Reference Data

Reference Data

Power Calculations

Calculations for Required Heat Energy

The total heat energy (kWH or BTU) required to satisfy the system needs will be either of the two values shown below depending on which calculated result is larger.

A. Heat required for start up

B. Heat required to maintain the desired temperature

The power required (kW) will be the heat energy value (kWH) divided by the required start up or working cycle time. The kW rating of the heater will be the greater of these values plus a safety factor.

The calculation of start up and operating requirements consist of several distinct parts that are best handled separately. However, a short method can also be used for a quick estimate of heat energy required. Both methods are defined and then evaluated using the following formulas and methods:

Short Method

Start-up watts = A + C + ⅔L + safety factor

Operating watts = B + D + L + safety factor

Safety factor is normally 10 to 35% based on application.

A = Watts required to raise the temperature of material and equipment to the operating point, within the time desired

B = Watts required to maintain temperature of the material during the working cycle

C = Watts required to melt or vaporize load material during start-up period

D = Watts required to melt or vaporize load material during working cycle

L = Watts lost from surfaces by:

- Conduction-use equation to the right
- Radiation-use heat loss curves
- Convection-use heat loss curves

Equation for A and B
(Absorbed watts-raising temperature)

$$\frac{\text{lbs} \times (\text{BTU}/[\text{lb} \times {}^\circ\text{F}]) \times {}^\circ\text{F}}{\text{hrs} \times 3.412}$$

- lbs = weight of material
- (BTU/[lb x °F]) = specific heat of material
- °F = temperature rise
- hrs = start-up or cycle time

Equation for C and D
(Absorbed watts-melting or vaporizing)

$$\frac{\text{lbs} \times \text{BTU/lb}}{\text{hrs} \times 3.412}$$

- lbs = weight of material
- BTU/lb = heat of fusion or vaporization
- hrs = start-up or cycle time

Equation for L
(Lost conducted watts)

$$\frac{\left(\dfrac{\text{BTU} \times \text{in.}}{\text{ft}^2 \times {}^\circ\text{F} \times \text{hr}}\right) \times \text{ft}^2 \times {}^\circ\text{F}}{\text{in} \times 3.412}$$

- BTU x in. over ft^2 x °F x hr = thermal conductivity of material or insulation
- ft^2 = surface area
- °F = temperature differential to ambient

Power Calculations

Conduction and Convection Heating

Absorbed Energy, Heat Required to Raise the Temperature of a Material

Because substances all heat differently, different amounts of heat are required in making a temperature change. The specific heat capacity of a substance is the quantity of heat needed to raise the temperature of a unit quantity of the substance by one degree. Calling the amount of heat added **Q**, which will cause a change in temperature **ΔT** to a weight of substance **W**, at a specific heat of material **C_p**, then $Q = w \times C_p \times \Delta T$.

Since all calculations are in watts, an additional conversion of 3.412 BTU = 1 Wh is introduced yielding:

Equation 1

$$Q_A \text{ or } Q_B = \frac{w \times C_p \times \Delta T}{3.412}$$

Q_A = heat required to raise temperature of materials during heat-up (Wh)

Q_B = heat required to raise temperature of materials processed in working cycle (Wh)

w = weight of material (lb)

C_p = specific heat of material (BTU/lb x °F)

ΔT = temperature rise of material ($T_{Final} - T_{Initial}$)(°F)

This equation should be applied to all materials absorbing heat in the application. Heated media, work being processed, vessels, racks, belts and ventilation air should be included.

Example: How much heat energy is needed to change the temperature of 50 lbs of copper from 10 to 70°F?

$$Q = w \times C_p \times \Delta T$$

$$= \frac{(50 \text{ lbs}) \times (0.10 \text{ BTU/[lb} \times °\text{F]}) \times (60°\text{F})}{3.412} = 88 \text{ (Wh)}$$

Heat Required to Melt or Vaporize a Material

In considering adding heat to a substance, it is also necessary to anticipate changes in state that might occur during this heating such as melting and vaporizing. The heat needed to melt a material is known as the latent heat of fusion and represented by **H_f**. Another state change is involved in vaporization and condensation. The latent heat of vaporization **H_v** of the substance is the energy required to change a substance from a liquid to a vapor. This same amount of energy is released as the vapor condenses back to a liquid.

Equation 2

$$Q_C \text{ or } Q_D = \frac{w \times H_f}{3.412} \quad \text{OR} \quad \frac{w \times H_v}{3.412}$$

Q_C = heat required to melt/vaporize materials during heat-up (Wh)

Q_D = heat required to melt/vaporize materials processed in working cycle (Wh)

w = weight of material (lb)

H_f = latent heat of fusion (BTU/lb)

H_v = latent heat of vaporization (BTU/lb)

Example: How much energy is required to melt 50 lbs of lead?

$$Q = w \times H_f$$

$$= \frac{(50 \text{ lbs}) \times (9.8 \text{ BTU/lb})}{3.412 \text{ BTU/(Wh)}} = 144 \text{ (Wh)}$$

Changing state (melting and vaporizing) is a constant temperature process. The **C_p** value (from Equation 1) of a material also changes with a change in state. Separate calculations are thus required using Equation 1 for the material below and above the phase change temperature.

Power Calculations

Conduction and Convection Heating

Conduction Heat Losses

Heat transfer by conduction is the contact exchange of heat from one body at a higher temperature to another body at a lower temperature, or between portions of the same body at different temperatures.

Equation 3A—Heat Required to Replace Conduction Losses

$$Q_{L1} = \frac{k \times A \times \Delta T \times t_e}{3.412 \times L}$$

Q_{L1} = conduction heat losses (Wh)
k = thermal conductivity (BTU x in./[ft^2 x °F x hour])
A = heat transfer surface area (ft^2)
L = thickness of material (in.)
ΔT = temperature difference across material (T_2-T_1) °F
t_e = exposure time (hr)

This expression can be used to calculate losses through insulated walls of containers or other plane surfaces where the temperature of both surfaces can be determined or estimated.

Convection Heat Losses

Convection is a special case of conduction. Convection is defined as the transfer of heat from a high temperature region in a gas or liquid as a result of movement of the masses of the fluid.

Equation 3B—Convection Losses

$$Q_{L2} = A \times F_{SL} \times C_F$$

Q_{L2} = convection heat losses (Wh)
A = surface area (in^2)
F_{SL} = vertical surface convection loss factor (W/in^2) evaluated at surface temperature
C_F = surface orientation factor
heated surface faces up horizontally = 1.29
vertical = 1.00
heated surface faces down horizontally = 0.63

Radiation Heat Losses

Radiation losses are not dependent on orientation of the surface. Emissivity is used to adjust for a material's ability to radiate heat energy.

Equation 3C—Radiation Losses

$$Q_{L3} = A \times F_{SL} \times e$$

Q_{L3} = radiation heat losses (Wh)
A = surface area (in^2)
F_{SL} = blackbody radiation loss factor at surface temperature (W/in^2)
e = emissivity correction factor of material surface

Example:

We find that a blackbody radiator (perfect radiator) at 500°F, has heat losses of 2.5 W/in^2. Polished aluminum, in contrast, ($e = 0.09$) only has heat losses of 0.22 W/in^2 at the same temperature ($2.5 \text{ W/in}^2 \cdot 0.09 = 0.22 \text{ W/in}^2$).

Combined Convection and Radiation Heat Losses

Some curves combine both radiation and convection losses. This saves you from having to use both Equations 3B and 3C. If only the convection component is required, then the radiation component must be determined separately and subtracted from the combined curve.

Equation 3D—Combined Convection and Radiation Heat Losses

$$Q_{L4} = A \times F_{SL}$$

Q_{L4} = surface heat losses combined convection and radiation (Wh)
A = surface area (in^2)
F_{SL} = combined surface loss factor at surface temperature (W/in^2)

This equation assumes a constant surface temperature.

Power Calculations

Conduction and Convection Heating

Total Heat Losses

The total conduction, convection and radiation heat losses are summed together to allow for all losses in the power equations. Depending on the application, heat losses may make up only a small fraction of total power required or it may be the largest portion of the total. Therefore, do not ignore heat losses unless previous experience tells you it is alright to do.

Equation 3E—Total Losses

$Q_L = Q_{L1} + Q_{L2} + Q_{L3}$ If convection and radiation losses are calculated separately. (Surfaces are not uniformly insulated and losses must be calculated separately.)

OR

$Q_L = Q_{L1} + Q_{L4}$ If combined radiation and convection curves are used. (Pipes, ducts, uniformly insulated bodies.)

Start-Up and Operating Power Required

Both of these equations estimate required energy and convert it to power. Since power (watts) specifies an energy rate, we can use power to select electric heater requirements. Both the start-up power and the operating power must be analyzed before heater selection can take place.

Equation 4—Start-Up Power (Watts)

$$P_s = \left[\frac{Q_A + Q_C}{t_s} \quad \frac{2}{3} \quad (Q_L) \right] \text{ x } (1 + \text{S.F.})$$

Q_A = heat absorbed by materials during heat-up (Wh)

Q_C = latent heat absorbed during heat-up (Wh)

Q_L = conduction, convection, radiation losses (Wh)

S.F. = safety factor

t_s = start-up (heat-up) time required (hr)

During start up of a system the losses are zero, and rise to 100% at process temperature. A good approximation of actual losses is obtained when heat losses (Q_L) are multiplied by $\frac{2}{3}$.

Equation 5—Operating Power (Watts)

$$P_o = \left[\frac{Q_B + Q_D}{t_c} + (Q_L) \right] \text{ x } (1 + \text{S.F.})$$

Q_B = heat absorbed by processed materials in working cycle (Wh)

Q_D = latent heat absorbed by materials heated in working cycle (Wh)

Q_L = conduction, convection, radiation losses (Wh)

S.F. = safety factor

t_c = cycle time required (hr)

Power Calculations

Conduction and Convection Heating

Radiant Heating

When the primary mode of heat transfer is radiation, we add a step after Equation 5.

Equation 6 is used to calculate the net radiant heat transfer between two bodies. We use this to calculate either the radiant heater temperature required or (if we know the heater temperature, but not the power required) the maximum power which can be transfered to the load.

Equation 6—Radiation Heat Transfer Between Infinite Size Parallel Surfaces

$$\frac{P_R}{A} = \frac{S \ (T_1^4 - T_2^4) \left(\frac{1}{e_f}\right) \ F}{(144 \text{ in}^2/\text{ft}^2) \quad (3.412 \text{ BTU/Wh})}$$

P_R = power absorbed by the load (watts) - from equation 4 or 5

A = area of heater (in^2) - known or assumed

S = Stephan Boltzman constant

= $0.1714 \cdot 10^{-8}$ (BTU/hr. sq. ft. °R^4)

T_1(°R) = emitter temperature (°F + 460)

T_2(°R) = load temperature (°F + 460)

e_f = emissivity correction factor - see Emissivity Correction Factor information to the right

F = shape factor (0 to 1.0) - see Shape Factor for Radiant Application graph to the right

Emissivity Correction Factor (e_f)

$$e_f = \frac{1}{e_S} + \frac{1}{e_L} - 1$$ plane surfaces

$$e_f = \frac{1}{e_S} + \frac{D_S}{D_L}\left(\frac{1}{e_L} - 1\right)$$ concentric cylinders inner radiating outward

$$e_f = \frac{1}{e_S} + \left(\frac{D_S}{D_L} \times \frac{1}{e_L}\right) - 1$$ concentric cylinders outer radiating inward

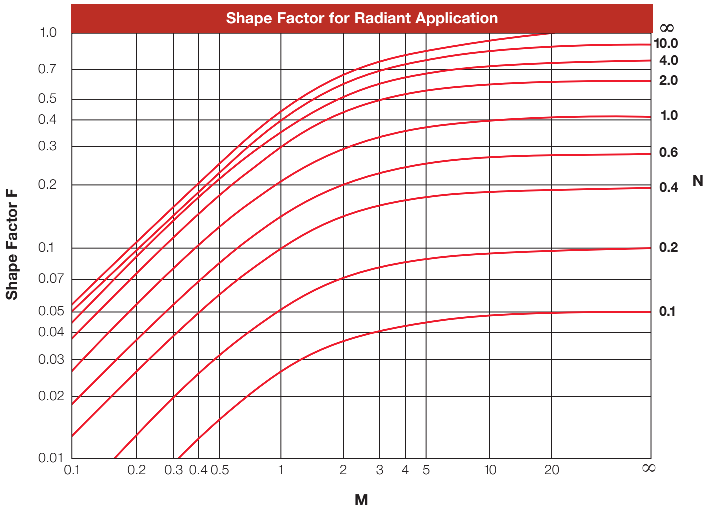
e_S = heater emissivity (from material emissivity tables)

e_L = load emissivity (from material emissivity tables)

D_S = heater diameter

D_L = load diameter

Shape Factor for Radiant Application



For Two Facing Panels:

$$\mathbf{N} = \left(\frac{\text{Heated Length}}{\text{Distance to Material}}\right)$$

$$\mathbf{M} = \left(\frac{\text{Heated Width}}{\text{Distance to Material}}\right)$$

Power Calculations

Conduction and Convection Heating

Power Evaluation

After calculating the start up and operating power requirements, a comparison must be made and various options evaluated.

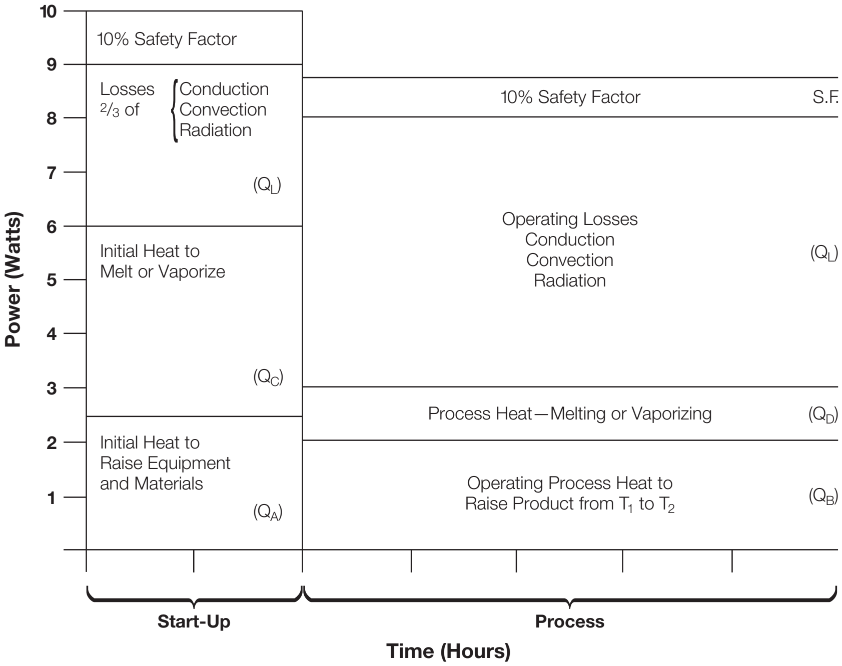
Shown in the graph below are the start up and operating watts displayed in a graphic format to help you see how power requirements add up.

With this graphic aid in mind, the following evaluations are possible:

- Compare start up watts to operating watts.
- Evaluate effects of lengthening start-up time such that start-up watts equals operating watts (use timer to start system before shift).
- Recognize that more heating capacity exists than is being utilized. (A short start-up time requirement needs more wattage than the process in wattage.)
- Identify where most energy is going and redesign or add insulation to reduce wattage requirements.

Having considered the entire system, a reevaluation of start-up time, production capacity and insulating methods should be made.

Comparison of Start Up and Operating Power Requirements



Equations

Ohm's Law

Volts

Volts = $\sqrt{\text{Watts x Ohms}}$

Volts = $\frac{\text{Watts}}{\text{Amperes}}$

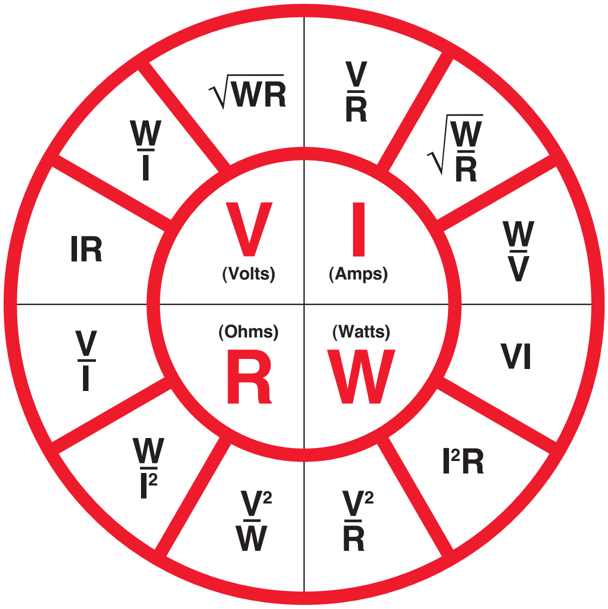
Volts = Amperes x Ohms

Ohms

Ohms = $\frac{\text{Volts}}{\text{Amperes}}$

Ohms = $\frac{\text{Volts}^2}{\text{Watts}}$

Ohms = $\frac{\text{Watts}}{\text{Amperes}^2}$



Amperes

Amperes = $\frac{\text{Volts}}{\text{Ohms}}$

Amperes = $\frac{\text{Watts}}{\text{Volts}}$

Amperes = $\sqrt{\frac{\text{Watts}}{\text{Ohms}}}$

Watts

Watts = $\frac{\text{Volts}^2}{\text{Ohms}}$

Watts = Amperes^2 x Ohms

Watts = Volts x Amperes

Wattage varies directly as ratio of voltages squared

$$W_2 = W_1 \times \left(\frac{V_2}{V_1}\right)^2$$

3 Phase Amperes = $\frac{\text{Total Watts}}{\text{Volts x 1.732}}$

Equations

Typical 3-Phase Wiring Diagrams and Equations for Resistive Heaters

Definitions

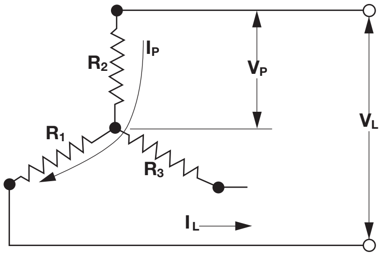
For Both Wye and Delta (Balanced Loads)

V_P = Phase voltage
V_L = Line voltage
I_P = Phase current
I_L = Line current
$R = R_1 = R_2 = R_3 =$ Resistance of each branch
W = Wattage

Wye and Delta Equivalents

$W_{DELTA} = 3\ W_{WYE}$
$W_{ODELTA} = \frac{2}{3}\ W_{DELTA}$
$W_{OWYE} = \frac{1}{2}\ W_{WYE}$

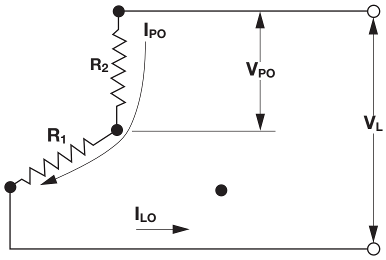
3-Phase Wye (Balanced Load)



Equations For Wye Only

$I_P = I_L$
$V_P = V_L/1.73$
$W_{WYE} = V_L^2/R = 3(V_P^2)/R$
$W_{WYE} = 1.73\, V_L I_L$

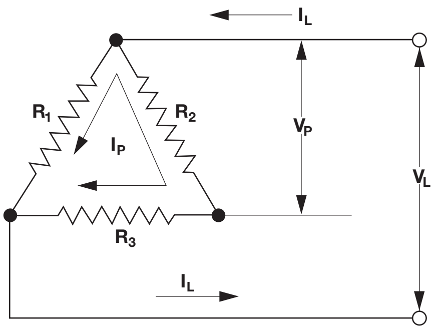
3-Phase Open Wye (No Neutral)



Equations For Open Wye Only

$I_{PO} = I_{LO}$
$V_{PO} = V_L/2$
$W_{OWYE} = 1/2\ (V_L^2/R)$
$W_{OWYE} = 2\ (V_{PO}^2/R)$
$W_{OWYE} = V_L I_{LO}$

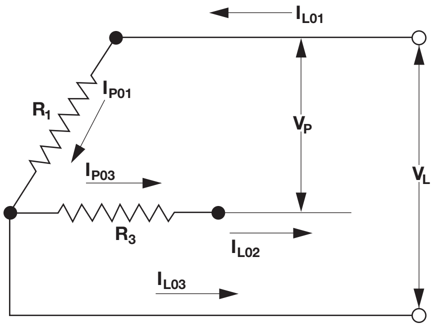
3-Phase Delta (Balanced Load)



Equations For Delta Only

$I_P = I_L/1.73$
$V_P = V_L$
$W_{DELTA} = 3\,(V_L^2)/R$
$W_{DELTA} = 1.73\, V_L I_L$

3-Phase Open Delta



Equations For Open Delta Only

$V_P = V_L$
$I_{P01} = I_{P03} = I_{L02}$
$I_{L03} = 1.73\ I_{P01}$
$W_{ODELTA} = 2\,(V_L^2/R)$

Wattage Requirements

The following equations can be used to make quick estimates of wattage requirements.

For Steel

Use equation:

$$\text{kW} = \frac{\text{kilograms x temperature rise } (^\circ\text{C})}{\text{5040 x heat-up time (hrs.)}}$$

OR

$$\text{kW} = \frac{\text{pounds x temperature rise } (^\circ\text{F})}{\text{20,000 x heat-up time (hrs.)}}$$

For Heating Water in Tanks

Use equation:

$$\text{kW} = \frac{\text{gallons x temperature rise } (^\circ\text{F})}{\text{375 x heat-up time (hrs)}}$$

OR

$$\text{kW} = \frac{\text{liters x temperature rise } (^\circ\text{C})}{\text{790 x heat-up time (hrs)}}$$

1 cu. ft. = 7.49 gallons

For Air

Use equation:

$$\text{kW} = \frac{\text{CFM}^{**①} \text{ x temperature rise } (^\circ\text{F})}{3000}$$

OR

$$\text{kW} = \frac{\text{cubic meters/min}^{①} \text{ x temperature rise } (^\circ\text{C})}{47}$$

For Oil

Use equation:

$$\text{kW} = \frac{\text{gallons x temperature rise } (^\circ\text{F})}{\text{800 x heat-up time (hrs.)}}$$

OR

$$\text{kW} = \frac{\text{liters x temperature rise } (^\circ\text{C})}{\text{1680 x heat-up time (hrs.)}}$$

1 cu. ft. = 7.49 gallons

For Heating Flowing Water

Use equation:

$$\text{kW} = \text{GPM}^{*} \text{ x temperature rise } (^\circ\text{F}) \text{ x } 0.16$$

OR

$$\text{kW} = \text{liters/min. x temperature rise } (^\circ\text{C}) \text{ x } 0.076$$

For Compressed Air

Use equation:

$$\text{kW} = \frac{\text{CFM}^{**②} \text{ x density}^{②} \text{ x temperature rise } (^\circ\text{F})}{228}$$

OR

$$\text{kW} = \frac{\text{cubic meters/min}^{②} \text{ x temperature rise } (^\circ\text{C}) \text{ x density } (\text{kg/m}^3)^{②}}{57.5}$$

* Gallons per minute

** Cubic feet per minute

① Measured at normal temperature and pressure

② Measured at heater system inlet temperature and pressure

Wattage Requirements

Kilowatt-Hours to Superheat Steam

1. Plot points on lines **P**, **Q** and **S**. **P** represents the inlet temperature (and saturation pressure) of the system.

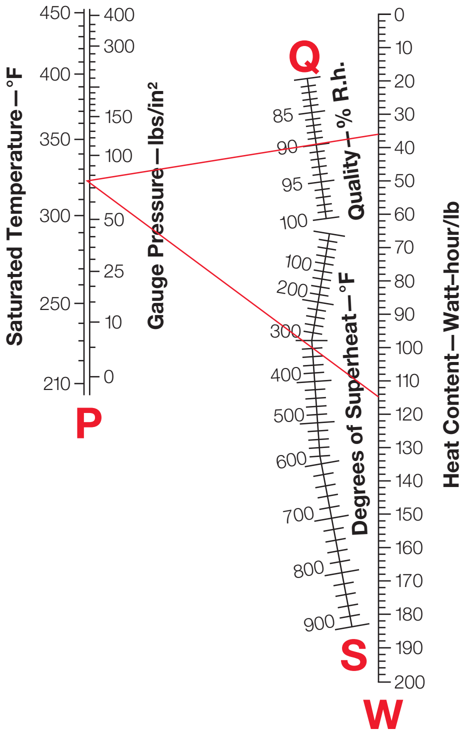
   Q represents the liquid content of the water vapor.

   S indicates the outlet temperature minus the saturated temperature.

   W indicates the heat content of the water vapor.
2. Draw a straight line from **P** through **Q** to **W**. Read **W_1**.
3. Draw a straight line from **P** through **S** to **W**. Read **W_2**.
4. Required watts = Weight (lbs.) of steam/hour x (W_2-W_1)

Watt density is critical. Review temperature and velocity prior to heater selection.

Reference is 80 percent quality at 20 psig.



Tubular Elements and Assembly Selection Guide

Watlow® tubular elements and assemblies are primarily used for direct immersion in water, oils, viscous materials, solvents, process solutions and molten materials as well as air and gases.

Additionally, round and flat surface tubular elements (WATROD and FIREBAR® heaters respectively) can be used for surface heating.

WATROD and FIREBAR heating elements may be purchased separately, or fabricated into process heating assemblies, including:

- Screw plug
- Flange
- Circulation
- Booster
- Engine preheater
- Over-the-side
- Vertical loop
- Drum
- Duct

Both elements and assemblies are available from stock. They can be configured with a variety of watt and volt ratings, terminations, sheath materials and mounting options to satisfy the most demanding applications.

If our stock products do not meet your application needs, Watlow can custom engineer the optimum heater.

Performance Capabilities

- Sheath temperatures up to 1800°F (983°C)
- Assembly wattages to 3 megawatts
- Process assembly ratings up to 3000psi
- Watt densities up to 120 W/in^2 (18.6 W/cm^2)
- Enhanced performance beyond these specifications is available upon request
- Watlow can design thermal systems to meet specific performance criteria. Contact your local Watlow representative for assistance.

Features and Benefits

36 standard bend formations

- Enables designing of the heating element around available space to maximize heating efficiency

FIREBAR flat surface geometry

- Enhances heat transfer in both immersion and air applications and also surface heating
- Increases surface area per linear inch allowing heaters to run cooler in viscous materials

Wattages from 95 watts to 3 megawatts (on individual elements and assemblies respectively)

- Makes tubular heaters one of the most versatile electric heating sources available

Applications

- Liquids
- Air
- Gases
- Molten materials
- Contact surface heating
- Radiant surface heating

Tubular Elements and Assembly Selection Guide

The following two charts will help you select an appropriate heater based on your application and watt density restrictions. These charts are application driven. The total wattage required by your application should be known before selecting a specific heater type(s) from the stock tables. If your required wattage is not known, please contact your Watlow representative.

Once the heater type has been identified, turn to the appropriate product section for information on the element or assembly.

Element and Assembly Selection Guide

To identify the tubular heater type best suited to your application, consult the *Element and Assembly Selection Guide*.

In most cases Watlow recommends using single tubular heating elements for low kilowatt applications.

Assemblies are better suited for large kilowatt applications to heat liquids, air or gases.

When selecting a heater according to watt density, be sure to consider the following:

- Liquid viscosity at start up and at process temperature
- Operating temperature
- Chemical composition

Under the “**Heating Method**” column in the *Element and Assembly Selection Guide* locate the method that applies to your application to find the recommended “Heater Type.”

After identifying the heater type(s) suitable for your application, refer to the *Supplemental Applications Chart* for further application data. This chart will assist you in selecting the appropriate watt density and sheath material for your specific application. It also presents the performance characteristics for both WATROD and FIREBAR elements.

Element and Assembly Selection Guide

Application	Heating Method	Heater Type
Liquids:		
Acids	Direct immersion (circulating/non-circulating)	FIREBAR, WATROD, screw plug, flange, over-the-side, vertical loop, and pipe insert
Caustic soda 12% concentrate 10% concentrate 75% concentrate	Direct immersion (circulating/non-circulating)	WATROD, screw plug, square flange, flange, over-the-side, vertical loop, circulation, and pipe insert
Degreasing solutions	Direct immersion (circulating/non-circulating)	FIREBAR, WATROD, screw plug, square flange, flange, over-the-side, and pipe insert
Electroplating	Direct immersion (circulating/non-circulating)	FIREBAR, WATROD, screw plug, square flange, flange, over-the-side, drum, vertical loop and pipe insert
Ethylene glycol 50% concentrate 100% concentrate	Direct immersion (circulating/non-circulating)	FIREBAR, WATROD, screw plug, flange, over-the-side, circulation, booster, and engine preheater
Oils Asphalt Fuel oils Light grades 1 and 2 Medium grades 4 and 5 Heavy grade 6 and Bunker C Heat transfer Lubricating SAE 10, 20, 30 SAE 40, 50 API STD 614 Vegetable (cooking)	Direct immersion (circulating/non-circulating)	FIREBAR, WATROD, screw plug, square flange, flange, over-the-side, drum, vertical loop, circulation, booster, and pipe insert
Paraffin or wax	Direct immersion (circulating/non-circulating)	FIREBAR, WATROD, screw plug, square flange, flange, over-the-side, drum, and pipe insert

CONTINUED

Tubular Elements and Assembly Selection Guide

Element and Assembly Selection Guide *(Continued)*

Application	Heating Method	Heater Type
Water Clean Deionized Demineralized Potable Process	Direct immersion (circulating/non-circulating)	FIREBAR (non-process water only) WATROD, screw plug, screw plug with control assembly, square flange, flange, over-the-side, drum, vertical loop, circulation, booster, engine preheater and pipe insert
Air:	Direct (forced or natural convection)	FIREBAR, WATROD, FINBAR, WATROD enclosure heater, screw plug, flange, circulation, and duct
Gas: Hydrocarbons, Nitrogen, Oxygen Ozone, Steam	Direct (forced)	FIREBAR, WATROD, screw plug, flange, and circulation
Molten Materials:		
Aluminum	Indirect (radiant)	WATROD
Lead	Direct (non-circulating)	FIREBAR and WATROD
Salt	Direct (non-circulating)	FIREBAR and WATROD
Solder	Direct (non-circulating)	FIREBAR and WATROD
Surface Heating:		
Dies, griddles, molds, platens	Direct	FIREBAR and WATROD

Supplemental Applications Chart

This *Supplemental Applications Chart* is provided in addition to the *Element and Assembly Selection Guide*. This chart will help you select watt density and sheath materials for either WATROD or FIREBAR heating elements according to the specific media being heated.

For example, if you're heating vegetable oil, either WATROD or FIREBAR elements at 30 and 40 W/in^2 respectively (4.6 and 6.2 W/cm^2) with 304 stainless steel, sheath can be used.

Supplemental Applications Chart

	Max. Operating Temperature		WATROD Element			FIREBAR Element		
Heated Material	°F	(°C)	Max. Watt Density W/in^2	(W/cm^2)	Sheath Material	Max. Watt Density W/in^2	(W/cm^2)	Sheath Material
Acid Solutions (Mild)								
Acetic	180	(82)	40	(6.2)	316 SS	40	(6.2)	Incoloy® 800
Boric (30% max.)	257	(125)	40	(6.2)	Titanium	40	(6.2)	304 SS
Carbonic	180	(82)	40	(6.2)	Inconel® 600	40	(6.2)	304 SS
Chromic	180	(82)	40	(6.2)	Titanium	N/A	N/A	N/A
Citric	180	(82)	23	(3.6)	Incoloy®	30	(4.6)	Incoloy® 800
Fatty Acids	150	(65)	20	(3.1)	316 SS	30	(4.6)	Incoloy® 800
Lactic	122	(50)	10	(1.6)	316 SS	N/A	N/A	N/A
Levulinic	180	(82)	40	(6.2)	Inconel® 600	40	(6.2)	304 SS
Malic	122	(50)	10	(1.6)	316 SS	16	(2.5)	Incoloy® 800
Nitric (30% max.)	167	(75)	20	(3.1)	316 SS	30	(4.6)	Incoloy® 800
Phenol—2-4 Disulfonic	180	(82)	40	(6.2)	316 SS	40	(6.2)	Incoloy® 800
Phosphoric	180	(82)	23	(3.6)	Incoloy®	30	(4.6)	Incoloy® 800
Phosphoric (Aerated)	180	(82)	23	(3.6)	304 SS	30	(4.6)	304 SS

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Tubular Elements and Assembly Selection Guide

Supplemental Applications Chart *(Continued)*

Heated Material	Max. Operating Temperature °F	(°C)	WATROD Element Max. Watt Density W/in^2	(W/cm^2)	WATROD Element Sheath Material	FIREBAR Element Max. Watt Density W/in^2	(W/cm^2)	FIREBAR Element Sheath Material
Proponic (10% max.)	180	(82)	40	(6.2)	Copper	40	(6.2)	304 SS
Tannic	167/180	(75/82)	23/40	(3.6/6.2)	Steel/304 SS	40	(6.2)	304 SS
Tartaric	180	(82)	40	(6.2)	316 SS	40	(6.2)	Incoloy® 800
Acetaldehyde	180	(82)	10	(1.6)	Copper	16	(2.4)	Incoloy® 800
Acetone	130	(54)	10	(1.6)	304 SS	16	(2.4)	304 SS
Air	①	①	①	①	Incoloy®	①	①	Incoloy® 800
Alcyl alcohol	200	(93)	10	(1.6)	Copper	16	(2.4)	Incoloy® 800
Alkaline solutions	212	(100)	40	(6.2)	Steel	48	(7.4)	304 SS
Aluminum acetate	122	(50)	10	(1.6)	316 SS	16	(2.5)	Incoloy® 800
Aluminum potassium sulfate	212	(100)	40	(6.2)	Copper	N/A	N/A	N/A
Ammonia gas	①	①	①	①	Steel	①	①	304 SS
Ammonium acetate	167	(75)	23	(3.6)	Incoloy®	30	(4.6)	Incoloy® 800
Amyl acetate	240	(115)	23	(3.6)	Incoloy®	30	(4.6)	Incoloy® 800
Amyl alcohol	212	(100)	20	(3.1)	304 SS	30	(4.6)	304 SS
Aniline	350	(176)	23	(3.6)	304 SS	30	(4.6)	304 SS
Asphalt	200-500	(93-260)	4-10	(0.6 - 1.6)	Steel	6-12	(0.9 - 1.8)	304 SS
Barium hydroxide	212	(100)	40	(6.2)	316 SS	40	(6.2)	Incoloy® 800
Benzene, liquid	150	(65)	10	(1.6)	Copper	16	(2.5)	304 SS
Butyl acetate	225	(107)	10	(1.6)	316 SS	16	(2.5)	Incoloy® 800
Calcium bisulfate	400	(204)	20	(3.1)	316 SS	N/A	N/A	N/A
Calcium chloride	200	(93)	5-8	(0.8 - 1.2)	Inconel® 600	N/A	N/A	N/A
Carbon monoxide	—	—	①	①	Incoloy®	①	①	Incoloy®
Carbon tetrachloride	160	(71)	23	(3.6)	Incoloy®	30	(4.6)	Incoloy®
Caustic soda:								
2%	210	(98)	48	(7.4)	Incoloy®	—	—	Contact Watlow
10% concentrate	210	(98)	23	(3.6)	Incoloy®	—	—	Contact Watlow
75%	180	(82)	23	(3.6)	Incoloy®	—	—	Contact Watlow
Citric juices	185	(85)	23	(3.6)	Incoloy®	30	(4.6)	Incoloy®
Degreasing solution	275	(135)	23	(3.6)	Steel	30	(4.6)	304 SS
Dextrose	212	(100)	20	(3.1)	304 SS	30	(4.6)	304 SS
Dyes and pigments	212	(100)	23	(3.6)	304 SS	30	(4.6)	304 SS
Electroplating Baths:								
Cadmium	180	(82)	40	(6.2)	304 SS	40	(6.2)	304 SS
Copper	180	(82)	40	(6.2)	316 SS	N/A	N/A	N/A
Dilute cyanide	180	(82)	40	(6.2)	316 SS	N/A	N/A	N/A
Rochelle cyanide	180	(82)	40	(6.2)	316 SS	N/A	N/A	N/A
Sodium cyanide	180	(82)	40	(6.2)	316 SS	N/A	N/A	N/A
Potassium cyanide	180	(82)	40	(6.2)	316 SS	40	(6.2)	304 SS
Ethylene glycol	300	(148)	30	(4.6)	Steel	40	(6.2)	304 SS
Formaldehyde	180	(82)	10	(1.6)	304 SS	16	(2.5)	304 SS
Freon® gas	300	(148)	2-5	(0.3 - 0.8)	Steel	①	①	304 SS
Gasoline	300	(148)	23	(3.6)	Steel	30	(4.6)	304 SS

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① Contact your Watlow representative.

Tubular Elements and Assembly Selection Guide

Supplemental Applications Chart *(Continued)*

Heated Material	Max. Operating Temperature °F	(°C)	WATROD Element Max. Watt Density W/in^2	WATROD Element (W/cm^2)	WATROD Element Sheath Material	FIREBAR Element Max. Watt Density W/in^2	FIREBAR Element (W/cm^2)	FIREBAR Element Sheath Material
Gelatin liquid	150	(65)	23	(3.6)	304 SS	30	(4.6)	304 SS
Gelatin solid	150	(65)	5	(0.8)	304 SS	7	(1.0)	304 SS
Glycerin	500	(260)	10	(1.6)	Incoloy®	12	(1.9)	304 SS
Glycerol	212	(100)	23	(3.6)	Incoloy®	30	(4.6)	304 SS
Grease:								
Liquid	—	—	23	(3.6)	Steel	30	(4.6)	304 SS
Solid	—	—	5	(0.8)	Steel	7	(1.0)	304 SS
Hydrazine	212	(100)	16	(2.5)	304 SS	20	(3.1)	304 SS
Hydrogen	①	①	—	—	Incoloy®	①	①	Incoloy® 800
Hydrogen chloride	①	①	—	—	Inconel® 600	①	①	N/A
Hydrogen sulfide	①	①	—	—	316 SS (heavy wall)	①	①	N/A
Magnesium chloride	212	(100)	40	(6.2)	Inconel® 600	40	(6.2)	Incoloy® 800
Magnesium sulfate	212	(100)	40	(6.2)	304 SS	40	(6.2)	304 SS
Magnesium sulfate	212	(100)	40	(6.2)	316 SS	40	(6.2)	304 SS
Methanol gas	①	①	—	—	304 SS	①	①	304 SS
Methylamine	180	(82)	20	(3.1)	Inconel® 600	30	(4.6)	304 SS
Methychloride	180	(82)	20	(3.1)	Copper	N/A	N/A	N/A
Molasses	100	(37)	4-5	(0.6 - 0.8)	304 SS	5-8	(0.8 - 1.2)	304 SS
Molten salt bath	800-900	(426-482)	25-30	(3.8 - 4.6)	Monel®	N/A	N/A	N/A
Naphtha	212	(100)	10	(1.6)	Steel	16	(2.5)	304 SS
Oils								
Fuel oils:								
Grades 1 and 2 (distillate)	200	(93)	23	(3.6)	Steel	30	(4.6)	304 SS
Grades 4 and 5 (residual)	200	(93)	13	(2.0)	Steel	16	(2.5)	304 SS
Grades 6 and Bunker C (residual)	160	(71)	8	(1.2)	Steel	10	(1.6)	304 SS
Heat transfer oils:②								
Static	500	(260)	16	(2.5)	Steel	23	(3.6)	304 SS
	600	(315)	10	(1.6)	Steel	16	(2.5)	304 SS
Circulating	500	(260)	23	(3.6)	Steel	30	(4.6)	304 SS
	600	(315)	15	(2.3)	Steel	20	(3.1)	304 SS
Lubrication oils:								
SAE 10, 90-100 SSU @ 130°F	250	(121)	23	(3.6)	Steel	30	(4.6)	304 SS
SAE 20, 120-185 SSU @ 130°F	250	(121)	23	(3.6)	Steel	30	(4.6)	304 SS
SAE 30, 185-255 SSU @ 130°F	250	(121)	23	(3.6)	Steel	30	(4.6)	304 SS
SAE 40, -80 SSU @ 210°F	250	(121)	13	(2.0)	Steel	18	(2.7)	304 SS
SAE 50, 80-105 SSU @ 210°F	250	(121)	13	(2.0)	Steel	18	(2.7)	304 SS

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① Contact your Watlow representative.
② Maximum operating temperatures and watt densities are detailed in *Heat Transfer Oil* charts on page 674.

Tubular Elements and Assembly Selection Guide

Supplemental Applications Chart *(Continued)*

			WATROD Element			FIREBAR Element		
Heated Material	**Max. Operating Temperature °F**	**(°C)**	**Max. Watt Density W/in^2**	**(W/cm^2)**	**Sheath Material**	**Max. Watt Density W/in^2**	**(W/cm^2)**	**Sheath Material**
Miscellaneous oils:								
Draw bath	600	(315)	23	(3.6)	Steel	30	(4.6)	304 SS
Hydraulic	—	—	15③	(2.3)	Steel	15③	(2.3)	304 SS
Linseed	150	(65)	50	(7.7)	Steel	60	(9.3)	304 SS
Mineral	200	(93)	23	(3.6)	Steel	30	(4.6)	304 SS
	400	(204)	16	(2.5)	Steel	23	(3.6)	304 SS
Vegetable/shortening	400	(204)	30	(4.6)	304 SS	40	(6.2)	304 SS
Paraffin or wax (liquid)	150	(65)	16	(2.4)	Steel	20	(3.1)	304 SS
Perchloroethylene	200	(93)	23	(3.6)	Steel	30	(4.6)	304 SS
Potassium chlorate	212	(100)	40	(6.2)	316 SS	N/A	N/A	N/A
Potassium chloride	212	(100)	40	(6.2)	316 SS	N/A	N/A	N/A
Potassium hydroxide	160	(71)	23	(3.6)	Monel®	N/A	N/A	N/A
Soap, liquid	212	(100)	20	(3.1)	304 SS	30	(4.6)	304 SS
Sodium acetate	212	(100)	40	(6.2)	Steel	50	(7.7)	304 SS
Sodium cyanide	140	(60)	40	(6.2)	Incoloy®	50	(7.7)	Incoloy® 800
Sodium hydride	720	(382)	28	(4.3)	Incoloy®	36	(5.5)	Incoloy® 800
Sodium hydroxide	—	—	—	—	See Caustic Soda	—	—	—
Sodium phosphate	212	(100)	40	(6.2)	Copper	50	(7.7)	304 SS
Steam, flowing	300	(148)	10	(1.6)	Incoloy®	①	①	Incoloy® 800
	500	(260)	5-10	(0.8-1.6)	Incoloy®	①	①	Incoloy® 800
	700	(371)	5	(0.8)	Incoloy®	①	①	Incoloy® 800
Sulfur, molten	600	(315)	10	(1.6)	Incoloy®	12	(1.8)	Incoloy® 800
Toluene	212	(100)	23	(3.6)	Steel	30	(4.6)	304 SS
Trichlorethylene	150	(65)	23	(3.6)	Steel	30	(4.6)	304 SS
Turpentine	300	(148)	20	(3.1)	304 SS	25	(3.8)	304 SS
Water								
Clean	212	(100)	60	(9.3)	Incoloy®	45	(7)	Incoloy® 800
Deionized	212	(100)	60	(9.3)	316 SS (passivated)	90	(14)	Incoloy® 800
Demineralized	212	(100)	60	(9.3)	316 SS (passivated)	90	(14)	Incoloy® 800
Potable	212	(100)	60	(9.3)	Incoloy®	45	(7)	Incoloy® 800
Process	212	(100)	48	(9.3)	Incoloy®			Contact Watlow

① Contact your Watlow representative.
③ Per API standards.

Tubular Elements and Assembly Selection Guide

Free Cross Sectional Area of WATROD and FIREBAR Circulation Heaters

Free cross sectional areas from the chart are in square feet. Calculations are based on:

- Flange 12 inches and under, pipes are schedule 40
- Flanges 14 inches and above, pipes are standard wall thickness 0.375 in. (9.5 mm)
- All WATROD heating elements are 0.475 in. (12 mm) diameter

Circulation Heater Size in.	Free Cross Sectional Area in Square Feet (Number of Elements in Parenthesis)		
WATROD			
2½ NPT	0.044 (3)		
3 Flange	0.044 (3)	0.037 (6)	
4 Flange	0.074 (6)		
5 Flange	0.124 (6)	0.117 (9)	
6 Flange	0.172 (12)	0.164 (15)	
8 Flange	0.303 (18)	0.296 (21)	0.288 (24)
10 Flange	0.481 (27)	0.460 (36)	
12 Flange	0.697 (36)	0.652 (54)	
14 Flange	0.848 (45)	0.781 (72)	
16 Flange	1.091 (72)	1.054 (87)	1.017 (102)
18 Flange	1.372 (102)	1.357 (108)	1.342 (114)
20 Flange	1.748 (108)	1.733 (114)	1.704 (126)
FIREBAR			
2½ NPT	0.0417 (3)		
4 Flange	0.0692 (6)		
6 Flange	0.1540 (15)		

Tubular Elements and Assembly Selection Guide

Heat Transfer Oil Chart

Heat Transfer Fluid	Recommended Max. Temperature °F (°C)				Flammability Data °F (°C)						Min. Velocity Thru Heater in Feet/second at W/in^2 (M/second at W/cm^2)							
	Process		Sheath		Flash Point		Fire Point		Autoignition		8	(1.2)	16	(2.8)	23	(3.6)	30	(4.7)
	F	(°C)	°F	(°C)	°F	(°C)	°F	(°C)	°F	(°C)	W/in^2	(W/cm^2)	W/in^2	(W/cm^2)	W/in^2	(W/cm^2)	W/in^2	(W/cm^2)
Calflo HTF	600	(316)	650	(343)	414	(212)	462	(239)	670	(354)	1.5	(0.5)	3.0	(0.9)	5.0	(1.52)	7.0	(2.1)
Calflo AF	550	(288)	600	(316)	400	(204)	437	(225)	650	(343)	1.5	(0.5)	3.0	(0.9)	5.0	(1.52)	7.0	(2.1)
Dow therm® A	750	(399)	835	(446)	255	(124)	275	(135)	1150	(621)	0.5	(0.15)	1.0	(0.3)	2.0	(0.61)	3.0	(0.9)
Dow therm® G	700	(371)	775	(413)	305	(152)	315	(157)	1150	(621)	0.7	(0.2)	1.5	(0.5)	2.5	(0.75)	3.5	(1.1)
Dow therm® J	575	(302)	650	(343)	145	(63)	155	(68)	806	(430)	1.0	(0.3)	2.0	(0.61)	3.0	(0.9)	4.5	(1.37)
Dow therm® LF	600	(316)	675	(357)	260	(127)	280	(138)	1020	(549)	0.7	(0.2)	1.5	(0.5)	2.5	(1.75)	3.5	(1.1)
Dow therm® HT	650	(343)	700	(371)	no data	no data	no data	no data	no data	no data	1.5	(0.5)	2.5	(0.75)	3.5	(1.1)	5.0	(1.52)
Dow therm® Q	625	(329)	700	(371)	no data	no data	no data	no data	773	(412)	0.7	(0.2)	1.5	(0.5)	2.5	(0.75)	3.5	(1.1)
Marlotherm S	662	(350)	698	(370)	374	(190)	no data	no data	932	(500)	1.5	(0.5)	3.0	(0.9)	5.0	(1.52)	7.0	(2.1)
Mobiltherm 603	590	(310)	625	(329)	380	(193)	no data	no data	no data	no data	1.5	(0.5)	3.0	(0.9)	5.0	(1.52)	7.0	(2.1)
Multitherm IG-2	600	(316)	650	(343)	440	(227)	500	(260)	700	(371)	0.8	(0.24)	1.7	(0.52)	2.3	(0.7)	3.0	(0.9)
Multitherm PG-1	600	(316)	640	(338)	340	(171)	385	(196)	690	(368)	1.0	(0.3)	2.0	(0.61)	3.0	(0.9)	4.0	(1.22)
Para Cymene	600	(316)	650	(343)	117	(47)	152	(72)	817	(438)	0.7	(0.2)	1.5	(0.5)	2.5	(0.75)	3.5	(1.1)
Syltherm 800	750	(399)	800	(427)	350	(177)	380	(193)	725	(385)	1.5	(0.5)	3.0	(0.9)	5.0	(1.52)	7.0	(2.1)
Syltherm XLT	500	(260)	550	(288)	116	(47)	130	(54)	662	(350)	1.5	(0.5)	2.5	(0.75)	4.0	(1.22)	5.0	(1.52)
Texatherm	600	(316)	640	(338)	430	(221)	no data	no data	no data	no data	2.0	(0.61)	4.0	(1.22)	6.0	(1.83)	8.0	(2.4)
Thermia 33	600	(316)	650	(343)	455	(235)	495	(257)	no data	no data	1.5	(0.5)	3.0	(0.9)	5.0	(1.52)	7.0	(2.1)
Therminol 44	400	(204)	475	(246)	405	(207)	438	(228)	705	(374)	1.0	(0.3)	2.0	(0.61)	3.0	(0.9)	4.0	(1.22)
Therminol 55	550	(288)	605	(318)	350	(177)	410	(210)	675	(357)	1.5	(0.5)	2.5	(0.75)	3.5	(1.1)	5.0	(1.52)
Therminol 59	600	(316)	650	(343)	302	(150)	335	(168)	770	(410)	1.5	(0.5)	2.5	(0.75)	3.5	(1.1)	5.0	(1.52)
Therminol 60	620	(327)	655	(346)	310	(154)	320	(160)	835	(448)	1.5	(0.5)	3.0	(0.9)	5.0	(1.52)	7.0	(2.1)
Therminol 68	650	(343)	705	(374)	350	(177)	380	(183)	705	(374)	1.5	(0.5)	2.5	(0.75)	3.0	(0.9)	4.5	(1.37)
Therminol 75	750	(399)	805	(429)	390	(199)	440	(227)	1000	(538)	1.0	(0.3)	2.0	(0.61)	3.0	(0.9)	4.0	(1.22)
Therminol LT	600	(316)	650	(343)	134	(57)	150	(66)	805	(429)	1.5	(0.5)	2.5	(0.75)	4.0	(1.22)	5.0	(1.52)
Therminol VP-1	750	(399)	800	(427)	255	(124)	280	(127)	1150	(621)	1.0	(0.3)	2.0	(0.61)	3.0	(0.9)	4.0	(1.22)
U-Con 500	500	(260)	550	(288)	540	(282)	600	(316)	750	(399)	1.0	(0.3)	2.0	(0.61)	3.0	(0.9)	4.0	(1.22)