe

The pipe selected for the flow of city water to and from the heat exchanger is Mild Steel ERW pipes. These pipes are specially designed by galvanising iron (Hot Dip Galvanised) process to avoid any corrosion due to constant contact with water. These pipes are generally used by construction companies and power producing industries.

General Specifications of ERW pipes are:

1) Size Range- ½ inch to 6 inch NB
2) Thickness range- 6.35 – 12.7 mm
3) Class- A, B, C
4) Grade- 1239/I OR BS: 1387 CLASS A, B OR C
5) Ends- With Screw & Socket or Plain Ends

Pipe fittings

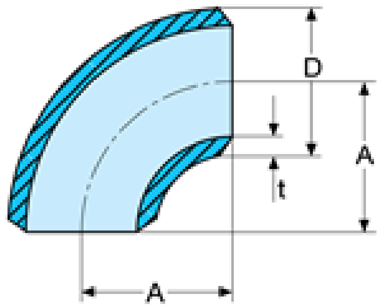
In the heat recovery system, the type of pipe fitting selected is Butt-weld fitting. In particular, to 90^{0} elbows, short radius butt-weld fitting for the flow of water through the heat exchanger. According to the requirement of pipe design, the pairs of butt-weld fitting would be selected in the pipes to flow the water through the heat exchanger into the water holding tank.

There are different forms of butt-weld fittings as:

1) Elbow 90^{0}, long radius
2) Ball Valves
3) MS Flanges
4) Water Flow meter
5) Water inlet and outlet Headers
6) Nut and Bolts

Dimensions for Pipe Fitting

The description for butt-weld pipe fitting selected according to the requirement are as follows:



1) Nominal Pipe size: 4 inches

2) Category: 10 sch (schedules)

3) Diameter: 100 mm

4) Thickness: 3.05 mm

5) Area: 101.6 mm^2

6) Weight (kg/pce): 1.720

7) Stainless Steel grade: ASTM A316/316L (Made from welded pipe or plate)

Material for Pipe Fitting

The material selected for butt-weld fitting in the pipe is Austenitic Stainless Steel. This material consists of steel grade- ASTM316/316L which is made from welded pipe or plate.

There are two types of materials used for butt-weld fitting construction as:

A. **Austenitic** Stainles **Steel:** Specifications are – Stainless steel grades ASTM 304/304L and ASTM 316/316L (dual marked and certified) acc. To ASTM A / ASME SA403, IC acc. To ASTM A262E and PMI tested.

B. **Duplex and Super Duplex Stainles Steel:** Specifications are – Duplex grade UNS S31803 (EN 1.4462 / SAF 2205) and super-duplex grade UNS S32750 (EN 1.4410 / SAF 2507) acc. To ASTM A815, G48A for UNS S32750 and PMI tested.

Calculations for Pipe Sizing

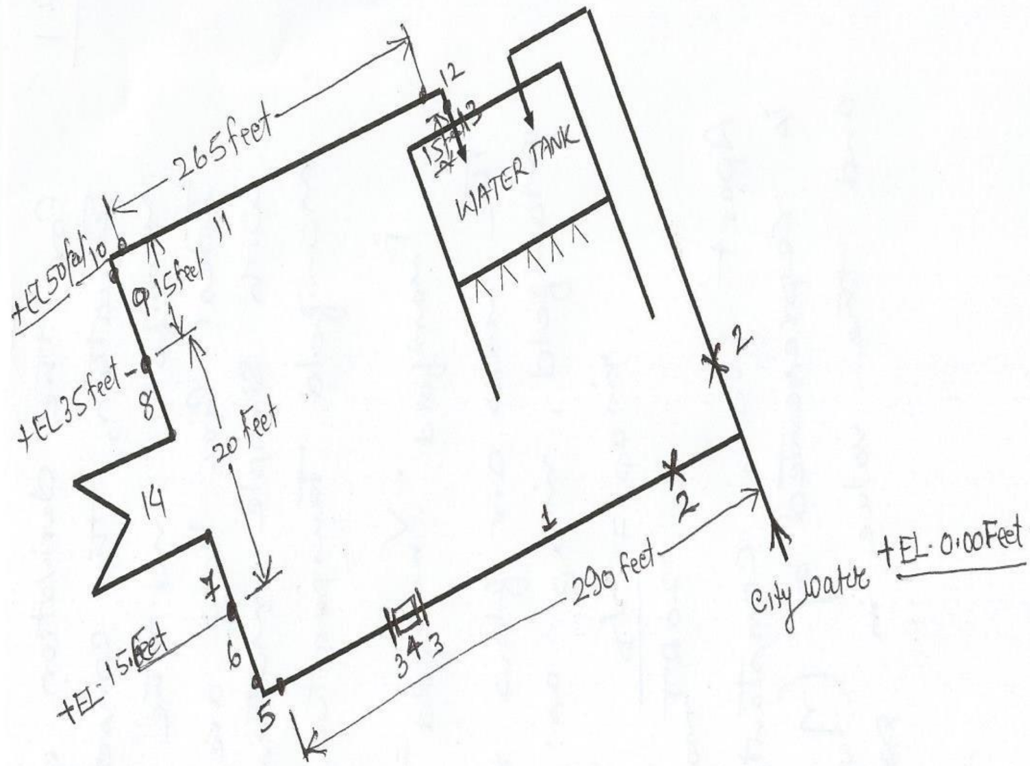
Pipe sizing			
Water flow rate		GPM	70
Q		Kg/hour	19093.9
Q		m3/hour	19.094
Q		m3/sec	0.005
Assuming water flow velocity		m/s	1.2
Area required for water		m2	0.00442
We know that A = ∏/4 X D 2			
Hence D2 = 4A /∏		m2	0.005630
		mm2	5630
Calculated Diameter of Pipe will be for water transporation		**mm**	**75**
Hence the next size of pipe would be		**mm**	**100**

The diameter of pipe for water transportation is selected as **100** mm. This is because pipe size is calculated as 75 mm but in actual, pipe size is selected as in the range of 1-1 1/2-1 1/4 inches and 100 mm is relatively equal to 4 inches. It is always desired to take one size higher than the calculated values to minimise the pressure drop across the pipeline considering a reduction in

various losses.

Routing

Water Pipe Line Routing



Bill Of Material

1	MS Pipe C Class 100 NB	290 Feet
2	MS Pipe Ball Valve 100 NB	2 No.s
3	MS Flange 100 NB, Table H	1 pair
4	Water Flow meter 100 NB "5-25 m3/hour"	1 No.
5	MS C Class Elbow-90 deg ,100 NB	1 No.
6	MS Pipe C Class 100 NB	15 Feet
7	Economiser Inlet Header 200 NB	15 Feet
8	Economiser Outlet Header 200 NB	15 Feet
9	MS Pipe C Class 100 NB	15 Feet
10	MS C Class Elbow-90 deg ,100 NB	1 No.
11	MS Pipe C Class 100 NB	265 Feet
12	MS C Class Elbow-90 deg ,100 NB	1 No.
13	MS Pipe C Class 100 NB	15 Feet
14	Economiser Heat Exchanger	1 No.

Construction Material for Pipe

The construction material selected for the pipe is Mild Steel C Class. The material required for the complete piping system are as follows:

Piping Material		
MS C Class Pipe Size 100 NB Length for inlet of heat exchanger	Feet	305
MS C Class Pipe Size 100 NB Length for outlet of heat exchanger	Feet	295
Hence total MS C class Pipe size 100 NB will be	Feet	600
MS C Class Bends 45^0	No's	3
Flow Meter Flange mounted Size 100 mm, Flow rate – 5-25 M^3/hour	No	1
MS C Class Flange Table F	Pairs	2
MS Nut Bolt	M16	16

Economic Calculations

Input Data

Natural Gas Rate: CAD $ 0.13/KG

Flue gas Capacity (2 Chimneys): 435583 Kcal/hour (16520 x 0.255 x 0.94 x 110)

Heat Recovery Capacity (2 Chimneys): - 186346 Kcal/hour

Operating Hours: 4872 hours

Cost of Heat Recovery Calculation

Case 1 - (Without Heat Recovery)

Heat Energy required to heat up city water 70 GPM from 45^{o}F (7.22^{o}C) to 85^{o}F (29.42^{o}C)

= m x cp_w x ρ x (to-ti) Kcal/hour

= 70 x 272.77 x (29.44-7.22) = 424266 Kcal/hour

Assuming Net CV of Natural gas = 9600 Kcal/hour

Hence the Natural Gas consumption would be = 44.19 Kg/hour

Hence the Natural gas consumption for 8 months (4872 hours) == 215294 kg / 8 months

Case II - (With Heat Recovery)

Heat Energy required to heat up city water 70 GPM from 45 ^oF (7.22 ^oC) to 63.66 ^oF (17.59 ^oC)

= m x cpw x ρ x (to-ti) Kcal/hour

= 70 x 272.77 x (17.59-7.22) = 197992 Kcal/hour

Assuming Net CV of Natural gas = 9600 Kcal/hour

Hence the Natural Gas consumption would be = 20.62 Kg/hour

N a tural gas consumption for 8 months (4872 Hours) ==100481 kg / 8 months

Net Saving in Natural Gas consumption (4872 Hours) == 100481 kg / 8 months

Hence the final natural gas consumption would be = 114813 Kg/ 8 months

Rate of natural gas == CAD $ 0.13/KG

Hence net cost saving in 8 months = 0.13 x 100481 == CAD $ 13063 .00

Payback Summary

Annual Natural Gas Cost Savings CAD $ 13063 /year

Heat Recovery Calculations		
Heat Energy utilised to convert water temperature from 45 oF to 63.66 oF	Kcal/hour	197992
Assumed GCV of Natural Gas	Kcal/Kg	9600
Natural Gas saving by heat recovery	Kg/hour	20.62
Time to be calculated (203 days x 24 Hours)	hours	4872
Gas qty saving in 8 months	Kg	100481
Assumed Rate of Natual Gas	CAD $	0.13
Cost saving of Natual gas for 8 months	CAD $	**13063**
Installation cost		
Cost of Heat Exchanger	CAD $	12000
Piping bends, Flanges and Flowmeter	CAD $	7200
Ducting and dampers	CAD $	12000
Insulation of inlet ducting and heat exchanger	CAD $	10000
Total Cost	CAD $	41200
Contigency @5%	CAD $	2060
Total Project cost	CAD $	**43260**

Operation cost		
Natural Gas required to heat up water from 63.66 oF to 85 oF for 70 GPM water	Kcal/hour	226317
Qty of Gas required to heat up water as above	Kg/hour	25.86
Qty of Gas required to heat up water as above (8 months)	Kg/Year	125990
Operation cost of Natural gas	**CAD $/Year**	**16379**
Man power Cost @ 15 CAD $/hour	CAD $/Year	73080
Total operating cost	CAD $/Year	**89458.7**
Maintenance Cost		
Stores and spares for Heat Exchanger, Ducting ,Dampers and burners @ 2% 0f project cost	CAD $/Year	865.2
Repair and Maint cost @ 3 % of project cost	CAD $/Year	1297.8
Total maintenance cost assumed @ 5 % of Project cost per year	CAD $/Year	**2163**
Grand Total - (Project cost + operation cost + Maintenance Cost)	CAD $/Year	**134882**
Pay back period (Project cost/ Annual saving)	Years	**3.31**

Payback Period for Investment

From the energy savings and implementation costs calculation, a simple payback period for the system design can be analysed. A simple payback calculates the number of years involved in the investment that would reduce the energy costs by the same amount as the initial cost of implementation.

The simple payback period follows as:

SP = IC / ES

= $43,260/ $13,063 per year

= 3.31 years

Where:

SP = Simple Payback Period

IC = Total Implementation Cost for the entire system

ES = Annual Energy Savings expected from the design

This system design is estimated to pay for itself in less than three years and 31 days.This simple payback is calculated based on the initial costs along with the estimated energy consumption reduction and it does not include any types of maintenance costs throughout the system life.

However, the system does not consist of many moving parts leading to the majority of the maintenance costs being associated with the cleaning of the heat exchangers. This maintenance is assumed to be minimal and should not impact the implementation of the system. However, certain maintenance interval estimations have been established and are discussed in previous Sections which can be used to provide a more accurate representation of the payback period.

Conclusion

1) The heat exchanger type selected is economiser cross flow heat exchanger as:
   a. Size – 6 x 4 m^2
   b. Length – 20 feet (6 m)
   c. Location –
      I. Distance of Heat exchanger from drying oven- 30 feet
      II. The distance of Heat exchanger from the water holding tank-

   250 feet d. Material Used – Medium Carbon Steel
2) Pump – Not required as the pressure of water flow is adequate to maintain pressure drop in the water pipeline.
3) Piping System as:
   I. Pipe Size (Nominal Diameter): 100 mm (4 inches)
   II. Pipe Length from Junction of city water to the Heat exchanger Inlet header: 305 feet
   III. Pipe Length from Heat Exchanger outlet header to the water holding tank: 295 feet
4) Material Used for pipe: Mild Steel C Class
5) Material Used for Pipe fitting: Austenitic Stainless Steel (ASTM A 316/316L)
6) Total Project Cost Involved: CAD $ 43260.00
7) Payback period**: 3.31** years

Used Tables

Table C.2 Representative values of the overall heat transfer coefficients (SI)

Type of Heat Exchanger	U (W/(m^2 °C))
Water-to-water	850–1700
Water-to-oil	100–350
Water-to-gasoline or kerosene	300–1000
Feedwater heater	1000–8500
Steam-to-light fuel oil	200–400
Steam-to-heavy fuel oil	50–200
Steam condenser	1000–6000
Freon condenser (water cooled)	300–1000
Ammonia condenser (water cooled)	800–1400
Alcohol condenser (water cooled)	250–700
Gas-to-gas	10–40
Water-to-air in finned tubes (water in tubes)	30–60 (air); 400–850 (water)
Steam-to-air in finned tubes (steam in tubes)	30–300 (air); 400–4000 (water)

Source: Çengel, Y.A. (2007) *Heat and Mass Transfer: A Practical Approach*, 3rd edn, McGraw-Hill, Inc., New York.

t	ρ	c_p	μ *10^6	ν *10^6
[^{O} C]	[kg/m^3]	[kJ/kgK]	[Pas]	[m^2/s]
0	1.295	1.042	15.8	12.2
100	0.95	1.068	20.4	21.54
200	0.748	1.097	24.5	32.8
300	0.617	1.122	28.2	45.81
400	0.525	1.151	31.7	60.38
500	0.457	1.185	34.8	76.3
600	0.405	1.214	37.9	93.61
700	0.363	1.239	40.7	112.1
800	0.33	1.264	43.4	131.8
900	0.301	1.29	45.9	152.5
1000	0.275	1.306	48.4	174.3
1100	0.257	1.323	50.7	197.1
1200	0.24	1.34	53	221

Fig: Flue Gas Property Table

TABLE A–6

Superheated water

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
	P = 0.01 MPa (45.81°C)*				P = 0.05 MPa (81.32°C)				P = 0.10 MPa (99.61°C)			
Sat.†	14.670	2437.2	2583.9	8.1488	3.2403	2483.2	2645.2		1.6941	2505.6	2675.0	7.3589
50	14.867	2443.3	2592.0	8.1741		7.5931						
100	17.196	2515.5	2687.5	8.4489					1.6959	2506.2	2675.8	7.3611
150	19.513	2587.9	2783.0	8.6893	3.4187	2511.5	2682.4		1.9367	2582.9	2776.6	7.6148
200	21.826	2661.4	2879.6	8.9049		7.6953			2.1724	2658.2	2875.5	7.8356
250	24.136	2736.1	2977.5	9.1015	3.8897	2585.7	2780.2		2.4062	2733.9	2974.5	8.0346
300	26.446	2812.3	3076.7	9.2827		7.9413			2.6389	2810.7	3074.5	8.2172
400	31.063	2969.3	3280.0	9.6094	4.3562	2660.0	2877.8		3.1027	2968.3	3278.6	8.5452
500	35.680	3132.9	3489.7	9.8998		8.1592			3.5655	3132.2	3488.7	8.8362
600	40.296	3303.3	3706.3	10.1631	4.8206	2735.1	2976.2		4.0279	3302.8	3705.6	9.0999
700	44.911	3480.8	3929.9	10.4056		8.3568			4.4900	3480.4	3929.4	9.3424
800	49.527	3665.4	4160.6	10.6312	5.2841	2811.6	3075.8		4.9519	3665.0	4160.2	9.5682
900	54.143	3856.9	4398.3	10.8429		8.5387			5.4137	3856.7	4398.0	9.7800
1000	58.758	4055.3	4642.8	11.0429	6.2094	2968.9	3279.3		5.8755	4055.0	4642.6	9.9800
1100	63.373	4260.0	4893.8	11.2326		8.8659			6.3372	4259.8	4893.6	10.1698
1200	67.989	4470.9	5150.8	11.4132	7.1338	3132.6	3489.3		6.7988	4470.7	5150.6	10.3504
1300	72.604	4687.4	5413.4	11.5857		9.1566			7.2605	4687.2	5413.3	10.5229
					8.0577	3303.1	3706.0					
	P = 0.20 MPa (120.21°C)				P = 0.30 MPa (133.52°C)				P = 0.40 MPa (143.61°C)			
Sat.	0.88578	2529.1	2706.3	7.1270	0.60582	2543.2	2724.9	6.9917	0.46242	2553.1	2738.1	6.8955
150	0.95986	2577.1	2769.1	7.2810	0.63402	2571.0	2761.2	7.0792	0.47088	2564.4	2752.8	6.9306
200	1.08049	2654.6	2870.7	7.5081	0.71643	2651.0	2865.9	7.3132	0.53434	2647.2	2860.9	7.1723
250	1.19890	2731.4	2971.2	7.7100	0.79645	2728.9	2967.9	7.5180	0.59520	2726.4	2964.5	7.3804
300	1.31623	2808.8	3072.1	7.8941	0.87535	2807.0	3069.6	7.7037	0.65489	2805.1	3067.1	7.5677
400	1.54934	2967.2	3277.0	8.2236	1.03155	2966.0	3275.5	8.0347	0.77265	2964.9	3273.9	7.9003
500	1.78142	3131.4	3487.7	8.5153	1.18672	3130.6	3486.6	8.3271	0.88936	3129.8	3485.5	8.1933
600	2.01302	3302.2	3704.8	8.7793	1.34139	3301.6	3704.0	8.5915	1.00558	3301.0	3703.3	8.4580
700	2.24434	3479.9	3928.8	9.0221	1.49580	3479.5	3928.2	8.8345	1.12152	3479.0	3927.6	8.7012
800	2.47550	3664.7	4159.8	9.2479	1.65004	3664.3	4159.3	9.0605	1.23730	3663.9	4158.9	8.9274
900	2.70656	3856.3	4397.7	9.4598	1.80417	3856.0	4397.3	9.2725	1.35298	3855.7	4396.9	9.1394
1000	2.93755	4054.8	4642.3	9.6599	1.95824	4054.5	4642.0	9.4726	1.46859	4054.3	4641.7	9.3396
1100	3.16848	4259.6	4893.3	9.8497	2.11226	4259.4	4893.1	9.6624	1.58414	4259.2	4892.9	9.5295
1200	3.39938	4470.5	5150.4	10.0304	2.26624	4470.3	5150.2	9.8431	1.69966	4470.2	5150.0	9.7102
1300	3.63026	4687.1	5413.1	10.2029	2.42019	4686.9	5413.0	10.0157	1.81516	4686.7	5412.8	9.8828
	P = 0.50 MPa (151.83°C)				P = 0.60 MPa (158.83°C)				P = 0.80 MPa (170.41°C)			
Sat.	0.37483	2560.7	2748.1	6.8207	0.31560	2566.8	2756.2	6.7593	0.24035	2576.0	2768.3	6.6616
200	0.42503	2643.3	2855.8	7.0610	0.35212	2639.4	2850.6	6.9683	0.26088	2631.1	2839.8	6.8177
250	0.47443	2723.8	2961.0	7.2725	0.39390	2721.2	2957.6	7.1833	0.29321	2715.9	2950.4	7.0402
300	0.52261	2803.3	3064.6	7.4614	0.43442	2801.4	3062.0	7.3740	0.32416	2797.5	3056.9	7.2345
350	0.57015	2883.0	3168.1	7.6346	0.47428	2881.6	3166.1	7.5481	0.35442	2878.6	3162.2	7.4107
400	0.61731	2963.7	3272.4	7.7956	0.51374	2962.5	3270.8	7.7097	0.38429	2960.2	3267.7	7.5735
500	0.71095	3129.0	3484.5	8.0893	0.59200	3128.2	3483.4	8.0041	0.44332	3126.6	3481.3	7.8692
600	0.80409	3300.4	3702.5	8.3544	0.66976	3299.8	3701.7	8.2695	0.50186	3298.7	3700.1	8.1354
700	0.89696	3478.6	3927.0	8.5978	0.74725	3478.1	3926.4	8.5132	0.56011	3477.2	3925.3	8.3794
800	0.98966	3663.6	4158.4	8.8240	0.82457	3663.2	4157.9	8.7395	0.61820	3662.5	4157.0	8.6061
900	1.08227	3855.4	4396.6	9.0362	0.90179	3855.1	4396.2	8.9518	0.67619	3854.5	4395.5	8.8185
1000	1.17480	4054.0	4641.4	9.2364	0.97893	4053.8	4641.1	9.1521	0.73411	4053.3	4640.5	9.0189
1100	1.26728	4259.0	4892.6	9.4263	1.05603	4258.8	4892.4	9.3420	0.79197	4258.3	4891.9	9.2090
1200	1.35972	4470.0	5149.8	9.6071	1.13309	4469.8	5149.6	9.5229	0.84980	4469.4	5149.3	9.3898
1300	1.45214	4686.6	5412.6	9.7797	1.21012	4686.4	5412.5	9.6955	0.90761	4686.1	5412.2	9.5625

TABLE A–6

Superheated water (*Continued*)

T °C	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg K	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg K	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg K
	P 1.00 MPa (179.88 C)				*P* 1.20 MPa (187.96 C)				*P* 1.40 MPa (195.04 C)			
Sat.	0.19437	2582.8	2777.1	6.5850	0.16326	2587.8	2783.8	6.5217	0.14078	2591.8	2788.9	6.4675
200	0.20602	2622.3	2828.3	6.6956	0.16934	2612.9	2816.1	6.5909	0.14303	2602.7	2803.0	6.4975
250	0.23275	2710.4	2943.1	6.9265	0.19241	2704.7	2935.6	6.8313	0.16356	2698.9	2927.9	6.7488
300	0.25799	2793.7	3051.6	7.1246	0.21386	2789.7	3046.3	7.0335	0.18233	2785.7	3040.9	6.9553
350	0.28250	2875.7	3158.2	7.3029	0.23455	2872.7	3154.2	7.2139	0.20029	2869.7	3150.1	7.1379
400	0.30661	2957.9	3264.5	7.4670	0.25482	2955.5	3261.3	7.3793	0.21782	2953.1	3258.1	7.3046
500	0.35411	3125.0	3479.1	7.7642	0.29464	3123.4	3477.0	7.6779	0.25216	3121.8	3474.8	7.6047
600	0.40111	3297.5	3698.6	8.0311	0.33395	3296.3	3697.0	7.9456	0.28597	3295.1	3695.5	7.8730
700	0.44783	3476.3	3924.1	8.2755	0.37297	3475.3	3922.9	8.1904	0.31951	3474.4	3921.7	8.1183
800	0.49438	3661.7	4156.1	8.5024	0.41184	3661.0	4155.2	8.4176	0.35288	3660.3	4154.3	8.3458
900	0.54083	3853.9	4394.8	8.7150	0.45059	3853.3	4394.0	8.6303	0.38614	3852.7	4393.3	8.5587
1000	0.58721	4052.7	4640.0	8.9155	0.48928	4052.2	4639.4	8.8310	0.41933	4051.7	4638.8	8.7595
1100	0.63354	4257.9	4891.4	9.1057	0.52792	4257.5	4891.0	9.0212	0.45247	4257.0	4890.5	8.9497
1200	0.67983	4469.0	5148.9	9.2866	0.56652	4468.7	5148.5	9.2022	0.48558	4468.3	5148.1	9.1308
1300	0.72610	4685.8	5411.9	9.4593	0.60509	4685.5	5411.6	9.3750	0.51866	4685.1	5411.3	9.3036
	P 1.60 MPa (201.37 C)				*P* 1.80 MPa (207.11 C)				*P* 2.00 MPa (212.38 C)			
Sat.	0.12374	2594.8	2792.8	6.4200	0.11037	2597.3	2795.9	6.3775	0.09959	2599.1	2798.3	6.3390
225	0.13293	2645.1	2857.8	6.5537	0.11678	2637.0	2847.2	6.4825	0.10381	2628.5	2836.1	6.4160
250	0.14190	2692.9	2919.9	6.6753	0.12502	2686.7	2911.7	6.6088	0.11150	2680.3	2903.3	6.5475
300	0.15866	2781.6	3035.4	6.8864	0.14025	2777.4	3029.9	6.8246	0.12551	2773.2	3024.2	6.7684
350	0.17459	2866.6	3146.0	7.0713	0.15460	2863.6	3141.9	7.0120	0.13860	2860.5	3137.7	6.9583
400	0.19007	2950.8	3254.9	7.2394	0.16849	2948.3	3251.6	7.1814	0.15122	2945.9	3248.4	7.1292
500	0.22029	3120.1	3472.6	7.5410	0.19551	3118.5	3470.4	7.4845	0.17568	3116.9	3468.3	7.4337
600	0.24999	3293.9	3693.9	7.8101	0.22200	3292.7	3692.3	7.7543	0.19962	3291.5	3690.7	7.7043
700	0.27941	3473.5	3920.5	8.0558	0.24822	3472.6	3919.4	8.0005	0.22326	3471.7	3918.2	7.9509
800	0.30865	3659.5	4153.4	8.2834	0.27426	3658.8	4152.4	8.2284	0.24674	3658.0	4151.5	8.1791
900	0.33780	3852.1	4392.6	8.4965	0.30020	3851.5	4391.9	8.4417	0.27012	3850.9	4391.1	8.3925
1000	0.36687	4051.2	4638.2	8.6974	0.32606	4050.7	4637.6	8.6427	0.29342	4050.2	4637.1	8.5936
1100	0.39589	4256.6	4890.0	8.8878	0.35188	4256.2	4889.6	8.8331	0.31667	4255.7	4889.1	8.7842
1200	0.42488	4467.9	5147.7	9.0689	0.37766	4467.6	5147.3	9.0143	0.33989	4467.2	5147.0	8.9654
1300	0.45383	4684.8	5410.9	9.2418	0.40341	4684.5	5410.6	9.1872	0.36308	4684.2	5410.3	9.1384
	P 2.50 MPa (223.95 C)				*P* 3.00 MPa (233.85 C)				*P* 3.50 MPa (242.56 C)			
Sat.	0.07995	2602.1	2801.9	6.2558	0.06667	2603.2	2803.2	6.1856	0.05706	2603.0	2802.7	6.1244
225	0.08026	2604.8	2805.5	6.2629								
250	0.08705	2663.3	2880.9	6.4107	0.07063	2644.7	2856.5	6.2893	0.05876	2624.0	2829.7	6.1764
300	0.09894	2762.2	3009.6	6.6459	0.08118	2750.8	2994.3	6.5412	0.06845	2738.8	2978.4	6.4484
350	0.10979	2852.5	3127.0	6.8424	0.09056	2844.4	3116.1	6.7450	0.07680	2836.0	3104.9	6.6601
400	0.12012	2939.8	3240.1	7.0170	0.09938	2933.6	3231.7	6.9235	0.08456	2927.2	3223.2	6.8428
450	0.13015	3026.2	3351.6	7.1768	0.10789	3021.2	3344.9	7.0856	0.09198	3016.1	3338.1	7.0074
500	0.13999	3112.8	3462.8	7.3254	0.11620	3108.6	3457.2	7.2359	0.09919	3104.5	3451.7	7.1593
600	0.15931	3288.5	3686.8	7.5979	0.13245	3285.5	3682.8	7.5103	0.11325	3282.5	3678.9	7.4357
700	0.17835	3469.3	3915.2	7.8455	0.14841	3467.0	3912.2	7.7590	0.12702	3464.7	3909.3	7.6855
800	0.19722	3656.2	4149.2	8.0744	0.16420	3654.3	4146.9	7.9885	0.14061	3652.5	4144.6	7.9156
900	0.21597	3849.4	4389.3	8.2882	0.17988	3847.9	4387.5	8.2028	0.15410	3846.4	4385.7	8.1304
1000	0.23466	4049.0	4635.6	8.4897	0.19549	4047.7	4634.2	8.4045	0.16751	4046.4	4632.7	8.3324
1100	0.25330	4254.7	4887.9	8.6804	0.21105	4253.6	4886.7	8.5955	0.18087	4252.5	4885.6	8.5236
1200	0.27190	4466.3	5146.0	8.8618	0.22658	4465.3	5145.1	8.7771	0.19420	4464.4	5144.1	8.7053
1300	0.29048	4683.4	5409.5	9.0349	0.24207	4682.6	5408.8	8.9502	0.20750	4681.8	5408.0	8.8786

T	v	u	h	s	V	u	h	s	v	u	h	s
°C	m^3/kg	kJ/kg	kJ/kg	kJ/kg K	m^3/kg	kJ/kg	kJ/kg	kJ/kg K	m^3/kg	kJ/kg	kJ/kg	kJ/kg K
	P 4.0 MPa (250.35 C)				P 4.5 MPa (257.44 C)				P 5.0 MPa (263.94 C)			
Sat.	0.04978	2601.7	2800.8	6.0696	0.04406	2599.7	2798.0	6.0198	0.03945	2597.0	2794.2	5.9737
275	0.05461	2668.9	2887.3	6.2312	0.04733	2651.4	2864.4	6.1429	0.04144	2632.3	2839.5	6.0571
300	0.05887	2726.2	2961.7	6.3639	0.05138	2713.0	2944.2	6.2854	0.04535	2699.0	2925.7	6.2111
350	0.06647	2827.4	3093.3	6.5843	0.05842	2818.6	3081.5	6.5153	0.05197	2809.5	3069.3	6.4516
400	0.07343	2920.8	3214.5	6.7714	0.06477	2914.2	3205.7	6.7071	0.05784	2907.5	3196.7	6.6483
450	0.08004	3011.0	3331.2	6.9386	0.07076	3005.8	3324.2	6.8770	0.06332	3000.6	3317.2	6.8210
500	0.08644	3100.3	3446.0	7.0922	0.07652	3096.0	3440.4	7.0323	0.06858	3091.8	3434.7	6.9781
600	0.09886	3279.4	3674.9	7.3706	0.08766	3276.4	3670.9	7.3127	0.07870	3273.3	3666.9	7.2605
700	0.11098	3462.4	3906.3	7.6214	0.09850	3460.0	3903.3	7.5647	0.08852	3457.7	3900.3	7.5136
800	0.12292	3650.6	4142.3	7.8523	0.10916	3648.8	4140.0	7.7962	0.09816	3646.9	4137.7	7.7458
900	0.13476	3844.8	4383.9	8.0675	0.11972	3843.3	4382.1	8.0118	0.10769	3841.8	4380.2	7.9619
1000	0.14653	4045.1	4631.2	8.2698	0.13020	4043.9	4629.8	8.2144	0.11715	4042.6	4628.3	8.1648
1100	0.15824	4251.4	4884.4	8.4612	0.14064	4250.4	4883.2	8.4060	0.12655	4249.3	4882.1	8.3566
1200	0.16992	4463.5	5143.2	8.6430	0.15103	4462.6	5142.2	8.5880	0.13592	4461.6	5141.3	8.5388
1300	0.18157	4680.9	5407.2	8.8164	0.16140	4680.1	5406.5	8.7616	0.14527	4679.3	5405.7	8.7124
	P 6.0 MPa (275.59 C)				P 7.0 MPa (285.83 C)				P 8.0 MPa (295.01 C)			
Sat.	0.03245	2589.9	2784.6	5.8902	0.027378	2581.0	2772.6	5.8148	0.023525	2570.5	2758.7	5.7450
300	0.03619	2668.4	2885.6	6.0703	0.029492	2633.5	2839.9	5.9337	0.024279	2592.3	2786.5	5.7937
350	0.04225	2790.4	3043.9	6.3357	0.035262	2770.1	3016.9	6.2305	0.029975	2748.3	2988.1	6.1321
400	0.04742	2893.7	3178.3	6.5432	0.039958	2879.5	3159.2	6.4502	0.034344	2864.6	3139.4	6.3658
450	0.05217	2989.9	3302.9	6.7219	0.044187	2979.0	3288.3	6.6353	0.038194	2967.8	3273.3	6.5579
500	0.05667	3083.1	3423.1	6.8826	0.048157	3074.3	3411.4	6.8000	0.041767	3065.4	3399.5	6.7266
550	0.06102	3175.2	3541.3	7.0308	0.051966	3167.9	3531.6	6.9507	0.045172	3160.5	3521.8	6.8800
600	0.06527	3267.2	3658.8	7.1693	0.055665	3261.0	3650.6	7.0910	0.048463	3254.7	3642.4	7.0221
700	0.07355	3453.0	3894.3	7.4247	0.062850	3448.3	3888.3	7.3487	0.054829	3443.6	3882.2	7.2822
800	0.08165	3643.2	4133.1	7.6582	0.069856	3639.5	4128.5	7.5836	0.061011	3635.7	4123.8	7.5185
900	0.08964	3838.8	4376.6	7.8751	0.076750	3835.7	4373.0	7.8014	0.067082	3832.7	4369.3	7.7372
1000	0.09756	4040.1	4625.4	8.0786	0.083571	4037.5	4622.5	8.0055	0.073079	4035.0	4619.6	7.9419
1100	0.10543	4247.1	4879.7	8.2709	0.090341	4245.0	4877.4	8.1982	0.079025	4242.8	4875.0	8.1350
1200	0.11326	4459.8	5139.4	8.4534	0.097075	4457.9	5137.4	8.3810	0.084934	4456.1	5135.5	8.3181
1300	0.12107	4677.7	5404.1	8.6273	0.103781	4676.1	5402.6	8.5551	0.090817	4674.5	5401.0	8.4925
	P 9.0 MPa (303.35 C)				P 10.0 MPa (311.00 C)				P 12.5 MPa (327.81 C)			
Sat.	0.020489	2558.5	2742.9	5.6791	0.018028	2545.2	2725.5	5.6159	0.013496	2505.6	2674.3	5.4638
325	0.023284	2647.6	2857.1	5.8738	0.019877	2611.6	2810.3	5.7596				
350	0.025816	2725.0	2957.3	6.0380	0.022440	2699.6	2924.0	5.9460	0.016138	2624.9	2826.6	5.7130
400	0.029960	2849.2	3118.8	6.2876	0.026436	2833.1	3097.5	6.2141	0.020030	2789.6	3040.0	6.0433
450	0.033524	2956.3	3258.0	6.4872	0.029782	2944.5	3242.4	6.4219	0.023019	2913.7	3201.5	6.2749
500	0.036793	3056.3	3387.4	6.6603	0.032811	3047.0	3375.1	6.5995	0.025630	3023.2	3343.6	6.4651
550	0.039885	3153.0	3512.0	6.8164	0.035655	3145.4	3502.0	6.7585	0.028033	3126.1	3476.5	6.6317
600	0.042861	3248.4	3634.1	6.9605	0.038378	3242.0	3625.8	6.9045	0.030306	3225.8	3604.6	6.7828
650	0.045755	3343.4	3755.2	7.0954	0.041018	3338.0	3748.1	7.0408	0.032491	3324.1	3730.2	6.9227
700	0.048589	3438.8	3876.1	7.2229	0.043597	3434.0	3870.0	7.1693	0.034612	3422.0	3854.6	7.0540
800	0.054132	3632.0	4119.2	7.4606	0.048629	3628.2	4114.5	7.4085	0.038724	3618.8	4102.8	7.2967
900	0.059562	3829.6	4365.7	7.6802	0.053547	3826.5	4362.0	7.6290	0.042720	3818.9	4352.9	7.5195
1000	0.064919	4032.4	4616.7	7.8855	0.058391	4029.9	4613.8	7.8349	0.046641	4023.5	4606.5	7.7269
1100	0.070224	4240.7	4872.7	8.0791	0.063183	4238.5	4870.3	8.0289	0.050510	4233.1	4864.5	7.9220
1200	0.075492	4454.2	5133.6	8.2625	0.067938	4452.4	5131.7	8.2126	0.054342	4447.7	5127.0	8.1065
1300	0.080733	4672.9	5399.5	8.4371	0.072667	4671.3	5398.0	8.3874	0.058147	4667.3	5394.1	8.2819

TABLE A–6

Superheated water (*Concluded*)

T °C	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg K	*V* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg K	*v* m³/kg	*u* kJ/kg	*h* kJ/kg	*s* kJ/kg K
	P _ 15.0 MPa (342.16 C)				*P* _ 17.5 MPa (354.67 C)				*P* _ 20.0 MPa (365.75 C)			
Sat.	0.010341	2455.7	2610.8	5.3108	0.007932	2390.7	2529.5	5.1435	0.005862	2294.8	2412.1	4.9310
350	0.011481	2520.9	2693.1	5.4438								
400	0.015671	2740.6	2975.7	5.8819	0.012463	2684.3	2902.4	5.7211	0.009950	2617.9	2816.9	5.5526
450	0.018477	2880.8	3157.9	6.1434	0.015204	2845.4	3111.4	6.0212	0.012721	2807.3	3061.7	5.9043
500	0.020828	2998.4	3310.8	6.3480	0.017385	2972.4	3276.7	6.2424	0.014793	2945.3	3241.2	6.1446
550	0.022945	3106.2	3450.4	6.5230	0.019305	3085.8	3423.6	6.4266	0.016571	3064.7	3396.2	6.3390
600	0.024921	3209.3	3583.1	6.6796	0.021073	3192.5	3561.3	6.5890	0.018185	3175.3	3539.0	6.5075
650	0.026804	3310.1	3712.1	6.8233	0.022742	3295.8	3693.8	6.7366	0.019695	3281.4	3675.3	6.6593
700	0.028621	3409.8	3839.1	6.9573	0.024342	3397.5	3823.5	6.8735	0.021134	3385.1	3807.8	6.7991
800	0.032121	3609.3	4091.1	7.2037	0.027405	3599.7	4079.3	7.1237	0.023870	3590.1	4067.5	7.0531
900	0.035503	3811.2	4343.7	7.4288	0.030348	3803.5	4334.6	7.3511	0.026484	3795.7	4325.4	7.2829
1000	0.038808	4017.1	4599.2	7.6378	0.033215	4010.7	4592.0	7.5616	0.029020	4004.3	4584.7	7.4950
1100	0.042062	4227.7	4858.6	7.8339	0.036029	4222.3	4852.8	7.7588	0.031504	4216.9	4847.0	7.6933
1200	0.045279	4443.1	5122.3	8.0192	0.038806	4438.5	5117.6	7.9449	0.033952	4433.8	5112.9	7.8802
1300	0.048469	4663.3	5390.3	8.1952	0.041556	4659.2	5386.5	8.1215	0.036371	4655.2	5382.7	8.0574
	P _ 25.0 MPa				*P* _ 30.0 MPa				*P* _ 35.0 MPa			
375	0.001978	1799.9	1849.4	4.0345	0.001792	1738.1	1791.9	3.9313	0.001701	1702.8	1762.4	3.8724
400	0.006005	2428.5	2578.7	5.1400	0.002798	2068.9	2152.8	4.4758	0.002105	1914.9	1988.6	4.2144
425	0.007886	2607.8	2805.0	5.4708	0.005299	2452.9	2611.8	5.1473	0.003434	2253.3	2373.5	4.7751
450	0.009176	2721.2	2950.6	5.6759	0.006737	2618.9	2821.0	5.4422	0.004957	2497.5	2671.0	5.1946
500	0.011143	2887.3	3165.9	5.9643	0.008691	2824.0	3084.8	5.7956	0.006933	2755.3	2997.9	5.6331
550	0.012736	3020.8	3339.2	6.1816	0.010175	2974.5	3279.7	6.0403	0.008348	2925.8	3218.0	5.9093
600	0.014140	3140.0	3493.5	6.3637	0.011445	3103.4	3446.8	6.2373	0.009523	3065.6	3399.0	6.1229
650	0.015430	3251.9	3637.7	6.5243	0.012590	3221.7	3599.4	6.4074	0.010565	3190.9	3560.7	6.3030
700	0.016643	3359.9	3776.0	6.6702	0.013654	3334.3	3743.9	6.5599	0.011523	3308.3	3711.6	6.4623
800	0.018922	3570.7	4043.8	6.9322	0.015628	3551.2	4020.0	6.8301	0.013278	3531.6	3996.3	6.7409
900	0.021075	3780.2	4307.1	7.1668	0.017473	3764.6	4288.8	7.0695	0.014904	3749.0	4270.6	6.9853
1000	0.023150	3991.5	4570.2	7.3821	0.019240	3978.6	4555.8	7.2880	0.016450	3965.8	4541.5	7.2069
1100	0.025172	4206.1	4835.4	7.5825	0.020954	4195.2	4823.9	7.4906	0.017942	4184.4	4812.4	7.4118
1200	0.027157	4424.6	5103.5	7.7710	0.022630	4415.3	5094.2	7.6807	0.019398	4406.1	5085.0	7.6034
1300	0.029115	4647.2	5375.1	7.9494	0.024279	4639.2	5367.6	7.8602	0.020827	4631.2	5360.2	7.7841
	P _ 40.0 MPa				*P* _ 50.0 MPa				*P* _ 60.0 MPa			
375	0.001641	1677.0	1742.6	3.8290	0.001560	1638.6	1716.6	3.7642	0.001503	1609.7	1699.9	3.7149
400	0.001911	1855.0	1931.4	4.1145	0.001731	1787.8	1874.4	4.0029	0.001633	1745.2	1843.2	3.9317
425	0.002538	2097.5	2199.0	4.5044	0.002009	1960.3	2060.7	4.2746	0.001816	1892.9	2001.8	4.1630
450	0.003692	2364.2	2511.8	4.9449	0.002487	2160.3	2284.7	4.5896	0.002086	2055.1	2180.2	4.4140
500	0.005623	2681.6	2906.5	5.4744	0.003890	2528.1	2722.6	5.1762	0.002952	2393.2	2570.3	4.9356
550	0.006985	2875.1	3154.4	5.7857	0.005118	2769.5	3025.4	5.5563	0.003955	2664.6	2901.9	5.3517
600	0.008089	3026.8	3350.4	6.0170	0.006108	2947.1	3252.6	5.8245	0.004833	2866.8	3156.8	5.6527
650	0.009053	3159.5	3521.6	6.2078	0.006957	3095.6	3443.5	6.0373	0.005591	3031.3	3366.8	5.8867
700	0.009930	3282.0	3679.2	6.3740	0.007717	3228.7	3614.6	6.2179	0.006265	3175.4	3551.3	6.0814
800	0.011521	3511.8	3972.6	6.6613	0.009073	3472.2	3925.8	6.5225	0.007456	3432.6	3880.0	6.4033
900	0.012980	3733.3	4252.5	6.9107	0.010296	3702.0	4216.8	6.7819	0.008519	3670.9	4182.1	6.6725
1000	0.014360	3952.9	4527.3	7.1355	0.011441	3927.4	4499.4	7.0131	0.009504	3902.0	4472.2	6.9099
1100	0.015686	4173.7	4801.1	7.3425	0.012534	4152.2	4778.9	7.2244	0.010439	4130.9	4757.3	7.1255
1200	0.016976	4396.9	5075.9	7.5357	0.013590	4378.6	5058.1	7.4207	0.011339	4360.5	5040.8	7.3248
1300	0.018239	4623.3	5352.8	7.7175	0.014620	4607.5	5338.5	7.6048	0.012213	4591.8	5324.5	7.5111

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