Technical Information

Determining Heat Energy Requirements - Steam Heating

Steam Heating with Heat Exchangers — Shell and tube heat exchangers are frequently used to heat liquids where steam is available from central boilers or waste heat from processes. Electric steam boilers can be used as a supplemental or alternate steam source.

Example — A chemical company uses a shell and tube heat exchanger to heat 10 gpm of water from 140°F to 185°F for a continuous process. The exchanger is supplied with 50 psig steam from a large central boiler. The company wishes to shut down the large boiler in the summer months. What size boiler is needed to replace the central steam supply during shut down? Condensate is returned to the boiler mixed with 50°F feed water.

The heat energy required can be calculated from the following formula:

$$Q = \frac{(500\ \text{lb/hr})\ (C_p)\ (SG)\ (F)\ (\Delta T)\ (C)}{H} \times 1.2\ \text{SF}$$

Where:
Q = Heat required in kW/hr
500 = Conversion factor — gpm to lbs/hr (1 gpm x 8.345 lbs/gal x 60 min = 500 lbs/hr)
Cp = Specific heat (Btu/lb/°F) — 1 for water
SG = Specific gravity of liquid — 1 for water
F = Flow of liquid — gal/min
ΔT = Temperature change of liquid °F (180°F - 140°F = 45°F)
C = Conversion factor — kW/lb of steam @ 50 psig (from kW/lb Conversion Table)
H = Latent heat of steam at operating pressure — Btu/lb (From Saturated Steam Table)
SF = Safety factor of 20%

$$Q = \frac{(500\ \text{lb/hr})\ (1)\ (1)\ (10)\ (45°\text{F})\ (0.3401\ \text{kW/lb})}{(912\ \text{Btu/lb})}$$

Q = 83.9 kW/hr x 1.2 SF - 100.7 kW/hr

A 20% safety factor is recommended to allow for unknown heat losses and the possible loss of heated condensate water due to flashing.

Steam Humidification in General Applications — The injection of steam into a moist air stream to increase humidity is a common air conditioning application. Calculations of steam humidification requirements can be separated into variable and constant air temperature applications. Equipment is usually sized based on boiler output in lbs/hr at 0-5 psig with 50°F feed water.

Variable Air Temperatures — The pounds of steam per hour required for variable temperature applications can be calculated from the formula:

$$F_H = \frac{(\Delta V)(F_M \times 60\ \text{min})}{100\ \text{CFM}}$$

Where:
F_H = Steam flow in lbs/hr
ΔV = Increase in moisture content lbs/ft^3 based on water vapor content of air at initial condition and at final condition
F_M - Air flow in CFM

Example — A greenhouse needs to increase the humidity of 850 CFM of incoming outside air at 40°F and 50% humidity; to 80°F and 75% humidity. Referring to the chart, "Water Content of Air" in the Reference Data Section, 40°F air at 50% humidity contains 0.021 lbs of water vapor per 100 ft^3. Air at 80°F and 75% humidity contains 0.119 lbs of water vapor per 100 ft^3. The pounds of water vapor to be added (ΔV) are 0.119 lbs - 0.021 lbs or 0.098 lbs per 100 cubic feet of air.

$$F_H = \frac{(0.098\ \text{lbs}/100\ \text{ft}^3)(850\ \text{CFM} \times 60\ \text{min})}{100\ \text{CFM}}$$

F_H - 49.98 lbs/hr

A 20% safety factor is recommended

F_H - 49.98 lbs/hr x 1.2 SF = 59.98 lbs/hr

Constant Air Temperature — Steam requirements for humidity in a typical constant air temperature application can be determined from the Booster Humidification Table.

Example — A laboratory room is supplied with 750 CFM of air at 75°F and 35% relative humidity. The company wants to boost the humidity in a laboratory from 35% to 60% while maintaining a temperature of 75°F. What size steam boiler is needed?

From the table, read the initial condition line at 75°F - 35% rh to the intersect of 60% rh = 2.03 lbs/hr/100 CFM

750 CFM ÷ 100 CFM x 2.03 lbs/hr = 15.225 lbs/hr

15.225 lbs/hr x 20% safety factor = 18.27 lbs/hr

Steam Super Heating — The primary objective in most steam superheating applications is to improve steam quality and eliminate "carryover". In steam heating applications, the most efficient heat transfer occurs when high quality (100%) steam at saturation temperature is condensed in the heat exchanger or process. The majority of the thermal energy in the steam (latent heat of vaporization) is transferred when the steam condenses to water.

Unfortunately, the steam discharge from most steam boilers contains water molecules or mist that has not evaporated. This is called "wet steam" and is rated by quality factors ranging from 85% to 95%. Wet steam has a lower thermal transfer efficiency and is undesirable in many commercial applications. The excessive "carryover" of liquid water and mist in wet steam can create major performance problems in sterilizers and autoclaves.

To improve steam quality, wet steam can be superheated to create 100% quality or "dry steam" using a circulation heater. For example, steam at 90 psig has a saturation temperature of 331°F. Raising the temperature of 90 psig steam to 340°F or 350°F will produce 100% quality steam. An increase of 10° to 20° is usually more than adequate for most applications. Higher temperatures may be necessary if there are excessive pipe and equipment losses.

Unless there are other operating conditions that require high steam temperatures, increasing the temperature more than 20° - 30° above saturation temperature is not recommended. Increasing the steam temperature without increasing the gauge pressure does not significantly increase the heat content or heat transfer characteristics of the steam. The heat energy required to superheat steam can be plotted from the Steam Superheat Nomograph shown in this section.

Booster Humidification

Initial Condition		Relative Humidity Desired						
°F	R.H.	40%	45%	50%	55%	60%	65%	70%
70	35%	0.345	0.690	1.03	1.38	1.72	2.07	2.42
70	40%	—	0.345	0.69	1.03	1.38	1.72	2.07
72	35%	0.368	0.728	1.10	1.46	1.83	2.20	2.57
72	40%	—	0.368	0.73	1.10	1.46	1.83	2.20
75	35%	0.405	0.810	1.22	1.62	2.03	2.43	2.84
75	40%	—	0.405	0.81	1.22	1.62	2.03	2.43

Note — Lbs-vapor/hr/100 CFM required to secure desired relative humidity with no change in air temperature.

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Steam Superheating

Calculating kW Requirements for Superheating Steam

The nomograph shown below can be used to determine the kilowatts required to superheat saturated steam to higher temperatures.

Example — Heat 560 lbs/hr of 90% quality steam at 110 psig to 440°F at the same pressure. On line P, plot the gauge pressure (psig). Read the saturated steam temperature at operating pressure. Subtract from desired final temperature to determine degrees of superheat (ΔT).

(ΔT) = 440°F - 344°F = 96°F

Draw a straight line from P through line Q and read the intersect at line $W(W_1)$. Next, draw a straight line from same point on line P through S (°F of superheat) and read the intersect on line $W(W_2)$. Determine kW using W_1 and W_2 in the following formula.

$$\text{kW/hr} = \frac{(\text{lbs/hr})\,(W_2 - W_1)}{1000 \text{ W/kW}} \times 1.2 \text{ SF}$$

$$\text{kW/hr} = \frac{(560 \text{ lbs/hr})\,(82-39)}{1000 \text{ W/kW}} \times 1.2 \text{ SF}$$

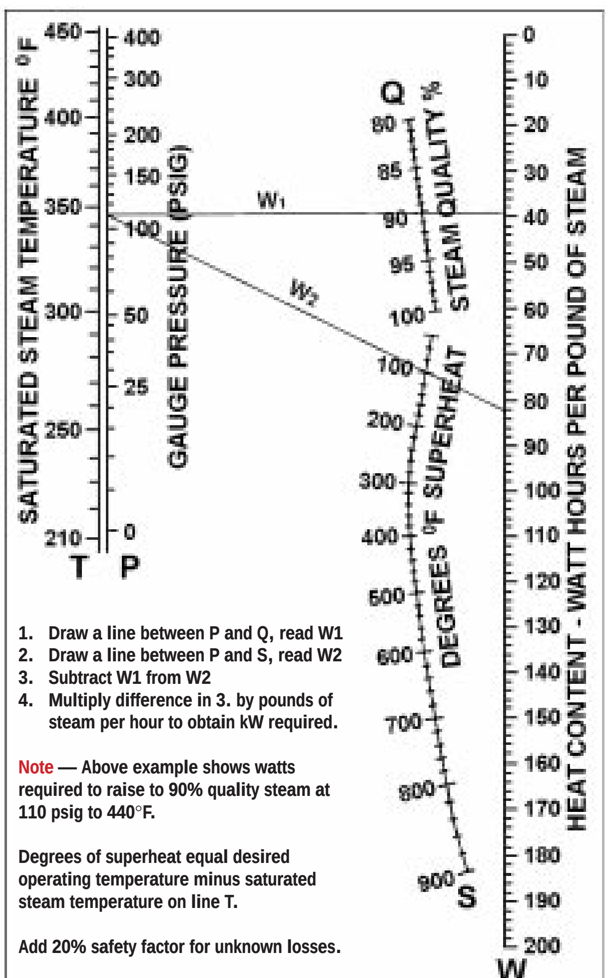
kW/hr = 28.896

Determining Sheath and Chamber Temperatures for Superheated Steam — Since superheated steam is essentially a gas, the last step in the above procedure is to determine maximum sheath and chamber temperatures of the circulation heater using Chart 236 and Graph G-237 for air and gas heating. In the above example, assume Series 6 heater with a standard 23 W/in² rating. From the charts:

Sheath Temperature = 1440°F
Chamber Temperature = 940°F

Select a Series 6 heater capable of the above operating conditions from the product pages in the Circulation Heater Section.

Steam Superheat Nomograph



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Properties of Steam

Saturated Steam

The thermodynamic properties of saturated steam are shown in the table to the right. Saturated steam is pure steam in direct contact with the liquid water from which it was generated and at the same temperature and pressure as the water. For example, saturated steam at 50 psig has a temperature of 298°F.

Steam pressure is commonly expressed as **psia** or **psig**. Psia is pounds per square inch absolute with reference to a perfect vacuum. Psig is pounds per square inch gauge with reference to atmospheric pressure of 14.7 psi psia = psig + 14.7 psi (1 atmosphere).

The heat content of liquid is the heat energy in Btu/lb required to heat the liquid to the condition indicated starting with water at 32°F.

Latent heat is the heat energy in Btu/lb absorbed when a pound of boiling water is converted to a pound of steam at the same temperature. The same amount of heat is released when the steam condenses back to water at the same temperature. Latent heat varies with temperature.

Saturated Steam — Thermodynamic Properties (nearest even digit)

Gauge Press. (psig)	(°F)	Btu/lb			Sat. Vapor (ft³/lb)	Gauge Press. (psig)	Temp. (°F)	Btu/lb			Sat. Vapor (ft³/lb)
		Liquid Heat	Latent Heat	Steam Total				Liquid Heat	Latent Heat	Steam Total	
0	212	180	970	1150	27.0	70	316	286	898	1184	5.2
1	216	183	968	1151	25.0	75	320	290	895	1185	4.9
2	219	187	965	1152	24.0	80	324	294	892	1186	4.7
3	222	190	964	1154	22.5	85	328	298	889	1187	4.4
4	224	193	962	1155	21.0	90	331	302	886	1188	4.2
5	227	195	961	1156	20.0	95	335	306	883	1189	4.0
6	230	198	959	1157	19.5	100	338	309	881	1190	3.9
7	232	201	957	1158	18.5	110	344	316	876	1192	3.6
8	235	203	956	1159	18.0	120	350	322	871	1193	3.3
9	237	206	954	1160	17.0	125	353	325	868	1193	3.2
10	240	208	952	1160	16.5	130	356	328	866	1194	3.1
15	250	218	945	1163	14.0	140	361	334	861	1195	2.9
20	259	227	940	1167	12.0	150	366	339	857	1196	2.7
25	267	236	934	1170	10.5	160	371	344	853	1197	2.6
30	274	243	929	1172	9.5	170	375	348	849	1197	2.5
35	281	250	924	1174	8.5	180	380	353	845	1198	2.3
40	287	256	920	1176	8.0	190	384	358	841	1199	2.2
45	292	262	915	1177	7.0	200	388	362	837	1199	2.1
50	298	267	912	1179	6.7	220	395	370	830	1200	2.0
55	303	272	908	1180	6.2	240	403	378	823	1201	1.8
60	307	277	905	1182	5.8	250	406	381	820	1201	1.75
65	312	282	901	1183	5.5	300	422	399	805	1204	1.48

Boiler Feed Water Temperature

The temperature of boiler feed water directly affects the steam output of a boiler. The following table can be used to determine the kilowatt rating of a boiler when the steam load, gauge pressure and boiler feed water temperature are known.

Example — A process requires 450 lbs of steam per hour at 75 psig. The available feed water temperature is 50°F. From the chart, read the kW/lb required for 50°F water and a gauge pressure of 75 psig. Multiply the factor by the pounds of steam: 0.3417 x 450 lbs = 153.8 kW.

Boiler Feed Water Temperature Vs. kW Required per Pound of Steam

Feed Water (°F)	Steam Gauge Pressure (psig)										
	0	2	10	15	25	40	50	75	100	125	150
40	.3347	.3355	.3375	.3388	.3406	.3422	.3431	.3447	.3458	.3464	.3470
50	.3318	.3326	.3345	.3359	.3376	.3392	.3401	.3417	.3429	.3435	.3441
60	.3288	.3296	.3316	.3329	.3347	.3363	.3372	.3388	.3400	.3407	.3411
70	.3259	.3267	.3287	.3300	.3318	.3334	.3343	.3359	.3370	.3376	.3382
80	.3229	.3238	.3278	.3271	.3288	.3305	.3313	.3329	.3341	.3347	.3353
90	.3200	.3208	.3238	.3242	.3259	.3275	.3284	.3300	.3312	.3318	.3324
100	.3171	.3179	.3199	.3212	.3229	.3246	.3255	.3271	.3283	.3288	.3294
110	.3142	.3150	.317	.3183	.3200	.3217	.3225	.3242	.3253	.3259	.3265
120	.3112	.3210	.314	.3154	.3171	.3187	.3196	.3212	.3224	.3230	.3236
130	.3083	.3091	.3111	.3124	.3142	.3160	.3167	.3183	.3195	.3200	.3206
140	.3054	.3062	.3082	.3095	.3113	.3129	.3137	.3154	.3165	.3171	.3177
150	.3025	.3032	.3052	.3066	.3083	.3099	.3108	.3124	.3136	.3142	.3148
160	.2995	.3003	.3029	.3036	.3054	.3070	.3079	.3095	.3107	.3113	.3118
170	.2966	.2974	.2994	.3001	.3025	.3041	.3050	.3066	.3077	.3083	.3089
180	.2937	.2945	.2964	.2978	.2995	.3011	.3020	.3036	.3048	.3054	.3060
190	.2907	.2915	.2935	.2948	.2966	.2982	.2981	.3007	.3019	.3025	.3030
200	.2878	.2886	.2906	.2919	.2937	.2953	.2962	.2978	.2989	.2995	.3001