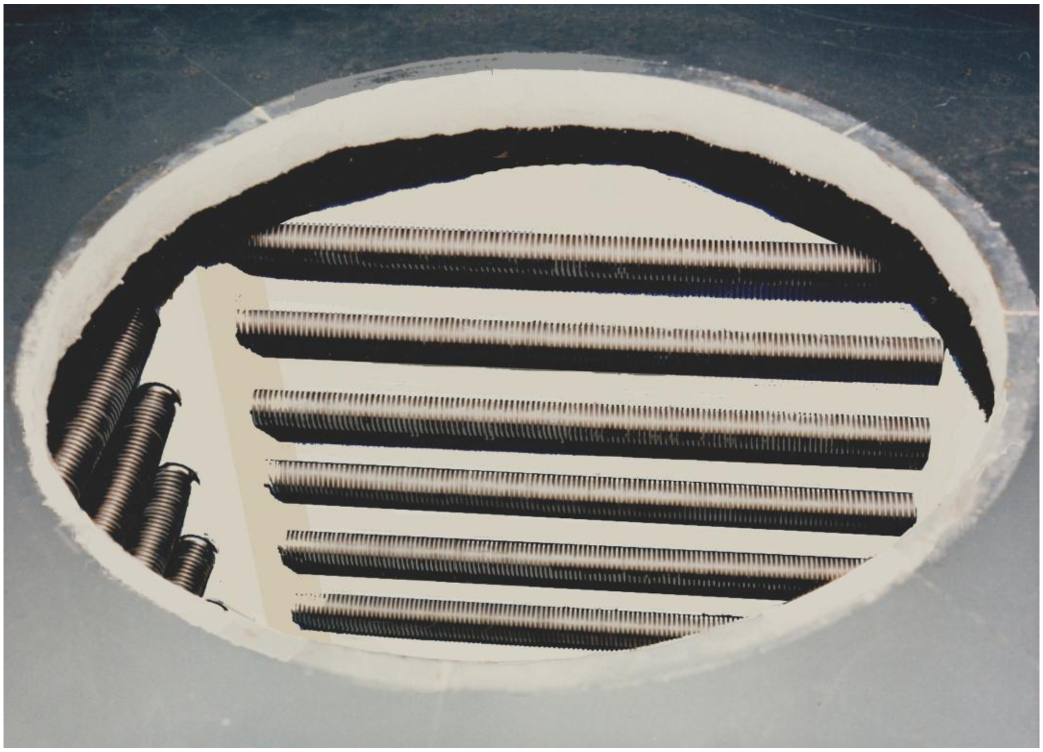
COMPARING
NICKEL-CHROME SERIES-WIRED HEATING ELEMENTS
WITH
RAYTEQ ICA PARALLEL-WIRED HEATING ELEMENTS

NICKEL-CHROME SERIES-WIRED ELEMENT DESIGN
Originally developed over fifty years ago for heat treat furnace applications, this basic element design was around long before Rayteq started in business. It is currently offered by several general purpose North American furnace manufacturers. Rayteq's iron-chrome-aluminum (ICA) parallel-wired elements are replacing series-connected nickel-chrome elements of all types and styles, mainly because of a number of detrimental nickel-chrome properties which result in inherently low reliability of heating elements produced from nickel-chrome alloys.

NICKEL-CHROME ELEMENT DESIGNS
Series-connected nickel-chrome heating elements are available in at least two basic styles: horizontal coils and rod-overbend types. Representative photos of each type may be found on the following page.

HORIZONTAL COIL NICKEL-CHROME ELEMENTS – Horizontal coil elements, regardless of the alloy used, are not recommended for metal melting furnace applications for a number of important reasons. First, they require the use of horizontal ceramic "towel rod" supports which must operate in tension on the bottom half of the rods due to the weight of the element coils and of the rods themselves. The tensile strength of all ceramics is typically 10% or less of their compressive strength. Ceramic rod failures can be triggered by element hot spots when coils burn out, by mechanical shocks from any source such as a fork truck bumping the furnace or by intermediate rod supports applying uneven force.

THE CASCADE EFFECT – When a rod breaks, it can drop all or part of the element coil it supports down onto the next element below, causing a short circuit and a probable break in the rod supporting it, which will then fall onto the next element below it, and so on. This cascade effect can take out the entire set of heating elements resulting in a near or total loss of power to the furnace, requiring immediate attention. A metal spill in the furnace can trigger another type of cascade effect with similar results whether support rods are broken or not.



ELECTRIC MELTING FURNACE EQUIPPED WITH SIX HORIZONTAL COILS OF SERIES-CONNECTED NICKEL-CHROME HEATING ELEMENTS

ROD-OVERBEND STYLE SERIES-CONNECTED NICKEL-CHROME HEATING ELEMENTS IN ELECTRIC RESISTANCE MELTING FURNACE

ROD-OVERBEND NICKEL-CHROME ELEMENTS – When first introduced, this element design appeared promising because of its seemingly robust heavy rod design. However, the large rods had insufficient surface area to dissipate adequate heat for metal melting without exceeding the recommended watt-density of the nickel-chrome alloy. Whenever it was exceeded to meet melting needs, it rapidly oxidized, resulting in reduced heat output and premature failures.

LIMITATIONS OF NICKEL-CHROME HEATING ELEMENTS – Nickel-chrome heating elements began falling out of favor for use in metal melting applications because at higher melting temperatures the chrome in nickel-chrome resistance alloys continuously oxidizes into chrome oxide (known in the industry as "green crud"). The higher the temperature, the faster the rate of oxidation. Because metal melting invariably involves operating elements at higher temperatures, the oxidation rate of nickel-chrome elements used for metal melting furnaces can be rapid.

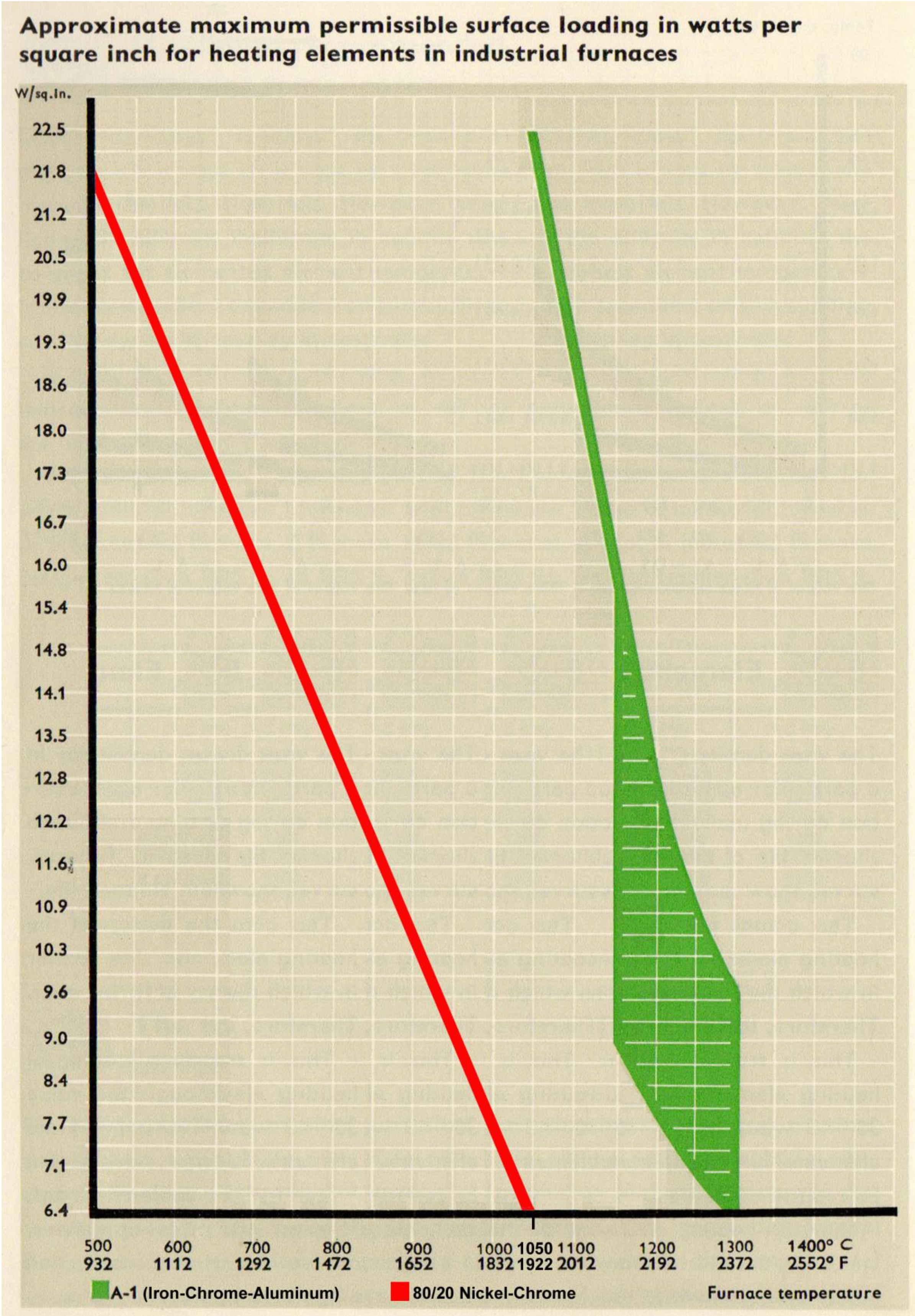
Melting furnaces with nickel-chrome elements typically start up without incident and initially operate acceptably. But as the alloy oxidizes, its resistance slowly increases which reduces current flow and the power output of the heating elements. This oxidation continues until either the effective cross sectional area of the element wire becomes so small that hot spots leading to burn-outs develop, or the elements can no longer dissipate sufficient power to reach the required melting rates and must be replaced.

REPAIRING AND REPLACING NICKEL-CHROME ELEMENTS – Burned out elements can be repaired by TIG welding but when oxidation has advanced to the point where the cross-sectional area of the element wire is insufficient to dissipate enough power, welding repairs are pointless. And if such repairs are made, because the element has already lost much of its cross-sectional area to chrome oxidation, burnouts will still recur, but at a more rapid rate. This predictable behavior has led to discontinued use of nickel-chrome alloys for most high production melting applications.

To repair or replace nickel-chrome elements, the furnace must be shut down and the crucible must be emptied and removed from the furnace. Burned out elements can be repaired by TIG welding but as noted above, repeat burn-outs at other locations along the coil are likely to occur. Replacing nickel-chrome elements is an arduous task because the elements are attached to hooks and anchors which are part of the lining. In many cases the entire element array together with the supporting refractory must be removed.

ELEMENT ALLOY SELECTION – The high heating element temperatures required for molten metal melting furnaces will put a strain on any electric resistance heating elements. Thus the highest temperature/watt-density rated element alloy which can operate comfortably at the high end of the temperature range should be used.

The chart on the next page shows two graphs produced by the same resistance wire supplier (Kanthal Corporation) which have become the "bible" of the electric resistance furnace industry. The red curve is for 80/20 nickel-chrome alloy which is closely representative of the family of nickel-based alloys that includes 70/30,


Approximate maximum permissible surface loading in watts per square inch for heating elements in industrial furnaces
W/sq.in.
22.5
21.8
21.2
20.5
19.9
19.3
18.6
18.0
17.3
16.7
16.0
15.4
14.8
14.1
13.5
12.8
12.2
11.6
10.9
10.3
9.6
9.0
8.4
7.7
7.1
6.4
500 932
600 1112
700 1292
800 1472
900 1652
1000 1832
1050 1922
1100 2012
1200 2192
1300 2372
1400° C 2552° F
A-1 (Iron-Chrome-Aluminum)
80/20 Nickel-Chrome
Furnace temperature

Inconel, etc. The green curve is for iron-chrome-aluminum (ICA) alloy used by Rayteq. Each curve plots maximum recommended watt-density vs. furnace temperature and also shows the recommended temperature limit for both. For easy comparison purposes, the red nickel-chrome alloy curve has been superimposed on the ICA graph.

Referring to these curves, note that when the nickel-chrome alloy (red curve) reaches its furnace temperature limit of 1050°C (1922°F) which is at the low end of the maximum watt-density curve at 6.4 watts/in^2, the ICA alloy is still at the high end of its watt-density curve at 22.5 watts/in^2 or 3.5 times the watt density capacity of the nickel-chrome alloy. At this point the ICA alloy still has 250°C (450°F) more to go until it reaches its furnace temperature limit of 1300°C! At this higher cut-off temperature, the watt-density rating of ICA alloy is still 9.8 watts/in^2 or 153% higher than the 6.4 watts/in^2 of the nickel-chrome alloy at its lower cut-off point.

HOW ICA ALLOYS WORK – The ICA alloy attains its remarkable metal melting capability because it includes aluminum which literally "sweats" out to the wire surface on startup. A surface coating of strong aluminum oxide then forms which oxygen molecules cannot penetrate. This layer effectively protects the chrome in the alloy from oxidation.

MELTING FURNACE NEEDS – These ICA properties are essential for melting furnaces. For example, a Rayteq ICA heating element operating at a maximum 2000°F element temperature might dissipate 12 watts per square inch which means it is operating very comfortably inside the green curve limits. But if a nickel-chrome element is operated at 12 watts/square inch, its furnace temperature is limited to a "red line" maximum of 850°C (1562°F) which is 438°F below the Rayteq element. Since the rate of radiant heat transfer is proportional to the *fourth power* of the temperature difference between the element and the crucible, a 438°F temperature disadvantage means that the nickel-chrome elements will reach only a small fraction of the Rayteq element melt rate. The only way to make up for this is to operate the nickel-chrome elements well above the recommended watt-density limits which accelerates the chrome oxidation rate and rapidly reduces the operating life.

In summary, these curves which were produced by an alloy manufacturer of both alloys with no bias towards either alloy indicate why it is not advisable to use elements made from nickel-based alloys such as 80/20, 70/30, Inconel, etc. for light metal melting furnaces. Instead, these applications clearly call for the higher temperature, higher watt-density rated ICA alloy which has much more room at the upper end for such high temperature use.

POWER SUPPLIES FOR NICKEL-CHROME ALLOY ELEMENTS

Because of the problem of continuous oxidation of nickel-chrome elements that increases resistance while reducing current and power, SCR solid state power supplies are frequently used to power nickel-chrome elements. When the elements are new the resistance is low and the SCRs limit the voltage and hence the amount of power dissipated by the elements. As the elements oxidize over time, the resistance increases and the SCRs increase the voltage to compensate. At some point the SCRs must remain on continuously, yet the oxidation and power reductions continue. Finally, when the dissipated power is inadequate to meet the required melting rates, whether or not the elements are intact, they must be replaced.

Because of the expense of SCR power supplies, furnace manufacturers are sometimes tempted to use *two-pole* SCRs instead of three-pole SCRs to switch 3-wire wye connected element arrays. With two-pole SCRs, one of the three element “legs” is always “hot” which means the element neutral cannot be connected to the plant neutral which has undesirable results: When one of the three elements in the wye connection burns out, the other two are left connected in series across one phase resulting in a 50% power loss instead of a smaller one-third power loss. Worse yet, when a second element burns out, power to this three-element group is completely lost instead of one-third power remaining. While two-pole SCRs are less costly the user is left to contend with these undesirable consequences.

All SCRs are semiconductors and all semiconductors generate waste heat proportional to the square of the current passing through them. There are no exceptions to this fundamental behavior. This waste heat reduces overall energy efficiency and must be disposed of. Uncooled control panels thus operate hotter than they would otherwise, resulting in heat stress on all components in the panel, particularly in summer. At some point air or water cooling must be employed to dispose of the waste heat, which requires fans and filters or water recirculation systems.

Finally, SCR power supplies are susceptible to failure caused by common electrical disturbances, such as large loads being switched on or off and particularly by lightning strikes on power lines, even miles away.

POWER SUPPLIES FOR RAYTEQ ICA HEATING ELEMENTS – Rayteq furnaces completely avoid the need for SCR power supplies by using ICA heating elements with a chrome-protecting layer of aluminum oxide that keeps element resistance nearly constant throughout their lifetime so that they can be switched by more reliable long-life contactors. Contactors permit elements to be connected to a common plant neutral to limit the power lost if an element goes out of service. There is no voltage drop across contactors so no waste heat is generated that can stress control panel components or require cooling. Most importantly, they are virtually immune to electrical disturbances including voltage spikes which keeps Rayteq furnaces up and running for reliable melting over long operating campaigns.

CONSEQUENCE OF ELEMENT FAILURE

When elements fail, the number of individual elements in the furnace, and whether they are *series* or *parallel-wired*, will determine if the furnace can continue operations and will also heavily influence the furnace’s overall up-time reliability.

Because the nickel-chrome series-wired element array, by its very nature, consists of a fewer number of large series-connected elements, failure of a single element, like inexpensive incandescent Christmas tree lights, will cause all elements in the affected series string to stop operating, resulting in a serious impact on melting production. Immediate furnace shutdown and repair will nearly always be required.

RAYTEQ MELTING FURNACE EQUIPPED WITH VERTICALLY MOUNTED, PARALLEL-WIRED IRON-CHROME-ALUMINUM (ICA) HEATING ELEMENTS

RAYTEQ SELF-SUPPORTING PARALLEL-WIRED ICA HEATING ELEMENTS

In contrast, Rayteq furnaces always have many more smaller elements, each independently ***parallel-wired*** with separate circuit breakers, so if one element goes out of service, all others remain operational. Because the loss of a single element has a negligible impact on the melting or production rate, it can either be simply ignored or handled later during routine maintenance without a major production shutdown. This is the second important reason why Rayteq furnaces can maintain long, uninterrupted production campaigns.

Rayteq uses independent, self-supporting, vertically mounted, parallel-wired, iron-chrome-aluminum (ICA) alloy heating elements that can operate continuously at higher temperatures and power densities than nickel-chrome alloys. Because they are parallel wired, if one element should go out of service the others maintain full operation. Since all Rayteq elements are vertically mounted, all ceramic components are in compression and not in tension, and if an element goes out of service, there is no danger to adjacent elements. Any metal spill damage will be limited to only those elements directly affected. Finally, they can be exchanged without removing the crucible, even when it contains molten metal. Rayteq's ICA elements can operate for many years with constant power output in high production 24/7 melting applications where up-time reliability is of paramount importance.

FURNACE SELECTION – If ICA alloy is the best heating element alloy choice for light metal furnace applications, the user should also be interested to learn that Rayteq has successfully adapted its heating element system to ICA's unique growth characteristics. ICA alloy, with or without the addition of yttrium (which helps but doesn't cure the growth problem), doesn't work well in a nickel-chrome series-wired element design because the continuous grain growth caused by the iron in the alloy leads to adjacent elements shorting together or getting close enough to induce mutual radiation, both of which lead to burnouts.

On the other hand, the growth characteristics of ICA alloy are not a problem in Rayteq's elements because each turn of each coil is uniformly supported by highly conductive refractory so shorting and mutual radiation cannot take place. And since Rayteq's ICA alloy coils are *semi*-embedded in *highly conductive* refractory which acts as a thermal heat sink, they don't require any watt-density derating as do elements which are fully embedded in more insulating refractory such as ceramic fiber. Rayteq's element design is well proven—a track record that speaks for itself.

SUMMARY – When choosing electric resistance furnaces, there are three important criteria to consider:

1. Which heating element alloy is used?
2. Which manufacturer's furnaces and elements will do the best job with that alloy?
3. Should *series* or *parallel* heating element wiring be used?

Rayteq strongly believes that today's light metal production melting furnace needs clearly call for ICA alloy, and Rayteq furnaces equipped with parallel-wired elements made from this alloy can do the best, most reliable job over the long haul.

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RAYTEQ™
PASSION FOR PEAK PERFORMANCE

P.O. Box 1343
Healdsburg, California 95448
Phone (510) 638-2000
E-mail: Information@Rayteq.com
Web Page: www.Rayteq.com