Heat Treat 2017: Proceedings of the
29th ASM Heat Treating Society Conference
October 24–26, 2017, Columbus, Ohio, USA
https://doi.org/10.31399/asm.cp.ht2017p0146

Improved Reliability of Dew Point Measurements of Furnace Atmosphere on a Continuous Basis

Liang He, Donald Bowe, Philips Thomas and Ranajit Ghosh
Air Products & Chemicals, Inc., Allentown, PA, USA, gigmrktg@airproducts.com

Abstract

Dew point (DP) is a function of the furnace atmosphere composition. In a metal processing furnace, maintaining appropriate atmosphere composition is critical to achieving the desired gas/metal reactions and quality and consistency of the treated product. Continuous measurement of DP is always challenging because of particulates and vapor-phase contaminants in sampled gas stream which can potentially accumulate in filtering systems and on sensors. The DP measurement can also be affected by temperature variations within the sampling unit. Thus, DP readings can drift significantly, necessitating frequent cleaning, recalibration, and sensor replacement. Air Products has developed a DP monitoring system that addresses these issues and based on long-term testing at a customer site, drifts/changes of DP readings on calibration gas were not observed after more than one year of operation, without any maintenance. The contamination and drift issues have been mitigated by incorporating an automated self-cleaning and sensor calibration process after pre-set measurement periods. Temperature control of the sensor and the sampling system are also essential to maintain consistency, and can be achieved via various design features. Drifts/changes in DP that are reported through local monitoring/alarms or remotely through cloud server access can also help to address furnace operational issues quickly and efficiently.

Introduction

Atmosphere quality plays a key role in the properties of a heat-treated part. Hardness, ductility, carbon content and microstructure are influenced not only by time and temperature of heat treatment process, but also by furnace atmosphere composition, flow rate, and stability. [1-2] Most of metal heat treatments in furnaces require atmospheres that have controlled water vapor concentrations, because water cannot be completely removed from heat treating atmosphere. For example, it is well known that hydrogen/water ratio must be kept high enough to prevent oxidation and discoloration when running annealing of steel parts in hydrogen or nitrogen-hydrogen atmosphere. [3]

DP is defined as the temperature to which a gas mixture at a given pressure must be cooled to achieve the saturation point of the water vapor contained in the mixture. Measurement of atmosphere DP is widely used to provide meaningful data to help heat treaters monitor water vapor concentration and optimize the process. Condensation (optical chilled mirror) hygrometers, metal oxide sensors, and thin film polymer sensors are among the available technologies. [4]

However, a heat-treating furnace is not an ideal environment for DP measurement sensors and probes. The temperatures involved are beyond the operating limits of most sensors, and the furnace environment may contain chemical vapors and contaminants such as oils, salts, and particulate. Special sampling systems typically are required to enable DP sensors to be used for furnace atmospheres, especially for continuous measurement.

In view of these challenges and to save costs, most furnace operators rely on periodic sampling and measurement of dew point, often using hand-held probes or portable systems. However, such practices do not provide the operator with proactive alerts related to changing conditions in the furnace atmosphere and makes it challenging to comply with regulatory requirements like CQI-9.

Selection of DP Sensor

In heat-treating furnaces, atmospheres can vary widely, based on the condition of the steel parts, loading baskets, furnace refractory and air ingress. Metal oxide and thin film polymer DP sensors are popular in the heat-treating industry due to their low cost and fast response, although each technology has its own limitations, especially for high humidity conditions and handling of atmospheres with particulate and vapor-phase contaminants.

Alumina (Al_2O_3) is a preferred metal oxide sensing material for DP sensors, and current Al_2O_3 DP sensors are fabricated by an anodization process. One limitation of alumina sensors is the significant degradation in sensitivity and drift in capacitance characteristics, that occurs after long exposure to high humidity. This is attributed to the gradual decrease of effective surface area and porosity caused by water absorption. Polymer-based DP sensors have been widely used in the industry for more than 30 years. Most of the thin film polymer sensors are based on porous polymer films thinner than a millimeter and their sensing principle is like that of ceramic sensors. The film is filled with micro-pores for water vapor condensation and some of the measurable physical properties change due to the water absorption. [5] While polymer-based DP sensors are designed to better resist particulate and vapor-phase contamination, long exposures to atmospheres containing contaminants such as oil vapor and carbon particles (soot) can cause issues due to condensation of the contaminants onto the filters and sensor, resulting in sensor drift or permanent damage. For use in such environments (e.g. continuous sintering furnaces), these sensors would necessitate frequent cleaning and recalibrations for optimal use.

Case Study: Continuous DP Monitoring in a Sintering Furnace

Common powder metallurgy (PM) techniques involve compacting a blend of metal powder with lubricant and graphite (for ferrous parts) into a green part in a press, and sintering the part in a batch or continuous furnace. Continuous mesh-belt furnaces are widely used for mass production of PM parts. [7] They typically have at least three zones—a preheating (or de-lubrication) zone, a hot (or sintering) zone, and a cooling zone. In addition, some continuous sintering furnaces have a specially designed rapid-cooling zone between the hot and cooling zones for sinter hardening steel parts.

Figure 1 shows a typical continuous sintering furnace design. Atmosphere quality plays a key role in the final properties of a sintered part. Different furnace zones require varying degrees of oxidizing or reducing power to develop optimum final sintered part properties. Generally, a reducing and carbon-neutral atmosphere is desired in the hot zone for ferrous parts. used in gear manufacturing. [8] Thus, monitoring and controlling hot-zone atmosphere DP is necessary for better sintering process control and production cost control. [9] Continuously measuring DP can also enable real-time monitoring of the furnace conditions. For example, a sudden, extremely high (wet) DP reading may indicate a leak in the muffle or cooling zone inside the furnace.

Although a thin-film polymer sensor is resistant to particulate contamination, condensation, and most chemicals, it can still be permanently damaged after long exposure in the hot, toxic sintering atmosphere. Thus, a special sampling and measurement system was designed to reliably and continuously measure the DP of a hot-zone atmosphere with less maintenance. As previously discussed, a reliable and accurate DP measurement of the complex hot-zone atmosphere also requires a well-designed filtering system. If contaminants in the sampled gas are not removed, they affect the measurement by permanently poisoning the instruments, especially the DP sensor, and shortening the service life of the entire system.

The Air Products system incorporates a staged filtration unit designed with several sintered stainless steel filters to completely remove different kinds of contaminants. Because the thin film polymer sensor measures relative humidity, a change in DP sensor temperature affects the DP reading due to the intrinsic physical properties of the sensor material. Thus, maintaining a stable sampled gas temperature and sensor temperature is the initial challenge in achieving a continuous, reliable DP measurement, considering the complicated operating environment in a sintering furnace atmosphere. Air Products' continuous DP monitoring system incorporates a low-cost air conditioning system designed for the filtration unit and DP sensor container, which enables continuous, precise control of the sampled gas and DP sensor temperatures.

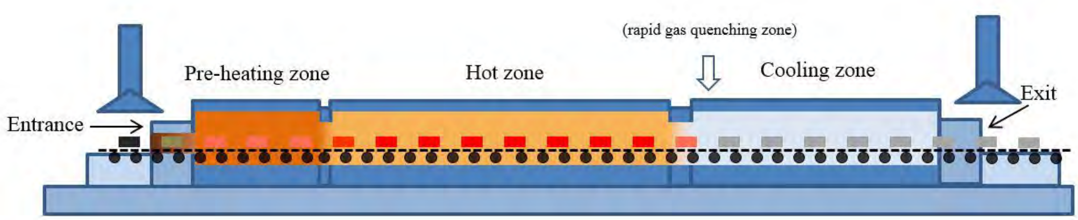

Fig. 1 Typical design of continuous sintering furnace

The reducing potential determines the rate at which powder particle surface oxides are reduced, which directly influences sintering bonding between particles in the compact. A dry or slightly humidified [7] nitrogen-hydrogen blend is used for steel PM operations. The hydrogen-to-moisture ratio in the hot zone determines reducing capability. Moisture is simply a product of powder oxides reduced by hydrogen introduced into the furnace, as well as belt reduction and air ingression. Properties of sintered parts, such as surface hardness and strength, are affected if uncontrolled carburization or decarburization occurs. In a carbon-neutral atmosphere based on nitrogen with hydrogen addition, the actual hydrogen-to-moisture ratio in the sintering zone can be used as the control parameter. For example, in nitrogen and hydrogen sintering atmospheres, maintaining an atmosphere DP below −30°F ensures a reducing and carbon-neutral hot zone for common steel grades

The Air Products' continuous DP monitoring solution enables sampling hot-zone atmosphere from the point of interest using a sampling pump. Passing the gas sample through a temperature-controlled filtering system conditions the gas before entering the DP sensor. DP measurements and other information are collected and sent to a cloud server, and customized reports can be easily accessed using a computer or smartphone. A schematic of the Air Products' continuous DP monitoring system is shown in Fig. 2.

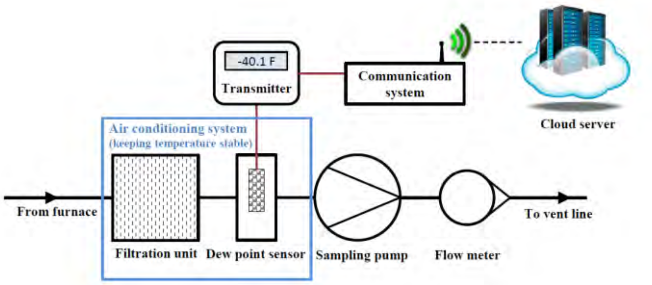

Fig.2 Schematic of novel continuous DP monitoring system

A periodic self-cleaning function can also be integrated into this system to eliminate frequent (sometimes monthly for sintering furnaces) recalibrations of the DP sensor as well as sampling system maintenance. This function ensures the cleanliness of the filtering system and DP sensor itself. The first installation of the Air Products DP monitoring system has now been continuously operating in a sintering furnace for over 20 months, without the need for sensor recalibration. The filtration system has also not been taken off-line for maintenance either, although it can be replaced or regenerated in a few minutes at minimal cost.

Air Products' continuous DP monitoring system also features a wireless/cloud-server data storage function. DP readings and operating parameters can be recorded and sent to a local or cloud server continuously. Process engineers can observe the current DP reading locally or review historical data archived on the cloud server and accessible in the form of customized reports. Stored historical data can help furnace operators or process engineers to identify and address furnace operation issues quickly and proactively. Analysis of DP readings could facilitate planning furnace shutdowns and scheduling preventive maintenance, which saves the cost of unnecessary maintenance work and reduces the possibility of unexpected downtime.

Air Products' continuous DP monitoring system can also send warning messages and alerts to furnace operators, based on the intelligent analysis of continuously measured DP results. For example, Fig.3 shows the recorded DP readings from 2/10/2016 to 4/10/2016. Over this period, the DP measurement results gradually dropped from DP-1 to DP-2 (reflecting a drier hot zone atmosphere). This gradual change in dew point is usually attributed to continuous accumulation of hydrocarbon deposits (or soot) inside the hot zone. On 4/1/2016, a burn-out was suggested by the DP monitoring system. After the furnace operator ran the burn-out, the DP measurement results went back to DP-1 levels on 4/2/2016.

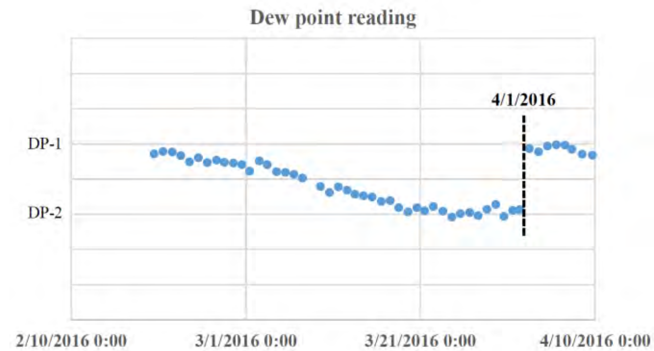

Fig.3 DP reading from 2/10/2016 to 4/10/2016

Conclusions

In the heat-treating industry, continuous measurement and control of furnace atmosphere is increasingly important to improve quality control, reduce costs and comply with regulatory requirements. Air Products' continuous DP monitoring system is designed to overcome common obstacles to analyzing heat treating atmospheres. The system can also be upgraded with an atmosphere control function to automatically adjust flow rates of process gases.

References

[1] Daniel H. Herring. Considerations in Heat Treatment Part One: Furnace Atmospheres. Industrial Heating, October 2009, 45-48

[2] Daniel H. Herring. Considerations in Heat Treatment Part Two: Furnace Atmosphere Control. Industrial Heating, December 2009, 47-49

[3] Daniel H. Herring. Annealing of Wire Products: Atmospheres. Wire Forming Technology International, Winter 2010

[4] Zhi Chen and Chi Lu, Humidity Sensors: A Review of Materials and Mechanisms. Sensor Letters, 2005 (3), 274-295

[5] Jinbo Tong (2014). Measurement and Modeling of Humidity Sensors. Master Thesis. University of Kentucky.

[6] Thomas Philips, John J. Dwyer, Jr. and Zbigniew Zurecki. Techniques and tips to optimize, control and stabilize the atmosphere inside a continuous sintering furnace. http://www.airproducts.com. 2017

[7] Thomas Philips, John J. Dwyer, Jr. and Zbigniew Zurecki. Controlling properties of sintered steel powder metal components using atmosphere composition as a variable. http://www.airproducts.com. 2017

[8] Zirconia Sensor Theory, http://www.supersystems.com/wp-content/uploads/T4401-1-R1-May2009.pdf. 2017

[9] James Tennermann. Furnace performance depends on dewpoint measurement accuracy. Heat Treating Progress. September/October 2006, 45-46