



Heat Requirement Calculations

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There are two basic heat energy requirements to be considered in the sizing of heaters for a particular application.

1. Start-Up Heat is the heat energy required to bring a process up to operating temperature. Start-up heat requirement calculations which include a material change of state should be calculated in three parts:

- 1) Heat requirement from ambient temperature to change of state temperature
- 2) Heat requirement during change of state (latent heat)
- 3) Heat requirement from change of state temperature to operating temperature

2. Operating Heat is the heat energy required to maintain the desired operating temperature through normal work cycles. The larger of these two heat energy values will be the wattage required for the application.

A safety factor is usually added to allow for unknown or unexpected operating conditions. The safety factor is dependent on the accuracy of the wattage calculation. A figure of 10% is adequate for small systems closely calculated, while 20% additional wattage is more common, and figures of 25% to 35% should be considered for larger systems with many unknown conditions existing.

Start-Up Heat requirements will include one or more of the following calculations, depending on the application.

1. Wattage required to heat material:

$$\frac{\text{Weight of material (lbs)} \times \text{Specific Heat (Btu/lb } ^\circ\text{F)} \times \text{Temperature rise (} ^\circ\text{F)}}{3.412 \text{ btu/watt hr.} \times \text{Heat-up time (hr.)}} = \text{Watts}$$



See page 16-4 for
Properties of Materials

2. Wattage required to heat container or tank:

$$\frac{\text{Weight of container (lbs)} \times \text{Specific Heat (Btu/lb } ^\circ\text{F)} \times \text{Temperature rise (} ^\circ\text{F)}}{3.412 \text{ btu/watt hr.} \times \text{Heat-up time (hr.)}} = \text{Watts}$$

3. Wattage required to heat hardware in container:

$$\frac{\text{Weight of hardware (lbs)} \times \text{Specific Heat (Btu/lb } ^\circ\text{F)} \times \text{Temperature rise (} ^\circ\text{F)}}{3.412 \text{ btu/watt hr.} \times \text{Heat-up time (hr.)}} = \text{Watts}$$

4. Wattage required to melt a solid to a liquid at constant temperature:

$$\frac{\text{Heat of fusion (Btu/lb)} \times \text{Weight of material to be melted (lb/hr)}}{3.412 \text{ btu/watt hr.}} = \text{Watts}$$

Heat of Fusion (Latent Heat): The amount of heat required to change one pound of a given substance from solid to liquid state without change in temperature is termed the heat of fusion.

It requires 144 Btu to change one pound of ice at 32°F to one

pound of water at 32°F, thus the heat of fusion of ice is 144 Btu per pound.

A change of state is usually accompanied by a change of specific heat. The specific heat of ice is 0.5; while that of water is 1.0.

5. Wattage required to change a liquid to a vapor state at constant temperature:

$$\frac{\text{Heat of vaporization (Btu/lb)} \times \text{Weight of material to be vaporized (lb/hr)}}{3.412 \text{ btu/watt hr.}} = \text{Watts}$$

Heat of Vaporization (Latent Heat): The amount of heat required to change one pound of a given substance from liquid to vapor state without change in temperature is termed the heat of vaporization.

It requires 965 Btu to change one pound of water at 212°F to one pound of steam at 212°F.

6. Wattage to counteract liquid surface losses: See Graph 3 for loss rates of water and oils.

$$\frac{\text{Total liquid surface area (sq. ft.)} \times \text{Loss rate at final temperature (watts/sq. ft.)}}{2} = \text{Watts}$$

7. Wattage to counteract surface losses from container walls, platen surfaces, etc.: See Graph 2 for losses from metal surfaces. See Graph 1 for losses from insulated surfaces.

$$\frac{\text{Total surface area (sq. ft.)} \times \text{Loss rate at final temperature (watts/sq. ft.)}}{2} = \text{Watts}$$

CONTINUED



Heat Requirement Calculations

Operating heat requirements will include one or more of the following calculations. Any additional losses particular to the application should also be estimated and included.

- 1. Wattage to counteract losses from open liquid surfaces:** See Graph 3 for loss rates of water and oils.

$$\text{Total liquid surface area (sq. ft.)} \times \text{Loss rate at operating temperature (watts/sq. ft.)} = \text{Watts}$$

- 2. Wattage to counteract container or platen surface losses,** either insulated (See Graph 1) or uninsulated (See Graph 2).

$$\text{Total surface area (sq. ft.)} \times \text{Loss rate at operating temperature (watts/sq. ft.)} = \text{Watts}$$

- 3. Wattage required to heat material transferred in and out of the system.**

(Metal dipped in heated tanks, air flows, make-up liquids, etc.)

$$\frac{\text{Weight of material to be heated (lbs)} \times \text{Specific Heat (Btu/lb } ^\circ\text{F)} \times \text{Temperature rise (} ^\circ\text{F)}}{3.412 \text{ btu/watt hr.} \times \text{Heat-up time (hr.)}} = \text{Watts}$$

- 4. Heat-up of racks of containers, etc. transferred in and out of the system:**

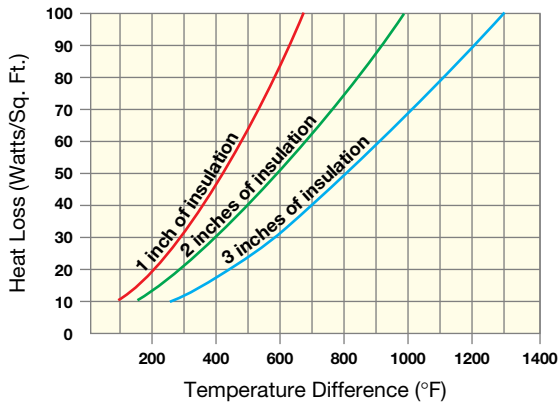
$$\frac{\text{Weight of items to be heated (lbs)} \times \text{Specific Heat (Btu/lb } ^\circ\text{F)} \times \text{Temperature rise (} ^\circ\text{F)}}{3.412 \text{ btu/watt hr.} \times \text{Heat-up time (hr.)}} = \text{Watts}$$

Specific Heat: The heat necessary to increase the temperature of all other substances has been referred to water as a standard. The ratio of the amount of heat required to increase the tempera-

ture of one pound of any substance by one degree to the amount necessary to increase one pound of water is known as the specific heat of that substance.

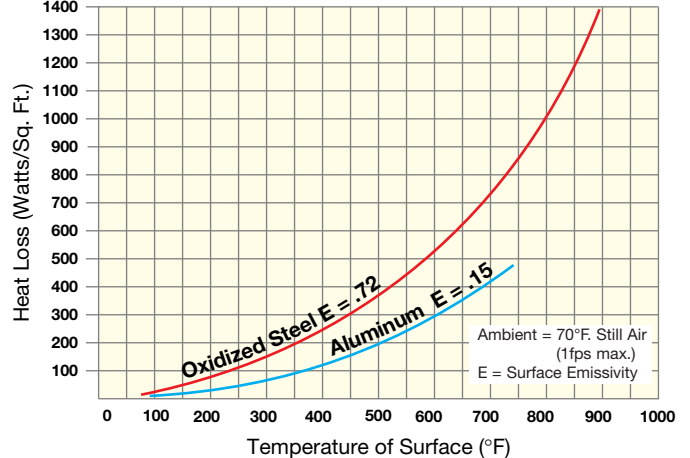
Heat Loss Information

Graph 1 Heat Losses through Insulated Walls (based on standard thermal insulations)

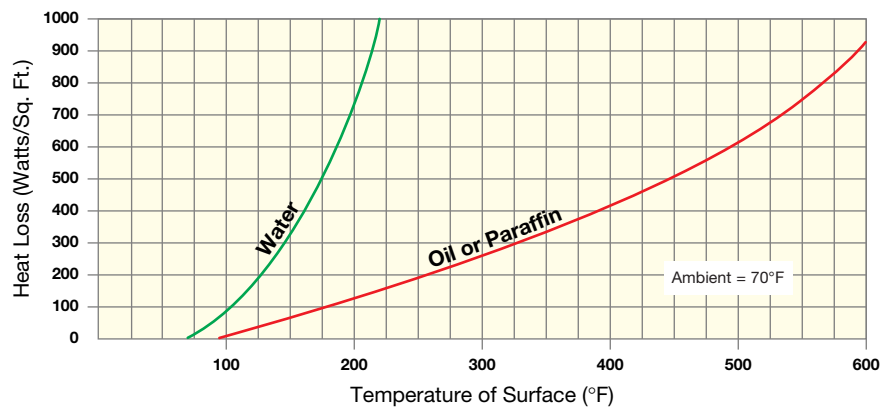


Figures are for vertical surfaces. Multiply by 120% for a horizontal top surface and by 60% for a horizontal bottom surface.

Graph 2 Heat Losses from Uninsulated Metal Surfaces



Graph 3 Heat Losses from the Surface of Water and Oil





Properties of Materials

Properties of Metals

Material	*Density lb./in ³	Specific Heat Btu (lb) (°F)	*Thermal Conductivity (Btu) (in.) (hr.) (ft ²) (°F)	Melting Point °F (Lowest)	Latent Heat of Fusion Btu/lb.	*Thermal Expansion in/in/°F × 10 ⁻⁶
Aluminum 1100-0	.098	.24	1540	1190	169.0	13.1
Brass, Yellow	.306	.096	816	1710		11.3
Copper	.324	.095	2736	1981	91.1	9.2
Gold	.698	.032	2064	1945	29.0	7.9
Incoloy® 800	.290	.13	80	2500		7.9
Inconel® 600	.304	.13	103	2500		5.8
Invar 36% Ni	.289	.12	76	2600		0.6
Iron, Malleable Cast	.260	.11	320	2250		6.0
Lead, Solid	.410	.032	241	621	11.3	16.3
Lead, Liquid	.372	.037	107			
Magnesium	.063	.25	1068	1202	160.0	14.0
Molybdenum	.369	.071	980	4750	126.0	2.94
Monel 400	.319	.11	151	2400		6.4
Nickel 200	.321	.12	520	2615	133.0	5.8
Nichrome (80% Ni-20% Cr)	.302	.11	104	2550		7.3
Palladium 99.5%	.432	.06	490	2830	69.5	6.5
Platinum	.775	.035	480	3217	49.0	4.9
Silver	.379	.057	2904	1761	38.0	11.4
Solder (50% Pb-50% Sn)	.321	.051	323	421	17	13.0
Steel, Mild	.284	.12	460	2760		6.7
Steel, Stainless 304	.290	.12	113	2550		9.6
Steel, Stainless 430	.280	.11	181	2600		5.8
Tantalum	.600	.035	372	5425		3.57
Tin, Solid	.264	.065	468	449	26.1	12.8
Tin, Liquid	.246	.052	228			
Titanium 99.0%	.163	.13	112	3020	187	4.8
Tungsten	.697	.03	1140	6170	79.0	2.45
Type Metal (85% Pb-15% Sb)	.387	.04		500	14	
Zinc	.258	.096	785	787	43.3	22.0
Zirconium	.234	.067	145	3350	108	3.22

Properties of Non-Metallic Solids

Liquid	*Density lb./Gal.	Specific Heat Btu (lb) (°F)	*Thermal Conductivity (Btu) (in.) (hr.) (ft ²) (°F)	Boiling Point °F	Heat of Vaporization Btu/lb.
Asphalt	.076	.22	5.16	250	40
Boron Nitride (Compacted)	.082	.33	125.00	5430	1-4
Brick, Hard	.072	.24	9.00		3-6
Carbon	.080	.20	165.00	6700	0.3-2.4
Cellulose Acetate	.048	.40	1.20-2.30		61-83
Delrin	.050	.35	1.56		45
Glass, Crown	.101	.16	7.50		5
Ice	.033	.49	15.60	32	144
Mica	.098	.12	4.80		18
MgO (Compacted)	.110	.21	14.40		7.7
Nylon	.042	.45	1.70		61-63
Paper	.033	.33	0.84		
Paraffin	.033	.69	1.60	133	63
Phenolic (Cast Resin)	.047	.35	1.1		44-61
Polyethylene (High Density)	.035	.55	3.36		94
Polystyrene	.038	.32	0.70-1.00		33-44
Rubber, Hard	.043	.48	1.12		340
Steatite	.073	.20	20.40		4.5-5.5
Sulfur	.072	.20	1.80	230	17
Teflon	.078	.25	1.70		55
Vinylidene	.062	.32	2.00		28-100
Wood, Oak	.027	.57	1.22		

Properties of Liquids

Liquid	*Density lb./Gal.	Specific Heat Btu (lb) (°F)	*Thermal Conductivity (Btu) (in.) (hr.) (ft ²) (°F)	Boiling Point °F	Heat of Vaporization Btu/lb.
Acetic Acid, 20%***	8.60	.91	3.70	214±	810±
Alcohol (ethyl)	6.74	.60	1.30	173	367
Brine (25% NaCl)**	9.91	.79	2.88	220±	730±
Caustic Soda (18% NaOH)**	10.00	.84	3.90	221±	795±
Dowtherm A	8.80	.44	0.96	496	42.2
Ethylene Glycol	9.36	.56		387	
Freon 12	10.94	.23	0.49	-21.6	62
Glycerine	10.52	.58	1.97	556	
Hydrochloric Acid 10%***	8.89	.93	3.90	221	
Nitric Acid, 7%***	8.65	.92	3.80	220±	918±
Oils (Petroleum)	7.35	.45			
Paraffin (melted)	7.49	.69±	1.68	572	70
Potassium (K)***	5.96	.18	253.20	1400	893
Sodium (Na)***	6.84	.30	446.40	1638	1810
Sulfuric Acid 10%***	9.90	.92	4.00	216	
Therminol FR-2	12.10	.30	0.70	648±	
Turpentine	7.22	.42	0.90	319	133
Vegetable Oil	7.75	.43±	1.10		
Water	8.34	1.00	4.08	212	965

Properties of Gases

Gas	*Density lb./ft ³	Specific Heat Btu/(lb) (°F)	*Thermal Conductivity (Btu) (in.)/(hr.) (ft ²) (°F)
Air at 80°F	.073	.240	.18
at 400°F	.046	.247	.27
Ammonia	.044	.523	.16
Argon	.102	.125	.12
Carbon Dioxide	.113	.199	.12
Carbon Monoxide	.072	.248	.18
Chlorine	.184	.115	.06
Helium	.011	1.250	1.10
Hydrogen	.0052	3.390	.13
Methane	.0447	.590	.21
Nitrogen	.072	.248	.19
Oxygen	.082	.218	.18
Sulphur Dioxide	.172	.152	.07



* At or near room temperature

*** At 1000 °F

** Percent concentration by weight in H₂O solution

± Approximate

Air Density Table (lb./cu. ft.)

Temp °F	Specific Heat	Gauge Pressure						
		0	10	50	100	200	250	300
0	.240	.086	.145	.380	.674	1.261	1.555	1.848
10	.240	.085	.142	.372	.659	1.234	1.522	1.808
20	.240	.083	.139	.364	.646	1.208	1.490	1.771
30	.240	.081	.136	.357	.632	1.184	1.459	1.735
40	.240	.079	.133	.350	.620	1.160	1.430	1.700
50	.240	.078	.131	.343	.608	1.137	1.402	1.667
60	.240	.076	.128	.336	.596	1.115	1.375	1.635
70	.240	.075	.126	.330	.585	1.094	1.349	1.600
80	.240	.074	.124	.324	.574	1.074	1.324	1.574
90	.240	.072	.121	.318	.563	1.055	1.300	1.546
100	.240	.071	.119	.312	.553	1.036	1.277	1.518
120	.240	.068	.115	.301	.534	1.000	1.233	1.466
140	.240	.066	.111	.291	.516	.967	1.192	1.417
160	.241	.064	.108	.282	.500	.936	1.153	1.371
180	.241	.062	.104	.273	.484	.906	1.117	1.328
200	.242	.060	.101	.265	.470	.879	1.084	1.288
220	.242	.058	.098	.257	.456	.853	1.052	1.250
240	.242	.057	.095	.250	.443	.829	1.022	1.215
260	.243	.055	.093	.243	.430	.806	.993	1.181
280	.243	.054	.090	.236	.419	.784	.966	1.149
300	.244	.052	.088	.230	.408	.763	.941	1.119
320	.244	.051	.086	.224	.397	.744	.917	1.090
340	.244	.050	.083	.219	.387	.725	.894	1.063
360	.246	.048	.081	.213	.378	.707	.872	1.037
380	.246	.047	.079	.208	.369	.691	.851	1.012
400	.247	.046	.078	.203	.360	.674	.832	.989
420	.247	.045	.076	.199	.352	.659	.813	.966
440	.247	.044	.074	.194	.344	.644	.795	.945
460	.248	.043	.073	.190	.337	.630	.777	.924
480	.248	.042	.071	.186	.330	.617	.761	.905
500	.249	.041	.070	.182	.323	.604	.745	.886
520	.249	.041	.068	.178	.316	.592	.730	.868
540	.249	.040	.067	.175	.310	.580	.715	.850
560	.250	.039	.065	.171	.304	.569	.701	.834
580	.251	.038	.064	.168	.298	.558	.688	.818
600	.252	.037	.063	.165	.292	.547	.675	.802
620	.252	.037	.062	.162	.287	.537	.662	.787
640	.252	.036	.061	.159	.281	.527	.650	.773
660	.253	.035	.060	.156	.277	.518	.639	.759
680	.253	.035	.059	.153	.272	.509	.627	.746
700	.254	.034	.058	.151	.267	.500	.616	.733
720	.254	.034	.057	.148	.263	.492	.606	.721
740	.255	.033	.056	.146	.258	.483	.596	.709
760	.256	.033	.055	.143	.254	.475	.586	.697
780	.256	.032	.054	.141	.250	.468	.577	.686
800	.257	.032	.053	.139	.246	.460	.568	.675
820	.257	.031	.052	.137	.242	.453	.559	.664
840	.257	.031	.051	.134	.238	.446	.550	.654
860	.258	.030	.051	.132	.235	.439	.542	.644
880	.259	.030	.050	.130	.231	.433	.534	.634
900	.260	.029	.049	.129	.228	.427	.526	.625
920	.260	.029	.048	.127	.225	.420	.518	.616
940	.260	.028	.048	.125	.221	.414	.511	.607
960	.261	.028	.047	.123	.218	.408	.504	.599
980	.261	.028	.046	.121	.215	.403	.497	.590
1000	.262	.027	.046	.120	.212	.397	.490	.582
1020	.262	.027	.045	.118	.209	.392	.483	.574
1040	.263	.026	.044	.117	.207	.387	.477	.567
1060	.264	.026	.044	.115	.204	.382	.470	.559
1080	.264	.026	.043	.114	.201	.377	.464	.552
1100	.265	.025	.043	.112	.199	.372	.458	.545
1120	.265	.025	.042	.111	.196	.367	.453	.538
1140	.265	.025	.042	.108	.194	.363	.447	.531
1160	.266	.025	.041	.108	.191	.358	.441	.525
1180	.266	.024	.041	.107	.189	.354	.436	.518
1200	.267	.024	.040	.105	.187	.349	.431	.512