Determining Heat Energy Requirements - Heating Liquids

Typical Steps in Determining Total Energy Requirements

Most heating problems involve three basic steps:
1. **Determine** required kW capacity for bringing application up to operating temperature in the desired time.
2. **Calculate** the kW capacity required to maintain the operating temperature.
3. **Select** the number and type of heaters required to supply the kW required.

**Example** — Heat the water to 180°F in 3 hours and heat 40 gallons per hour of make up water from 60°F to 180°F thereafter.

Specific heat of steel = 0.12 Btu/lb/°F

Specific heat of water = 1.0 Btu/lb

Weight of steel = 490 lb/ft³

Weight of water = 8.345 lb/gal

**To Find Initial (Start-Up) Heating Capacity** —

\[
Q_S = \left( \frac{Q_A + Q_C + Q_{LS}}{2} \right) t
\]

Where:

- \(Q_S\) = The total energy required in kilowatts
- \(Q_A\) = kW to raise the temperature of the water
- \(Q_C\) = kW to raise the temperature of the steel tank
- \(Q_{LS}\) = kW lost from surfaces by radiation, convection and evaporation

**To Find Heat Required for Operating** —

\[
Q_o = (Q_{wo} + Q_{LS} + Q_{ws})(1 + SF)
\]

Where:

- \(Q_{wo}\) = kW to heat additional water
- \(Q_{ws}\) = kW to heat steel 300 Lbs. x 0.12 x (180 - 60°F)/3412 = 1.27 kW

**Heat for Steel Tank** —

\[
Q_C = \frac{32 \text{ ft}^2 \times 0.6 \text{ W/ft}^2 \times (180 - 70°F)}{1000 \text{ W/kW}} = 4.4 \text{ kW}
\]

**Heat for Start-Up** —

\[
Q_S = \frac{(26.9 \text{ kW} + 1.89 \text{ kW} + 4.4 \text{ kW} + 2.11 \text{ kW}) \times 1.2}{3 \text{ hrs}} = 15.42 \text{ kW}
\]

**Heat Required for Operating** —

\[
Q_o = (11.7 \text{ kW} + 1.27 \text{ kW} + 4.4 \text{ kW} + 2.11 \text{ kW}) \times 1.2
\]

**Installed Capacity** — Since the heat required for operating (21.85 kW) is greater than the heat required for start up (15.42 kW), the installed heating capacity should be based on the heat required for operation. With 22 kW installed, the actual initial heating time will be less than 3 hours.

**Suggested Equipment** — Moisture resistant terminal enclosures are recommended for industrial liquid heating applications. Install two stock 12 kW MT-2120E2 or 12 kW MT-3120E2 screw plug heaters or two 12 kW KTLC-312A over-the-side heaters with an automatic temperature control. Automatic temperature control will limit the kWh consumption to actual requirements during operation. A low water level cutoff control is also recommended.

Liquid Heating Example

One of the most common electric heating applications is the direct immersion heating of liquids. The following example illustrates the steps in determining total energy requirements of a typical direct immersion application.

Application — A final rinse tank requires water at 180°F. The tank is 2 feet wide by 4 feet long by 2 feet high and is uninsulated with an open top. The tank is made of 3/8" steel and contains 100 gallons of water at 70°F at start up. Make up water with a temperature of 60°F is fed into the tank at the rate of 40 gallons per hour during the process. There is an exhaust hood over the tank and the relative humidity in the area is high. Work product is 300 lbs. of steel per hour.
Flow Through Water Heating

Circulation heater applications frequently involve “flow through” heating with no recirculation of the heated media. These applications have virtually no start-up requirements. The equation shown below can be used to determine the kilowatts required for most “flow through” applications. The maximum flow rate of the heated medium, the minimum temperature at the heater inlet and the maximum desired outlet temperature are always used in these calculations. A 20% safety factor is recommended to allow for heat losses from jacket and piping, voltage variations and variations in flow rate.

\[ Q = \frac{F \times C_p \times \Delta T \times SF}{3412 \text{ Btu/kW}} \]

Where:
- \( Q \) = Power in kilowatts
- \( F \) = Flow rate in lbs/hr
- \( C_p \) = Specific heat of water = 1 Btu/lb/°F
- \( \Delta T \) = Temperature rise in °F
- \( SF \) = Safety Factor

Example — Heat 5 gpm of water from 70°F to 115°F in a single pass through a circulation heater. Determine flow rate in lbs/hr. (Density of water is 8.35 lbs/gal)

\[ 5 \text{ gpm} \times 8.35 \text{ lbs/gal} \times 5 \text{ min} = 2505 \text{ lbs/hr} \]

Step 1 — Determine flow rate in lbs/hr.

Step 2 — Calculate kW:

\[ kW = \frac{2505 \text{ lbs} \times 1 \text{ Btu/lb/°F} \times (115 - 70 \text{°F})}{3412 \text{ Btu/kW} \times 1.2 \text{ SF}} \]

\[ kW = 39.6 \text{ kW} \]

Flow Through Oil Heating

Oil Heating with Circulation Heaters — The procedure for calculating the requirements for “flow through” oil heating with circulation heaters is similar to water heating. The weight of the liquid being heated is factored by the specific gravity of oil. The specific gravity of a particular oil can be determined from the charts on properties of materials or can be calculated from the weight per cubic foot relative to water.

Example — Heat 3 gpm of #4 fuel oil with a weight of approximately 56 lbs/ft³ from 70°F to 100°F.

Step 1 — Determine flow rate in lbs/hr. 

\[ 3 \text{ gpm} \times 8.35 \text{ lbs/gal} \times 0.9 \times 60 \text{ min} = 1353 \text{ lbs/hr} \]

Step 2 — Calculate kW:

\[ kW = \frac{1353 \text{ lbs} \times 0.42 \text{ Btu/lb/°F} \times (100 - 50 \text{°F}) \times 1.2 \text{ SF} \times 3412 \text{ Btu/kW}}{2} \]

\[ kW = 9.99 \text{ kW} \]

Suggestion — Choose watt density for fuel oil and then select heater. Use a stock NWHOR-05-015P, 10 kW circulation heater with an AR-215 thermostat.

Graph G-236 — Oil Heating

To Find Operating Requirements —

\[ Q_t = \frac{(Q_A + Q_F + Q_L + Q_C + Q_S)(1 + SF)}{t} \]

Where:
- \( Q_A \) = kW to heat lead to melting point. 
  \[ 400 \text{ lbs} \times 0.0306 \text{ Btu/lb/°F}(621 - 70 \text{°F}) \div 3412 \]
- \( Q_F \) = kW to melt lead (400 lbs x 10.8 Btu/lb) ÷ 3412
- \( Q_L \) = kW to heat lead from melting point to 800°F
  \[ 400 \text{ lbs} \times 0.038 \text{ Btu/lb/°F}(800 - 621 \text{°F}) \div 3412 \]
- \( Q_C \) = kW to heat steel crucible
  \[ 150 \text{ lbs} \times 0.12 \text{ Btu/lb/°F}(800 - 70 \text{°F}) \div 3412 \]
- \( Q_S \) = Surface losses from lead and outside shell
  \[ ([1000 \text{ W} x 3 \text{ ft}^2] + (62 \text{ W} x 20 \text{ ft}^2))/2 + 1000 \times \frac{1}{10} \]

\[ t = 1 \text{ hour} \]

\[ Q_t = 9.98 \text{ kW} \times 1.2 = 11.99 \text{ kW} \]

To Find Start-Up Heating Requirements —

\[ Q_s = (Q_A + Q_F + Q_L + Q_C + Q_S)(1 + SF) \]

To Find Operating Requirements —

\[ Q_t = (Q_A + Q_F + Q_L + Q_C + Q_S)(1 + SF) \]

Where:
- \( Q_A \) = kW to heat lead to melting point. 
  \[ 400 \text{ lbs} \times 0.0306 \text{ Btu/lb/°F}(621 - 70 \text{°F}) \div 3412 \]
- \( Q_F \) = kW to melt lead (400 lbs x 10.8 Btu/lb) ÷ 3412
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- \( Q_S \) = Surface losses from lead and outside shell
  \[ ([1000 \text{ W} x 3 \text{ ft}^2] + (62 \text{ W} x 20 \text{ ft}^2))/2 + 1000 \times \frac{1}{10} \]

\[ t = 1 \text{ hour} \]

\[ Q_t = 6.69 \text{ kW} \times 1.2 = 8.03 \text{ kW} \]

Since start-up requirements exceed the operating requirements, 12 kW should be installed.