Nichrome Alloys for Heating Applications

Choosing a Nichrome Heating element

The Nickel-Chrome alloys have been in use back to 1900 and these have been successfully employed in heating element applications. Hence the realistic field experience of equipments and industrial furnaces gives a confidence in the usage of these alloys in the advanced and already established design applications.

What is a resistance heating alloy?

The selection of electric heating materials depends on inherent resistance to the current flow to produce heat. Copper wire doesn't produce sufficiently heat when conducts electricity. Hence for an alloy as wire, rod, strip or ribbon to treat as an electric heating element it should oppose the flow of electricity.

Generally common steels and alloys like stainless steel prevent the electricity flow. This property term is known as resistivity. In North America, the tradition is to use ohms per circular mil ft to describe resistivity and this term has been following in the data. The technically suitable designation would be ohm.cmil/ft or ohm times circular mils per foot. In European countries, common unit of resistivity is ohm mm2 per m.

If resistivity solely was considered as the major factor for an electric heating element, the option could be from several alloy materials in a wide array of cost. By its extreme nature, an electric heating element gets hot often red hot and ordinary alloys cannot endure such extent of heat for a long period. They fail and it is called as poor life as a heating element.

The alloy families were prepared traditionally with suitable combination of two certain properties:

1. High electric resistivity
2. Prolong service life, endurance potential as a heating material

These alloy groups can be categorized in the six major classes. While the whole alloy families are enlisted for comprehensiveness, this post states about Nichrome alloys. These are most commonly employed in US and Canada. The major grades of these alloys are shown with their composition and resistivity.

Nickel-Chromium Alloys	
80 Nickel 20 Chromium	650 ohm-CMF
70 Nickel 30 Chromium	710 ohm-CMF

60 Nickel 16 Chromium Rem Iron	675 ohm-CMF
35 Nickel 20 Chromium rem Iron	610 ohm-CMF
Iron-Chromium-aluminum	
22 chromium 5 aluminum rem iron	875 ohm-CMF
22 chromium 4 aluminum rem iron	815 ohm-CMF
15 chromium 4 aluminum rem iron	750 ohm-CMF
Copper-Nickel alloys for low temperature applications	
45 Nickel rem Cu	300 ohm-CMF
22 Nickel rem Cu	180 ohm-CMF
11 Nickel rem Cu	90 ohm-CMF
6 Nickel rem Cu	60 ohm-CMF
2 Nickel rem Cu	30 ohm-CMF
Stainless steel, Monel and various alloys for low temperature applications	
Nickel Manganese 94 Nickel 5 Manganese	102 ohm-CMF
99.98 Nickel	45 ohm-CMF
Monel 67 Nickel 30 Copper	290 ohm-CMF
Nickel Silicon 3 silicon balance Nickel	190 ohm-CMF
UNS S30400 18 chromium 8 nickel rem iron	433 ohm-CMF
Metals for vacuum applications	
Molybdenum	
Tungsten	
Tantalum	

American standards for testing and materials

B63	Resistivity of metallic conducting resistance and contact metals
B70	Test method for variable resistance with temperature of electric heating elements
B76	Accelerated service test of nichrome and Nickel-chrome-iron alloys for electric heating purposes
B78	Increased life test for FeCrAl electric heating alloys
B344	Specification for drawn or rolled nickel-chromium and nickel-chromium-iron alloys for heating applications
B603	Specification for drawn or rolled FeCrAl alloys

Characteristics

To become a significant electric heating element, a metal or alloys should possess the following attributes:

1. Good high electric resistivity to keep small cross sectional area
2. High strength and ductility at the service temperatures
3. Low temperature coefficient of electric resistance to prevent changes in resistance at the service temperature significantly from that attained to room temperature.
4. Excellent resistance to oxidation in air while moderate procedures
5. Suitable working and potential for being formed into the required shape.

The materials that possess these properties are 80/20 Nichrome, 70/30 Nichrome, 60/15 Nichrome and 35/20 Nichrome. The evaluation of the properties of these alloys in air is made following:

	A grade 80/20 NiCr	70/30 NiCr	C Grade 60/15 NiCr	D Grade 35/20 NiCr
UNS	N06003	N06008	N06004	None
Highest service temperature in air	1200oC or 2200oF	1260oC or 2300oF	1150oC or 2100oF	1100oC or 2000oF
Melting point	1400oC or 2550 oF	1380oC or 2520 oF	1390oC or 2530oF	1390oC or 2530oF
Specific gravity	8.41	8.11	8.25	7.95
Density	0.304 lb/in3	0.293 lb/in3	0.298 lb/in3	0.287 lb/in3
Specific heat	.107 Btu/lb/F	.110 Btu/lb/F	.107 Btu/lb/F	.110 Btu/lb/F
Tensile strength	830 MPa or 120 ksi	900 MPa or 130 ksi	760 Mpa or 110 ksi	620 Mpa or 90 ksi
Yield strength, .2 %	415 MPa or 60 ksi	485 MPa or 70 ksi	380 Mpa or 55 ksi	345 MPa or 50 ksi
Elongation %	240 MPa or 35 ksi	240 MPa or 35 ksi	240 MPa or 35 ksi	240 MPa or 35 ksi
Reduction of area	55 %	55 %	55 %	55 %

The most popular resistance alloy made up of 80% nickel and 20 % chromium is still extensively employed, however a variety of researches have suggested some enhancements in the basic chemistry. The inclusion of nominal magnitudes of iron, manganese and silicon and slight contents of rare earth metals and others are made that enable the alloy to be employed up to 1200oC or 2192oF.

70/30 Nickel-Chromium alloy is made to provide an enhanced service life in air up to 1260oC or 2300oF. It gives outstanding performance in resisting oxidation in the low oxygen conditions, a mechanism known as green rot due to green shade of oxide.

The Nichrome alloy comprising of 60% Nickel and 16%chromium and remaining iron is normally chosen when the application temperature doesn’t need to be above 1100oC or 2012oF like in electric flat irons.

Alloy comprising of 35% nickel, 20% chromium and rem iron is used in industrially controlled condition furnaces working at temperatures 800oC to 1000oC or 1472oF to 1832oF. It provides significant contribution in preventing the damage that may take place in above two alloys when the service temperature is same but conditions vary between reducing and oxidizing. Nichrome A or 80/20 is not suggested for employ in the conditions that reduce nickel and oxidize chromium.

All of the heating alloys mentioned in above table have great service life as the heating material when designed adequately in the suitable wire size and coil specification.

Resistance wire or strip forms are normally introduced in the annealed form, unless otherwise individually request. These are conveniently formed by coiling or bending in the annealed condition.

The suitable life of a heating element starts with the production of alloy and subsequent outcomes from the suitable care of the alloy- wire, ribbon, strip when it is formed as a heating element and installed in the consumer’s appliance. The nichrome alloys are corrosion resistant similar to stainless steels however these are vigorously damaged in the few conditions therefore precautions are required to keep them clean.

Variety of heating elements

Resistance elements are used in the several manners and applications as stated following:

Wire or ribbon can be exposed or covered. The exposed heater distributes heat more efficiently, permits it to function at the elevated temperature without the need of heavy material. But it is not secured from the external factors like rust and short circuits and may cause potential risks of electric shock for the user.

The concept of mounting wire or strip is of utmost significance. It can be hanged up or implanted. The standard suspension applications can be seen in air heaters in which a heating coil is threaded by an array of doughnut-shaped beads supported through a wire-frame.

The supported materials are commonly employed in furnaces where regular support is offered for the coil to lie on the walls. Generally, such supported kind of heater is made of Iron based alloys (FeCrAl) that have small hot strength. They are slow in thermal response as the supporting material requires to be heated. The major reason for using these alloys is their economical price.

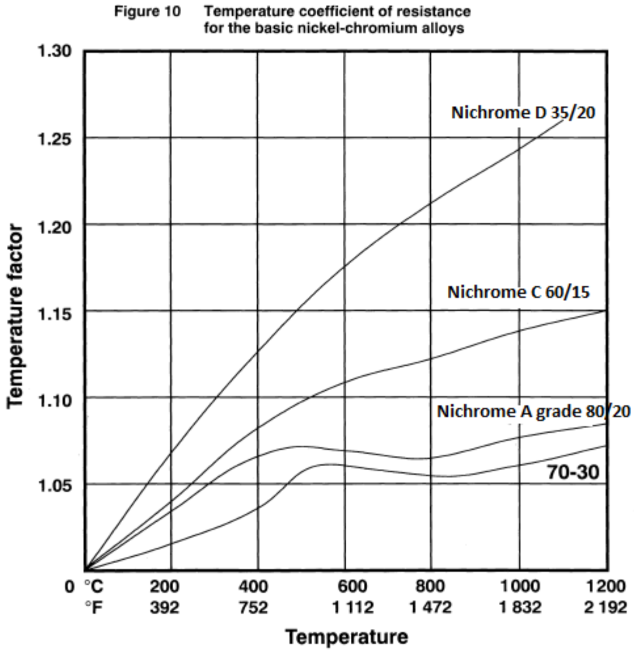
There are a variety of heaters classified as tubular or sheathed heaters in which the wire is inserted in stainless steel or heat resistant material cover. The wire coil coated by magnesium oxide packed in a tube, the coating offers sufficient electrical insulation and heat transfer by conduction to the outside. The heaters vary from the peak grades employed in top and oven operations to cheap small heaters for immersion in a bowl.

How electric resistance alloys perform

An electric resistance alloy generates heat, depending on its composition, it opposes the flow of electricity. The alloy should be able of conducting electricity to an appropriate temperature to perform as a heating material.

Temperature coefficient resistance

The resistance to the current flow, stated in ohms for a specific alloy varies as per the variation in the alloy's temperature. This variation is stated as percentage change from the actual room temperature resistance. Normally, with increase in temperature, resistance increases, thus a heating element as a wire, has a resistance of 1 ohms at RT (20oC or 68oF) may attain resistance up to 1.08 ohms at 650oC or 1202oF, hence 8% increase in resistance because of heating. Following diagram describes the standard resistance for the major heating alloys.



With the continuous function of a heating element, its variation in resistance should be considered while choosing an element design. Choose the hot condition then work back to return at the room temperature resistance that an element should be made. Resistance heating wire, ribbon and strip are every time offered with their mention room temperature resistance.

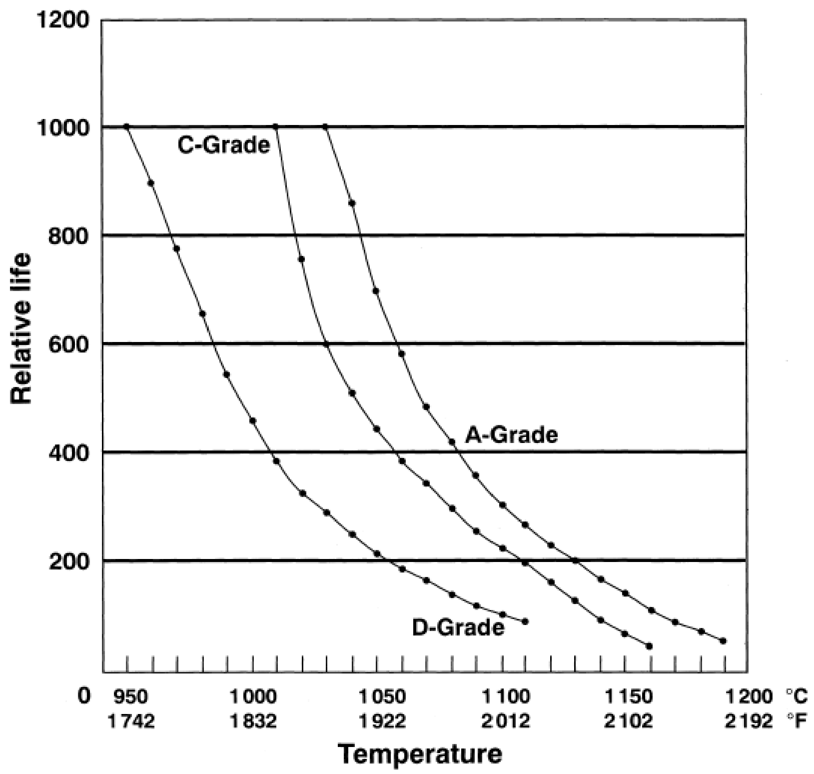
Oxide production and service life

All metals can perform as a heating element, if they do not have sufficiently very high resistance, but their cross section area should be kept very small to make it practical. After choosing an alloy as a heating element, it should have the required potential of producing an adherent oxide layer in hot form in fact while the repeated hot cold cycles.

The oxide layer tends to secure the metal beneath it from the tragic oxidation to the level of failure. It is similar to rust that keeps the under steel secured from the quick corrosion. When the surface layer is removed, it shows beneath a new surface of the steel. It is essential that oxide layer on the heating element remains isolated to protect the underlying element.

Every manufacturer when develops an alloy, a specimen wire is constructed and evaluated prior the melt is allowed for production. The evaluated is performed by a method stated in ASTM B-76 and shows life stated in hours. Following chart shows the temperatures lives of different Nichrome alloys.

Figure 11 Relative life versus temperature, experimental data*



*These data are for information only

Effect of processing on resistivity

Electric resistance is an internal property of every metal, lead by its composition as well as configuration. The resistance can be in influenced by fabricating and processing methods like cold processing and annealing processing, to the extent that they change the physical structure of the material.

Change in resistivity with cooling rate is particularly significant with bright annealed material in which processing includes annealing in a secured media then quick quenching. When the material functions at temperatures above 300oC or 572oF, resistivity may be altered from its original value, specifically if the elements are cooled slightly. The following variations may occur:

Nichrome 80/20	6 % increase
Nichrome 70/30	4% increase
Nichrome 60/15	2% increase
Nichrome 35/20	nominal increase

However, the capability for variation in resistivity of shining annealed wire or ribbon is subjected to the section size. As the light parts cool down more quickly than massive parts, light parts describe more specific influence of cooling rate on electric resistivity. The influence is maximum with Nichrome 80/20 and Nichrome 70/30, and moderate with 60/15 alloy. No considerable size effect has been noticed with 35Ni20Cr alloy.

When precise calibration of heater is essential before installation, an oxidized layer is stated for the wire or strip due to production of oxide, metal is slightly quenched in air condition from annealing temperature. No significant change in electric resistance will occur while application because its initial resistance will be stabilized by the actual annealing process close to the maximum value for alloy.

The basic resistance of annealed wire can be modified by coiling process in developing the heating element as the coiling includes cold processing. The extent of cold processing should be kept identical in the whole coil to maintain the uniform resistance and to produce coils developing uniform stretch properties. The coiling stress should be kept constant and uniform as much as possible while the coiling process without any abrupt jerks on the wire. Consistency of stretch shows the consistency of cold process and diameter across the coiled wire.

Nichrome alloy heating elements

Electric resistance heating element has been used for a prolong time. Therefore many designs are enhanced to provide excellent performance. It is essential to test the whole factors that will give design of heater that will offer a satisfactory functionality at an affordable cost. To perform this task, following factors should be taken into account:

<u>Application:</u> All heating elements are not same. They are categorized as industrial furnaces and equipments. In furnaces such as industrial heaters, cost of heating element is not crucial because of mass production. In appliances, a small mistake may cause early damage which is a critical factor as it may need to recall several devices. 1% defect may be accepted by some companies but having a defective appliance is 100% failure for a customer. The design engineer is always making attempts to prevent any issue overall.

<u>Mechanical effects</u>: if the heated equipment is to be subjected to serious mechanical shock, the method of installing the elements becomes should be given utmost importance.

<u>Temperature:</u> It is the major factor while choosing an alloy and size of a heating material. The application states the required temperature. It is also essential to differentiate between the ambient temperature and of resistance wire. In a furnace, they kept quite close, but at the other extreme in an electric teapot, the water rises to 100oC or 212oF while the wire itself may be increased to 1000oC or 1832oF. The same is followed in a super heater.

<u>Space needed</u>: The space introduced for installing the heater is normally controlled. This states that the adequate space may not be practical. For even toasting of bread in a toaster, the material should be kept away from the surface, yet offset space introduced for the equipment should be adequate.

<u>Atmosphere</u>**:** It states gases or solids to interact with the heater. The security layer in a furnace or splattering in a broiler are normally determined.

<u>Thermal cycling</u>**:** The suitable operating condition for a heating element is to remain at the constant temperature. It is normally impractical. At the elevated service temperature such as 800oC or 1472of and above, lab tests have described the regular energized heater to have long total life. Due to outstanding service life of a non-cycling heater, many tests are designed to cycle at a high rate. The

cycle time is determined by the length needed to cycle the device between stabilized test temperature and room temperature.

Safety**:** Safety is must in the appliances involving high heat or subjected to electrical conductors included. Installing the appliances behind the barriers can cause abrupt increase in temperature than expected.

Power density**:** The essential factor to be understood is power density showing a number expressing watts dissipated per unit area and is commonly called as watt loading. For greater loading applications, higher temperatures are required. It is a suitable design concept to select the maximum value as it refers to minimum magnitude of material, providing cost-effective system while offering suitable service life. It is received by a combination of the smallest conductor cross-section and suitable resistivity. In heating coils and furnace ribbons a self heating between loops is allowed by radiation from coil turns.

Nichrome 60 versus Nichrome 80

As Nichrome 80 was discovered, efforts have been made to decrease the cost of material by decreasing nickel and chromium magnitudes. Several alloys have been tested and many have been failed. In the recent years, enhancements in the alloy melting process and cleaner raw materials have encouraged the manufacturing of Nichrome 60 material with life properties similar to or even better than Nichrome 80 for several temperature limits. Nichrome 80 is preferred when the material has to be exposed to its temperature limit. Although in various applications, Nichrome C can be successfully employed as it gives a chance to cut off the cost.

As heater alloys are drawn, rolled to resistance, it is common for users to ask for an alloy be drawn to obtain the same resistance in ohms per foot similar to Nichrome 80. As Nichrome 60 has higher resistivity, the wire diameter will be nominally larger to accompany this. It refers to the application temperature, that is found by the power density, will be decreased. This temperature reduction is slight but in the correct manner, as life is inversely proportional to temperature.

Nichrome 60 is not employed in the industrial furnaces because of the net cost of overall furnace setup over the cost of heating elements, therefore Nichrome 80, 70/30 grade or 35/20 grades are employed in the furnaces.

Resistivity Data –Nichrome A and Nichrome C

			N80CR20			N60CR15			
Diameter mm)	Diameter tolerance	Cross Sectional Area (mm²)	Resistance per metre(20ºC Ω/m)	Length per kg (m/kg)	Weight Per metre (kg/m)	Resistance per metre (20ºC Ω/m)	Length per kg (m/kg)	Weight per metre (kg/m)	Toleran of materia resistan (%)
).020 mm	± 0.003	0.000314 mm2	3472	-	-	3567	-	-	± 15 %
).025 mm	± 0.003	0.000491 mm2	2220	-	-	2281	-	-	± 15 %
).028 mm	± 0.003	0.000616 mm2	1770	-	-	1818	-	-	± 15 %

).032 mm	± 0.003	0.000804 mm2	1356	-	-	1393	-	-	± 14 %
).036 mm	± 0.003	0.001018 mm2	1071	-	-	1100	-	-	± 14 %
).040 mm	± 0.004	0.001257 mm2	867	-	-	891	-	-	± 13 %
).045 mm	± 0.004	0.001591 mm2	685	74828	0.00001	704	76649	0.00001	± 13 %
).050 mm	± 0.004	0.001964 mm2	555.1	60617	0.00002	570.3	62092	0.00002	± 12 %
).060 mm	± 0.004	0.002828 mm2	385.5	42097	0.00002	396.0	43122	0.00002	± 11 %
).070 mm	± 0.005	0.003849 mm2	283.2	30930	0.00003	291.0	31683	0.00003	± 10 %
).080 mm	± 0.005	0.005027 mm2	216.9	23682	0.00004	222.8	24259	0.000041	± 10 %
).100 mm	± 0.006	0.007854 mm2	138.8	15158	0.000065	142.6	15527	0.000064	± 9 %
).120 mm	± 0.006	0.01131 mm2	96.38	10526	0.000095	99.03	10788	0.000092	± 9 %
).132 mm	± 0.007	0.01369 mm2	79.62	8697	0.00011	81.81	8907	0.00011	± 8 %
).150 mm	± 0.008	0.01767 mm2	61.68	6738	0.00014	63.38	6901	0.00014	± 8 %
).152 mm	± 0.008	0.01815 mm2	60.05	6557	0.00015	61.70	6720	0.00015	± 8 %
).170 mm	± 0.008	0.02270 mm2	48.02	5243	0.00019	49.34	5373	0.00018	± 8 %
).173 mm	± 0.008	0.02351 mm2	46.37	5062	0.00020	47.64	5186	0.00019	± 8 %
).190 mm	± 0.009	0.02835 mm2	38.44	4198	0.00023	39.50	4301	0.00023	± 8 %
).193 mm	± 0.009	0.02926 mm2	37.24	4069	0.00025	38.27	4168	0.00024	± 8 %
).210 mm	± 0.010	0.03464 mm2	31.47	3437	0.00029	32.34	3521	0.00028	± 8 %
).250 mm	± 0.010	0.04909 mm2	22.21	2425	0.00041	22.82	2484	0.00040	± 8 %
).270 mm	± 0.012	0.05726 mm2	19.04	2079	0.00048	19.56	2129	0.00046	± 7 %
).280 mm	± 0.013	0.06158 mm2	17.70	1933	0.00052	18.19	1980	0.00051	± 7 %
).290 mm	± 0.013	0.06605 mm2	16.50	1802	0.00055	16.96	1846	0.00054	± 7 %
).300 mm	± 0.013	0.07070 mm2	15.41	1684	0.00059	15.84	1724	0.00058	± 7 %
).310 mm	± 0.013	0.07548 mm2	14.44	1577	0.00063	14.84	1615	0.00061	± 7 %
).315 mm	± 0.013	0.07794 mm2	13.98	1527	0.00065	14.37	1564	0.00064	± 7 %
).345 mm	± 0.013	0.09349 mm2	11.66	1273	0.00079	11.98	1304	0.00077	± 7 %
).350 mm	± 0.013	0.09621 mm2	11.33	1237	0.00080	11.64	1267	0.00078	± 7 %
).355 mm	± 0.013	0.09899 mm2	11.01	1203	0.00083	11.31	1232	0.00081	± 7 %
).375 mm	± 0.015	0.11046 mm2	9.87	1078	0.00093	10.14	1104	0.00091	± 7 %
).400 mm	± 0.016	0.125 mm27	8.674	947	0.00105	8.913	970	0.00103	± 7 %

).450 mm	± 0.016	0.1591 mm2	6.853	748	0.00133	7.042	766	0.00130	± 7 %
).475 mm	± 0.016	0.1772 mm2	6.153	672	0.00148	6.323	688	0.00145	± 7 %
).500 mm	± 0.016	0.1963 mm2	5.551	606	0.00164	5.704	621	0.00161	± 7 %
).560 mm	± 0.016	0.2463 mm2	4.424	483.3	0.00206	4.546	495.0	0.00202	± 7 %