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:

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

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/ft³ 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. In this scenario, 40°F air at 50% humidity contains 0.021 lbs of water vapor per 100 ft³. Air at 80°F and 75% humidity contains 0.119 lbs of water vapor per 100 ft³. 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 on the previous page.

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.