Considerations in Heat Treatment

Part Two: Furnace Atmosphere Control

Daniel H. Herring – The HERRING GROUP, Inc., Elmhurst, Ill.

Whether neutral or case hardening, the monitoring and control of a constantly changing furnace atmosphere is critical to good workpiece quality.

The composition of the furnace atmosphere is constantly changing, so we must use measurement and control devices to ensure good quality control. In particular, for atmospheres designed to run "neutral," avoiding decarburization and/or carburization is critical to the proper functionality of the component. This is accomplished by making sure that one or several of the following control methods is monitoring and/or controlling the process:

- Dew point analysis
- Infrared analyzer (single- or multiple-gas analyzers)
- Oxygen (carbon) probe

The trend today is to use multiple measurement tools to obtain the most accurate snapshot of the atmosphere in real time.

Whether neutral or case hardening, a number of variables determine how well a furnace does its job. Throughout the entire cycle it is critical to the process that we control the percentage of carbon dioxide, oxygen and water vapor and the ratio of enriching gas (or air) to carrier gas. For example, surface carbon can be controlled within ±0.10% by measuring one or more of these constituents.

Table 1. Typical dew point levels

Dew Point, ˚F (˚C)	Water Vapor (ppm)
+46 (+8)	10,590
+25 (-4)	4,320
0 (-18)	1,240
-40 (-40)	127
-90 (-68)	3.4
Note: 1.04% moisture = 10,590 ppm water vapor = +46ºF dew point	

Table 2. Dew point vs. surface carbon (%)

Dew Point, ˚F (˚C)	1500˚F	1600˚F	1700˚F
+30 (-1.1)	1.10	0.80	0.55
+40 (4.4)	0.85	0.60	0.40
+50 (10)	0.60	0.40	0.27

Dew Point Control

Dew point is defined as the temperature at which water vapor starts to condense. In simplest terms, a dew point analyzer measures the amount of water vapor present in the furnace atmosphere (Table 1). This information can then be used to determine the carbon potential of the atmosphere (Table 2). It is considered an indirect measurement technique if it involves pulling a gas sample from the furnace into the instrument.

If performed properly, dew point is a simple and accurate atmosphere measurement technique and indicates the condition inside the atmosphere generator or heat-treat furnace. It will tell you if the reaction is stable or unstable (constant dew point or changing dew point over time). It can tell you when the catalyst bed in your endothermic gas generator is starting to soot and if there is a water leak, an air leak or non-uniformity ("breathing") of the atmosphere inside your furnace.

The types of dew point analyzers available include capacitance sensors, chilled mirrors and fog chambers (Alnor®, dew cup). Condensation is a problem for all dew point devices if the sample temperature is less than the dew point of the gas. One

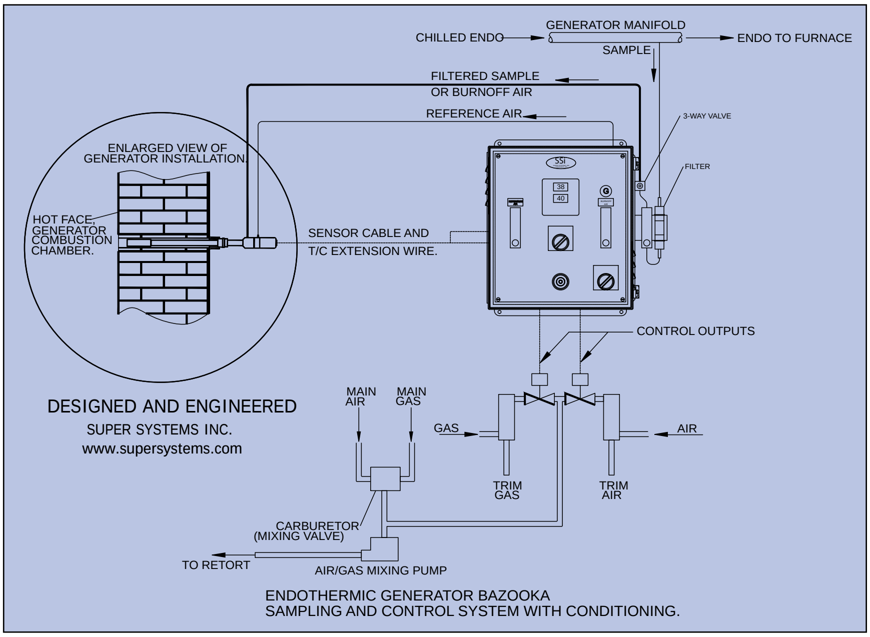

Fig. 1. Endothermic generator dew point control scheme via oxygen probe *(Courtesy of Super Systems, Inc.)*

solution is to heat trace the sample lines. If the ambient temperature exceeds 105°F (as it often does in heat-treat shops), the instruments will not give accurate readings unless special precautions are taken. Dew point control can also be measured using an oxygen-probe arrangement (Fig. 1).

Infrared Control

Infrared analysis uses the infrared spectrum (light, for example, is in the middle of the spectrum in the "visible" range) to analyze a gas sample and determine the percentage of that constituent in the furnace atmosphere. Single-gas (carbon monoxide) or multiple-gas (carbon dioxide, carbon monoxide, methane) analyzers detect the presence of these gases in the furnace atmosphere.

The amount of carbon dioxide in the furnace is another indirect way of measuring the carbon potential of the atmosphere.

Today, three-gas infrared analyzers are used to monitor the carbon monoxide, carbon dioxide and methane contents of generators (Table 3) and furnaces (Fig. 2). Individual gases absorb infrared radiation of very specific wavelengths. The amount of absorption increases with gas concentration. The unit operates under the principle that a gas sample passes through a cell where a heated wire emits infrared energy of known wavelength. The sensor converts measured infrared energy into an electrical signal. These values are usually compared to the values obtained with a reference gas. Infrared analyzers are known for their fast response and are easily calibrated.

Oxygen-Probe Control

The oxygen (or carbon) probe is an in-situ device that looks similar to a thermocouple for measuring temperature and typically sits inside the furnace, inside the generator above the catalyst bed or in a separate heated "well" into which the furnace atmosphere is pumped. In whatever location, the oxygen probe measures changes in the furnace atmosphere. A difference in partial pressure of oxygen in the furnace atmosphere and the partial pressure

Table 3. Typical field data for an operating endothermic gas generator[1,2]

Constituent	1^{ST} Quarter	2^{nd} Quarter	3^{rd} Quarter	4^{th} Quarter
% CO	19.02	19.66	19.32	19.21
% CO_2	0.260	0.252	0.254	0.257
% CH_4	0.07	0.08	0.09	0.09
Generator Dew Point, ˚F	+39	+39	+40	+39
Dew Point at Furnace Inlet, ˚F	+37	+38	+38	+38
Zonal Dew Point (Z1–Z4), °F[3]	+40 to +42	+40 to +42	+40 to +42	+40 to +42

Notes: [1] 3,000 CFH (85 m^3/hour) output; [2] Natural gas feedstock; [3] Neutral hardening

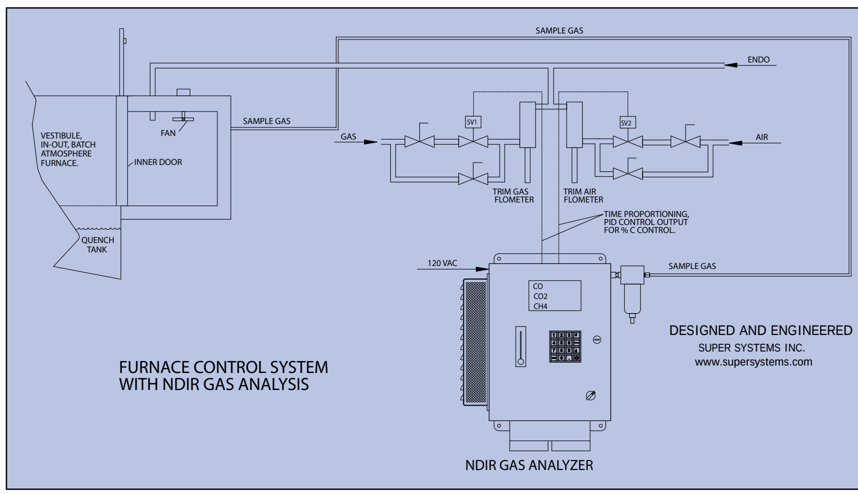

Fig. 2. Furnace infrared (three-gas) control scheme *(Courtesy of Super Systems, Inc.)*

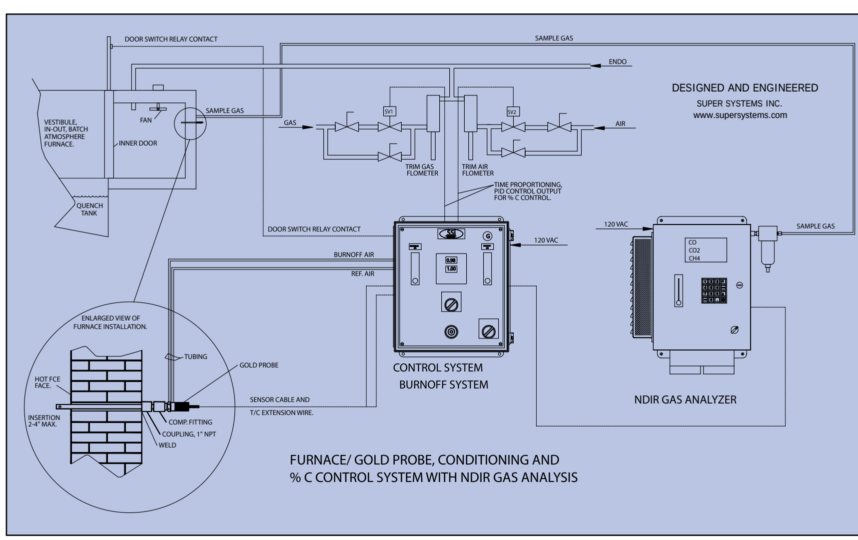

Fig. 3. Combination furnace oxygen-probe and infrared control *(Courtesy of Super Systems, Inc.)*

Table 4. Control settings – mesh-belt conveyor furnace

Steel	Process	Setpoint Values (Oxygen Probe), %C	Actual Values (Oxygen Probe), %C
10B21	Carbonitriding	1.05	0.69–0.83
1038	Neutral hardening	0.38	0.19–0.34

of oxygen in the room air induces a voltage – electromotive force, or EMF – across the electrodes in the probe. At any given temperature, there is a known relationship between the voltage output and the oxygen potential of the atmosphere. The oxygen potential can be directly related to the carbon potential. Therefore, the carbon potential of the furnace atmosphere can be controlled by monitoring the furnace temperature and the probe output.

The oxygen probe uses a conductive ceramic sensor manufactured from zirconium oxide (Zr_2O_3) that can be mounted in-situ inside the furnace (Fig. 3). Operating range is between 1200°F (650°C) and 1800°F (980°C). Oxygen probes can be used for a variety of gases, but they need to be calibrated for the specific atmosphere used. They are fast-response devices and subject to contamination by carbon or zinc. When used in carbonitriding applications, the presence of ammonia will shorten the life of the probe.

Typical oxygen-probe data for a mesh-belt conveyor furnace (Table 4) running at the rate of 4,000 pounds/hour (1,815 kg/hour) shows deviations from setpoint values due to non-equilibrium conditions present within the furnace.

Important Cautions

In more than one instance, data was being analyzed and adjustments made based on improper sample-port locations, instrumentation that was not properly calibrated and/or sample ports not extending fully into the furnace chamber. Mistakes such as these can be devastating to both equipment and part quality. **IH**

References:

1. Herring, D. H., *Understanding Furnace Atmospheres, Atmosphere Operation and Atmosphere Safety*, Heat Treating Hints, Vol. 1 No. 7.
2. Mr. James Oakes, Super Systems, Inc. (www.supersystems.com), private correspondence.

For more information: Contact the author at The HERRING GROUP, Inc., P.O. Box 884, Elmhurst, IL 60126; tel: 630.834.3017; fax: 630.834.3117; e-mail: dherring@heat-treat-doctor.com; web: www.heat-treat-doctor.com