

A. Power Requirement for Initial Heat-up

1. Heat absorbed by all materials:

$$\frac{\text{Weight of material (lb)} \times \text{Specific heat (Btu/lb-°F)} \times \text{Temperature difference (final - initial) (°F)}}{3412(\text{Btu/kWh})} = \text{_____ kWh}$$

Note: The above step must be repeated for each material heated. See Tables 1, 2, 3, and 4 on pages D38 and D39 for specific heats and weights.

2. Heat required for fusion or vaporization:

$$\frac{\text{Weight of material (lb)} \times \text{Heat of fusion or vaporization (Btu/lb)}}{3412 (\text{Btu/kWh})} = \text{_____ kWh}$$

Note: When the specific heat of a material changes at some temperature during the heat-up, due to melting (fusion) or evaporation (vaporization), perform Step 1 for the heat absorbed from the initial temperature up to the temperature at the point of change, add Step 2, then repeat Step 1 for heat absorbed from the point of change to the final operation temperature. See Tables 1, 2, 3, and 4 on pages D38 and D39 for heats of fusion and vaporization and temperatures at which these changes in state occur.

3. Heat required to replace average heat losses:

$$\frac{\text{Exposed surface area (sq. ft.)} \times \text{Heat loss at final operating temperature (W/sq. ft.)} \times \text{Time allowed for heat-up (hrs)}}{1000 (\text{W/kW})} \times \frac{1}{2} \left(\text{to obtain an average loss} \right) = \text{_____ kWh}$$

Note: See Figures 1 - 4 on pages D40 and D41 for normal heat losses

$$\text{4. Heat to provide for contingencies, Safety Factor: } 20\% [\text{Step 1 (kWh)} + \text{Step 2 (kWh)} + \text{Step 3 (kWh)}] = \text{_____ kWh}$$

$$\text{Total Heat Requirement for Initial Heat-up:} = \text{_____ kWh}$$

$$\text{Total Power Requirement for Initial Heat-up:} \frac{\text{Step 1 (kWh)} + \text{Step 2 (kWh)} + \text{Step 3 (kWh)} + \text{Step 4 (kWh)}}{\text{Time allowed for heat-up (hrs)}} = \text{_____ kW}$$

B. Power Requirement for Operating Heat

1. Heat absorbed by all materials added to the process:

$$\frac{\text{Weight of material added (lb)} \times \text{Specific heat (Btu/lb-°F)} \times \text{Temperature difference (final - initial) (°F)}}{3412(\text{Btu/kWh})} = \text{_____ kWh}$$

Note: The above step must be repeated for each material heated. See Tables 1, 2, 3, and 4 on pages D38 and D39 for specific heats and weights.

2. Heat required for fusion or vaporization during process:

$$\frac{\text{Weight of material (lb)} \times \text{Heat of fusion or vaporization (Btu/lb)}}{3412 (\text{Btu/kWh})} = \text{_____ kWh}$$

Note: When the specific heat of a material changes at some temperature during the heat-up, due to melting (fusion) or evaporation (vaporization), perform Step 1 for the heat absorbed from the initial temperature up to the temperature at the point of change, add Step 2, then repeat Step 1 for heat absorbed from the point of change to the final operation temperature. See Tables 1, 2, 3, and 4 on pages D38 and D39 for heats of fusion and vaporization and temperatures at which these changes in state occur.

3. Heat required to replace heat losses:

$$\frac{\text{Exposed surface area (sq. ft.)} \times \text{Heat loss at final operating temperature (W/sq. ft.)} \times \text{Working cycle time (hrs)}}{1000 (\text{W/kW})} = \text{_____ kWh}$$

Note: See Figures 1 - 4 on pages D40 and D41 for normal heat losses

$$\text{4. Heat to provide for contingencies, Safety Factor: } 20\% [\text{Step 1 (kWh)} + \text{Step 2 (kWh)} + \text{Step 3 (kWh)}] = \text{_____ kWh}$$

$$\text{Total Heat Requirement per Working Cycle:} = \text{_____ kWh}$$

$$\text{Total Power Requirement for Operating Heat:} \frac{\text{Step 1 (kWh)} + \text{Step 2 (kWh)} + \text{Step 3 (kWh)} + \text{Step 4 (kWh)}}{\text{Working cycle time (hrs)}} = \text{_____ kW}$$

Heating Liquids (Water)

An open steel tank, 2 ft. wide, 3 ft. long, 2 ft. deep and weighing 270 lbs., is filled with water to within 6 inches of the top. Bottom and sides have 3 inches of insulation. Water is to be heated from 50°F to 150°F within 2 hours and, from then on, approximately 4 gallons per hour will be drawn off and replaced.

From Table 1 on page D38, Specific Heat of steel:
0.12 Btu/lb.-°F

From Table 3 on page D39, Specific Heat of water:
1.0 Btu/lb.-°F

From Table 3 on page D39, Weight of water:
62.5 lb./cu. ft. (8.3 lb./gal.)

Water in tank:
(2 x 3 x 1.5)cu. ft. x 62.5 lb./cu. ft. = 563 lb.

From Fig. 3 on page D41, Water surface loss at 150°F:
270 W/sq. ft.

From Fig. 4 on page D41, Insulated wall loss at 100°F rise:
7 W/sq. ft.

A. INITIAL HEAT-UP REQUIREMENT

- 1a.** To heat water:
$$\frac{563 \text{ lb.} \times 1.0 \text{ Btu/lb.-}^\circ\text{F} \times (150 - 50)^\circ\text{F}}{3412 \text{ Btu/kWh}} = 16.5 \text{ kWh}$$
- 1b.** To heat tank:
$$\frac{270 \text{ lb.} \times 0.12 \text{ Btu/lb.-}^\circ\text{F} \times (150 - 50)^\circ\text{F}}{3412 \text{ Btu/kWh}} = 0.95 \text{ kWh}$$
- 2.** Heat of fusion or vaporization: None
- 3a.** Average water surface loss:
$$\frac{6 \text{ sq. ft.} \times 270 \text{ W/sq. ft.} \times 2 \text{ hrs.}}{1000 \text{ W/kWh} \times 2} = 1.62 \text{ kWh}$$
- 3b.** Average tank surface loss:
$$\frac{26 \text{ sq. ft.} \times 7 \text{ W/sq. ft.} \times 2 \text{ hrs.}}{1000 \text{ W/kWh} \times 2} = 0.18 \text{ kWh}$$
- 4.** Safety factor:
20% (16.5 + 0.95 + 1.62 + 0.18) = 3.85 kWh
- Total Heat Requirement** = 23.10 kWh
- Power Required for Initial Heat-up:**
23.10 kWh / 2 hrs. = 11.55 kW

B. OPERATING REQUIREMENT

- 1.** To heat additional water
$$\frac{4 \text{ gal./hr.} \times 8.3 \text{ lb./gal.} \times 1.0 \text{ Btu/lb.-}^\circ\text{F} \times (150 - 50)^\circ\text{F}}{3412 \text{ Btu/kWh}} = 0.97 \text{ kW}$$
- 2.** Heat of fusion or vaporization: None
- 3a.** Water surface loss:
$$\frac{6 \text{ sq. ft.} \times 270 \text{ W/sq. ft.}}{1000 \text{ W/kWh}} = 1.62 \text{ kW}$$
- 3b.** Tank surface loss:
$$\frac{26 \text{ sq. ft.} \times 7 \text{ W/sq. ft.}}{1000 \text{ W/kWh}} = 0.18 \text{ kW}$$
- 4.** Safety factor:
20% (0.97 + 1.62 + 0.18) kW = 0.55 kW
- Power Required for Operation** = 3.32 kW

Melting Solids (Paraffin)

An open top uninsulated steel tank, 1½ ft. wide, 2 ft. long, 2 ft. deep, and weighing 140 lb., contains 168 lb. of paraffin to be heated from 70°F to 150°F in 2 hours. Steel drills, each weighing 0.157 lb. are to be placed in a 60 lb. rack and dip coated in the melted paraffin. 1500 drills can be processed per hour with 20 lb. of paraffin.

From Table 1 pg. D38, Specific Heat of steel: 0.12 Btu/lb.-°F
From Table 2 pg. D38, Specific Heat of solid paraffin: 0.70 Btu/lb.-°F

From Table 2 pg. D38, Melting Point of paraffin: 133°F
From Table 2 pg. D38, Heat of Fusion of paraffin: 63 Btu/lb.
From Table 3 pg. D39, Specific Heat of melted paraffin: 0.71 Btu/lb.-°F

From Fig. 3 pg. D41, Paraffin surface loss at 150°F: 70 W/ft.²

From Figs. 1 & 2 pg. D40, Steel surf. loss at 150°F: 55 W/ft.²

A. INITIAL HEAT-UP REQUIREMENT

- 1a.** To heat tank:
$$\frac{140 \text{ lb.} \times 0.12 \text{ Btu/lb.-}^\circ\text{F} \times (150 - 70)^\circ\text{F}}{3412 \text{ Btu/kWh}} = 0.39 \text{ kWh}$$
- 1b.** To heat solid paraffin:
$$\frac{168 \text{ lb.} \times 0.70 \text{ Btu/lb.-}^\circ\text{F} \times (133 - 70)^\circ\text{F}}{3412 \text{ Btu/kWh}} = 2.17 \text{ kWh}$$
- Fusion occurs at this point**
- 1c.** To heat melted paraffin:
$$\frac{168 \text{ lb.} \times 0.71 \text{ Btu/lb.-}^\circ\text{F} \times (150 - 133)^\circ\text{F}}{3412 \text{ Btu/kWh}} = 0.59 \text{ kWh}$$
- 2.** Heat of fusion, to melt paraffin
$$\frac{168 \text{ lb.} \times 63 \text{ Btu/lb.}}{3412 \text{ Btu/kWh}} = 3.10 \text{ kWh}$$
- 3a.** Average paraffin surface loss:
$$\frac{3 \text{ sq. ft.} \times 70 \text{ W/sq. ft.} \times 2 \text{ hrs.}}{1000 \text{ W/kWh} \times 2} = 0.21 \text{ kWh}$$
- 3b.** Average tank surface loss:
$$\frac{13.5 \text{ sq. ft.} \times 55 \text{ W/sq. ft.} \times 2 \text{ hrs.}}{1000 \text{ W/kWh} \times 2} = 0.74 \text{ kWh}$$
- 4.** Safety factor:
20% (0.39 + 2.17 + 0.59 + 3.10 + 0.21 + 0.74) = 1.44 kWh
- Total Heat Requirement** = 8.64 kWh
- Power Required for Initial Heat-up:**
8.64 kWh / 2 hrs. = 4.32 kW

B. OPERATING REQUIREMENT

- 1a.** To heat drills and rack:
$$\frac{(1500 \times 0.157 + 60) \text{ lb./hr.} \times 0.12 \text{ Btu/lb.-}^\circ\text{F} \times (150 - 70)^\circ\text{F}}{3412 \text{ Btu/kWh}} = 0.83 \text{ kW}$$
- 1b.** To heat additional solid paraffin:
$$\frac{20 \text{ lb./hr.} \times 0.70 \text{ Btu/lb.-}^\circ\text{F} \times (133 - 70)^\circ\text{F}}{3412 \text{ Btu/kWh}} = 0.26 \text{ kW}$$
- Fusion occurs at this point**
- 1c.** To heat additional melted paraffin:
$$\frac{20 \text{ lb./hr.} \times 0.71 \text{ Btu/lb.-}^\circ\text{F} \times (150 - 133)^\circ\text{F}}{3412 \text{ Btu/kWh}} = 0.07 \text{ kW}$$
- 2.** Heat of fusion, to melt additional paraffin:
$$\frac{20 \text{ lb./hr.} \times 63 \text{ Btu/lb.}}{3412 \text{ Btu/kWh}} = 0.37 \text{ kW}$$
- 3a.** Paraffin surface loss:
$$\frac{3 \text{ sq. ft.} \times 70 \text{ W/sq. ft.}}{1000 \text{ W/kWh}} = 0.21 \text{ kW}$$
- 3b.** Tank surface loss:
$$\frac{13.5 \text{ sq. ft.} \times 55 \text{ W/sq. ft.}}{1000 \text{ W/kWh}} = 0.74 \text{ kW}$$
- 4.** Safety factor:
20% (0.83 + 0.26 + 0.07 + 0.37 + 0.21 + 0.74) kW = 0.50 kW
- Power Required for Operation** = 2.98 kW