Technical Information

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.

Note — Some applications, such as instantaneous heating of gas or air in ducts, comfort heating and pipe tracing only require calculation of the operating kW and selection of heaters.

Design Considerations

In order to calculate the initial and operating kW capacity requirements, the following factors should be considered:

- Specified heat-up time
- Start-up and operating temperatures
- Thermal properties of material(s) being heated
- Weight of material(s) being heated
- Weight of container and equipment being heated
- Weight of make up material (requirements per hour)
- Heat carried away by products being processed or equipment passing through heated area
- Heat absorbed due to a change of state
- Thermal properties and thickness of insulation
- Heat losses from the surface of material and/or container to the surrounding environment.

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.

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 = 1.00 Btu/lb/°F
Weight of steel = 490 lb/ft^3
Weight of water = 8.345 lb/gal

To Find Initial (Start-Up) Heating Capacity —

$$Q_S = \left(\frac{Q_A + Q_C}{t} + \frac{Q_{LS}}{2}\right)(1 + SF)$$

Where:
Q_S = The total energy required in kilowatts
Q_A = kWh required to raise the temperature of the water
Q_C = kWh required to raise the temperature of the steel tank
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
SF = Safety Factor
t = Start-up time in hours (3)

kW to Heat Water —

$$\frac{100 \text{ gal} \times 8.345 \text{ lb/gal} \times 1.0 \text{ Btu/lb } (180 - 70°F)}{3412 \text{ Btu/kW}}$$

Q_A = 26.9 kW

kW to Heat Steel Tank —

Lbs of steel = Area x thickness x 490 lbs/ft^3

$$32 \text{ ft}^2 \times \frac{0.375 \text{ in.}}{12} \times 490 \text{ lb/ft}^3 = 490 \text{ lbs}$$

$$\frac{490 \text{ lbs} \times 0.12 \text{ Btu/lb } (180 - 70°F)}{3412 \text{ Btu/kW}}$$

Q_C = 1.89 kW

Heat Losses from Surfaces —

$Q_{LS} = L_{SW} + L_{SC}$

Where:
Q_{LS} = kWh lost from all surfaces
L_{SW} = Losses from the surface of the water
L_{SC} = Losses from the surfaces of the tank

L_{SW} = Surface losses from water (Graph G126S, Curve 2 fps @ 60% rh)

$$\frac{8 \text{ ft}^2 \times 550 \text{ W/ft}^2}{1000 \text{ W/kW}} = 4.4\text{kW}$$

L_{SC} = Surface losses from uninsulated tank walls (Graph G125S)

$$\frac{32 \text{ ft}^2 \times 0.6 \text{ W/ft}^2 \times (180 - 70°F)}{1000 \text{ W/kW}} = 2.11 \text{ kW}$$

Heat Required for Start-Up —

$$\left(\frac{26.9 \text{ kW} + 1.89 \text{ kW}}{3 \text{ hrs}} + \frac{4.4 \text{ kW} + 2.11 \text{ kW}}{2}\right) \times 1.2$$

Q_S = 15.42 kW

To Find Heat Required for Operating —

$Q_O = (Q_{WO} + Q_{LS} + Q_{WS})(1 + SF)$

Where:
Q_{WO} = kW to heat additional water

$$\frac{40 \text{ gal} \times 8.345 \text{ lb/gal} \times 1.0 \text{ Btu/lb } (180 - 60°F)}{3412 \text{ Btu/kW}}$$

Q_{WO} = 11.7 kW

Q_{WS} = kW to heat steel 300 Lbs. x 0.12 x (180 - 60°F)/3412 = 1.27 kW

Heat Required for Operating —

Q_O = (11.7 kW + 1.27 kW + 4.4 kW + 2.11 kW) 1.2

Q_O = 23.38 kW

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.

Technical Information

Determining Heat Energy Requirements

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 in Btu/lb/°F
ΔT = Temperature rise in °F
SF = Safety Factor

Example — Heat 5 gpm of water from 70 - 115°F in a single pass through a circulation heater.

Step 1 — Determine flow rate in lbs/hr.
(Density of water is 8.35 lbs/gal)
5 gpm x 8.35 lbs/gal x 60 min = 2505 lbs/hr

Step 2 — Calculate kW:
C_p = Specific heat of water = 1 Btu/lb/°F

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

kW= 39.6 kW

Temperature Rise Vs. Water Flow[1]

Temp. Rise (°F)	Heater Rating (kW)						
	6	9	12	15	18	24	30
	Flow rate in GPH for given Temperature Rise						
20	122	184	245	306	368	490	613
30	81	122	163	204	245	327	409
40	61	92	122	153	184	245	306
50	49	73	98	122	147	196	245
60	40	61	81	102	122	163	204
70	35	52	70	87	105	140	175
80	30	46	61	76	92	122	153
90	27	40	54	68	81	109	136
100	24	36	49	61	73	98	122
110	22	33	44	55	66	89	111
120	20	30	40	51	61	81	102
130	18	28	37	47	56	75	94

1. Safety Factor and losses not included.

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/ft^3 from 50°F to 100°F.

Step 1 — Determine flow rate in lbs/hr.
Specific gravity = 56 lbs/ft^3 ÷ 62.4 lbs/ft^3 = 0.9
3 gpm x 8.35 lbs/gal x 0.9 x 60 min = 1353 lbs/hr

Step 2 — Calculate kW:
Specific heat of fuel oil is 0.42 Btu/lb/°F

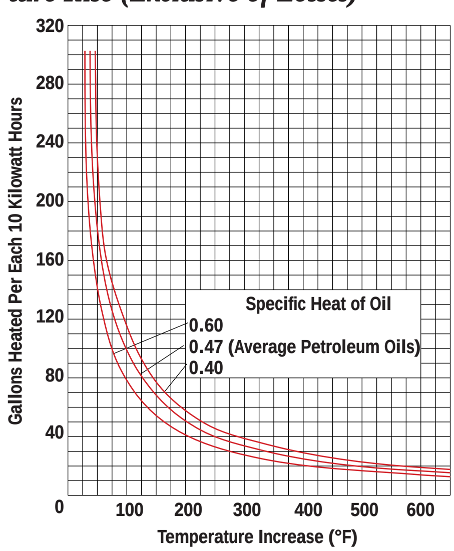
$$\text{kW} = \frac{1353 \text{ lbs} \times 0.42 \text{ Btu/lb/°F} \times (100 - 50\text{°F})}{3412 \text{ Btu/kW}} \times 1.2 \text{ SF}$$

kW = 9.99

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

Heat Required for Various Temperature Rise (Exclusive of Losses)



CAUTION — Consult recommendations elsewhere in this section for watt density and maximum sheath temperatures for oil heating.

Heating Soft Metal with Melting Pots or Crucibles

Most soft metal heating applications involve the use of externally heated melting pots or crucibles. The following example represents a typical soft metal application.

A steel melting pot weighing 150 lbs contains 400 lbs of lead. The pot is insulated with 2 inches of rock wool and has an outside steel shell with 20 ft^2 of surface area. The top surface of the lead has 3 ft^2 exposed to the air. Determine the kilo-watts required to raise the material and container from 70°F to 800°F in one hour, and heat 250 lbs of lead per hour (70°F to 800°F) thereafter.

Melting point of lead = 621°F
Specific heat of solid lead = 0.0306 Btu/lb/°F
Specific heat of molten lead = 0.038 Btu/lb/°F
Heat of fusion/lead = 10.8 Btu/lb
Specific heat of steel crucible = 0.12 Btu/lb/°F
Radiation loss from molten lead surface = 1000 W/ft^2 (from curve G-128S).
Surface loss from outside shell of pot 62 W/ft^2 (from curve G-126S).
SF = Safety Factor 20%

To Find Start-Up Heating Requirements —

$$Q_T = \left(\frac{Q_A + Q_F + Q_L + Q_C}{t} + \frac{Q_{LS}}{2}\right)(1 + SF)$$

Where:
Q_A = kW to heat lead to melting point.
[400 lbs x 0.0306 Btu/lb/°F (621 - 70°F)] ÷ 3412
Q_F = kW to melt lead (400 lbs x 10.8 Btu/lb) ÷ 3412
Q_L = kW to heat lead from melting pt. to 800°F
[400 lbs x 0.038 Btu/lb/°F (800 - 621°F)] ÷ 3412
Q_C = kW to heat steel pot
[150 lbs x 0.12 Btu/lb/°F (800 - 70°F)] ÷ 3412
Q_{LS} = Surface losses from lead and outside shell
[(1000 W x 3 ft^2) + (62 W x 20 ft^2)]/2 ÷ 1000
t = 1 hour
Q_T = 9.98 kW x 1.2 = 11.99 kW

To Find Operating Requirements —

$$Q_T = (Q_A + Q_F + Q_L + Q_{LS})(1 + SF)$$

Where:
Q_A = kW to heat added lead to melting point.
(250 lbs x 0.0306 Btu/lb/°F [621 - 70°F]) ÷ 3412
Q_F = kW to melt added lead
(250 lbs x 10.8 Btu/lb) ÷ 3412
Q_L = kW to heat lead from melting pt. to 800°F
(250 lbs x 0.038 Btu/lb/°F [800 - 621°F]) ÷ 3412
Q_{LS} = Surface losses from lead and outside shell
(1000W x 3 ft^2) + (62W x 20 ft^2) ÷ 1000
Q_T = 6.69 kW x 1.2 = 8.03 kW

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