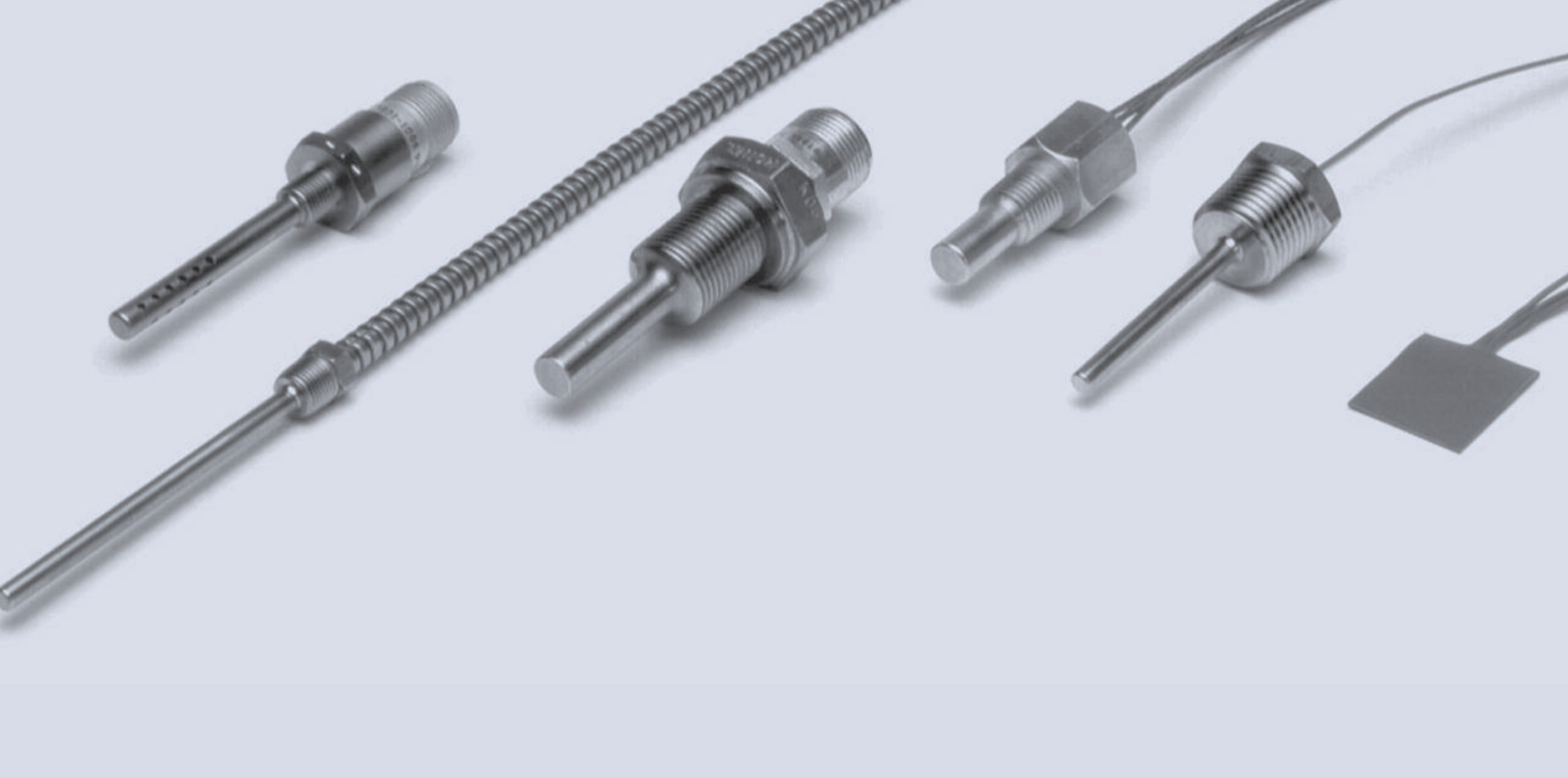


► SECTION 11: TECHNICAL INFORMATION

Your Sensors & Instruments Product Guide

How To Get Started

1. Understand and define your application requirements

Many factors should be a part of the sensor system design process. The factors listed below can help you define the sensing requirements for your application.

Define the typical and extremes of these environmental conditions:

- minimum and maximum temperatures
- pressure
- humidity
- shock
- vibration
- flow rate

Also ask:

- What is the sensed medium (a surface or immersed in solid, liquid or gas)?
- Is the medium chemically reactive (corrosive) or hazardous (explosive)?
- Is there high electromagnetic interference potential from power switching, rectification, or radio waves?

Finally, define the significance of these performance specifications in your application?

- sensing accuracy at a calibration point and/or over a temperature span
- repeatability
- stability
- sensor time constant
- insulation resistance

2. Determine which sensing technology options meet your requirements

Several potential sensing technologies may meet the essential environmental and performance specifications of your application. This section of the *Sensors and Instruments Product Guide* will provide you with a basic understanding of Minco's sensing and instrumentation technology. For more information go to www.minco.com.

3. Compare sensor construction alternatives for best fit and ease of use

While a sensing technology may appear to be capable of meeting the requirements of your application, the actual sensor packaging and construction must be evaluated in order to select the optimal cost/performance balance from the available technology options.

Regardless of which sensing technology you consider, the packaging of the sensor introduces some level of specification compromise in terms of cost, performance or durability. Use this guide to compare Minco's various sensor constructions and instrumentation solutions to find the best fit for your application.

4. Obtain parts for testing as prototypes in your application

Minco has a wide selection of standard sensor components that can often be used for prototype testing and production systems. We would appreciate the opportunity to discuss your application with you. We can help ensure that the right sensor construction is selected for your application as well as any accessory components. Often times, we are able to offer recommendations for customization to improve performance and/or lower installed cost.

Order sensors and instruments easily online with our Sensors Configurator at www.minco.com or contact Minco Sales and Customer Service today to talk to an engineer about your application.

Many Industry Applications

Process Control and Building Automation

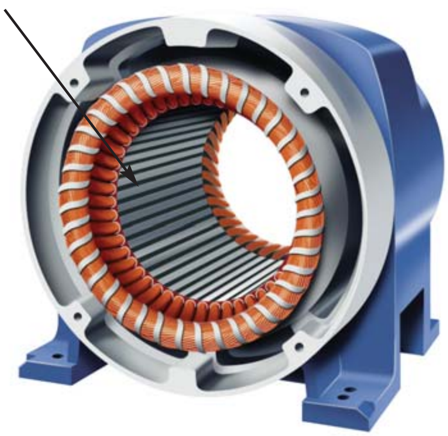
Minco temperature and humidity sensors and instruments are used in process and HVAC/R applications in the most critical environments. Our sensing solutions achieve the lowest total cost of ownership (TCO) while maintaining accuracy, reliability and ease of installation.

The Thermal-Vial Temperature Sensing System encompasses a wire-wound RTD element capable of -200°C operation to provide accurate measurement and documentation of freezing, process and storage methodology.

Machinery and Motor Protection

Minco RTDs and Thermocouples are used worldwide to safeguard valuable rotating apparatus machinery. Accurate and fast-responding temperature measurement provides overtemperature protection, and our sensors can be manufactured to integrate with any instrumentation package.

Bearing and stator sensors provide accurate sensing in this motor component while Minco's 12-channel temperature monitor (CT224) provides easy and efficient thermal protection.



Defense and Aerospace

Minco temperature sensors are used when ruggedness and reliability are key to an applications success. Our sensors can be manufactured to fit in the smallest spaces or across wide expanses. Fast time response and wide temperature capabilities (from -260°C to 650°C) handle nearly any type of harsh or extreme environment.

RTDs monitor the temperature of a heated windshield.

Flexible Thermal-Ribbons sense wing surface temperatures for wing surface de-icing.

Temperature sensors in hydraulic lines monitor fluid temperatures to prevent overheating.

Industrial and Commercial Equipment

Minco products are manufactured to provide dependability and repeatability in any application. Our sensors and instruments are used in industrial and commercial equipment to ensure accurate process and quality output.

Fast response RTDs monitor oil temperature for perfect cooking results.

Designed for Optimal Performance

Minco offers the perfect fit for any temperature and humidity sensing application. From miniature detectors to 100 foot averaging thermometer and heavy duty probe assemblies, our selection lets you choose the best model for your needs.

Sensing technology options provide flexibility

Minco can supply sensors to work with nearly any type of instrument option.

- Resistance Temperature Detectors (RTDs)
  - Platinum RTDs with wide range of TCRs
    - Range from 0.00375 to 0.003927
    - 0.00385 (Minco element "PD") is most popular
  - Nickel, copper, and nickel-iron RTD elements
  - Non-standard resistance-temperature curves
  - Base resistances up to thousands of ohms
  - Thin film or wire wound constructions
- Thermistor temperature sensors
- Thermocouple temperature sensors
- Integrated Circuit temperature sensors
- High accuracy humidity sensors and transmitters
- Signal conditioning
  - Linearizing transmitters with 4 to 20 mA, 1 to 5 VDC or other voltage/current outputs, and HART® Protocol
- Explosionproof temperature and humidity sensor and transmitter assemblies
- Controllers, monitors and alarms for optimal compatibility with sensors

From simple elements to complex assemblies

Minco can configure a sensor style to best fit your application and capabilities:

- Basic sensing elements for assembly into your own housing or protective sheath
- Addition of leadwires and terminations to elements
- Packaging into protective sheaths, laminates, custom housings, cabling
- Bendable case designs or preformed to your specifications
- Assembly with fittings, connection heads, thermowells, connectors, feedthroughs
- Assembly with signal conditioning electronics, standard or customized
- Certified measurement and test in our metrology lab
- Certified designs for hazardous locations

Machining and materials

A sensor's construction has a large impact on its thermal time response and resistance to corrosive media. Minco has an advanced machine shop with CAD/CAM capability for economic production of cases and fittings.

We have extensive machining capabilities in a variety of materials:

- Stainless steel in various grades
- Brass
- Copper
- Monel
- Hastelloy
- Titanium
- Rubber, PTFE, plastics

We can plate with nickel, gold, and other metals. Additional services include electro-polishing, passivating, and pressure testing.

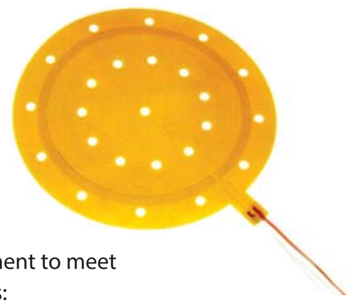
Leadwires

Sensors may be furnished with many different types of leadwire and cables to meet application parameters:

- PTFE, silicone rubber, polyimide, Tefzel, PVC, mica/glass, and glass braid insulation over silver or nickel plated copper wire are common selections or specify your own leadwire or cable requirements
- Stainless steel overbraid or flexible armor
- Flat ribbon leads or sensor/flex circuit hybrids

Lamination

Minco's winding and lamination technology enables manufacture of flat, flexible sensors in any size or shape. The custom Thermal-Ribbon™ below has a wire element to average temperatures over its entire area.



Testing

Minco has complete in-house testing and metrology equipment to meet stringent quality requirements:

- NIST traceable calibrations
- Hydrostatic testing of thermowells
- Helium leak testing
- Automated resistance measurement
- Humidity testing

Designing for accuracy

How accurate is a temperature sensor? To many, the answer to this question is the sensor's interchangeability specification. For example, 100 Ω platinum RTDs are typically interchangeable within 0.1 Ω (0.3°C) at 0°C.

But interchangeability only tells how closely the electrical characteristics of a sensor conform to its published tables. What you really want to know is how much the temperature seen at your readout or controller deviates from the actual temperature of the material you are sensing. Interchangeability is only one of the potential sources of error in the system, and it is usually not the largest. Following are some other error modes along with suggested solutions.

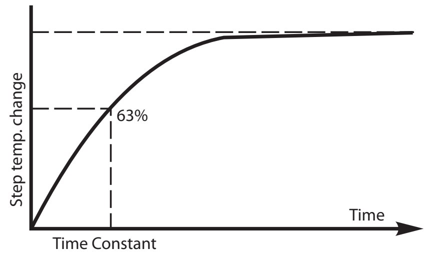
Repeatability/stability: Repeatability tells how well the sensor repeats subsequent readings at the same temperature. Stability is the absence of long term drift. In many cases, the user is less concerned with absolute accuracy than with the ability of a sensor to maintain a process at the same point once properly set.

Solution: Platinum RTDs are the most stable sensor in common use and are used to interpolate over the standard temperature scale from -260 to 962°C. Ordinary industrial models will drift less than 0.1°C per year in normal use.

Time lag: When temperatures change rapidly, sensors may not keep up.

Solution: Minco specializes in fast response RTDs. Most models in this guide have a time constant of 2 seconds or less. Certain custom-designed models are faster yet.

Time constant is defined as the time it takes a sensor to reflect 63% of a step temperature change:



Conduction errors: Heat conducted into sensors from ambient air alters the temperature of the sensing tip.

Solution: Use smaller sensors or tip-sensitive probes, and be sure they are sufficiently immersed or embedded in the sensed medium.

Point sensing errors: In places where temperatures are stratified or gradients are large, the temperature at a single point may be unrepresentative or misleading.

Solution: Use temperature averaging probes or Thermal-Ribbons.

Leadwire resistance: Resistance in the leads between RTDs and control points elevates apparent readings.

Solutions:

- Specify sensors with higher resistances.
- Use 3 or 4-wire compensating circuits (see page 11-9).
- Eliminate leadwire effects with a 4 to 20 mA transmitter.

Self-heating: The measuring current through an RTD can raise its temperature above the true value.

Solution: As a general rule, limit current to 5 mA for industrial applications. Most Minco RTDs, and especially Thermal-Ribbons, have a large surface area to dissipate heat and reduce self-heating effects.

Custom designs

If you have special requirements - or an OEM design - Minco can typically manufacture a custom sensor solution to improve accuracy and reduce cost at the same time. Contact Minco Sales and Customer Service today to discuss your application.

Temptran™ Transmitter Solutions

Why use Temptrans?

Long distance accuracy

Temptran transmitters amplify the low-level signals from RTDs or thermocouples to an industry-standard 4 to 20 mA current signal proportional to temperature or HART® Protocol/output. Unlike resistance or voltage, current signals are immune to resistance in extension wires and stray electrical noise. This lets you receive accurate signals from a sensor located thousands of feet away.

The 4 to 20 mA or HART® output signal and DC power share the same wire pair. You don't need to run power wires to every sensor location. In fact, using HART® transmitters configured in multidrop mode, up to 15 transmitters can be connected in parallel on the same pair of wires.

RTD transmitters also linearize the signal to temperature, making them excellent low cost signal conditioners. Their signal increases from 4mA at the lowest temperature to 20mA at the highest temperatures.

Engineered for reliability

Over 500,000 Minco transmitters are currently giving trouble-free service in installations around the world. Two factors behind Temptran's exceptional stability and longevity are:

- Minco encapsulates all electronics in epoxy to exclude contaminants and protect components.
- Standard fixed-range transmitters feature ±5% adjustability using 20 turn trimpots. Because a complete rotation of the trimpot represents only 0.25% of the adjustment range, slight movements from mechanical shock cause only negligible output change. In contrast, many competitive transmitters have wide ranging zero and span. With zero and span far more sensitive to potentiometer shifts, a minor bump can void the transmitter's calibration.

See Section 4 for complete details and ordering information.

Easy to install

Compact Temptrans fit nearly anywhere. You can install most models in standard electrical utility boxes and elbows. Or Minco offers a complete selection of complementary connection heads in Section 3.

Intrinsic safety

Most Temptrans are rated intrinsically safe by Factory Mutual (FM), a recognized testing authority for safety in hazardous areas. Division 1 installations must include a suitable barrier. Go to www.minco.com for a list of barriers FM approved under the system concept for use with Temptrans.

Special high-accuracy calibration

Standard transmitters can be calibrated to the nominal resistance values of the RTD at the zero and span points. Total system error includes the tolerance of both the transmitter and the RTD sensor. If you order Minco Temptrans match calibrated to the actual resistance of the RTD (traceable to NIST), this effectively eliminates the sensor tolerance from the system accuracy specifications.

Temptrans match calibrated to a sensor are always ordered as assemblies. Common examples are shown in Section 1.

For example, consider a transmitter with a range of 0 to 500°C. The transmitter itself is accurate to ±1.0°C (±0.2% of span, including calibration accuracy and linearity). The RTD inter-changeability contributes an additional error of ±0.3°C at 0°C and ±2.8°C at 500°C. Total system error would be ±1.3°C at 0°C and ±3.8°C at 500°C. Calibration of the sensor and transmitter as a set cancels the sensor error, reducing system error to ±1.0°C over the full range — all for a nominal extra cost. Get more information on page 4-22.

RTD, Thermocouple, or Thermistor?

Resistance temperature detectors (RTDs)

An RTD sensing element consists of a wire coil or deposited film of pure metal. The element's resistance increases with temperature in a known and repeatable manner. RTDs exhibit excellent accuracy over a wide temperature range and represent the fastest growing segment among industrial temperature sensors. Their advantages include:

- **Temperature range:** Minco models cover temperatures from -260 to 650°C (-436 to 1202°F).
- **Repeatability and stability:** The platinum resistance thermometer is the primary interpolation instrument used by the National Institute of Standards and Technology from -260 to 962°C. Ordinary industrial RTDs typically drift less than 0.1°C/year.
- **Sensitivity:** The voltage drop across an RTD provides a much larger output than a thermocouple.
- **Linearity:** Platinum and copper RTDs produce a more linear response than thermocouples or thermistors. RTD non-linearities can be corrected through proper design of resistive bridge networks.
- **Low system cost:** RTDs use ordinary copper extension leads and require no cold junction compensation.
- **Standardization:** Manufacturers offer RTDs to industry standard curves, most commonly 100 Ω platinum to EN60751 (Minco element code PD or PM).

Thermocouples

A thermocouple consists of two wires of dissimilar metals welded together into a junction. At the other end of the signal wires, usually as part of the input instrument, is another junction called the reference junction, which is electronically compensated for its ambient temperature. Heating the sensing junction generates a thermoelectric potential (emf) proportional to the temperature difference between the two junctions. This millivolt-level emf, when compensated for the known temperature of the reference junction, indicates the temperature at the sensing tip.

Thermocouples are simple and familiar. Designing them into systems, however, is complicated by the need for special extension wires and reference junction compensation. Thermocouple advantages include:

- **Extremely high temperature capability:** Thermocouples with precious metal junctions may be rated as high as 1800°C (3272°F).
- **Ruggedness:** The inherent simplicity of thermocouples makes them resistant to shock and vibration.
- **Small size/fast response:** A fine-wire thermocouple junction takes up little space and has low mass, making it suitable for point sensing and fast response. Note, however, that many Minco RTDs have time constants faster than equivalent thermocouples.

Thermistors

A thermistor is a resistive device composed of metal oxides formed into a bead and encapsulated in epoxy or glass. A typical thermistor shows a large negative temperature coefficient. Resistance drops dramatically and non-linearly with temperature. Sensitivity is many times that of RTDs but useful temperature range is limited. Some manufacturers offer thermistors with positive coefficients. Linearized models are also available.

There are wide variations of performance and price between thermistors from different sources. Typical benefits are:

- **Low sensor cost:** Basic thermistors are quite inexpensive. However, models with tighter interchangeability or extended temperature ranges often cost more than RTDs.
- **High sensitivity:** A thermistor may change resistance by tens of ohms per degree temperature change, versus a fraction of an ohm for RTDs.
- **Point sensing:** A thermistor bead can be made the size of a pin head for small area sensing.

	RTD	Thermocouple	Thermistor
Temp. range	-260 to 850°C (-436 to 1562°F)	-270 to 1800°C (-454 to 3272°F)	-80 to 150°C (-112 to 302°F) (typical)
Sensor cost	Moderate	Low	Low
System cost	Moderate	High	Moderate
Stability	Best	Low	Moderate
Sensitivity	Moderate	Low	Best
Linearity	Best	Moderate	Poor
Specify for:	• General purpose sensing • Highest accuracy • Temperature averaging	• Highest temperatures	• Best sensitivity • Narrow ranges (e.g. medical) • Point sensing

TECHNICAL INFORMATION

Choosing Sensor Elements

RTD element types

Platinum is the most widely specified RTD element type due to its wide temperature range, stability, and standardization between manufacturers. Copper, nickel, and nickel-iron can offer comparable accuracy at lower cost in many applications.

Element material	Temperature range	Benefits	Typical base resistance	Sensitivity (Avg. Ω/°C, 0 to 100°C)	TCR Ω/Ω/°C
Platinum	-260 to 650°C (-436 to 1202°F)	• Greatest range • Best stability • Good linearity	100 Ω at 0°C 1000 Ω at 0°C	0.39 3.90	0.00375 to 0.003927
Copper	-100 to 260°C (-148 to 500°F)	• Best linearity	10 Ω at 25°C	0.04	0.00427
Nickel	-100 to 260°C (-148 to 500°F)	• Low cost • High sensitivity	100 Ω at 0°C 120 Ω at 0°C	0.62 0.81	0.00618 0.00672
Nickel-iron	-100 to 204°C (-148 to 400°F)	• Low cost • Highest sensitivity	604 Ω at 0°C 1000 Ω at 70°F 2000 Ω at 70°F	3.13 4.79 9.58	0.00518 to 0.00527

RTD and thermistor interchangeability

The tables below show temperature tolerance — the allowable deviation from nominal curves — for RTDs and thermistors in this guide. Minco can supply sensors with tighter overall tolerance, or with the narrowest tolerance at a point other than 0°C.

Temperature °C	Interchangeability						
	Platinum RTD						
	0.06% at 0°C (Class A)	0.1% at 0°C (Class B)	0.22% at 0°C	0.36% at 0°C	0.5% at 0°C	0.1% at 70°F	0.24% at 70°F
-200	±0.55°C	±1.3°C			±2.1°C		
-100	±0.35°C	±0.8°C	±1.3°C		±1.7°C		
0	±0.15°C	±0.3°C	±0.5°C	±0.9°C	±1.3°C	±0.3°C	±0.7°C
20	±0.19°C	±0.4°C	±0.7°C	±1.3°C	±1.6°C	±0.3°C	±0.6°C
100	±0.35°C	±0.8°C	±1.8°C	±2.3°C	±2.9°C	±0.7°C	±1.1°C
200	±0.55°C	±1.3°C	±3.1°C	±3.7°C	±4.4°C	±1.3°C	±1.8°C
260	±0.67°C	±1.6°C	±3.7°C	±4.6°C	±5.5°C		
300	±0.75°C	±1.8°C					
400	±0.95°C	±2.3°C					
500	±1.15°C	±2.8°C					
600	±1.35°C	±3.3°C					
700		±3.8°C					
800		±4.3°C					
850		±4.6°C					

Temperature °C	Interchangeability									
	Copper RTD		Nickel RTD		Nickel-iron RTD					Thermistor
	±0.2% at 25°C	±0.5% at 25°C	±0.3% at 25°C	±0.5% at 0°C	±0.26% at 0°C	±0.5% at 0°C	±0.5% at 25°C	±0.12% at 70°F	±0.25% at 70°F	±0.1% at 0°C
-100	±1.5°C	±2.2°C				±2.5°C	±2.9°C			
0	±0.7°C	±1.5°C	±0.5°C	±0.8°C	±0.6°C	±1.1°C	±1.4°C	±0.5°C	±1.4°C	±0.2°C
20	±0.5°C	±1.3°C	±0.8°C	±1.2°C	±0.8°C	±1.4°C	±1.2°C	±0.3°C	±0.7°C	±0.2°C
100	±1.5°C	±2.5°C	±1.8°C	±2.2°C	±1.7°C	±2.4°C	±2.2°C	±1.1°C	±2.0°C	±0.3°C
150	±2.2°C	±3.3°C	±2.5°C	±3.0°C	±2.3°C	±3.1°C	±2.9°C	±1.6°C	±2.9°C	±1.0°C
200	±2.8°C	±4.1°C	±3.1°C	±3.7°C	±2.9°C	±3.8°C	±3.6°C	±2.1°C	±3.8°C	
260	±3.6°C	±5.1°C	±3.4°C	±4.0°C						

Thermocouple limits of error per NBS (NIST) Monograph 175, based on ITS-90

Junction type:	E (Chromel-Constantan)	J (Iron-Constantan)	K (Chromel-Alumel)	T (Copper-Constantan)
Limits of error:	±1.7°C or ±0.5% 0 to 900°C	±2.2°C or ±0.75% 0 to 750°C	±2.2°C or ±0.75% 0 to 1250°C	±1.0°C or ±0.75% 0 to 350°C

RTD Connections: 2-Wire, 3-Wire, 4-Wire?

Because an RTD is a resistance type sensor, resistance introduced by connecting copper extension wires between the RTD and control instrument will add to readings. Furthermore, this additional resistance is not constant but increases with ambient temperature. To estimate leadwire error in 2-wire circuits, multiply the total length of the extension leads times the resistance per foot in the table below. Then divide by the sensitivity of the RTD, given in the next two pages, to obtain an error figure in °C. For example, assume you have connected 100 feet of AWG 22 wires to a 100 Ω platinum RTD (PD element). Lead resistance is:

$R = (200\ ft.) \times (0.0165\ \Omega / ft.) = 3.3\ \Omega$

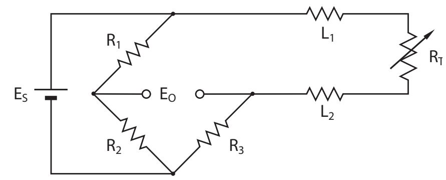
Approximate error is:

$$E = \frac{3.3\,\Omega}{0.385\,\Omega / °C} = 8.6\,°C$$

Copper Leadwire AWG	Ohms/ft. at 25°C
12	0.0016
14	0.0026
16	0.0041
18	0.0065
20	0.0103
22	0.0165
24	0.0262
26	0.0418
28	0.0666
30	0.1058

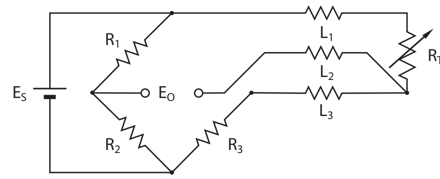
You can reduce leadwire error by:

- Using larger gauge extension wires.
- Specifying an RTD with greater sensitivity; 1000 Ω instead of 100 Ω, for example.
- Employing a 3 or 4-wire resistance canceling circuit as shown at right. Common leads, connected to the same end of the sensing element, are the same color.
- Using a 2-wire current transmitter. Its linearized signal is immune to electrical noise as well as resistance and can maintain accuracy over runs of several thousand feet. See Section 4 for more information on temperature transmitters.



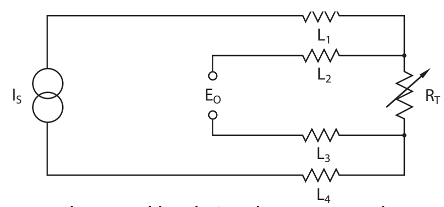
2-wire circuit

Shown above is a 2-wire RTD connected to a typical Wheatstone bridge circuit. E_S is the supply voltage; E_O is the output voltage; R_1, R_2, and R_3 are fixed resistors; and R_T is the RTD. In this uncompensated circuit, lead resistances L_1 and L_2 add directly to R_T.



3-wire circuit

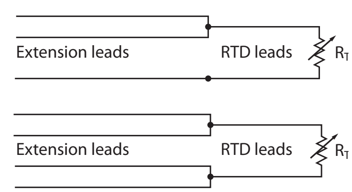
In this circuit there are three leads coming from the RTD instead of two. L_1 and L_3 carry the measuring current while L_2 acts only as a potential lead. No current flows through it while the bridge is in balance. Since L_1 and L_3 are in separate arms of the bridge, resistance is canceled. This circuit assumes high impedance at E_O and close matching of resistance between wires L_1 and L_3. Minco matches RTD leads within 5%.



4-wire circuit

4-wire RTD circuits not only cancel leadwires but remove the effects of mismatched resistances such as contact points. A common version is the constant current circuit shown above. I_S drives a precise measuring current through L_1 and L_4. L_2 and L_3 measure the voltage drop across the RTD element. E_O must have high impedance to prevent current flow in the potential leads. 4-wire circuits may be usable over longer distances than 3-wire, but you should consider using a transmitter in electrically noisy environments.

If necessary you can connect a 2-wire RTD to a 3-wire circuit or 4-wire circuit, as shown to the right. As long as the junctions are near the RTD, as in a connection head, errors are negligible.



Resistance/Temperature Tables

Platinum elements												
Element code	PJ	PA	PB	PD, PE*	PN	PL	PH	PP	PG	PF	PW	PS
Resistance at 0°C	25.5 Ω	100 Ω	100 Ω	100 Ω	200 Ω	470 Ω	500 Ω	500 Ω	500 Ω	1000 Ω	1000 Ω	10k Ω
TCR (Ω/Ω/°C)	0.00392	0.00392	0.00391	0.00385	0.00385	0.00392	0.00392	0.00391	0.00385	0.00385	0.00375	0.00385
Sensitivity (Average Ω/°C)	0.1	0.392	0.391	0.385	0.77	1.845	1.963	1.955	1.925	3.85	3.75	38.5
Temperature (°C)	Resistance (ohms)											
-200	4.33	17.00	17.26	18.52	37.04	79.88	84.98	86.30	92.60	185.20		1,852
-180	6.56	25.72	25.97	27.10	54.19	120.88	128.59	129.84	135.48	270.96		2,710
-160	8.75	34.31	34.54	35.54	71.09	161.28	171.57	172.72	177.72	355.43		3,554
-140	10.91	42.80	43.01	43.88	87.75	201.15	213.99	215.03	219.38	438.76		4,388
-120	13.05	51.19	51.37	52.11	104.22	240.57	255.93	256.83	260.55	521.10		5,211
-100	15.17	59.49	59.64	60.26	120.51	279.58	297.43	298.19	301.28	602.56		6,026
-80	17.27	67.71	67.83	68.33	136.65	318.23	338.55	339.17	341.63	683.25		6,833
-60	19.35	75.87	75.96	76.33	152.66	356.57	379.53	379.80	381.64	763.28		7,633
-40	21.41	83.96	84.03	84.27	168.54	394.63	419.82	420.13	421.35	842.71	846.57	8,427
-20	23.46	92.01	92.04	92.16	184.32	432.43	460.03	460.19	460.80	921.60	923.55	9,216
0	25.50	100.00	100.00	100.00	200.00	470.00	500.00	500.00	500.00	1000.00	1000.00	10,000
20	27.53	107.95	107.92	107.79	215.59	507.35	539.73	539.58	538.96	1077.94	1075.96	10,779
40	29.54	115.85	115.78	115.54	231.08	544.47	579.23	578.92	577.70	1155.41	1151.44	11,554
60	31.54	123.70	123.60	123.24	246.48	581.38	618.49	618.02	616.21	1232.42	1226.44	12,324
80	33.53	131.50	131.38	130.90	261.79	618.06	657.51	656.90	654.48	1308.97	1300.96	13,090
100	35.51	139.26	139.11	138.51	277.01	654.53	696.31	695.54	692.53	1385.06	1375.00	13,851
120	37.48	146.97	146.79	146.07	292.14	690.77	734.86	733.94	730.34	1460.68	1448.56	14,607
140	39.43	154.64	154.42	153.58	307.17	726.79	773.18	772.11	767.92	1535.84	1521.63	15,358
160	41.37	162.25	162.01	161.05	322.11	762.59	811.27	810.05	805.27	1610.54	1594.22	16,105
180	43.31	169.82	169.55	168.48	336.96	798.18	849.12	847.75	842.39	1684.78	1666.33	16,848
200	45.22	177.35	177.04	175.86	351.71	833.54	886.74	885.22	879.28	1758.56	1737.96	17,586
220	47.13	184.82	184.49	183.19	366.38	868.68	924.12	922.46	915.94	1831.88	1809.11	18,319
240	49.02	192.25	191.89	190.47	380.95	903.59	961.27	959.46	952.36	1904.73	1879.78	19,047
260	50.91	199.64	199.24	197.71	395.42	938.29	998.18	996.22	988.56	1977.12	1949.96	19,771
280	52.78	206.97	206.55	204.91	409.81	972.77	1034.86	1032.76	1024.52	2049.05	2019.67	20,490
300	54.64	214.26	213.81	212.05	424.10	1007.03	1071.31	1069.06	1060.26	2120.52	2088.89	21,205
320	56.48	221.50	221.02	219.15	438.30	1041.06	1107.51	1105.12	1095.76	2191.52	2157.63	21,915
340	58.32	228.70	228.19	226.21	452.41	1074.88	1143.49	1140.95	1131.03	2262.06	2225.89	22,621
360	60.14	235.85	235.31	233.21	466.43	1108.47	1179.23	1176.55	1166.07	2332.14	2293.67	23,321
380	61.95	242.95	242.38	240.18	480.35	1141.85	1214.73	1211.91	1200.88	2401.76	2360.96	24,018
400	63.75	250.00	249.41	247.09	494.18	1175.00	1250.00	1247.04	1235.46	2470.92	2427.78	24,709
420	65.54	257.01	256.39	253.96	507.92	1207.93	1285.03	1281.94	1269.81	2539.62	2494.11	25,396
440	67.31	263.97	263.32	260.79	521.57	1240.64	1319.83	1316.60	1303.92	2607.85	2559.96	26,078
460	69.07	270.88	270.21	267.56	535.12	1273.14	1354.40	1351.03	1337.81	2674.62	2625.33	26,756
480	70.83	277.75	277.04	274.29	548.59	1305.41	1388.73	1385.22	1371.46	2742.93	2690.22	27,429
500	72.56	284.57	283.84	280.98	561.96	1337.46	1422.83	1419.18	1404.89	2808.78	2754.63	28,098
520	74.29	291.34	290.58	287.62	575.23	1369.28	1456.69	1452.91	1438.08	2876.16		28,762
540	76.01	298.06	297.28	294.21	588.42	1400.89	1490.31	1486.40	1471.04	2942.08		29,421
560	77.71	304.74	303.93	300.75	601.51	1432.28	1523.70	1519.66	1503.77	3007.54		30,075
580	79.40	311.37	310.54	307.25	614.51	1463.45	1556.86	1552.68	1536.27	3072.54		30,725
600	81.08	317.96	317.09	313.71	627.42	1494.39	1589.78	1585.47	1568.54	3137.08		31,371
620	82.75	324.49	323.60	320.12	640.23	1525.12	1622.47	1618.02	1600.58	3201.16		
640	84.40	330.98	330.07	326.48		1555.62	1654.92	1650.35				
660	86.04	337.43	336.49	332.79		1585.91	1687.14	1682.43				
680	87.67	343.82	342.86	339.06		1615.97	1719.12	1714.29				
700	89.29	350.17	349.18	345.28		1645.81	1750.87	1745.91				
720				351.46								
740				357.59								
760				363.67								
780				369.71								
800				375.70								
820				381.65								
840				387.55								
850				390.48								

** PD is the most common platinum sensor element used by industry. PE has a wider manufacturing tolerance than PD.*
Note: More element options and complete tables in 1°C or 1°F increments are available from Minco at www.minco.com/

Resistance/Temperature Tables

Most RTD tables follow the modified Callendar-Van Dusen equation:

$$R_t = R_0\left[1 + At + Bt^2 + Ct^3\right]$$

or some variation thereof, where R_t is the modified resistance at temperature t, R_0 is the ice point resistance, and A, B, and C are coefficients describing a given thermometer. Download Minco's white paper entitled *Resistance Thermometry: Principles and Applications of Resistance Thermometers and Thermistors* at www.minco.com for a complete set of equations and coefficients for numerical calculation of resistance vs temperature.

	Copper	Nickel	Nickel-iron			Thermistors			
Element code	CA	NA	FA	FB	FC	TA	TB	TF	TK
Base resistance	10 Ω at 25°C	120 Ω at 0°C	604 Ω at 0°C	1000 Ω at 70°F	2000 Ω at 70°F	2252 Ω at 25°C	10k Ω at 25°C	50k Ω at 25°C	10k Ω at 25°C
TCR (Ω /Ω /°C)	.00427	.00672	.00518	.00527	.00527	$R_{25}/R_{125} = 29.2$	$R_{25}/R_{125} = 23.5$	$R_{25}/R_{125} = 31.2$	$R_{25}/R_{125} = 26.6$
Sensitivity (Average Ω/°C)	0.039	0.806	3.133	4.788	9.576	-72	-287	-1523	-324
Temperature (°C)	Resistance (ohms)								
-100	5.128		372.79						
-80	5.923	66.60	410.73			1660 K	3558 K		
-60	6.712	79.62	452.82			316.5 K	845.9 K		
-40	7.490	92.76	499.06			75.79 K	239.8 K	1380 K	348.9 K
-20	8.263	106.15	549.46	826.90	1653.81	21.87 K	78.91 K	431.8 K	100.2 K
0	9.035	120.00	604.00	908.40	1816.81	7355	29.49 K	155.6 K	33.15 K
20	9.807	134.52	660.97	995.04	1990.09	2814	12.26 K	62.24 K	12.52 K
40	10.580	149.79	720.79	1086.49	2172.99	1200	5592	26.64 K	5323
60	11.352	165.90	783.45	1182.50	2365.01	560.3	2760	12.31 K	2510
80	12.124	182.84	848.97	1282.83	2565.66	282.7	1458	6117	1293
100	12.897	200.64	917.33	1387.21	2774.44	152.8	816.8	3256	718.5
120	13.669	219.29	988.54	1495.42	2990.84	87.7	481.8	1836	425.0
140	14.442	238.85	1062.60	1607.18	3214.37	53.0	297.2		
160	15.217	259.30	1139.50	1722.26	3444.54				
180	15.996	280.77	1219.26	1840.41	3680.84				
200	16.776	303.46	1301.86	1961.38	3922.77				
220	17.555	327.53							
240	18.335	353.14							
260	19.116	380.31							

Note: More element options and complete tables in 1°C or 1°F increments are available from Minco at www.minco.com

Thermocouple Voltage/Temperature Tables

Junction type:	E Chromel-Constantan + − Purple Red	J Iron-Constantan + − White Red	K Chromel-Alumel + − Yellow Red	T Copper-Constantan + − Blue Red
Sensitivity (mV/°C):	0.063	0.053	0.041	0.043
Temperature (°C)	Millivolts			
-200	-8.824	-7.890	-5.891	-5.603
-150	-7.279	-6.499	-4.912	-4.648
-100	-5.237	-4.632	-3.553	-3.378
-50	-2.787	-2.431	-1.889	-1.819
0	0.000	0.000	0.000	0.000
50	3.047	2.585	2.022	2.035
100	6.317	5.268	4.095	4.277
150	9.787	8.008	6.137	6.702
200	13.419	10.777	8.137	9.286
250	17.178	13.553	10.151	12.011
300	21.033	16.325	12.207	14.860
350	24.961	19.089	14.292	17.816
400	28.943	21.846	16.395	20.869
450	32.960	24.607	18.513	
500	36.999	27.388	20.640	
550	41.045	30.210	22.772	

Note: Complete tables in 1°C or 1°F increments are available from Minco at www.minco.com

Temperature Coefficient of Resistance (TCR)

TCR differentiates RTDs by their resistance/temperature curves. Sometimes called alpha (α), it is specified in various ways by different manufacturers.

In this guide TCR is the RTD's resistance change from 0 to 100°C, divided by the resistance at 0°C, divided by 100°C:

$$TCR(\Omega/\Omega/°C)=\frac{R_{100°C}-R_{0°C}}{R_{0°C}\times 100°C}$$

For example, a platinum thermometer measuring 100 Ω at 0°C and 139.11 Ω at 100°C has TCR 0.00391 Ω/Ω/°C:

$$TCR=\frac{139.11\,\Omega-100\,\Omega}{100\,\Omega\times 100°C}$$

For a copper RTD, 10 Ω at 25°C, TCR is:

$$TCR=\frac{12.897\,\Omega-9.035\,\Omega}{9.035\,\Omega\times 100°C}=0.00427$$

Stated another way, TCR is the average resistance increase per degree of a hypothetical RTD measuring 1 Ω at 0°C.

The most common use of TCR is to distinguish between curves for platinum, which is available with TCRs ranging from 0.00375 to 0.003927. The highest TCR indicates the highest purity platinum, and is mandated by ITS-90 for standard platinum thermometers.

There are no technical advantages of one TCR versus another in practical industrial applications. 0.00385 platinum is the most popular worldwide standard and is available in both wire-wound and thin-film elements.

In most cases, all you need to know about TCR is that it must be properly matched when replacing RTDs or connecting them to instruments.

SensorCalc Program

RTD and thermocouple tables are available online at www.minco.com

You can create and store tables in a variety of formats. You can also enter resistances and coefficients for custom tables, using Callendar-Van Dusen or ITS-90 equations.

Miscellaneous Specifications and Codes

Thread specifications

Thread	Applicable specifications
G½	• ISO 228/1 • DIN 259 • BS 2779 • JIS B0202
R¼ R⅛	• ISO 7/1 • DIN 2999 • BS 21 • JIS B0203

Wire gauge conversion

Wire Gauge Number AWG	Cross Sectional Area mm²		Resistance Ω/ft. at 25°C
	Stranded	Solid	
30	0.057	0.051	0.1058
28	0.089	0.080	0.0666
26	0.141	0.128	0.0418
24	0.227	0.205	0.0262
22	0.355	0.324	0.0165
20	0.563	0.519	0.0103
18	0.897	0.823	0.0065

Ingress Protection (IP) Codes

	First Number Protection against solid bodies	Second Number Protection against liquid
0	No protection	No protection
1	Objects > 50 mm	Vertically dripping water
2	Objects > 12 mm	75° to 90° dripping water
3	Objects > 2.5 mm	Sprayed water
4	Objects > 1 mm	Splashed water
5	Dust-protected	Water jets
6	Dust-tight	Heavy seas
7		Effects of immersion
8		Indefinite immersion

Approximate US Enclosure Type Equivalent to IPXX					
Type	IP	Type	IP	Type	IP
1	10	3S	54	6 & 6P	67
2	11	4 & 4X	55	12 & 12K	52
3	54	5	52	13	54
3R	14				

Material Selection Guide

This guide lists the least expensive materials compatible with various corrosive media. The user should also consider unusual temperatures or levels of concentration. Contact Minco Sales and Customer Service for assistance.

Medium	°F (°C)	Material
Acetic acid	212 (100)	Monel
Acetic anhydride	300 (149)	Nickel
Acetone	212 (100)	304 SS
Acetylene	400 (204)	304 SS
Alcohols	212 (100)	304 SS
Alum. (Potassium or sodium)	300 (149)	Hastelloy C
Aluminum chloride	212 (100)	Hastelloy B
Aluminum sulfate	212 (100)	316 SS
Ammonia, dry	212 (100)	316 SS
Ammonium hydroxide	212 (100)	316 SS
Ammonium chloride 50%	300 (149)	Monel
Ammonium nitrate	300 (149)	304 SS
Ammonium sulfate	212 (100)	316 SS
Amyl acetate	300 (149)	304 SS
Aniline	25 (-4)	Monel
Asphalt	250 (121)	304 SS
Atmosphere (industrial and marine)		304 SS
Barium compounds	See calcium	
Beer	70 (21)	304 SS
Benzene	212 (100)	Steel
Benzoic acid	212 (100)	316 SS
Bleaching powder 15%	70 (21)	Monel
Borax	212 (100)	Brass
Bordeaux mixture	200 (93)	304 SS
Boric acid	400 (204)	316 SS
Bromine, dry	125 (52)	Monel
Butane	400 (204)	Steel
Butyric acid	212 (100)	Hastelloy C
Calcium bisulphite	75 (24)	Hastelloy C
Calcium chloride	212 (100)	Hastelloy C
Calcium hydroxide 20%	300 (149)	Hastelloy C
Calcium hypochlorite	See bleaching powder	
Carbolic acid	See phenol	
Carbon dioxide, dry	800	Brass
Carbonated water	212 (100)	304 SS
Carbonated beverages	212 (100)	304 SS
Carbon disulfide	200 (93)	304 SS
Carbon tetrachloride	125 (52)	Monel
Chlorine, dry	100 (38)	Monel
Chlorine, moist	100 (38)	Monel
Chloracetic acid	212 (100)	Monel
Chloroform, dry	212 (100)	Monel
Chromic acid	300 (149)	Hastelloy C
Cider	300 (149)	304 SS
Citric acid	212 (100)	Hastelloy C
Copper (10) chloride	212 (100)	Hastelloy C
Copper (10) nitrate	300 (149)	316 SS
Copper (10) sulfate	300 (149)	316 SS
Copper plating solution (cyanide)	180 (82)	304 SS
Copper plating solution (acid)	75 (24)	304 SS
Corn oil	200 (93)	304 SS
Creosote	200 (93)	304 SS
Crude oil	300 (149)	Monel
Ethyl acetate	See lacquer thinner	
Ethyl chloride, dry	500 (260)	Steel
Ethylene glycol (uninhibited)	212 (100)	304 SS
Ethylene oxide	75 (24)	Steel
Fatty acids	500 (260)	316 SS
Ferric chloride	75 (24)	Hastelloy C
Ferric sulphate	300 (149)	304 SS
Formaldehyde 40%	212 (100)	316 SS
Formic acid	300 (149)	316 SS
Freon	300 (149)	Steel
Fluorine, anhydrous	100 (38)	304 SS
Furfural	450 (232)	316 SS
Gasoline	300 (149)	Steel
Glucose	300 (149)	304 SS
Glue, pH 6-8	300 (149)	304 SS
Glycerine	212 (100)	Brass
Hydrobromic acid	212 (100)	Hastelloy C
Hydrochloric acid 37-38%	225 (107)	Hastelloy B
Hydrogen chloride, dry	500 (260)	304 SS
Hydrocyanic acid	212 (100)	304 SS

Medium	°F (°C)	Material
Hydrofluoric acid 60%	212 (100)	Monel
Hydrogen fluoride, dry	175 (79)	Steel
Hydrofluogilicic acid 40%	212 (100)	Monel
Hydrogen peroxide 10-100%	125 (52)	304 SS
Kerosene	300 (149)	Steel
Lacquers & thinners	300 (149)	304 SS
Lactic acid	300 (149)	316 SS
Lime	212 (100)	316 SS
Linseed oil	75 (24)	Steel
Magnesium chloride 50%	212 (100)	Nickel
Magnesium hydroxide (or oxide)	75 (24)	304 SS
Magnesium sulphate 40%	212 (100)	304 SS
Mercuric chloride 10%	75 (24)	Hastelloy C
Mercury 100%	700 (371)	Steel
Methylene chloride	212 (100)	304 SS
Methyl chloride, dry	75 (24)	Steel
Milk, fresh or sour	180 (82)	304 SS
Molasses	See glucose	
Natural gas	70 (21)	304 SS
Nitric acid	75 (24)	304 SS
Nitric acid	300 (149)	316 SS
Oxygen	75 (24)	Steel
Oleic acid	See fatty acids	
Oxalic acid	212 (100)	Monel
Photographic bleaching	100 (38)	304 SS
Palmitic acid	See fatty acids	
Phosphoric acid	212 (100)	316 SS
Phenol	212 (100)	316 SS
Potassium compounds	See sodium compounds	
Propane	300 (149)	Steel
Rosin 100%	700 (371)	316 SS
Sea water	75 (24)	Monel
Soap & detergents	212 (100)	304 SS
Sodium bicarbonate 20%	212 (100)	316 SS
Sodium bisulphite 20%	212 (100)	304 SS
Sodium bisulphate 20%	212 (100)	304 SS
Sodium carbinate 40%	212 (100)	316 SS
Sodium chloride 30%	300 (149)	Monel
Sodium chromate	212 (100)	316 SS
Salt or brine	See sodium chloride	
Sodium cyanide	212 (100)	304 SS
Sodium hydroxide 30%	212 (100)	316 SS
Sodium hypochlorite 10%	75 (24)	Hastelloy C
Sodium nitrate 40%	212 (100)	304 SS
Sodium nitrite 20%	75 (24)	316 SS
Sodium phosphate 10%	212 (100)	Steel
Sodium silicate 10%	212 (100)	Steel
Sodium sulfide 30%	212 (100)	316 SS
Sodium sulfite 10%	212 (100)	316 SS
Sodium sulfate 30%	212 (100)	304 SS
Sodium thiosulfate	212 (100)	304 SS
Steam		304 SS
Stearic acid	See fatty acids	
Sugar solution	See glucose	
Sulfur	500 (260)	304 SS
Sulfur chloride, dry	75 (24)	316 SS
Sulfur dioxide, dry	500 (260)	316 SS
Sulfur trioxide, dry	500 (260)	316 SS
Sulfuric acid 10%	212 (100)	316 SS
Sulfuric acid 10-90%	212 (100)	Hastelloy B
Sulfuric acid 90-100%	212 (100)	316 SS
Sulfuric acid, fuming	175 (79)	Hastelloy C
Sulfurous acid 20%	75 (24)	316 SS
Titanium tetrachloride	75 (24)	316 SS
Tannic acid 40%	75 (24)	Hastelloy B
Toluene	75 (24)	Steel
Trichloracetic acid	75 (24)	Hastelloy B
Trichloroethylene, dry	300 (149)	Monel
Turpentine	75 (24)	316 SS
Varnish	150 (66)	Steel
Zinc chloride	212 (100)	Hastelloy B
Zinc sulfate	212 (100)	316 SS