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:

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

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

4. Heat to provide for contingencies, Safety Factor: 20% [Step 1 (kWh) + Step 2 (kWh) + Step 3 (kWh)] = ________kWh

Total Heat Requirement for Initial Heat-up: = ________kWh

Total Power Requirement for Initial Heat-up:

$$\frac{\text{Step 1 (kWh) + Step 2 (kWh) + Step 3 (kWh) + Step 4 (kWh)}}{\text{Time allowed for heat-up (hrs)}} = \_\_\_\_\_\_\_\_ \text{kW}$$

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

4. Heat to provide for contingencies, Safety Factor: 20% [Step 1 (kWh) + Step 2 (kWh) + Step 3 (kWh)] = ________kWh

Total Heat Requirement per Working Cycle: = ________kWh

Total Power Requirement for Operating Heat:

$$\frac{\text{Step 1 (kWh) + Step 2 (kWh) + Step 3 (kWh) + Step 4 (kWh)}}{\text{Working cycle time (hrs)}} = \_\_\_\_\_\_\_\_ \text{kW}$$

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 10°C to 66°C (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 D42:
Specific Heat of Steel: 0.12 Btu/lb - °F

From Table 3 on Page D43:
Specific Heat of Water: 1.0 Btu/lb - °F

From Table 3 on page D43:
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 Figure 3 on page D45:
Water surface loss at 66°C (150°F): 270 W/sq. ft.

From Figure 4 on page D45:
Insulated wall loss at 38°C (100°F) rise: 7 W/sq. ft.

Initial Heat-Up Requirement

1a. To heat water:
$\frac{563 \text{ lb.} \times 1.0 \text{ Btu/lb.-°F} \times (150 - 50)\text{°F}}{3412 \text{ Btu/kWh}}$ = 16.5 kWh

1b. To heat tank:
$\frac{270 \text{ lb.} \times 0.12 \text{ Btu/lb.-°F} \times (150 - 50)\text{°F}}{3412 \text{ Btu/kWh}}$ = 0.95 kWh

2. Heat of fusion or vaporization: None

3a. Average water surface loss:
$\frac{6 \text{ sq. ft.} \times 270 \text{ W/sq. ft.} \times 2 \text{ hrs.}}{1000 \text{ W/kW} \times 2}$ = 1.62 kWh

3b. Average tank surface loss:
$\frac{26 \text{ sq. ft.} \times 7 \text{ W/sq. ft.} \times 2 \text{ hrs.}}{1000 \text{ W/kW} \times 2}$ = 0.18 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

Operating Requirement

1. To heat additional water
$\frac{4 \text{ gal./hr.} \times 8.3 \text{ lb./gal.} \times 1.0 \text{ Btu/lb.-°F} \times (150 - 50)\text{°F}}{3412 \text{ Btu/kWh}}$
= 0.97 kW

2. Heat of fusion or vaporization: None

3a. Water surface loss:
$\frac{6 \text{ sq. ft.} \times 270 \text{ W/sq. ft.}}{1000 \text{ W/kW}}$ = 1.62 kW

3b. Tank surface loss:
$\frac{26 \text{ sq. ft.} \times 7 \text{ W/sq. ft.}}{1000 \text{ W/kW}}$ = 0.18 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, 1 1/2 ft wide, 2 ft long, 1 1/2 ft. deep, and weighing 140 lbs, contains 168 lb of paraffin to be heated from 21°C to 66°C (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. 150 drills can be processed per hour with 20 lb of paraffin.

From Table 1 on Page D42:
Specific Heat of Steel: 0.12 Btu/lb - °F

From Table 2 on page D42:
Specific heat of solid paraffin: 0.70 Btu/lb - °F

From Table 2 on page D42:
Melting Point of Paraffin: 56°C (133°F)

From Table 2 on Page D42:
Heat of Fusion of Paraffin: 63 Btu/lb

From Table 3 on Page D43:
Specific Heat of Melted Paraffin: 0.71 Btu/lb. - °F

From Figure 3 on Page D45:
Paraffin Surface Loss at 66°C (150°F): 70 W/ft.^{2}

From Figures 1 & 2 on Page D44:
Steel Surface Loss at 66°C (150°F): 55 W/ft.^{2}

Initial Heat-Up Requirement

1a. To heat tank:
$\frac{140 \text{ lb.} \times 0.12 \text{ Btu/lb.-°F} \times (150 - 70)\text{°F}}{3412 \text{ Btu/kWh}}$ = 0.39 kWh

1b. To heat solid paraffin:
$\frac{168 \text{ lb.} \times 0.70 \text{ Btu/lb.-°F} \times (133 - 70)\text{°F}}{3412 \text{ Btu/kWh}}$ = 2.17 kWh

Fusion occurs at this point

1c. To heat melted paraffin:
$\frac{168 \text{ lb.} \times 0.71 \text{ Btu/lb.-°F} \times (150 - 133)\text{°F}}{3412 \text{ Btu/kWh}}$ = 0.59 kWh

2. Heat of fusion, to melt paraffin
$\frac{168 \text{ lb.} \times 63 \text{ Btu/lb.}}{3412 \text{ Btu/kWh}}$ = 3.10 kWh

3a. Average paraffin surface loss:
$\frac{3 \text{ sq. ft.} \times 70 \text{ W/sq. ft.} \times 2 \text{ hrs.}}{1000 \text{ W/kW} \times 2}$ = 0.21 kWh

3b. Average tank surface loss:
$\frac{13.5 \text{ sq. ft.} \times 55 \text{ W/sq. ft.} \times 2 \text{ hrs.}}{1000 \text{ W/kW} \times 2}$ = 0.74 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

Operating Requirement

1a. To heat drills and rack:
$\frac{(1500 \times 0.157 + 60)\text{lb./hr.} \times 0.12 \text{ Btu/lb.-°F} \times (150 - 70)\text{°F}}{3412 \text{ Btu/kWh}}$
= 0.83 kW

1b. To heat additional solid paraffin:
$\frac{20 \text{ lb./hr.} \times 0.70 \text{ Btu/lb.-°F} \times (133 - 70)\text{°F}}{3412 \text{ Btu/kWh}}$ = 0.26 kW

Fusion occurs at this point

1c. To heat additional melted paraffin:
$\frac{20 \text{ lb./hr.} \times 0.71 \text{ Btu/lb.-°F} \times (150 - 133)\text{°F}}{3412 \text{ Btu/kWh}}$ = 0.07 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 kW

3a. Paraffin surface loss:
$\frac{3 \text{ sq. ft.} \times 70 \text{ W/sq. ft.}}{1000 \text{ W/kW}}$ = 0.21 kW

3b. Tank surface loss:
$\frac{13.5 \text{ sq. ft.} \times 55 \text{ W/sq. ft.}}{1000 \text{ W/kW}}$ = 0.74 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