Thermocouples

The most common problems associated with thermocouple sensing controls are:

1) Using the wrong type of thermocouple

Each instrument is calibrated to work with a particular thermocouple type. Connecting a ‘K’ thermocouple to a ‘J’ instrument will result in severe overshoot and probable heater damage.

2) Reversing of lead wires

Thermocouple leads are polarized. The red wire is always negative. Reversing leads will cause reverse reading at the instrument and loss of control.

3) Using the wrong extension wire

The correct thermocouple extension wire must be used. For example: type J themocouple extension wire must be used with J thermocouples. Copper wire cannot be used. A mixture of copper and thermocouple wire creates extra thermocouple junctions which will cause unpredictable reading errors.

Refer to the following charts for proper physical identification:

Thermocouple Identification

TABLE 1 - Thermocouple Identification

ANSI TYPE	DESCRIPTION	COLOURS POS+	COLOURS NEG-	JACKET
J	Iron Constantan	White	Red	Black
K	Chromel Alumel	Yellow	Red	Yellow
T	Copper Constantan	Blue	Red	Blue
E	Chromel Constantan	Purple	Red	Purple
R	Platinum Rhodium 13%	Black	Red	Green
S	Platinum Rhodium 10%	Black	Red	Green
N	Nicrosil NISIL	Orange	Red	Brown

Thermocouple Output

TABLE 2 - Millivolt vs. Temperature

TEMP. °F	TEMP. °C	J (iron constantan) MILLIVOLTS	K (chromel alumel) MILLIVOLTS
0	-18	-0.885	-
32	0	-0.000	0.000
100	38	1.942	1.520
212	100	5.268	4.095
300	149	7.947	6.092
500	260	14.108	10.560
700	371	20.253	15.178
1000	538	29.515	22.251
1250	677	37.688	28.146
1500	816	46.503	33.913
2000	1093	63.392	44.856

Thermocouple Extension Wire Resistance

Thermocouple wires have the resistance outlined in the following chart (Table 3). Resistances should be kept as low as possible. Increase the gauge of wire for long runs. Although modern instrumentation will accept an input impedence up to 100 ohms or more, the signal degrades and the instrument becomes more susceptible to external interference.

For long runs between sensing point and instrumentation of 50 meters (150 feet) or more, a transmitter should be considered.

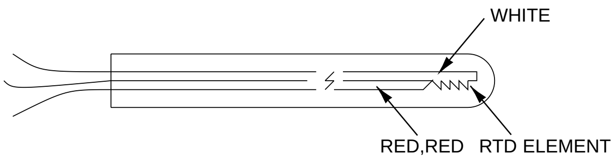
TABLE 3 - Loop Resistance (2 Wires)

CALIBRATION	Ohms per 33m (100') 8 GA	12 GA	14 GA	16 GA
JX Iron Constantan	2.15	5.42	8.63	13.71
KX Chromel Alumel	3.65	9.22	14.66	23.30
TX Copper Constantan	1.84	4.66	7.41	11.78
EX Chromel Constantan	4.36	11.01	17.51	27.83

CALIBRATION	Ohms per 33m (100') 18 GA	20 GA	22 GA	24 GA
JX Iron Constantan	21.80	35.69	55.11	87.66
KX Chromel Alumel	37.07	58.97	93.68	149.00
TX Copper Constantan	18.74	29.82	46.91	75.34
EX Chromel Constantan	44.27	70.43	111.90	178.00

RTD's

RTD's are available in 2, 3 and 4 wire construction. The most common (as shown) is 3 wire. With instrumentation designed to accept 3 wire RTD's, the second red wire is used in a circuit to calculate lead wire resistance. This resistance is automatically deducted from the sensor reading to eliminate potential errors.



RTD Output

TABLE 4 - 100Ω Platinum (.00385 Ω/Ω/°C) Resistance vs. Temperature

TEMP. °F	TEMP. °C	OHMS	TEMP. °F	TEMP. °C	OHMS
-40	-40	84.27	302	150	157.31
-4	-20	92.16	392	200	175.84
32	0	100.00	482	250	194.07
68	20	107.79	572	300	212.02
122	50	119.40	662	350	229.67
212	100	138.50	752	400	247.04

Electrical Equations

Single phase relationships:

$$V = \sqrt{WR} = W/I = IR$$

$$RW/I^2 = V^2/W = V/I$$

$$I = V/R = W/V = \sqrt{W/R}$$

$$W = V^2/R = I^2R = VI$$

For current in electrically balanced three phase A.C. circuits:

$$I = \frac{W}{V(\sqrt{3})}$$

NOTE: For circuits wired in 3 phase delta, wattage may be reduced to 1/3 by rewiring to a 3 phase wye connection.

FIG. 1 - THREE PHASE DELTA CONNECTION

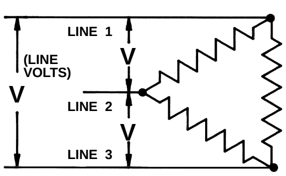


FIG. 2 - THREE PHASE WYE OR STAR CONNECTION

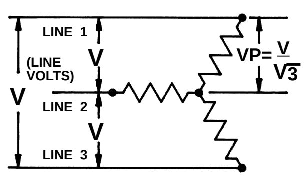


FIG. 3 - SPECIAL USE OF TWO POLE THERMOSTAT

Single phase circuit split with half of the current load across each thermostat contact.

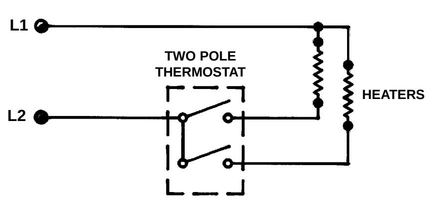


FIG. 4 - USE OF CONTACTOR (SINGLE PHASE)

Single phase circuit for conditions where the line current exceeds the thermostat rating and a contactor is added.

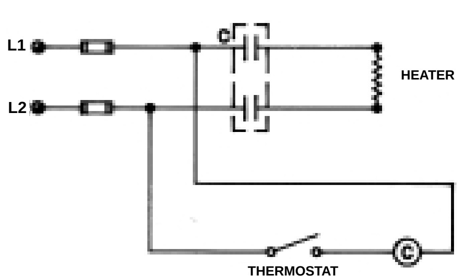


FIG. 5 - USE OF CONTACTOR (THREE PHASE)

Three phase circuit for conditions where the line current exceeds the thermostat rating and a contactor is added.

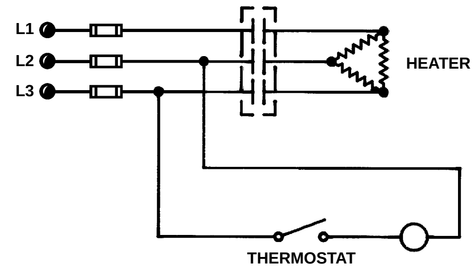


FIG. 6 - SERIES TO PARALLEL DELTA TRANSFORMATION

Special circuit with two thermostats and two contactors. When both contactors are closed, elements are wired in 3 phase parallel delta and circuit operates at full power. When only one of the contactors is closed, elements are wired in 3 phase series delta and the circuit operates at 1/4 power.

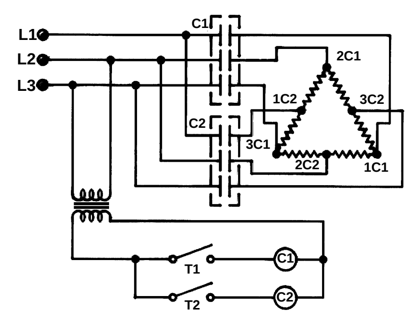
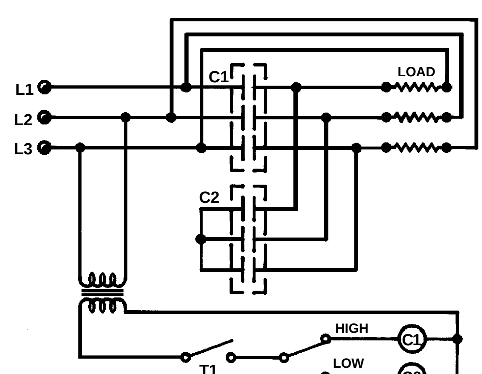


FIG. 7 - WYE TO DELTA TRANSFORMATION

Special circuit with two contactors, thermostat and two position switch.

When contactor 1 (C1) is closed, elements are wired in 3 phase delta and circuit operates at full power. When contactor 2 (C2) is closed, contactor 1 (C1) is opened, elements are wired in 3 phase wye and the circuit operates at 1/3 power. **CAUTION:** Contactors C1 and C2 must be mechanically interlocked in this configuration.

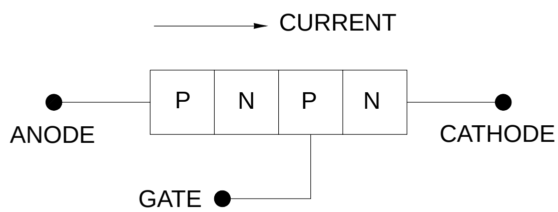


SCR'S, THYRISTORS, TRIACS & SSR'S

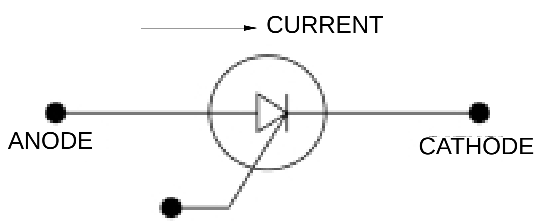
An SCR (Silicon Controlled Rectifier) as a component is one commonly used type of **thyristor**. Essentially, it consists of four layers of silicon which, in their normal state, are non-conductive.

The SCR can be made to conduct by applying a very small current to its "gate". This feature allows a combination of SCR's to have broad application, one of which is the switching of resistive loads characteristic of electric heating.

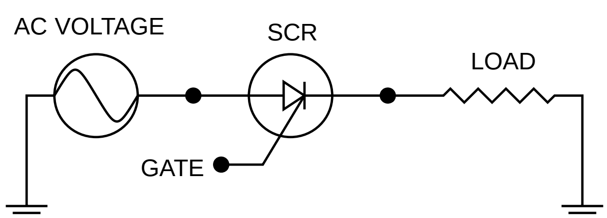
Diagramatically, the SCR is represented as follows:



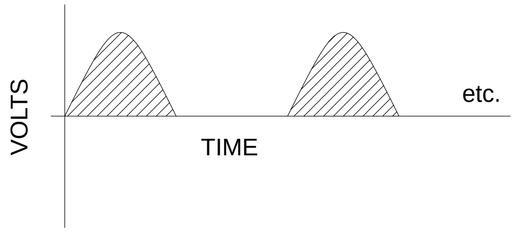
However, for electrical circuits, the SCR is depicted as follows:



If we connect a supply voltage and load (resistance) to the above circuit

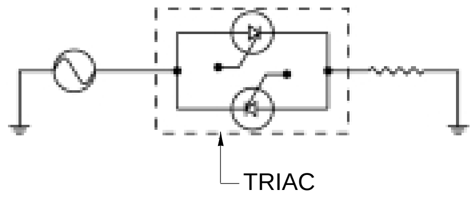


the single SCR will act as a half wave rectifier, and at best, it will only allow the positive (+) part of the AC voltage to reach the load.

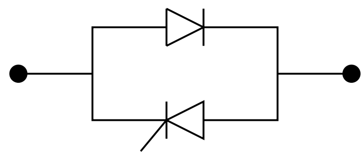


To allow the negative (-) part of the voltage waveform to get through to the load requires a second SCR of opposite polarity in parallel with the first.

For example, the circuit below will allow the full waveform or a part of it to reach the load. Two SCR's



combined in this fashion make up a **triac**. A triac is generally depicted as follows:



For single phase circuits, one triac will be sufficient to control the load. For three phase circuits, two triacs are normally used.

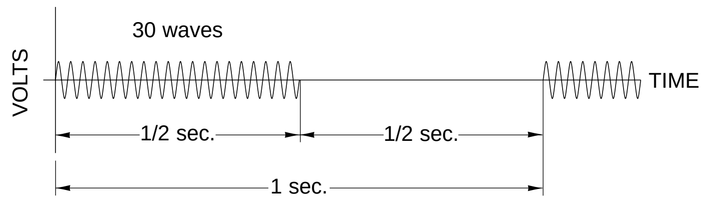
Controls are available which can apply a current to the gate at rapid intervals, blocking out some of the waveforms or a part of each waveform. The load output will then vary as a percentage of the blocked to the total cycles.

Two gate switching methods are in use to provide variable output from the load:

i) **Zero crossover fired** or **burst firing** where only full cycles of the voltage waveform are permitted to pass through the SCR to the load. Again, there are several variations as to how this can be done.

(a) **Fixed time base** where the cycle interval is built into the controller at the factory and the power is switched through only one "on" and one "off" cycle during that time. For example, if the time base is 1 second, at 60 cycles per second, any sequential number of the 60 voltage waves could be allowed to pass through to the load. At 50% demand the first 30 waves would pass and the last 30 would be blocked.

FIGURE 1 - Fixed (one second) time base at 50% output



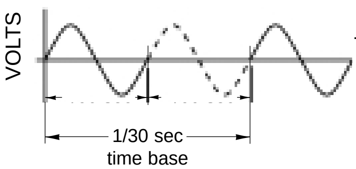
The SCR is equipped with circuitry (firing board) that will modify or proportion the “on” and “off” time during each subsequent cycle based on the amplitude of the temperature related signal it receives from an external controller.

Earlier SCR’s employed fixed time bases up to 90 seconds. However, typical controls now in use tend to have time bases set at ten seconds or less. Most Caloritech™ SCR’s have four second or one second fixed time bases.

SSR’s (solid state relays) employ a similar method of control except that the time base is set by an external controller which signals the SSR's built-in firing circuitry when it should fire (conduct).

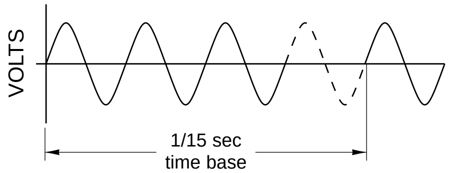
(b) **Variable time base** (also burst fired) where the time base depends on the demand. At 50% demand the time base would be 1/30 of a second or two cycles;

FIGURE 2 - Variable time base at 50% output



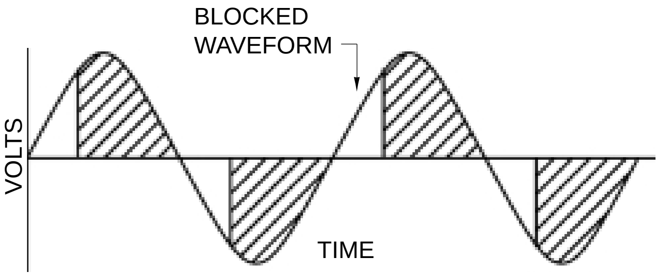
at 75% demand the time base would be 1/15 of a second or four cycles, etc.

FIGURE 3 - Variable time base at 75% output



Zero crossover firing is used to control resistive loads which change little with aging and temperature. Since the voltage is switched at zero amplitude, negligible radio frequency interference (RFI) is generated.

ii) A second method of gate switching is **phase angle firing** where a part of each waveform is blocked.



Phase angle firing is most frequently used on inductive loads with high inrush currents. If possible, it is best to avoid phase angle type SCR's since RFI may be generated.

Fortunately, with Caloritech™ equipment we seldom have to resort to this type of control.

ADVANTAGES

SCR switching has as its main advantage the ability to switch loads at high speed. Properly employed, they can contribute to excellent system temperature control and prolong heater service life.

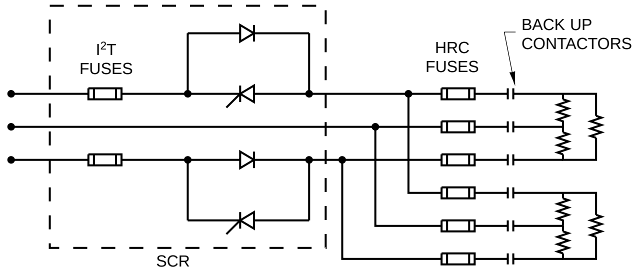
They are silent during operation and, if sized conservatively, will prove to be low maintenance devices.

PROTECTION

SCR's can fail "ON" and it is vital to protect the device against short circuits at the load. Special I^2t semi-conductor fuses are utilized for this purpose. Back-up fused magnetic contactors are frequently employed as in Figure 4. These contactors can be de-energized by a limit device but in the normal state they remain closed allowing the full load to be switched by the SCR.

With contactors, it is most economical to limit switching to 45 amps, and for this reason the load is usually divided into smaller circuits.

FIGURE 4 - SCR with back-up contactors



FIRING BOARDS

Packaged SCR’s incorporate a firing board which is essentially an electronic circuit that accepts various inputs from a temperature controller and converts these inputs into a corresponding gate signal.

HEAT SINKS

All solid state switches have an internal resistance which is converted into heat when the SCR is in the conduction mode. High surface area aluminum heat sinks are used to transfer this heat away from the silicon wafer. For larger SCR’s, cooling fans are also required for this purpose.

SCR - AS A PACKAGED CONTROL

As a matter of convenience, current practice is to call the combination of component SCR’s, firing board, heat sink, fusing, fan, enclosure, interconnecting wiring, etc. an SCR! It’s probably best to adopt this “control” meaning as opposed to the more limited (but more correct) “component” meaning.

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

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:

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

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

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 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:
563 lb. x 1.0 Btu/lb.-°F x (150 - 50)°F / 3412 Btu/kWh = 16.5 kWh

1b. To heat tank:
270 lb. x 0.12 Btu/lb.-°F x (150 - 50)°F / 3412 Btu/kWh = 0.95 kWh

2. Heat of fusion or vaporization: None

3a. Average water surface loss:
6 sq. ft. x 270 W/sq. ft. x 2 hrs. / 1000 W/kW x 2 = 1.62 kWh

3b. Average tank surface loss:
26 sq. ft. x 7 W/sq. ft. x 2 hrs. / 1000 W/kW x 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

B. OPERATING REQUIREMENT

1. To heat additional water
4 gal./hr. x 8.3 lb./gal. x 1.0 Btu/lb.-°F x (150 - 50)°F / 3412 Btu/kWh = 0.97 kW

2. Heat of fusion or vaporization: None

3a. Water surface loss:
6 sq. ft. x 270 W/sq. ft. / 1000 W/kW = 1.62 kW

3b. Tank surface loss:
26 sq. ft. x 7 W/sq. ft. / 1000 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 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:
140 lb. x 0.12 Btu/lb.-°F x (150 - 70)°F / 3412 Btu/kWh = 0.39 kWh

1b. To heat solid paraffin:
168 lb. x 0.70 Btu/lb.-°F x (133 - 70)°F / 3412 Btu/kWh = 2.17 kWh

Fusion occurs at this point

1c. To heat melted paraffin:
168 lb. x 0.71 Btu/lb.-°F x (150 - 133)°F / 3412 Btu/kWh = 0.59 kWh

2. Heat of fusion, to melt paraffin
168 lb. x 63 Btu/lb. / 3412 Btu/kWh = 3.10 kWh

3a. Average paraffin surface loss:
3 sq. ft. x 70 W/sq. ft. x 2 hrs. / 1000 W/kW x 2 = 0.21 kWh

3b. Average tank surface loss:
13.5 sq. ft. x 55 W/sq. ft. x 2 hrs. / 1000 W/kW x 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

B. OPERATING REQUIREMENT

1a. To heat drills and rack:
(1500 x 0.157 + 60)lb./hr. x 0.12 Btu/lb.-°F x (150 - 70)°F / 3412 Btu/kWh = 0.83 kW

1b. To heat additional solid paraffin:
20 lb./hr. x 0.70 Btu/lb.-°F x (133 - 70)°F / 3412 Btu/kWh = 0.26 kW

Fusion occurs at this point

1c. To heat additional melted paraffin:
20 lb./hr. x 0.71 Btu/lb.-°F x (150 - 133)°F / 3412 Btu/kWh = 0.07 kW

2. Heat of fusion, to melt additional paraffin:
20 lb./hr. x 63 Btu/lb. / 3412 Btu/kWh = 0.37 kW

3a. Paraffin surface loss:
3 sq. ft. x 70 W/sq. ft. / 1000 W/kW = 0.21 kW

3b. Tank surface loss:
13.5 sq. ft. x 55 W/sq. ft. / 1000 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

TABLE 1 - PROPERTIES OF METALS

Material	Average specific heat Btu/(lb.)(°F)	Latent heat of fusion Btu/lb.	Density lbs./in.^{3}	Melting point °F (lowest)	Thermal Conductivity K (Btu)(in.)/(hr.)(sq.ft.)(°F)	Thermal expansion in./in./°F x10^{-6}
Aluminum	.24	169	.098	1190	1540	13.1
Antimony	.049	69	.239	1166	131	
Babbit - lead base	.039		.370	470	165.6	
Babbit - tin base	.071		.267	465	278.4	
Barium	.068		.130	1562		
Beryllium	.052		.066	2345	1121.0	
Bismuth	.031	22.4	.353	520	59	
Boron	.309		.083	4172		
Brass (80-20)	.091		.310	1700	82	
Brass (70-30)	.10		.304	1700	672	
Brass (yellow)	.096		.306	1710	830	11.2
Bronze (75/25)	.082	75	.313	1832	180	
Cadmium	.055	23.8	.313	610	660	
Calcium	.149	140	.056	1564	912	
Carbon	.165		.080	6422	173	
Chromium	.11		.260	2822	484	
Cobalt	.099	115.2	.321	2696	499	
Constantan	.098		.321			
Copper	.095	91.1	.322	1981	2680	9.8
German silver	.109		.311	1761	168	
Gold	.032	29.0	.698	1945	2030	7.9
Incoloy 800	.13		.290	2500	80	7.9
Incoloy 600	.126		.304	2500	103	5.8
Inconel 600	.11		.304	2470	109	5.8
Iron, cast	.12		.260	2150	346	6.0
Iron, wrought	.12		.278	2800	432	
Lead, solid	.032	11.3	.410	620	240	16.4
Lead, liquid	.037		.387		108	
Linotype	.04		.363	480		
Lithium	.79	59	.212	367	516	
Magnesium	.27	160	.063	1202	1106	14
Manganese	.115	116	.268	2268	80.6	
Mercury	.033	5.0	.488	-38	60.8	
Molybdenum	.071	126	.369	4750	980	2.94
Monel 400	.11		.319	2400	151	6.4
Nickel 200	.12	133	.321	2615	520	5.8
Nichrome	.11		.302	2550	104	7.3
Platinum	.035	49	.775	3225	480	4.9
Potassium	.058	26.2	.434	146	720	
Rhodium	.059		.449	3570	636	
Silicon	.162		.008	2570	600	
Silver	.057	38	.379	1760	2900	10.8
Sodium	.295	49.5	.035	207	972	
Solder	.051	17	.323	361	310	13.1
Steel, mild	.122		.284	2760	460	6.7
Stn. Stl. 304	.12		.286	2550	105	9.6
Stn. Stl. 430	.11		.275	2650	155	6.0
Tantalum	.035		.60	5425	375	3.57
Tin, liquid	.052		.253		218	
Tin, solid	.065	26.1	.263	450	455	13
Titanium 99.0 %	.13		.164	3035	112	4.7
Tungsten	.040	79	.697	6170	1130	2.45
Type Metal	.040	14	.388	500	180	
Uranium	.028		.677	3075	193.2	
Zinc	.096	43.3	.258	787	740	22.1
Zirconium	.067	108	.234	3350	145	3.22

TABLE 2 - PROPERTIES OF NON-METALLIC SOLIDS

Material	Average specific heat Btu/(lb.)(°F)	Latent heat of fusion Btu/lb.	Average Density lbs./in.^{3}	Melting point °F (lowest)	Thermal Conductivity K (Btu)(in.)/(hr.)(sq.ft.)(°F)	Thermal expansion in./in./°F x10^{-6}
ABS Plastic	.35		.042		1.32 2.28	
Acrylic	.34		.041		1.0	
Alumina			.087			
Aluminum Silicate	.2		.086	3690	9.1	
Asbestos	.25		.021		.44	
Ashes	.2		.025		.49	
Asphalt	.40		.046		5.3	
Bakelight, Pure Resin	.3 - .4		.045			
Barium Chloride	.10		.139	1697		
Beeswax		75	.035	144	1.67	
Boron Nitride	.33		.082	5430	125	1 - 4

TABLE 2 - PROPERTIES OF NON-METALLIC SOLIDS (cont)

Material	Average specific heat Btu/(lb.)(°F)	Latent heat of fusion Btu/lb.	Average Density lbs./in.^{3}	Melting point °F (lowest)	Thermal Conductivity K (Btu)(in.)/(hr.)(sq.ft.)(°F)	Thermal expansion in./in./°F x10^{-6}
Brickwork	.22		.076		3 - 7	3 - 6
Calcium Chloride	.17	72	.091	1422		
Carbon	.28		.080	6700	165	0.3 - 2.4
Canauba Wax	.8		.036			
Cellulose Acetate	.3 - .5		.047		1.2 - 2.3	61 - 83
Cement	.19		.054		2.04	
Ceramic Fiber	.27		.007			
Chalk	.215		.083		5.76	
Clay	.224		.052	3160	9	
Coal (Coarse Anthercite)	.32		.046		11	
Coal Tars	.35 - .45		.045			
Coke	.265		.043			
Concrete (Cinder)	.16		.058		5.3	
Concrete (Stone)	.156		.083		9.5	
Cork	.5		.008		.36	
Cotton (Flax, Hemp)	.31		.053		.41	
Delrin	.35		.051		1.6	45
Diamond	.147		.127		13872	
Earth, Dry & Packed	.44		.054		.9	
Epoxy	.25 - .3		.045		1.2 - 2.4	
Ethyl Cellulose	.32 - .46		.041			
Fiberglass			.0004		.28	
Firebrick, Fireclay	.243		.083	2900	6.6	
Firebrick, Silica	.258		.089	3000	7.2	
Flourspar	.21					
Fluoroplastics	.28		.081		1.68	
Glass, crown	.161		.101		7.5	5
Granite	.192		.097		13 - 28	
Graphite	.20		.075		1.25	
Ice	.53	144	.0324	32	11	28.3
Isoprene	.48		.034		1.0	
Limestone	.217		.088		3.6-9	
Magnesia	.234		.130	5070	.48	
Magnesite Brick	.222		.092		10.8 - 30	
Magnesium Silicate			.101		15.6	
Marble	.21		.097		14.4	
Marinite I @ 400°F	.29		.027		.89	
Mica	.21		.102		3.0	18
MgO (Before Compacted)	.21		.085		3.6	
MgO (Compacted)	.209		.112		20	7.7
Nylon	.4		.040		1.5	61 - 63
Paper	.45		.034		.82	
Paraffin	.70	63	.032	133	1.6	
Phenolic Plastic	.35		.060		1.02	
Phenolic Resin, Cast	.3 - .4		.049		1.1	
Phenolic, Sheet or Tube Laminated	.3 - .5		.045		2.4	
Pitch, Hard			.048	300		
Polycarbonate	.3		.044		1.38	
Polyester	.2 - .35		.046		3.96 - 5	
Polyethylene	.55		.035		2.3	94
Polypropylene	.46		.032		1.72	
Polystyrene	.32		.038		.7 - 1.0	33 - 44
Polyvinyl Chloride Acetate	.2 - .3		.049		.84 - 1.2	
Porcelain	.26		.087		6 - 10	
Potassium Chloride	.17		.072	1454		
Potassium Nitrate	.26		.076	633		
Quartz	.26		.080		9.6	
Rock Salt	.219			1495		
Rubber	.44		.044		1.1	340

TABLE 2 - PROPERTIES OF NON-METALLIC SOLIDS (cont)

Material	Average specific heat Btu/(lb.)(°F)	Latent heat of fusion Btu/lb.	Average Density lbs./in.^{3}	Melting point °F (lowest)	Thermal Conductivity K (Btu)(in.)/(hr.)(sq.ft.)(°F)	Thermal expansion in./in./°F x10^{-6}
Sand, Dry	.191		.054		2.26	
Sandstone	.22		.081			
Silica (fused)	.316				10.0	
Silicon Carbide	.20 - .23		.069		105	
Silicone Rubber	.45		.045		1.5	
Soapstone	.22		.097		11.3	
Sodium Carbonate	.30		.078	520		
Sodium Chloride	.22		.078	1474		
Sodium Cyanide	.30		.054	1047		
Sodium Nitrate	.29		.082	584		
Sodium Nitrite	.30		.078	520		
Soil, Dry						
Steatite	.20		.094		17.5 - 23	4.5 - 5.5
Stone	.20					
Sugar	.30		.061	320		
Sulfur	.175	17	.075	246	1.9	36
Tallow			.035	90		
Teflon	.25		.078		1.7	55
Urea, Formaldehyde	.4		.056			
Vinyl	.3 - .5		.046		.8 - 2.0	28 - 100
Wood, Oak	.57		.029		1.1	

TABLE 3 - PROPERTIES OF LIQUIDS

Material	Average specific heat Btu/(lb.)(°F)	Heat of vapor-ization Btu/lb.	Density lbs./U.S. Gal.	Boiling point °F	Thermal Conductivity K (Btu)(in.)/(hr.)(sq.ft.)(°F)
Acetic acid, 20%	.91	810	8.6	214	3.7
Acetic acid, 100%	.48	175	8.7	245	1.14
Acetone, 100%	.514	225	6.5	133	1.15
Alcohol (allyl)	.665	293	7.4	207	
Alcohol (amyl)	.65	216	7.4	280	
Alcohol (butyl)	.687	254	6.1	244	
Alcohol (ethyl)	.60	367	6.6	173	1.3
Alcohol (propyl)	.57	295.2	6.7	208	
Ammonia, 100%	1.1	589	6.4	-27	3.48
Asphalt	.42		8.3		5.04
Benzene	.42	170	7.5	175	1.04
Brine (25% CaCl)	.689		10.2		3.36
Brine (25% NaCl)	.786	730	9.9	220	2.88
Brine (25% NiCl)	.81	728	9.9	221	4.0
Carbon Tetrachloride	.21		13.2	170	
Caustic soda (18%)	.84	795	10.0	221	3.9
Corn Syrup, Dextrose	.65		11.7	231	
Cottonseed Oil	.47		7.9		1.2
Dowtherm A	.44	42.2	8.8	496	.96
Ether	.503	160	6.1	95	.95
Ethyl Acetate	.475	183.5	6.9	180	
Ethyl Bromide	.215	108	12.1	101	
Ethyl Chloride	.367	166.5	7.6	54	
Ethyl Iodide	.161	81.3	15.1	160	
Ethylene Bromide	.172	83	16.0	270	
Ethylene Chloride	.299	139	9.6	240	
Ethylene Glycol	.555		9.4	387	
Formic Acid	.525	216	9.3	213	
Freon 11	.208		12.3	74.9	.600
Freon 12	.232	62	10.9	-21.6	.492
Freon 22	.300		10.0	-41.36	.624
Fuel Oil #1	.47	86	6.8	440	1.008
Fuel Oil #2	.44		7.2		.96
Fuel Oil #3, #4	.425	67	7.4	580	.918
Fuel Oil #5, #6	.41		7.9		.852
Gasoline	.53	116	5.5 - 5.7	280	.936
Glycerine	.61		10.5	556	2.0
Heptane	.49	137.1	5.1	210	
Hexane	.6	142.5	5.1	155	
Hydrochloric 10%	.93		8.9	221	3.9
Ice	.5		7.5		3.96
Lard	.64		7.7		
Linseed Oil	.44		7.7	552	
Mercury	.033	117	113.0	675	59.64
Methyl Acetate	.47	176.5	7.3	133	
Methyl Chloroform	.26	95	11.1	165	

TABLE 3 - PROPERTIES OF LIQUIDS (continued)

Material	Average specific heat, Btu/(lb.)(°F)	Heat of vapor-ization Btu/lb.	Density lbs./U.S. Gal.	Boiling point °F	Thermal Conductivity K (Btu)(in.)/(hr.)(sq.ft.)(°F)
Methylene Chloride	.288	142	11.0	104	
Molasses	.60		11.7	220	
NaK (78% K)	.21		6.2	1446	167.0
Napthalene	.396	103	7.2	424	
Nitric acid, 7%	.92	918	8.6	220	3.8
Nitric acid, 95%	.5	207	12.5	187	
Nitrobenzene	.35	142.2		412	
Oil (SAE10-30)	.43		7.4		
Oil (SAE40-50)	.43		7.4		
Olive Oil	.47		7.8	570	
Paraffin (melted)	.71		6.3		1.0
Perchlorethylene	.21	90	13.5	250	
Phenol	.56		8.9	346	
Phosphoric 10%	.93		8.7		
Phosphoric 20%	.85		9.2		
Potassium (K)	.18	893	6.0	1400	320.0
Propane (Comp)	.576		0.02	-48.1	1.81
Sea Water	.94		8.6		
Sodium (Na)	.30	1810	6.8	1621	580.0
Sodium Hydroxide					
30% Solution	.84		11.1		
50% Solution	.78		12.8		
Soybean Oil	.24-.33		7.7		
Starch			12.8		
Sucrose, 40% Sugar	.66		9.8	214	
Sucrose, 60% Sugar	.74		10.7	218	
Sulfur, Melted 500°F	.24	120	15.0	832	
Sulfuric acid, 10%	.92		9.9	216	4.0
Sulfuric acid, 20%	.84		9.5	218	
Sulfuric acid, 60%	.52		12.5	282	2.88
Sulfuric acid, 98%	.35	219	15.3	625	1.8
Therminol FR-2	.30		12.1	648	.70
Toluene	.42		7.2		1.032
Trichloroethylene	.23	103	12.2	188	.84
Transformer Oils	.42		7.5		.9
Turpentine	.41	123	7.3	318	.90
Vegetable oil	.43		7.7		1.1
Water	1.0	970	8.3	212	4.2
Xylene	.411	149.2	7.2	288	

TABLE 4 - PROPERTIES OF GASES

Gas	Specific heat Btu/lb./°F	Density lbs./ft.^{3}	Thermal Conductivity K (Btu)(in.)/(hr.)(sq.ft.)(°F)
Acetylene	.35	.073	.129
Air at 80°F	.240	.073	.18
at 400°F	.245	.046	.27
Alcohol, Ethyl (Vapor)	.4534		
Alcohol, Methyl (Vapor)	.4580		
Ammonia	.523	.044	.16
Argon	.125	.102	.12
Butane		.1623	.0876
Butylene		.148	
Carbon dioxide	.199	.113	.12
Carbon monoxide	.248	.072	.18
Chlorine	.115	.184	.06
Chloroform	.1441		.046
Chloromethane	.24	.1309	.0636
Ethyl Chloride		.1703	.066
Ethyl Ether	.4380		.0924
Ethylene	.40	.0728	.1212
Helium	1.25	.011	1.10
Hydrochloric Acid	.191	.0946	
Hydrogen	3.39	.0052	.13
Hydrogen Sulfide	.2451	.096	.091
Methane	.528	.041	.25
Nitric Oxide	.231	.0779	.1656
Nitrogen	.248	.072	.19
Nitrous Oxide	.221	.1143	.1056
Oxygen	.218	.082	.18
Sulphur dioxide	.152	.172	.07
Water Vapor (212°F)	.482	.0372	.16

TABLE 1 - PROPERTIES OF AIR

Temp. (°F)	Specific Heat (BTU/lb.°F)	Density (lb./ft.^{3})
0	.240	.086
50	.240	.078
100	.240	.071
150	.241	.065
200	.242	.060
250	.243	.056
300	.244	.052
350	.245	.049
400	.247	.046
500	.249	.041
600	.252	.037
700	.254	.034
800	.257	.032
900	.260	.029
1000	.262	.027
1100	.265	.025
1200	.267	.024

TABLE 2 - THERMAL CONDUCTIVITY OF INDUSTRIAL INSULATION

Type of Insulation	Maximum Service Temp. (°F)	Typical K Values BTU/hr./sq.ft./°F/in. — Mean Temp. (°F) Between Inner and Outer Insulation Surface					
		100	200	300	500	700	900
Mineral Wool Blanket flexible felt	450	.26	.34	.45			
Mineral Wool Block and Board resin binder	600	.28	.35	.43			
85% Magnesia Block and Board	600	.35	.38	.42	.46		
Foam Glass Block and Board	800	.41	.48	.55			
Calcium Silicate low density	1200	.38	.41	.44	.52	.62	.72
Mineral Wool Blanket metal reinforced	1200	.29	.35	.42	.56		
Silica Lime Block and Board	1200	.33	.38	.43	.53	.64	.75
Mineral Wool Block and Board inorganic binder	1600	.34	.39	.44	.54	.64	
Calcium Silicate high density	1800				.63	.74	.95

TABLE 3 - VISCOSITIES

Material	SSU			CENTIPOISE		
	4.4°C 40°F	26.7°C 80°F	49°C 120°F	4.4°C 40°F	26.7°C 80°F	49°C 120°F
Asphalt RS-1 MS-1 SS-1	400	160			86	34
Asphalt RC-0 MC-0 SC-0	950	340				
Asphalt RC-3 MC-3 SC-3	40000	7000				
Asphalt RC-5 MC-5 SC-5	500000	45000				
Asphalt 100-120 penetration	3500 at 250°F					
Asphalt 40-50 penetration	8000 at 250°F					
Benzene				.8	.62	.46
Gasoline				.7	.55	.44
No.1 Fuel Oil (Kerosene)	40	36		3.3	2.1	1.4
No.2 Fuel Oil - PS100	43	36	33	4.6	2.6	1.6
No.3 Fuel Oil - PS200	84	52	41	15.0	7.0	4.0
No.4 Fuel Oil	480	125	62	92.0	24.0	9.6
No.5 Fuel Oil - PS300		1600	370		390.0	75.0
No.6 Fuel Oil. Bunker C		4500	650		1000.0	155.0
Transformer Oil. Light	170	72	49	34.2	12.1	6.3
Transformer Oil. Medium	460	145	70	89.0	28.2	11.9
34°API Mid-continent crude	88	51	37	15	6.5	3.0
28°API gas oil	135	59	48	25	9.0	6.0
Quench and tempering Oil						
SAE-5W	550	160	74			
SAE-10W	1500	265	120	170	50	22
SAE-20	2900	500	170			
SAE-30	5000	870	260	1200	200	60
SAE-40	8500	1400	380			
SAE-50	23000	3600	720		400	100

Figure 1 - Heat losses from uninsulated smooth solid surfaces (60 - 180°F). Assumed external ambient temperature of 70°F.

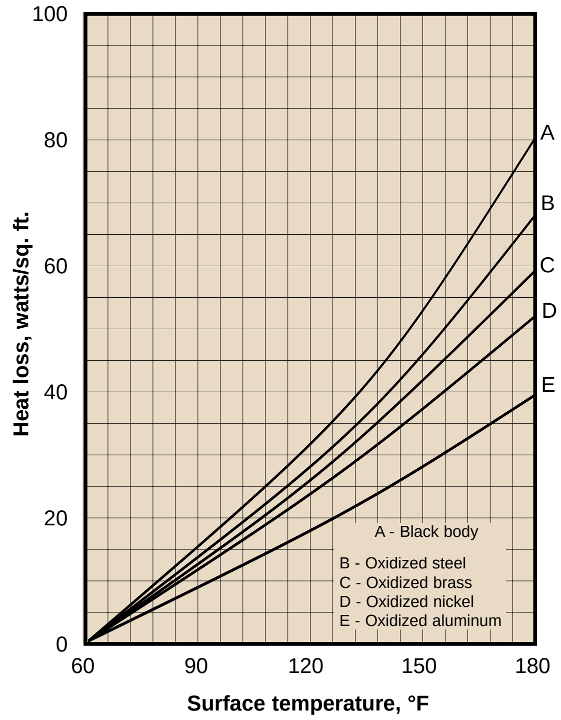


Figure 2 - Heat losses from uninsulated smooth solid surfaces (150 - 1000°F). Assumed external ambient temperature of 70°F.

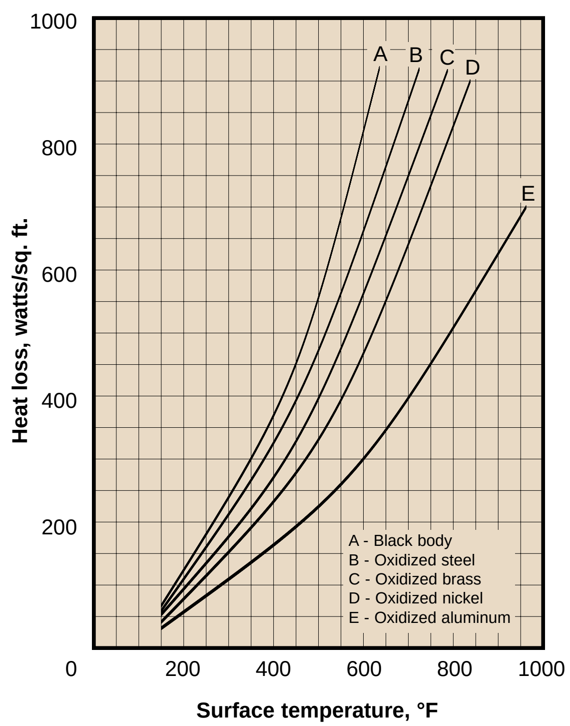


Figure 3 - Heat losses from liquid surfaces. Assumed external ambient temperature of 70°F.

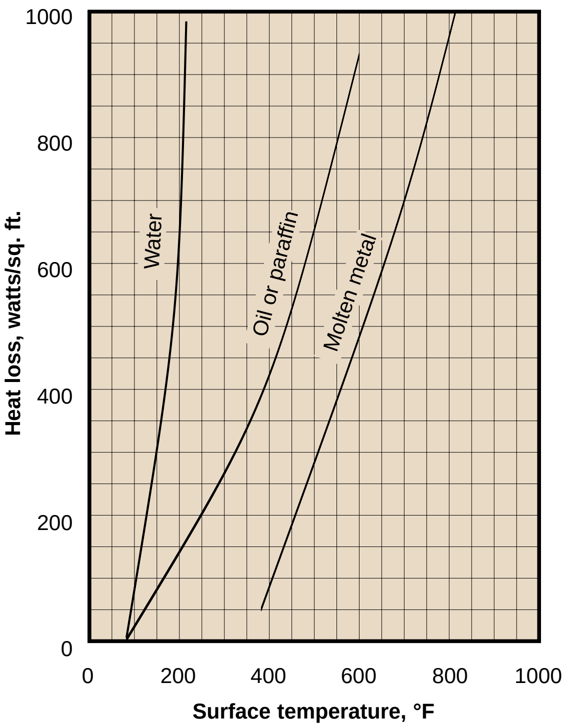
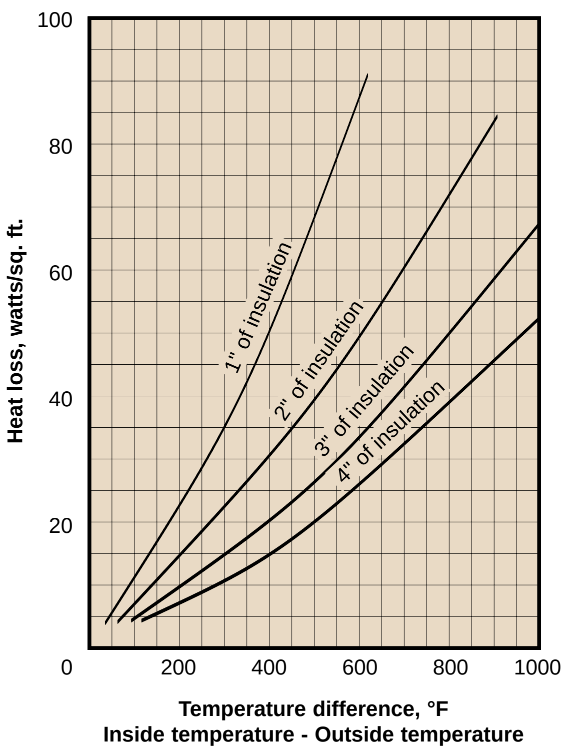


Figure 4 - Heat losses from insulated walls. Curves are for standard high-grade material, such as 85% magnesia, Rockwool, etc.



WIND VELOCITY AND HEAT LOSS

Wind velocity will increase surface heat losses. Table 1 can be used as a guide for estimating the factors to be applied to the still air heat losses from Figs. 1, 2 and 4.

TABLE 1 - WIND VELOCITY FACTORS

WIND VELOCITY	WELL SEALED INSULATED SURFACE			UNINSULATED SURFACE (TEMP. °F)		
(MPH)	1"	2"	3"	200	600	1000
5	-	-	-	1.7	1.5	1.3
10	-	-	-	2.1	1.7	1.4
15	1.1	-	-	2.4	2.0	1.6
20	1.2	1.1	-	2.7	2.3	1.7
25	1.3	1.2	1.1	3.0	2.6	1.8
30	1.4	1.3	1.2	3.3	3.0	1.9

HEAT LOSSES FROM INSULATED PIPES

To find the heat loss from the insulated pipes, in watts/ft. multiply the appropriate factor from Table 2 by the °F difference between the pipe holding temperature and the minimum ambient temperature.

If the pipe holding temperature is above 200°F, multiply the above answer by 1.2.

TABLE 2 - HEAT LOSS FACTORS FOR PIPE

PIPE SIZE	INSULATION THICKNESS AND FACTORS						
	1/2"	1"	1 1/2"	2"	2 1/2"	3"	4"
1/2	0.086	0.054	0.043	0.037			
1/4	0.102	0.062	0.048	0.041			
1	0.123	0.073	0.056	0.047			
1 1/4	0.142	0.083	0.063	0.052			
1 1/2	0.164	0.094	0.070	0.058			
2	0.192	0.109	0.081	0.066			
2 1/2	0.229	0.128	0.093	0.076			
3	0.259	0.142	0.107	0.083			
3 1/2	0.287	0.157	0.113	0.091			
4	0.316	0.172	0.123	0.098	0.083	0.073	0.060
4 1/2	0.347	0.189	0.134	0.107	0.090	0.079	0.065
5	0.417	0.219	0.155	0.121	0.103	0.089	0.073
6	0.472	0.250	0.174	0.136	0.114	0.099	0.080
7	0.526	0.275	0.192	0.151	0.126	0.109	0.088
8	0.571	0.305	0.212	0.166	0.137	0.119	0.095
9	0.634	0.338	0.234	0.183	0.151	0.130	0.104
10	0.634	0.338	0.234	0.183	0.151	0.130	0.104
12	0.776	0.397	0.275	0.212	0.175	0.149	0.119
14	0.834	0.431	0.298	0.230	0.190	0.162	0.128
16	0.961	0.498	0.334	0.258	0.212	0.181	0.142
18	1.088	0.555	0.379	0.289	0.236	0.200	0.156
20	1.190	0.598	0.416	0.319	0.260	0.219	0.171
24	1.430	0.731	0.490	0.374	0.305	0.259	0.200

Galvanic Corrosion

Table 1 is the galvanic series of commonly used metals when immersed in sea water. This list will vary slightly when a different electrolyte forms the galvanic couple.

Metals which are grouped show negligible corrosion when joined.

For galvanic corrosion to occur the following conditions must be met.

i) Two or more electrochemically dissimilar metals are present and in electrical contact (which is not necessarily physical contact).

ii) The metals must be in contact with an electrolyte.

Quite often other types of corrosion are incorrectly attributed to galvanic corrosion. If the foregoing conditions are met and the corrosion is localized near the junction of the metals, it was probably caused by galvanic effects. Otherwise, look elsewhere.

The best one can do is to try to avoid designs which involve electrically coupled metals. This is not always practical. However, the choice of metals can help to lessen corrosive effects. Try to select metals as close together as possible on the galvanic series.

Keep in mind that the least noble or more active metal will deplete during corrosion. Never couple a small anode with a large cathode.

Quite often it is practical to electrically insulate the metals from one another. If it is determined that dissimilar uninsulated metals must be used, make the anodic part of heavier material. Also, design the part for easy replacement.

Useful Corrosion Terminology

BIMETALLIC CORROSION - Galvanic corrosion.

CORROSION-EROSION - Corrosion which is increased because of the abrasive action of a moving stream.

CREVICE CORROSION - Localized corrosion resulting from the formation of a concentration cell in a crevice formed between a metal and a nonmetal or between two metal surfaces.

FRETTING CORROSION - Fretting refers to metal deterioration caused by repetitive slip at the interface between two surfaces.

HYDROGEN EMBRITTLEMENT - Embrittlement of a metal caused by hydrogen.

IMPINGEMENT ATTACK - Erosion-corrosion caused by turbulence or impinging flow at certain points.

INTERGRANULAR CORROSION - Corrosion which occurs preferentially at grain boundaries.

PITTING - Highly localized corrosion resulting in deep penetration at only a few spots.

SCALING - High temperature corrosion resulting in formation of thick corrosion product layers.

STRESS CORROSION - Corrosion which is accelerated by stress.

TABLE 1 - GALVANIC SERIES OF COMMONLY USED METALS WHEN EXPOSED TO SEA WATER

ACTIVE OR LEAST NOBLE ↑	Magnesium Magnesium Alloys Zinc Galvanized Steel
	Aluminum 1100
	Aluminum 6053 Alclad
	Cadmium
	Aluminum 2024 (4.5 Cu, 1.5 Mg 0.6 Mn)
	Mild Steel Wrought Iron Cast Iron
	13% Chromium Stainless Steel Type 410 (Active) 18-8 Stainless Steel Type 304 (Active) 18-12-3 Stainless Steel Type 316 (Active)
	Lead-Tin Solders Lead Tin
	Manganese Bronze Naval Brass
	Nickel (Active) 76 Ni - 16 Cr - 7 Fe Alloy (Active)
	60 Ni - 30 Mo - 6 Fe - 1 Mn
	Yellow Brass Admiralty Brass Aluminum Brass Red Brass Copper Silicon Bronze
	70:30 Cupro Nickel G-Bronze M-Bronze Silver Solder Nickel (Passive) 76 Ni - 16 Cr - 7 Fe Alloy (Passive) 67 Ni - 33 Cu Alloy (Monel)
	13% Chromium Stainless Steel Type 410 (Passive) Titanium
	18-8 Stainless Steel Type 304 (Passive) 18-12-3 Stainless Steel Type 316 (Passive)
	Silver
↓ PASSIVE OR MORE NOBLE	Graphite Gold Platinum

Corrosion Guide

The sheath materials in the following tables are to be used as a guide only and not as a firm recommendation. Such factors as temperature of solution, percentage of concentration, watt density and contamination are all factors in corrosion rates which make it impossible to make an absolute recommendation. For further information on corrosiveness of a solution, check the supplier of your solution.

Due to the above factors which are beyond our control, CCI Thermal cannot be responsible for electric heater failure due to corrosion.

WARNING: Certain solutions, due to their viscosity or flammability are not suitable for heating with direct immersion heaters unless special precautions are taken. Check factory if you require assistance in the selection of a safe and reliable heating method for your application.

LEGEND: A - GOOD
F - FAIR
C - DEPENDS ON CONDITIONS
X - UNSUITABLE

SOLUTION	IRON AND STEEL	300 SERIES STAINLESS	MONEL	INCOLOY	INCONEL	COPPER	TITANIUM	ALUMINUM	QUARTZ	TEFLON
Acetaldehyde		A-316				A				
Acetic Acid, Crude	X	F	F	C	C	F		F		
Pure			A	C	C	F		A		
Vapors			F	C	C	F	F	C		
150 PSI; 400°F			F	C	C	F		C		
Aerated	X	F-316 X-304	X		X	X	A	C		
No Air		C	A		X	F	A	C		
Acetone	C	A	A	A	A	A	A	F	A	
Alboloy Process	A									
Allyl Alcohol		A	A	A	A	A	A	F		
Alcohol	F	A-316	A	A	A	A	A	F	A	
Alkaline Solutions	A	A-304								
Alkaline Cleaners		A-304								X
Alkaline Soaking Cleaners	A									
Alum										
Aluminum (molten)										
Aluminum Acetate	X	A-316	F		F	F	A			
Aluminum Bright Dip									A	A
Aluminum Chloride	X	X	X	X	X	X	X	X	A	A
Aluminum Cleaners	C	A	A	A	A	X	F	X	X	
Aluminum Potassium Sulphate (Alum)		C-316 X-304	F		F	A	F	X		
Aluminum Sulphate	X	F	F	X	X	F	A	X	A	
Ammonia	X	X	X	C	F	X	A	C	A	
Ammonia Gas, Cold	A	A	A		A	C	A	A		
Hot	C	C	C		A	X				
Ammonia and Oil	A									
Ammonium Acetate	A	A	A	A	A	X		A		
Ammonium Bifluoride	X	X	X	X	X	X	X	X	X	A
Ammonium Chloride	C	F	F	C	C	X	A	X	A	A
Ammonium Hydroxide	A	A	C	A	A	X	A	C	X	

SOLUTION	IRON AND STEEL	300 SERIES STAINLESS	MONEL	INCOLOY	INCONEL	COPPER	TITANIUM	ALUMINUM	QUARTZ	TEFLON
Ammonium Nitrate	A	A	C	X	X	X	X	F	A	
Ammonium Persulphate	X	F	X		X	X		X	A	A
Ammonium Sulphate	A	A	A	F	F	F	A	X	A	
Anhydrous Ammonia	A					X				
Aniline	F	A	F	F	F	X	A	F	A	
Aniline, Aniline Oil	A	A	A	F	F	X	A	X	A	
Aniline, Dyes		A	A							
Anodizing Solutions 10%										
Chromic Acid 96°F	C	A					A			
Sodium Hydroxide Alkaline	A			A			A			
Nickel Acetate			A							
Arsenic Acid	X	C	X	X	X	X	X	X	A	A
Asphalt	A	A	X	A	A	X	A	X	A	
Barium Chloride		F-304 X-316			A			X		
Barium Hydroxide		A		F	F	X	X	X	A	
Barium Sulphate	F	F	F	F	F	F	A		A	
Barium Sulphide		A	A			X				
Barium Sulphite		F-304								
Black Nickel									A	A
Black Oxide		A-304								
Bonderizing	C	A		C	C		A		A	A
Boric Acid	X	C	C	C	C	C	A	X	A	A
Brass Cyanide		A-304								
Bright Nickel							A		A	
Brine (Salt Water)			A		F					
Bronze Plating	A	A-304								
Butanol (Butyl Alcohol)	A	A	A	A	A	A	A	F	A	A
Cadmium Black									A	
Cadmium Fluoborate										A
Cadmium Plating				A	A					
Calcium Chlorate	F	F	F	F	F	C			A	
Calcium Chloride	F	F	F	F	F	F	A	C	A	A
Carbolic Acid, Phenol	C	A	A	F	F	X	A	F		
Carbon Dioxide, Dry	A	A	A	A	A	A	X	A	A	X
Wet	F	A	A	A	A	F	X	A	A	X
Carbon Tetrachloride	C	C	A	A	A	C	A	X	A	
Carbonic Acid	C	A-304	C	F	A	C	A	C	A	A
Castor Oil	A	A	A	A	A		A	A	A	A
Caustic Etch	A	A	A	X	X	X	A	X	A	X
Caustic Soda (Lye) (Sodium Hydroxide)	X	C-316 X-304	C	C	F	X	C	X	X	A
2%	F	F-316 X-304	A	A	A	F	A	X		
10 - 30%, 210°F	F	A	A	A	A	F	A	X		
76%, 180°F	X	F	F	A	A	X	F	X		
Chlorine, Dry	A	A	A	C	F	A	F	X	A	F
Wet	X	X	X	X	X	X	X	X	A	X
Chloroacetic Acid	X	X		C	C	X	A	X	A	A
Chromic Acetate									A	
Chromic Acid	C	A	F	X	X	X	A	X	A	X
Chrome Plating				X	X		A		A	X
Citric Acid	X	A	A	F	F	A	A	C	A	A
Clear Chromate		A-316								
Cobalt Acetate 130°F			A	F	F					
Cobalt Nickel									A	
Cobalt Plating		A-304							A	
Coconut Oil			F							
Cod Liver Oil		A		A	A			A		
Copper Acid							A		A	

Corrosion Guide (continued)

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LEGEND: A - GOOD
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SOLUTION	IRON AND STEEL	300 SERIES STAINLESS	MONEL	INCOLOY	INCONEL	COPPER	TITANIUM	ALUMINUM	QUARTZ	TEFLON
Copper Bright		A								
Copper Bright Acid									A	
Copper Chloride	F	X	F	X	X	C	A	C	A	A
Copper Cyanide	A			X	X			X	A	A
Copper Fluoborate		F	F	F	F					A
Copper Nitrate	X	F	X	X	X	X		X	A	A
Copper Plating	A									
Copper Sulphate	X	A	A	F	F	C		X	A	
Creosote	A	A	A	F	F	A		C	A	
Deionized Water	X	A	A	A	A	X		X		
Deoxidine		A								
Deoxidizer (Etching)									A	
Diethylene Glycol	F	A	F	F	F	F	A	F	A	A
Diphenyl 300°-350°	A				A			A		
Disodium Phosphate 25% 180°F	A				A		A		A	A
Dowtherm A	A			A						
Electro Polishing									A	
Electroless Nickel							A		A	
Electroless Tin (Acid)									A	
(Alkaline)		A-316					A			
Ethers	A		A	F	F	A	A	F	A	
Ethyl Chloride	A	A	A	F	A	A	A	F	A	A
Ethylene Gycol 300°F		A	A	F	F		A	A	A	A
Fatty Acids	X	A-316	F	F	F	X	A	A	A	
Ferric Chloride	X	X	X	X	X	X	A	X	A	A
Ferric Nitrate	X	F	X	X	X	X		X	A	
Ferric Sulphate	X	F-304 A-316	X	C	C	X	A	X	A	
Fluorine Gas, Dry	C	C	A	C	A	X	A	X	C	
Formaldehyde	F	A	A	F	F	F	A	F	A	

SOLUTION	IRON AND STEEL	300 SERIES STAINLESS	MONEL	INCOLOY	INCONEL	COPPER	TITANIUM	ALUMINUM	QUARTZ	TEFLON
Formic Acid	X	F	C	F	C	F	X	X	A	
Freon	C	C	A	A	A	A		A		
Fuel Oil	A	A	A	F	F	A	A	A		
Fuel Oil, Acid	C	C	A	C	C	C	A	X		
Gasoline, Refined	A	A	A	F	F	A		A	A	
Gasoline, Sour	C	A	A	X	X	C		C	A	
Glycerine, Glycerol	A	A	A	A	A	F		A	A	
Gold - Acid	A						A		A	
Gold - Cyanide		A								
Grey Nickel							A		A	A
Hydrochloric Acid <150°F	X	X	C	X	X	X	X	X	A	
>150°F	X	X	C	X	X	X	X	X	A	A
Hydrocyanic Acid (No Air)	X	F	F	F	F	X		F	A	
Hydrofluoric Acid, Cold <65%	X	X	F	X	X	C	X	X	X	A
>65%	F	X	A	X	X	F	X	X		
Hot <65%	X	X	C			X		X		
>65%	C	X	A	X	X	F	X	X		
Hydrogen Peroxide	X	A	F	F	F	X	A	A	A	
Indium									A	A
Iron Phosphate (Parkerizing)	C	A								
Isopropanol	C		A		A	F				
Kerosene	A	A	A	A	A	A		A		
Lacquer Solvents	C	A	A	F	F	C	A	A	A	
Lard	F									
Lead Acetate	X	A	A	A	A	X	A	X	A	
Lead Acid Salts		A-304								
Lime Saturated Water	F	A-316	F	F	F	F		X	X	
Linseed Oil	A	A	A	F	F	A	A	F		
Magnesium Chloride	F	F	F	F	A	F	A	X	A	
Magnesium Hydroxide	A	A	A	A	A	X		F	A	
Magnesium Nitrate	F	F	F	F	X	F	F	F	A	
Magnesium Sulphate	A	A	A	F	A	A	A	F	A	
Mercuric Chloride	C	X	X	X	X	X	F	X	A	
Mercury	A	A	A	A	F	X	X	X	A	
Methyl Alcohol, Methanol	A	A	A	F	A	A	A	C	A	
Methyl Bromide	C	A	F	F	F	F	A	X	A	
Methyl Chloride	A		A	C	C	A	A	X	A	
Methylene Chloride	X	C	C	C	F	C	A	C	A	
Mineral Oils	A	A	A	A	A	A	A	A	A	
Muriato									A	A
Naptha	A	A	A	A	A	A	A	A	A	A
Napthalene	A			F	F		A	F		
Nickel Acetate Seal		A-316								
Nickel Chloride		F	C	C	F	X	F	X	A	A
Nickel Copper Strike (Cyanide Free)		A								
Nickel Plating, Bright							A		A	A
Nickel Plating, Dull									A	A
Nickel Plating, Watts Solution							A		A	A
Nickel Sulphate	X	A	C	C	C	X		X	A	A
Nitric Acid, Crude	X	C	X	X	X	X		X	A	A
Concentrated	X	F	X	X	X	X		X	A	A
Diluted	X	A	X	X	X	X		X	A	A
Nitric Hydrochloric Acid	X	X	X	X	X	X	X	X	A	A
Nitric 6% Phosphoric Acid		C-316							A	A
Nitric Sodium Chromate		A-316							A	A
Nitrobenzene	A	A	A	A	A	F	A	A	A	
Oakite No. 20	A									
Oakite No. 23	A									
Oakite No. 24	A									

SOLUTION	IRON AND STEEL	300 SERIES STAINLESS	MONEL	INCOLOY	INCONEL	COPPER	TITANIUM	ALUMINUM	QUARTZ	TEFLON
Oakite No. 30	A									
Oakite No. 51	A									
Oakite No. 67		A-304								
Oakite No. 90 @ 180°F	A									
Oleic Acid	C	A	A	F	A	X	F	C	A	A
Oxalic Acid	C	C	A	X	F	C	X	F	A	A
Paint Stripper (High Alkaline Type)	A									
Paint Stripper (Solvent Type)		A-316								
Paraffin	A	A				A		A		
Parkerizing										
Perchlorethylene		A		F	A		A	C	A	
Petroleum Oils, Crude <500°F	A	A	C	A		C		A	A	
>500°F	A	A	X			X		A		
>1000°F	X	C A-347	X			X		X		
Phenol										
Phenol 85%, 120°F	C	A		F	F		A	A		
Phosphate		A-316								X
Phosphate Cleaner		A-304								X
Phosphatizing		A-316								X
Phosphoric Acid, Crude	C	C	X			X		X		
Pure <45%	X	A	F	A	A	F	X	C		
>45% Cold	X	A	F	A		F	X	X		
Hot	X	X-304 C-316	C	A	F	C	X	X		
Photo Fixing Bath		A	C							
Potassium Bichromate (Potassium Dichromate)	C	A-316	F	F			F	F	A	A
Potassium Chloride	A	A	A	C	F	A	A	X	A	
Potassium Cyanide	A	A	A	F	F	X	X	X	A	A
Potassium Hydrochloride									A	A
Potassium Hydroxide	C	F	A	C	F	X	X	X	X	A
Potassium Nitrate (Salt Peter)	F	F	F	F	F	F	A	A	A	
Potassium Sulphate	A	F	A	F	F	A	A	A	A	A
Prestone 350°F	A		A							
Sea Water	X	C	A	F	F	X	A	X	A	
Silver Bromide	X	X	C			X	A	X	A	A
Silver Cyanide	C	A	F	A		X		X	A	
Silver Nitrate	X	C	X	C	C	X	A	X	A	
Soap Solutions	A	A	A			C		X		
Sodium - Liquid Metal	C	A-304	C	A	A	X		X	X	
Sodium Bisulphate	X	X	C		F	F		C		
Sodium Bromide	F	C	F	F	F	F		X	A	A
Sodium Carbonate <20%	A			F	F		A	X	C	A
Sodium Chlorate	X	F	A	F	A	A	A	F	A	A
Sodium Chloride	A	F-304 A-316	A	F	A	F	C	X	A	
Sodium Citrate	X	F				X		X	A	A
Sodium Cyanide	A	A-316	F	A	A	X	C	X	A	
Sodium Dichromate (Sodium Bichromate)	F	F				X	C	C	A	
Sodium Disulphate	X	X	C		C		C	C	A	
Sodium Hydroxide	A	F	A	A	A	X	A			
Sodium Hypochlorite	X	X	C	X	X	C	A	X	A	A
Sodium Nitrate	A	F-304 A-316	A	A	A	F	A	C	A	
Sodium Peroxide	C	A	A		F			C		
Sodium Phosphate	C	A-316	A	F	A	F	A	X	A	A
Sodium Salicylate	F	F	F	F	F	F			A	A
Sodium Silicate	A	A-316	A	F	F	C		X	A	A

SOLUTION	IRON AND STEEL	300 SERIES STAINLESS	MONEL	INCOLOY	INCONEL	COPPER	TITANIUM	ALUMINUM	QUARTZ	TEFLON
Sodium Stannate	C	F	F	F	F				A	A
Sodium Sulphate	A	A	A	F	F	A	C	F	A	A
Sodium Sulphide	A	A	F	C	C	X	C	C	C	A
Solder Bath	X	X	X	X	X	X	X	X	X	X
Soybean Oil		A								
Steam <500°F	A	A	A	A	A	A				
500-1000°F	C	A	C	A	A	C				
>1000°F	X	A	X	A	A	X				
Stearic Acid	C	A	A			C		C	A	
Sugar Solution	A	A	A	A	A	A	A	A	A	A
Sulphur	A	F	X	A	A	X	A	A	A	
Sulphur Chloride	X	C-304 X-316	X	C	F	X		X	A	A
Sulphur Dioxide	C	C	X	C	C	C	A	C	A	
Sulphuric Acid <10% Cold	X	F	C		X	C		C		
Hot	X	F-316 X-304	C		F	X		C		
10-75% Cold	X	X-304 F-316	C		X	X	X	X		
Hot	X	X	C		X	X	X	X		
75-95% Cold	C	A	C		X	X	X	X		
Hot	F	X	C			X	X	X		
Fuming	C	C-304 F-316	X	C	C	X		X		
Sulphurous Acid	A	C-316 X-304	X		C	C	A	C		
Tannic Acid		F	A		A	A	A	C	A	
Tar	A	A		A	A			A		
Tartaric Acid		C-304 A-316	C		F		F	C		
Tetrachlorethylene	A			F	A		A	C	A	
Thermoil Granodine	F									
Tin (Molten)	F	F	X		X	X	A	X		X
Tin-Nickel Plating									A	A
Tin Plating - Acid										A
Tin Plating - Alkaline	A	A-304								
Toluene	A	A	A	A	A	C	A	A		
Triad Solvent	C									
Trichloroethane	A	A-304	F	F	F	F	A	F	A	
Trichloroethylene	C	C	A	A	A	C	A	F	A	
Triethylene Glycol	A	A	A	A	A	A	A	A	A	
Trioxide (Pickle)									A	A
Trisodium Phosphate	A	C	C			C		X	X	X
Turpentine	C	A	A			C		A		
Urea Ammonia Liquor 48°F	A									
Vegetable Oil	C	A	A	A		X		F		
Vinegar	C	F-304 A-316	A					C		
Water, Fresh	C	A	A	A	A	A	A		A	
Distilled, Lab Grade	X	A	C	A	A	X				
Return Condensate	A	A	A	A	A	A				
Whiskey and Wines	X	F-304 A-316	A	A	A	A				
Yellow Dichromate		A-316							A	
X-Ray Solution		A								
Zinc (Molten)		X	X	X	X	X	X	X		X
Zinc Chloride	C	X	A	F	F	X	F	X	A	A
Zinc Plating Acid									A	
Zinc Plating Cyanide	A	A-304								
Zinc Sulphate	C	A	A	A	A	X	A	C		

Typical Watt Densities

1. Watt density is determined by dividing the heater wattage by the total surface area of all heated surfaces on the element. Remember that electric heating elements will continue to increase their surface temperature until all heat produced by the element is transferred to the work.
2. Typical watt densities shown in the table below are based on non-circulated liquids unless noted otherwise.
3. Use of watt density lower than listed will prolong heater service life.
4. This data is for use as a general guideline only. System conditions may exist that may mandate densities lower or higher than listed. Certain substances of high viscosity and low heat transfer may be subject to coking if density is too high.

MATERIAL BEING HEATED		MAXIMUM WATTS PER SQUARE INCH	OPERATING TEMP. (°F)
Acetaldehyde		14	180
Acetone		14	130
Acid Solutions (Mild)	Acetic	40	180
	Boric	40	257
	Carbonic	40	180
	Chromic	40	180
	Citric	25	180
	Fatty Acids	25	150
	Lactic	10	122
	Malic	14	120
	Nitric	25	167
	Phenol - 2-4 Disulfonic	40	180
	Phosphoric	28	180
	Phosphoric (Aerated)	26	180
	Proponic	40	180
	Tannic	30 / 40	160 / 180
Alkaline Solutions		44	212
Aluminum Acetate		14	122
Aluminum Potassium Sulfate		40	212
Ammonium Acetate		28	167
Amyl Acetate		28	240
Amyl Alcohol		24	212
Aniline		26	350
Asphalt		4 - 10	200 - 500
Barium Hydroxide		40	212
Benzene, liquid		14	150
Butyl Acetate		14	225
Calcium Bisulfate		20	400
Calcium Chloride		5 - 8	200
Carbon Monoxide		25	—
Carbon Tetrachloride		25	160
Caustic Soda	2%	50	210
	10%	28	210
	75%	26	180
Citrus Juices		26	185
Degreasing Solution		25	275
Dextrose		25	212
Dowtherm A	1 ft. sec. or more	23	750
	non-flowing	10	750
Dowtherm E		12 - 18	400
Dyes & Pigments		23	212
Electroplating Baths	Cadmium	40	180
	Copper	40	180
	Dilute Cyanide	40	180
	Sodium Cyanide	40	180
	Potassium Cyanide	40	180
Ethylene Glycol		30	300
Formaldehyde		12	180
Freon gas		2 - 5	300
Fuel Oils	Grades 1 & 2 (distilate)	23	200
	Grades 4 & 5 (residual)	14	200

MATERIAL BEING HEATED		MAXIMUM WATTS PER SQUARE INCH	OPERATING TEMP. (°F)
Fuel Oils	Grades 6 & bunker C (residual)	8	160
Gasoline		25	300
Gelatin	Liquid	25	150
	Solid	6	150
Glycerine		10	500
Glycerol		26	212
Grease	Liquid	26	—
	Solid	5	—
Heat Transfer Oils	Static	18 14	500 600
	Circulating	24 22	500 600
Hydrazine		18	212
Linseed Oil		50	150
Lubrication Oil	SAE 10	26	250
	SAE 20	24	250
	SAE 30	23	250
	SAE 40	16	250
	SAE 50	14	250
Magnesium Chloride		40	212
Magnesium Sulfate		40	212
Manganese Sulfate		40	212
Methylamine		22	180
Methylchloride		20	180
Mineral Oil		25 18	200 400
Molasses		5	100
Molten Salt Bath		25 - 30	800 - 900
Naptha		12	212
Oil Draw Bath		25	600
Paraffin or Wax (liquid state)		20	150
Perchloroethylene		25	200
Potassium Chlorate		40	212
Potassium Chloride		40	212
Potassium Hydroxide		23	160
Soap, liquid		24	212
Sodium Acetate		45	212
Sodium Cyanide		45	140
Sodium Hydride		30	720
Sodium Hydroxide			
Sodium Phosphate		40	212
Sulfur, Molten		10	600
Therminols		26 23 15	500 600 650
Toluene		25	212
Trichlorethylene		25	150
Turpentine		22	300
Vegetable Oil & Shortening		40	400
Water (Process)		60 - 90	212

PRACTICAL FLOW VELOCITIES IN PIPE

FLOW/SERVICE	PSIG	VELOCITY
Saturated Steam	0-25	4000-6000 ft./min.
	25 and up	6000-10000 ft./min.
Superheated Steam	200 and up	7000-20000 ft./min.
Water/Boiler Feed	-	8 - 15 ft./sec.
Water/Pump Suction	-	4 - 7 ft./sec.
Water/Drain	-	4 - 7 ft./sec.
Water/General Service	-	4 - 10 ft./sec.

ALLOWABLE PRESSURE RATINGS FOR PIPES AND FLANGES

The information included on this page is to be used as a guide only in the pre-selection of pipe and flange sizes for various temperatures and pressures.

When calculating thickness requirements in accordance with the ASME code for safe pressure vessel design, stress values may often be less than shown in Table 1.

TABLE 1 - APPROXIMATE ALLOWABLE STRESS FOR PIPE IN PSIG

	PIPE MATERIAL AND TYPE			
TEMP. °F	A53B WELDED STEEL	A106B SEAMLESS STEEL	A312 304 S.S. WELDED	A312 316 S.S. WELDED
100	14,600	17,100	17,000	17,000
300	14,600	17,100	16,100	17,000
500	14,600	17,100	14,800	15,300
650	14,600	17,100	13,800	14,100
700	13,300	15,600	13,500	13,900
900	5,000	5,900	12,400	13,200
1100	-	-	8,300	10,500
1300	-	-	3,100	3,500

DETERMINATION OF APPROXIMATE PIPE WALL THICKNESS (t_N) FOR VARIOUS PRESSURES AND TEMPERATURES

$$t_N = \frac{.5PD}{SE - .6P} \quad (1.143)$$

t_N = Nominal pipe wall thickness (page D48) not including corrosion allowance

P = Max. pressure (PSIG)

D = Inside pipe diameter (in.)

S = Allowable stress from Table 1

E = Joint efficiency (assume a value of 1.0 for seamless pipe or welded pipe where full radiography is done).

FLANGE PRESSURE - TEMPERATURE RATINGS

		MAX. ALLOWABLE PRESSURE (PSIG)					
METAL	TEMP. °F	150 LB.	300 LB.	400 LB.	600 LB.	900 LB.	1500 LB.
CARBON STEEL	100	285	740	990	1480	2220	3705
	200	260	675	900	1350	2025	3375
	300	230	655	875	1315	1970	3280
	400	200	635	845	1270	1900	3170
	500	170	600	800	1200	1795	2995
	600	140	550	730	1095	1640	2735
	650	125	535	715	1075	1610	2685
	700	110	535	710	1065	1600	2665
	750	95	505	670	1010	1510	2520
	800	80	410	550	825	1235	2060
	850	65	270	355	535	805	1340
	900	50	170	230	345	515	860
	950	35	105	140	205	310	515
	1000	20	50	70	105	155	260
304 S.S.	100	275	720	960	1440	2160	3600
	200	235	600	800	1200	1800	3000
	300	205	540	720	1080	1620	2700
	400	190	495	660	995	1490	2485
	500	170	465	620	930	1395	2330
	600	140	435	580	875	1310	2185
	700	110	425	565	850	1275	2125
	800	80	405	540	805	1210	2015
	900	50	390	520	780	1165	1945
	1000	20	320	430	640	965	1605
	1100	-	255	345	515	770	1285
	1200	-	155	205	310	465	770
	1300	-	85	115	170	255	430
	1400	-	50	65	90	145	240
	1500	-	25	35	55	80	135
316 S.S.	100	275	720	960	1440	2160	3600
	200	235	620	825	1240	1860	3095
	300	215	560	745	1120	1680	2795
	400	195	515	685	1030	1540	2570
	500	170	480	635	955	1435	2390
	600	140	450	600	900	1355	2255
	700	110	430	580	870	1305	2170
	800	80	420	565	845	1265	2110
	900	50	415	555	830	1245	2075
	1000	20	350	465	700	1050	1750
	1100	-	305	405	610	915	1525
	1200	-	185	245	370	555	925
	1300	-	115	155	235	350	585
	1400	-	75	100	150	225	380
	1500	-	40	55	85	125	205
304L 316L S.S.	100	230	600	800	1200	1800	3000
	200	195	505	675	1015	1520	2530
	300	175	455	605	910	1360	2270
	400	160	415	550	825	1240	2065
	500	145	380	510	765	1145	1910
	600	140	360	480	720	1080	1800
	700	110	345	460	685	1030	1715
	800	80	330	440	660	985	1645

REFERENCE ASME/ANSI B16.5 - 1998

TABLE 1 - Sheet metal gauges in approximate decimals of an inch

No. of Sheet Metal Gauge	Manufacturers' Standard Gauge for Steel Thk.	lbs./ft^2	300 Series Stainless Steel Thk.	lbs./ft^2	Galvanized Sheet Steel Thk.
9	0.1495	6.2500	—	—	0.1532
10	0.1345	5.6250	0.134	5.628	0.1382
11	0.1196	5.0000	0.119	4.998	0.1233
12	0.1046	4.3750	0.103	4.326	0.1084
13	0.0897	3.7500	—	—	0.0934
14	0.0747	3.1250	0.074	3.108	0.0785
15	0.0673	2.8125	—	—	0.0710
16	0.0598	2.5000	0.059	2.478	0.0635
17	0.0538	2.2500	—	—	0.0575
18	0.0478	2.0000	0.047	1.974	0.0516
19	0.0418	1.7500	—	—	0.0456
20	0.0359	1.5000	0.035	1.470	0.0396
21	0.0329	1.3750	—	—	0.0366
22	0.0299	1.2500	0.030	1.260	0.0336
23	0.0269	1.1250	—	—	0.0306
24	0.0239	1.0000	0.024	1.008	0.0276
25	0.0209	0.87500	—	—	0.0247
26	0.0179	0.75000	0.019	0.798	0.0217
27	0.0164	0.68750	—	—	0.0202
28	0.0149	0.62500	—	—	0.0187
29	0.0135	0.56250	—	—	0.0172
30	0.0120	0.50000	—	—	0.0157
31	0.0105	0.43750	—	—	0.0142
32	0.0097	0.40625	—	—	0.0134
33	0.0090	0.37500	—	—	—
34	0.0082	0.34375	—	—	—
35	0.0075	0.31250	—	—	—
36	0.0067	0.28125	—	—	—

TABLE 2 - 80-20 NiCr wire properties (650 ohms circ. mil/ft)

B & S	DIAM. (INS.)	OHMS/FT (77°F)	B & S	DIAM. (INS.)	OHMS/FT (77°F)
13	.072	0.125	25	.0179	2.029
14	.064	0.158	26	.0159	2.571
15	.057	0.200	27	.0142	3.224
16	.051	0.250	28	.0126	4.094
17	.045	0.321	29	.0113	5.090
18	.040	0.406	30	.0100	6.500
19	.036	0.501	31	.0089	8.206
20	.032	0.635	32	.0080	10.160
21	.0285	0.800	33	.0071	12.890
22	.0253	1.015	34	.0063	16.330
23	.0226	1.273	35	.0056	20.730
24	.0201	1.609	36	.0050	26.000

TABLE 3 - DIMENSIONS OF STEEL PIPE

DIAMETER IN INCHES NOMINAL (O.D.)	SCHEDULE NO.	WALL THICKNESS INCHES
1/8 (0.405)	10S	0.049
	40ST, 40S	.068
	80XS, 80S	.095
1/4 (0.54)	10S	.065
	40ST, 40S	.088
	80XS, 80S	.119
3/8 (0.675)	10S	.065
	40ST, 40S	.091
	80XS, 80S	.126
1/2 (0.84)	5S	.065
	10S	.083
	40ST, 40S	.109
	80XS, 80S	.147
	160	.188
	XX	.294
3/4 (1.05)	5S	.065
	10S	.083
	40ST, 40S	.113
	80XS, 80S	.154
	160	.219
	XX	.308
1 (1.315)	5S	.065
	10S	.109
	40ST, 40S	.133
	80XS, 80S	.179
	160	.250
	XX	.358
1 1/4 (1.66)	5S	.065
	10S	.109
	40ST, 40S	.140
	80XS, 80S	.191
	160	.250
	XX	.382
1 1/2 (1.9)	5S	.065
	10S	.109
	40ST, 40S	.145
	80XS, 80S	.200
	160	.281
	XX	.400
2 (2.375)	5S	.065
	10S	.109
	40ST, 40S	.154
	80ST, 80S	.218
	160	.344
	XX	.436
2 1/2 (2.875)	5S	.083
	10S	.120
	40ST, 40S	.203
	80XS, 80S	.276
	160	.375
	XX	.552
3 (3.5)	5S	.083
	10S	.120
	40ST, 40S	.216
	80SX, 80S	.300
	160	.438
	XX	.600
3 1/2 (4.0)	5S	.083
	10S	.120
	40ST, 40S	.226
	80XS, 80S	.318
4 (4.5)	5S	.083
	10S	.120
	40ST, 40S	.237
	80SX, 80S	.337
	120	.438
	160	.531
	XX	.674
5 (5.563)	5S	.109
	10S	.134
	40ST, 40S	.258
	80XS, 80S	.375
	120	.500
	160	.625
	XX	.750
6 (6.625)	5S	.109
	10S	.134
	40ST, 40S	.280
	80XS, 80S	.432
	120	.562
	160	.719
	XX	.864
8 (8.625)	5S	.109
	10S	.148
	20	.250
	30	.277
	40ST, 40S	.322
	60	.406
	80XS, 80S	.500
	100	.594
	120	.719
	140	.812
	XX	.875
	160	.906
10 (10.75)	5S	.134
	10S	.165
	20	.250
	30	.307
	40ST, 40S	.365
	80S, 60XS	.500
	80	.594
	100	.719
	120	.844
	140, XX	1.000
	160	1.125
12 (12.75)	5S	0.156
	10S	0.180
	20	0.250
	30	0.330
	ST, 40S	0.375
	40	0.406
	XS, 80S	0.500
	60	0.562
	80	0.688
	100	0.844
	120, XX	1.000
	140	1.125
	160	1.312
14 (14)	5S	0.156
	10S	0.188
	10	0.250
	20	0.312
	30, ST	0.375
	40	0.438
	XS	0.500
	60	0.594
	80	0.750
	100	0.938
	120	1.094
	140	1.250
	160	1.406
16 (16)	5S	0.165
	10S	0.188
	10	0.250
	20	0.312
	30, ST	0.375
	40, XS	0.500
	60	0.656
	80	0.844
	100	1.031
	120	1.219
	140	1.438
	160	1.594
18 (18)	5S	0.165
	10S	0.188
	10	0.250
	20	0.312
	ST	0.375
	30	0.438
	XS	0.500
	40	0.562
	60	0.750
	80	0.938
	100	1.156
	120	1.375
	140	1.562
	160	1.781

Atmospheric Conditions and Temperature Codes

The information listed on this page is to be used only as a general guide. Consult the latest edition of the Code to check the suitability of the explosion-proof heater to your needs.

For detailed information concerning the installation of electrical equipment in hazardous locations, refer to either the Canadian Electrical Code Part 1 Section 18, available from the Canadian Standards Association, or the National Electrical Code Chapter 5 Articles 500 through 503, available from the National Fire Protection Association.

Where electrical equipment is required by Section 18 or Chapter 5 to be approved for the class of location, it shall also be approved for the specific gas, vapour, or dust that will be present. Such approval may be indicated by one or more atmospheric group designations which have been established for the purpose of testing and approval.

Note that the maximum external temperature of the equipment shall not exceed the minimum ignition temperature of the atmosphere as listed in Table 2.

For example:
Assume the maximum heater temperature is listed as T2C or 230°C (446°F). This heater would not be suitable for use in atmospheres containing octanes but would be suitable for use in atmospheres containing gasoline.

For octanes, select a heater having a temperature code that does not exceed 206°C (403°F).

TABLE 1 - Equipment Maximum Temperature

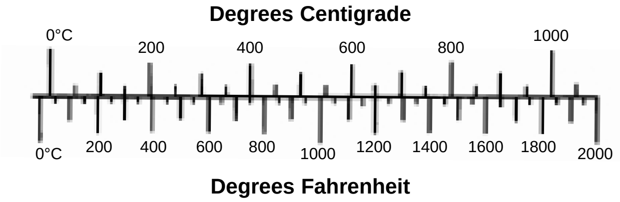
Temperature Code	Maximum External Temperature
T1	450°C / 842°F
T2	300°C / 572°F
T2A	280°C / 536°F
T2B	260°C / 500°F
T2C	230°C / 446°F
T2D	215°C / 419°F
T3	200°C / 392°F
T3A	180°C / 356°F
T3B	165°C / 329°F
T3C	160°C / 320°F
T4	135°C / 275°F
T4A	120°C / 248°F
T5	100°C / 212°F
T6	85°C / 185°F

TABLE 2 - Atmospheric Conditions

ATMOSPHERE	MIN. IGNITION TEMP. LIMIT
GROUP A CONTAINING	
acetylene	305°C / 581°F
GROUP B CONTAINING	
butadiene	420°C / 788°F
ethylene oxide	429°C / 804°F
hydrogen	500°C / 932°F
manufactured gases containing more than 30% hydrogen (by volume)	500°C / 932°F
propylene oxide	499°C / 930°F
GROUP C CONTAINING	
acetaldehyde	175°C / 347°F
cyclopropane	498°C / 928°F
diethyl ether	160°C / 320°F
ethylene	450°C / 842°F
unsymmetrical dimethyl hydrazine (UDMH 1, 1-dimethyl hydrazine)	249°C / 480°F
GROUP D CONTAINING	
acetone	465°C / 869°F
acrylonitrile	481°C / 898°F
alcohol (see ethyl alcohol)	
ammonia	651°C / 1204°F
benzene	498°C / 928°F
benzine (see petroleum naphtha)	
benzol (see benzene)	
butane	287°C / 549°F
1-butanol (butyl alcohol)	343°C / 649°F
2-butanol (secondary butyl alcohol)	405°C / 761°F
butyl acetate	425°C / 797°F
isobutyl acetate	421°C / 790°F
ethane	472°C / 882°F
ethanol (ethyl alcohol)	363°C / 685°F
ethyl acetate	426°C / 799°F
ethylene dichloride	413°C / 775°F
gasoline	280°C / 536°F
heptanes	204°C / 399°F
hexanes	223°C / 433°F
isoprene	395°C / 743°F
methane	537°C / 999°F
methanol (methyl alcohol)	385°C / 725°F
3-methyl-1-butanol (isoamyl alcohol)	350°C / 662°F
methyl ethyl ketone	404°C / 759°F
methyl isobutyl ketone	448°C / 838°F
2-methyl-1-propanol (isobutyl alcohol)	415°C / 779°F
2-methyl-2-propanol (tertiary butyl alcohol)	478°C / 892°F
naphtha (see petroleum naphtha)	
natural gas	482°C / 900°F
octanes	206°C / 403°F
pentanes	260°C / 500°F
1-pentanol (amyl alcohol)	300°C / 572°F
petroleum naphtha	288°C / 550°F
propane	432°C / 810°F
1-propanol (propyl alcohol)	412°C / 774°F
2-propanol (isopropyl alcohol)	399°C / 750°F
propylene	455°C / 851°F
styrene	490°C / 914°F
toluene	480°C / 896°F
vinyl acetate	402°C / 756°F
vinyl chloride	472°C / 882°F
xylenes	463°C / 865°F
GROUP E COMPRISING atmospheres containing metal dust, including aluminum, magnesium, and their commercial alloys, and other metals of similarly hazardous characteristics	
GROUP F COMPRISING atmospheres containing carbon black, coal, or coke dust	
GROUP G COMPRISING atmospheres containing flour, starch, or grain dust, and other dusts of similarly hazardous characteristics	

Temperature Conversion

°F = 9/5°C + 32 °R = °F + 460
°C = 5/9 (°F - 32) °K = °C + 273



COMMON CONVERSION FACTORS

To Convert From	To	Multiply By
Atmospheres	mm Mercury (32°F)	760.
Atmospheres	Newtons / sq. meter	101,325.
Atmospheres	Ft. water (39.1°F)	33.90
Atmospheres	Ins. mercury (32°F)	29.921
Atmospheres	Pounds / sq. in.	14.696
Bars	Pounds / sq. in.	14.504
Boiler H.P.	Kilowatts	9.803
B.t.u.	Calories (gram)	252.
B.t.u. / hour	Watts	0.29307
B.t.u. / sec.	Watts	1,054.4
B.t.u. / sq. ft. / min.	Kilowatts / sq. ft.	0.1758
Circular mills	Square inches	7.854×10^{-7}
Cubic feet water	Pounds	62.37
Cubic feet / minute	Cubic cm / sec.	472.0
Cubic feet / minute	U.S. gallons / sec.	0.1247
Cubic feet / second	U.S. gallons / min.	448.8
Feet / min.	Miles / hour	0.011364
Gallons (U.S.)	Gallons (Imperial)	0.8327
H.P. (British)	Watts	745.7
Pounds	Grains	7,000.

SPECIAL CONVERSION FACTORS

To Convert From	To	Multiply By
Heat transfer		
p.c.u. / (hr.)(ft.^{2})(°C)	B.t.u. / (hr.)(ft.^{2})(°F)	1.
kg-cal. / (hr.)(m^2)(°C)	B.t.u. / (hr.)(ft.^{2})(°F)	0.2048
g-cal. / (sec.)(cm^2)(°C)	B.t.u. / (hr.)(ft.^{2})(°F)	7,380.
watts / (cm^2)(°C)	B.t.u. / (hr.)(ft.^{2})(°F)	1,760.
watts / (in^2)(°F)	B.t.u. / (hr.)(ft.^{2})(°F)	490.
B.t.u. / (hr.)(ft.^{2})(°F)	p.c.u. / (hr.)(ft.^{2})(°C)	1.
B.t.u. / (hr.)(ft.^{2})(°F)	kg-cal. / (hr.)(m^2)(°C)	4.88
B.t.u. / (hr.)(ft.^{2})(°F)	g-cal. / (sec.)(cm^2)(°C)	0.0001355
B.t.u. / (hr.)(ft.^{2})(°F)	watts / (cm^2)(°C)	0.000568
B.t.u. / (hr.)(ft.^{2})(°F)	watts / (in^2)(°F)	0.00204
B.t.u. / (hr.)(ft.^{2})(°F)	hp / (ft.^{2})(°F)	0.000394
B.t.u. / (hr.)(ft.^{2})(°F)	joules / (sec.)(m^2)(°C)	5.678
kg-cal. / (hr.)(m^2)(°C)	joules / (sec.)(m^2)(°C)	1.163
watts / (m^2)(°C)	joules / (sec.)(m^2)(°C)	1.0
Viscosity		
centipoises	g / (sec.)(cm) or poise	0.01
centipoises	lb. / (sec.)(ft.)	0.000672
centipoises	lb. / (hr.)(ft.)	2.42
centipoises	kg / (hr.)(m)	3.60
centipoises	(newton)(sec.) / m^2	0.001
lb. / (sec.)(ft.)	(newton)(sec.) / m^2	1.488
Thermal Conductivity		
g-cal. / (sec.)(cm^2)(°C / cm)	B.t.u. / (hr.)(ft.^{2})(°F / in.)	2903.0
watts / (cm^2)(°C / cm)	B.t.u. / (hr.)(ft.^{2})(°F / in.)	694.0
g-cal. / (hr.)(cm^2)(°C / cm)	B.t.u. / (hr.)(ft.^{2})(°F / in.)	0.8064
B.t.u. / (hr.)(ft.^{2})(°F / ft.)	joules / (sec.)(m^2)(°C)	1.731
B.t.u. / (hr.)(ft.^{2})(°F / in.)	joules / (sec.)(m^2)(°C)	0.1442

S. I. Conversions

BASIC CONVERSION FACTORS

Velocity			**Power**		
1 fps	=	0.3048 m/s	1 Btu/h(int.)	=	0.29307 W
1 fpm	=	0.00508 m/s	1 Btu/s(int.)	=	1.05506 kW
1 mph	=	0.44704 m/s	1 HP mech. (UK)	=	0.74570 kW
1 mph	=	1.60934 km/h	1 HP boiler	=	9.8095 kW
Length			**Density**		
1 inch	=	25.4 mm	1 lb./ft^3	=	16.01846 kg/m^3
1 foot	=	0.3048 m	1 lb./gal (imp.)	=	99.77633 kg/m^3
1 mile	=	1.60934 km	1 lb./gal (US)	=	119.82640 kg/m^3
Area			**Thermal Conductivity**		
1 sq. inch	=	6.4516 cm^2	1 Btu.ft/ft^{2}h.°F	=	1.73073 W/m°C
1 sq. foot	=	0.09290 m^2	1 Btu.in/ft^{2}h.°F	=	0.14423 W/m°C
Volume			**Volumetric Flow**		
1 inch^3	=	16.38706 cm^3	1 ft^3/s	=	0.028317 m^3/s
1 foot^3	=	0.02832 m^3	1 ft^3/s	=	101.9406 m^3/h
Capacity Imp. Measure			**Kinematic Viscosity**		
1 fluid oz.	=	28.41306 ml	1 ft^2/s	=	0.092903 m^2/s
1 gallon	=	4.54609 l	1 centistoke (cSt)	=	1.0×10^{-6} m^2/s
Weight or Mass			**Dynamic Viscosity**		
1 oz.	=	28.34952 g	1 centipoise (cP)	=	0.001 Pa-s
1 lb.	=	0.45359 kg	1 lb./ft.s	=	1.488164 Pa-s
Pressure			**Heat Transfer**		
1 psi	=	6.89476 kPa	1 Btu/ft^{2}h.°F	=	5.67826 W/m^2°C
1 bar	=	10^5 Pa	1 kcal/m^{2}h.°F	=	1.163 W/m^2°C
Energy			**Specific Energy**		
1 kWh	=	3.6 MJ	1 Btu/lb.	=	2.326 kJ/kg
1 watt-hour	=	3.6 kJ	1 cal/g	=	4.1868 kJ/kg
Frequency			**Specific Heat**		
1 cps	=	1 Hz	1 Btu/lb.°F	=	4.1868 kJ/kg°C

DERIVED UNITS WITH SPECIAL NAMES

Measurement	Unit	Symbol	Derivation
Frequency	hertz	Hz	s-1
Force	newton	N	kg•m/s^2
Pressure	pascal	Pa	N/m^2
Energy	joule	J	N•m
Power	watt	W	J/s
Electric potential	volt	V	W/A
Electric resistance	ohm	Ω	V/A
Electric conductance	siemens	S	1/Ω
Electric charge	coulomb	C	A•s
Capacitance	farad	F	C/V
Magnetic flux	weber	Wb	V•s
Magnetic flux density	tesla	T	Wb/m^2
Inductance	henry	H	Wb/A
Luminous flux	lumen	lm	cd•sr
Illumination	lux	lx	lm/m^2
Temperature	Celsius degree	°C	K - 273.15
Pressure	bar	bar	10^5 Pa
Volume	liter	l	dm^3

THE PREFERRED PREFIXES

Prefix	Symbol	Meaning	Prefix	Symbol	Meaning
tera-	T	10^{12}	milli-	m	10^{-3}
giga-	G	10^9	micro-	µ	10^{-6}
mega-	M	10^6	nano-	n	10^{-9}
kilo-	k	10^3	pico-	p	10^{-12}
deci-	d	10^{-1}	femto-	f	10^{-15}
centi-	c	10^{-2}	atto-	a	10^{-18}