DELTACONTROLS CORPORATION

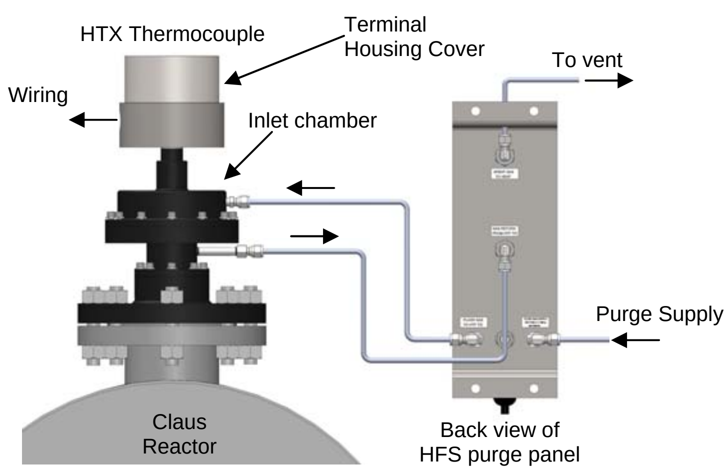
Failure Diagnosis
of
Delta Controls Model HTP or HTX Claus Thermal Reaction Furnace Thermocouple

Measurement of temperature in the Claus Thermal Sulfur Reaction furnace is a severe and demanding application. Properly installed devices must tolerate the high temperatures, thermal shock, corrosion, vibration and even some shifting refractory. In addition, without careful handling and attention to detail during installation, the thermocouples can be damaged and perhaps without the installer realizing it. If so, manifestation of any problem may not be apparent for a month or so after startup.

The following diagnostic procedures are done with the use of a digital Volt/Ohmmeter and the Delta Controls Model HFS Purge Control Station that regulates the purge gas flow and pressure through the thermocouple assembly.

I. Understanding the Delta Controls purged thermocouples.

Delta Controls Model HTP and HTX rely on the well-known temperature vs. voltage characteristics of high purity noble metal conductors to produce very accurate measurement of the high temperatures encountered in a Claus thermal reaction furnace. Even though the thermocouple is encased in a ceramic thermowell surrounded by an external separate alumina “refractory well”, the operating conditions inside a Claus reactor are severe enough that certain species of the reaction gases can slowly diffuse through the wall of the gas-tight inner “Element” Well. If the reaction gases contact the thermocouple junction, they will, over time, corrode and contaminate it, causing a gradual reduction in voltage output and an erroneously low measurement of temperature. To prevent this, a purge system is used to sweep away these corrosive gaseous elements as they migrate through the thermowell wall, before they can collect and contaminate the thermocouple junction. This provides for long thermocouple life in this very hostile environment.



The Model HFS Purge Control Station is connected to the thermocouple as shown. The purge supply is connected to the inlet of the pressure regulator. The outlet of the regulator is connected to the top inlet connection of the thermocouple (to the upper inlet purge chamber). The lower (outlet) connection of the thermocouple is connected to the inlet (bottom connection) of the flowmeter on the purge station. The outlet of the flowmeter may be connected to any vent (or left open to atmosphere).

Under normal conditions of operation, the purge pressure should be set at least 5 PSIG (0.3 barg) above the max operating pressure of the reaction furnace. The flow rate should be set and maintained at approximately 0.2 to 0.4 scfh (5-11 lph). The exact rate is not important, only that some purge gas is always flowing through the thermocouple. Excessive flow will “cool” the thermocouple and cause inaccurate readings.

II. Causes of Failure

Thermocouple failure is almost always because process gases have reached the thermocouple element wires and corroded them. This can be caused by a variety of reasons:

a. Element well **breakage** during installation. This failure is usually due to:
   i. Mishandling, improper installation / insertion.
   ii. Misalignment / improper location of the refractory borehole causing breakage by shifting refractory pushing on the inserted ceramic component parts. *The borehole must be centered and perpendicular to the vessel nozzle flange face to minimize the possibility of failure due to shifting refractory. Use of the Delta Controls H6G series Refractory drilling kit eliminates this problem*.

b. **Thermal shock** during startup. Startup should be gradual, even if refractory does not need a dry-out cycle. Generally, the recommended limit for the rate of temperature change on refractory is about 100°F/hour, although this rate is often exceeded. Thermowells are constructed of essentially the same materials as refractory firebrick, but are of much less mass and therefore somewhat more vulnerable to thermal shock than firebrick. Thermal shock that damages a thermocouple's thermowell will always cause similar damage to firebrick, particularly choke rings and tube sheet ferrules. Temperature cycling causes tiny stress fractures mainly because off differential expansion (i.e., the hot face of firebrick expands faster than the cold side).
c. Direct **impingement of the burner flame** on the thermowell tip.
d. **Process upsets** which cause sudden temperature changes that can break the thermowell by thermal shock. Large temperature excursions can exceed the melting point of the thermocouple element, causing immediate failure. Sudden cooling (quenching) may also cause failure of the ceramic well.
e. **Shifting Refractory**. Different coefficients of thermal expansion between the vessel shell, the insulating layer of refractory, and the firebrick can cause shifting of the refractory that can break the thermocouple's outer refractory well. When properly installed, the refractory well can withstand some shifting of the refractory, but any significant shifting would cause failure. Breakage of the outer refractory well does not, in itself, cause thermocouple failure; it only removes the added protection that it provides to the inner element well.
f. **Loss of Purge** – Incorrect installation or operation of the purge system will allow contaminating reaction gases to slowly corrode and eventually destroy the thermocouple. Interrupting the purge flow or reversing the purge inlet and outlet tubing connections may ultimately cause failure.

III. Diagnosis of Cause of Failure

In Claus service, all thermocouple failures are due to corrosion of the thermocouple elements (unless of course, a wire breaks, a terminal screw becomes loose or the transmitter to which it is connected fails). In general, the rate at which a thermocouple fails is directly related to the amount of exposure that the thermocouple has to the reaction gases. A broken element well (the pressure containing well) will usually cause thermocouple failure within days. A loss of purge may go unnoticed for months as the thermocouple output slowly degrades.

Examination of the temperature profile for a period of time prior to failure usually provides the explanation. These are:

a. **Very gradual decline of temperature** over a period of many months indicates a loss of proper purge for an extended period.
b. **A sudden spike in temperature preceding a drop** in reported temperature to near zero generally indicates the thermocouple melted because of excessive temperature. This also indicates that other refractory furnace components (i.e., tube sheet ferrules, choke rings, transitions) may have been damaged as well. If the thermocouple is equipped with two separate elements and both failed, melting of the thermocouple wires due to excessive heat is definitely the cause of failure.
c. If in a period of a few days after startup, **one thermocouple element of the two begins to indicate a declining temperature** relative the other element, it is likely that the element well has been damaged, probably during installation or initial startup because of shifting refractory, particularly if the bore hole through the refractory was not properly centered and perpendicular to the vessel's thermocouple mounting flange. If the time of failure is within six months or so of installation, the element well was likely broken during installation or upon initial startup by shifting refractory and that reaction gases are in direct contact with the primary element assembly. The reason for the disparity between the two elements is that inside the element well, one thermocouple element is encased in solid ceramic material (the reference element) and the other (Operating element) is not. The reason for this design is that if an element well becomes broken, reaction gases will be in immediate contact with the newly exposed Operating Element but not with the encased Reference element adjacent to it. This causes differential corrosion damage and an increasing disparity between readings which indicates that a failure has occurred. This condition is likely caused by the element well becoming broken by:
    1. a few episodes of thermal shock whereby early episodes would damage the outer refractory well (in itself causing no apparent indication of a problem) exposing the inner element well to further thermal shock episodes resulting in failure.
    2. Shifting refractory that exerts excessive physical stresses on the outer refractory well causing breakage and exposing the inner element well to subsequent thermal shock

d. One thermocouple element suddenly drops to “zero” while the other appears to remain accurate would indicate a broken wire, loose terminal or temperature transmitter issue. This would be confirmed by a mV measurement at the thermocouple element terminals.

IV. Purge Diagnostics

a. **Purge Installation** - Check the purge piping to verify that the installation is correct as described above.

b. **Purge Pressure Setting** - Check the purge panel to verify that the pressure regulator is set at least 5 psi above the maximum operating pressure of the reactor, normally 15 to 20 PSIG (1-1.4 bar) is suitable. *If it is lower than the furnace pressure, reaction gases can enter the thermowell through any slight void or crack in a seal or in the thermowell and eventually cause contamination. With the elevated purge pressure, purge gas will harmlessly leak through any void into the reaction furnace.*

c. **Purge Flow Setting** - Verify that the correct flow (.2-.4 scfh or 6-11 lph) is indicated on the rotameter. By adjusting the flowmeter needle control valve, observe that the purge flow will read over the full range of the flowmeter. *(Note: If the flow was found to be reading “zero”, it is likely that the cause of failure of a thermocouple element was due to a clogged line from the thermocouple. Yellow deposits of sulfur inside the flowmeter glass tube are a sure indication of a broken thermowell. Also, if another means of purge rate measurement and control is used in lieu of the HFS Purge Control Station, insure that the flow rate is no higher than 1 scfh as this will begin to cool the thermocouple junction.*

d. **Quick Check for Purge Integrity** -Elevate the pressure on the HFS Purge Panel Pressure regulator to approx 30 - 35 PSIG. *The flow rate reading on the flowmeter should increase.*

e. **Quick Check for Leaks or Well Breakage**

i. Gently close the needle control valve on the flowmeter (do not attempt to achieve a positive shut off, as this is merely a flow throttling valve and tightening may damage it). Remove any piping connection from the outlet (top connection) of the flowmeter and attach a pressure gage in its place.

ii. Open the flowmeter valve and observe the pressure on the gage attached to the flowmeter outlet. Compare this reading with the gage on the pressure regulator. They should read approximately the same value. *If the gage attached to the flowmeter outlet cannot read the same as the gage on the regulator (i.e., the test gage on the flowmeter reads the vessel pressure or less), it is likely that the HTP’s inner Element Well is broken. In this case, simply maintain a positive pressure on the pressure regulator to keep a high purge gas flow through the thermocouple into the (broken) element well and into the outer refractory well. This <u>may</u> provide an extended operating time for any surviving thermocouple junction, but remain aware that a problem exists and that a growing inaccuracy will ensue.*

f. **A More Rigorous Test for Leaks or Well Breakage**

i. Pipe a shut-off valve in the line between the pressure regulator and the inlet to the thermocouple.

ii. With this valve open, pressurize the thermocouple purge loop to the gage fitted to the outlet connection of the flow meter. 25 to 35 PSIG is sufficient. Check for any leaks.

iii. With no leaks observed, close the inline valve, reduce the pressure setting of the regulator to near zero.

iv. Loosen a connection fitting between the regulator and the in-line valve.

v. Observe the rate of pressure drop on the gage attached to the flowmeter outlet fitting. *Loss of pressure within two minutes indicates the there is a leak source in the element well or element well seal. To replace the element well and/or element well seal, the entire thermocouple unit must be removed from the vessel and to do so requires that the furnace be shut down.*

vi. Any attempt to dismantle any thermocouple component (other than electrical) with the furnace in operation is not recommended under any circumstances for safety reasons.

g. **Electrical Checks** - It is normally more convenient to gain access to the temperature transmitter signal input wires than the thermocouple. Therefore, begin by checking the wiring connections at the temperature transmitter to which the thermocouple is connected.

i. Remove the wires from the transmitter terminals and check to see that there is continuity between the positive and negative wires of each thermocouple element. *Continuity indicates that the thermocouple junctions have not corroded away and that wiring is intact. If there is no continuity between the two wires, either the thermocouple junction is corroded away, the extension leadwire from the thermocouple is disconnected or broken or internal wiring of the thermocouple is broken* *or disconnected inside the assembly, either under the top connection terminals or in the connection blocks located inside the inlet chamber housing (containing the upper inlet purge connection*).

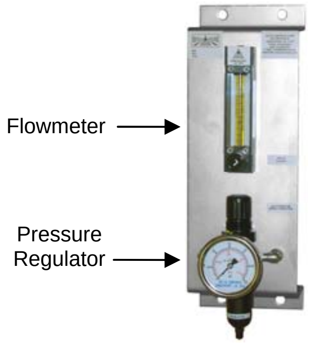
ii. If there is continuity between the thermocouple wires, check to verify that there is no continuity from either wire to ground. *Continuity to ground could indicate a short that might introduce errors.*

iii. Check to see that there is a mV reading across the two thermocouple wires that is of appropriate value for the type thermocouple and the approximate furnace temperature. (If the mV reading is unstable, it is sometimes helpful to temporarily ground one of the wires while making this measurement.) (See www.claustemp.com/an-htp15.htm to obtain thermocouple temperature vs. millivolt charts) *If the value appears approximately correct, the problem likely lies within the transmitter system, which can be checked by placing a known mV value on the input terminals of the temperature transmitter and observing the corresponding transmitter output signal.*

h. **Check the thermocouple terminal enclosure wiring**.
   i. Remove the thermocouple terminal enclosure cover and check that terminals are connected and tight.
   ii. Inspect the jacket of each thermocouple extension leadwire connected to the transmitter to see that the jacket has not been overheated and that no wire is grounded through the jacket at the conduit hubs. It is essential to use high temperature jacketed thermocouple extension leadwire from the thermocouple to the transmitter.

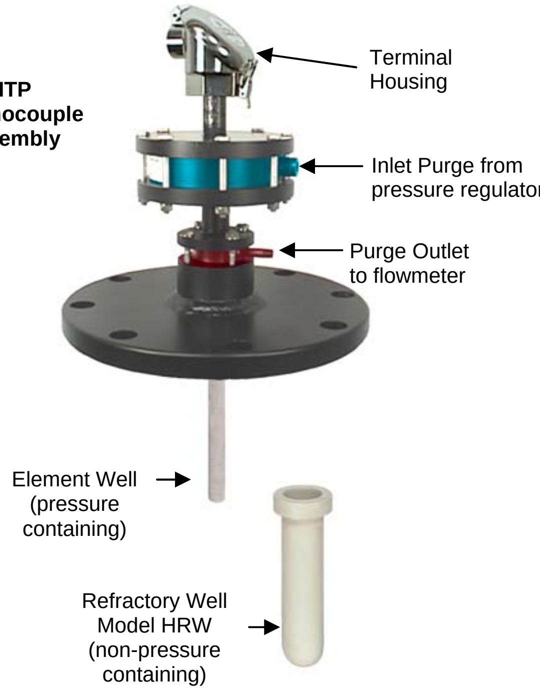
i. **Disassembly of the HTP / HTX to access the thermocouple element connections** (blocks) located inside the purge inlet chamber (upper circular housing containing the purge inlet fitting). **Do not** perform these tests until you have first tested for leaks or breakage of the thermowell as described above. *If you disassemble the purge inlet chamber of a unit with a broken thermowell, some reaction gases could be released.*
   i. For Model HTP series:
      1. Remove the bolts and nuts that surround the inlet purge chamber.
      2. Using one's hand, apply side pressure on the terminal housing to separate the chamber components (upper flange from the chamber ring from the lower flange.)
      3. Tilt the top works over to the side and secure in position to avoid breaking the thermocouple leadwires.
   ii. For Model HTX series:
      1. Remove the cap screws surrounding the inlet purge chamber
      2. Using one's hand, apply side pressure on the terminal housing to separate the chamber components (upper cover from the base).
      3. Tilt the top works over to the side and secure in position to avoid breaking the thermocouple leadwires.
   iii. Check that all wiring is intact and secure in all terminals.
   iv. Check to see that no wires or connectors are loose or broken.
   v. One at a time, remove the negative lead thermocouple junction wire from the block and check continuity between the wire and the corresponding positive wire. *Continuity indicates that the element junction is intact. Any element that shows no continuity indicates that the junction is open and the entire thermocouple assembly (ceramic support with seal and all thermocouple elements) must be replaced. Further disassembly is necessary to replace this element assembly. Normally, the unit must be removed from the reaction furnace to perform the remaining disassembly.*

V. Other Issues
   a. Breakage of the large outer Refractory Well (Model HRW) does not in itself cause thermocouple failure. This component serves to provide physical protection for the pressure containing inner Element Well; it keeps any dislodged refractory material from wedging against the Element Well, suppresses the effects of thermal shock and shields it from flying debris. Ideally this outer Refractory Well should protrude about one inch beyond the refractory hot face.
   b. If, upon removal of the thermocouple assembly, inspection indicates that shifting refractory has caused breakage of the Refractory Well and/or Element Well, complete inspection of the refractory must be performed. If no refractory repairs are deemed necessary, the borehole through the refractory may be corrected by use of the Delta H6G refractory drilling kit to restore alignment.



HFS Purge Control Panel

HTP Thermocouple Assembly



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