

Techniques and Tips to Optimize, Control and Control and Stabilize the Atmosphere Inside a Continuous Sintering Furnace

Thomas Philips, John J. Dwyer, Jr. and Zbigniew Zurecki
Air Products and Chemicals, Inc.



TECHNIQUES AND TIPS TO OPTIMIZE, CONTROL AND STABILIZE THE ATMOSPHERE INSIDE A CONTINUOUS SINTERING FURNACE

**Thomas Philips, John J. Dwyer, Jr. and Zbigniew Zurecki
Air Products and Chemicals, Inc.**

ABSTRACT

The quality of the atmosphere inside a sintering furnace plays a key role in the final properties of the sintered part. Properties such as the hardness, ductility, dimensions, carbon content, microstructure and magnetic properties among others are influenced not only by time and temperature, but also by the composition, flow rate and stability of the atmosphere within the furnace. The different physical zones within the furnace require different degrees of oxidizing or reducing power to develop the optimum properties in the final sintered part. Presented in this paper are practical techniques and technologies developed over the last 30 years of experiences with production sintering furnaces. The concept of distributed atmosphere introduction, combined with the use of directional atmosphere injectors, flame curtains, and gas curtains are used to stabilize and maintain the atmosphere profile within the furnace. Optimum and proven designs for atmosphere injectors, flame curtains, gas curtains and exhaust systems are presented.

INTRODUCTION

One of the key advantages of the powder metal technology is its ability to manufacture high volumes of near net shape metal components with reproducible and identical metallurgical and physical properties. To get reproducible properties we need to keep constant all of the variables that influence the making of the final P/M part. It is not enough to select and use the right atmosphere composition, but essential to keep the atmosphere profile constant within the sintering furnace. Over the last 30 years, the predominant atmosphere system has changed from endothermic atmospheres to nitrogen based atmospheres¹⁰. There is a greater understanding of the role of the atmosphere in general and more specifically its role and function in each section of the sintering furnace. In very basic terms the furnace can be considered to be made of three separate physical zones, each zone performing a different function and requiring a different atmosphere composition. There have been several papers^{1, 2, 9, 10} published that discuss in detail the selection and the benefits of using a nitrogen based atmosphere systems. These systems can be custom tailored to meet specific requirements of the material being sintered.

Let us now examine a few techniques that can be used to optimize and stabilize the atmosphere inside the furnace.

- Atmosphere Zoning
- Nitrogen gas curtains / Rotatable Gas injectors
- Fiber curtains
- Flame curtains
- Interactive Atmosphere Control
- Exhaust Hood designs

ATMOSPHERE ZONING

The concept of atmosphere zoning² was developed in the early 80's when the nitrogen based atmosphere system was developed. The primary function of the pre-heat zone is to eliminate all of the lubricant that is added to the powder blend. The de-lubrication step^{4,6} requires an oxidizing atmosphere to oxidize the hydrocarbon lubricant vapors so that no solid carbon residue is left behind to interfere with the sintering process. The hydrogen to moisture ratio determines the oxidizing or reducing potential and in the high heat zone this ratio needs to be maintained as high as possible at the lowest costs. The oxidation/reduction potential also determines the rate at which the surface oxides of the powder particles are reduced, which in turn directly influences the sintering or bonding between the particles.

This reducing effect is additionally, a function of the alloy system being sintered and any variation in the oxidizing-reducing potential of the zoned atmosphere will manifest itself in the final sintered properties. In the cooling zones the primary atmosphere function is to prevent oxidation and maximize cooling rates. Generally, nitrogen by itself does an effective job of keeping oxygen out of the furnace. However it has been shown that the cooling rate can be further enhanced by increasing hydrogen content of the atmosphere and by providing a forced circulation of the atmosphere.

Atmosphere zoning is made possible by the availability of atmosphere components, nitrogen and hydrogen as individual streams of gases and mixing them in the desired ratios as dictated by the metallurgical requirements of each furnace zone. For most continuous belt furnaces an ideal atmosphere distribution consists of 20% wet or dry nitrogen introduced into the pre-heat zone, 60% nitrogen + hydrogen into the hot zone and 20% dry nitrogen into the cooling zone. This type of zoned atmosphere helps to minimize the total gas flow rates required and concentrate the hydrogen where it is most needed. A simplified schematic of such a system is shown in figure 1.

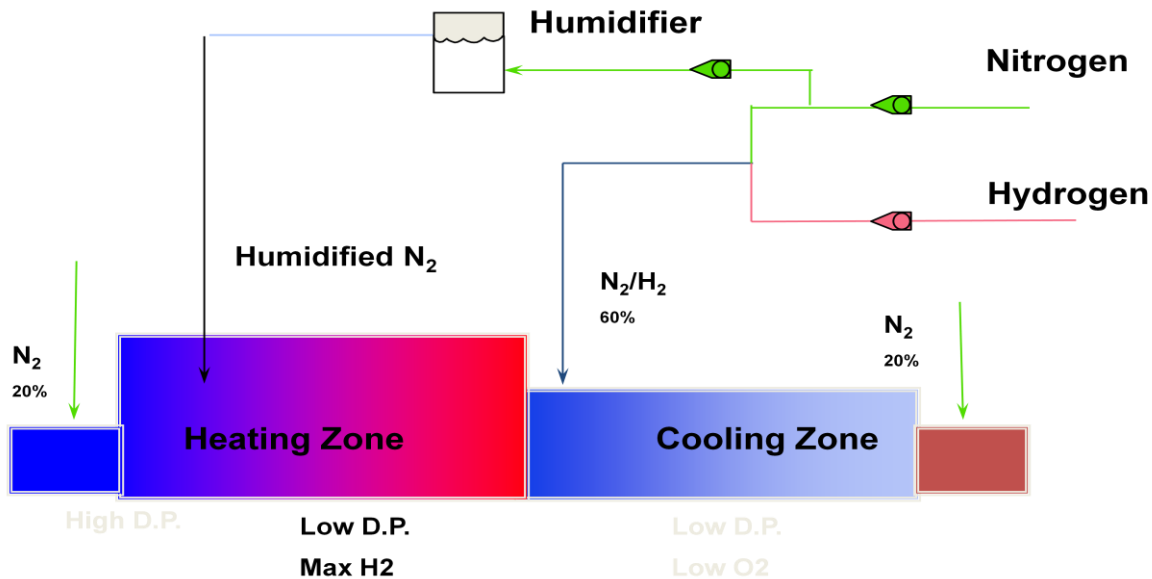


Figure 1. A typical zoned nitrogen/hydrogen atmosphere system.

NITROGEN GAS CURTAINS

Ambient air containing 20.9 vol% oxygen may enter the ends of an open-ended, continuous belt furnace when the furnace atmosphere is insufficiently controlled. A positive pressure of the atmosphere in the furnace should be assured to force the gas outflow through the ends at a velocity determined by the ratio of the flow to the cross sectional area of the door opening. For a given belt width and door opening height, the exit velocity increases with

increasing flow rate. It would seem logical to assume that higher the velocity, the better it would be at blocking the ingress of air. This is not necessarily however. Computational fluid dynamics studies³ and production experience has shown that beyond a certain optimum velocity, the ingress of air is aggravated by the formation of vortices that entrain the oxygen molecules into the furnace, primarily at the belt level. Therefore, increasing the total flow beyond the optimum value may increase rather than decrease the oxygen contamination in the furnace. Over the years of experience with nitrogen based atmospheres, an empirical rule of thumb has emerged indicating that the total flow rate ranging from 75 to 100 scfh of per inch of belt width is sufficient to keep the oxygen levels in the furnace within acceptable limits for door openings not exceeding 3 inches.

It has been demonstrated that using a nitrogen gas curtain at the ends of the furnace may further reduce the infiltration of air. A properly designed gas curtain that produces a transverse laminar flow across the width of the furnace will act as a physical barrier to the air ingress, while allowing the parts to pass through without interference. One such design incorporates a rotatable nitrogen discharging feature to enable preferential flow directionality. The directional flow capability also helps to direct most of the atmosphere towards the front end. Figure 2 shows a schematic of such a rotational gas injector. To ensure that the flow of gases is uniform across the width of the injector, the total area of all the distribution holes should be less than half the area of the cross section (I.D) of the main injector tube. It is also desirable to have two rows of holes with an included angle of about 30°. It has been shown that a similar design is beneficial for the introduction of the main dry N₂+H₂ atmosphere in the slow cool section. The centerline of the holes should be pointed towards the front (loading) end of the furnace to facilitate the flow of the atmosphere towards the front. A welded pin on the tube section outside the furnace can be used to indicate the orientation of the holes. A heavy walled ceramic, stainless steel or inconel tube may be used to minimize thermal distortion and sagging of the tube.

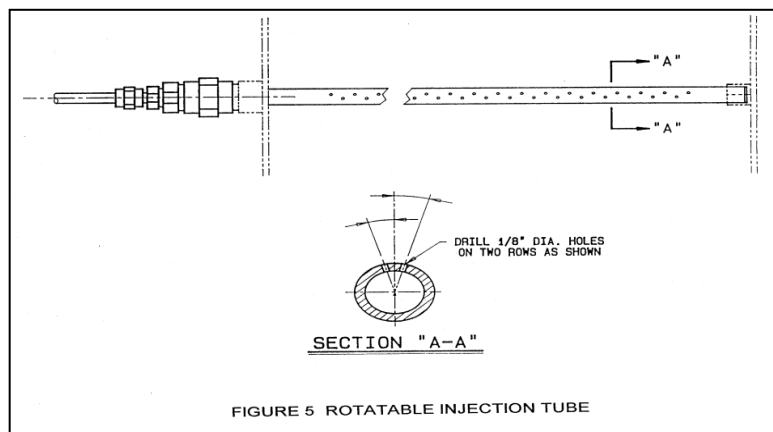


Figure 2. A design of a rotatable gas injection tube

FIBER CURTAINS

A physical curtain made from a fiber like cordage will act as a barrier to the air (O₂) when installed at the exit end. Curtain materials include fiber glass, Refrasil® and Siltemp®. Curtains made up of multiple rows of thin strands in a mop-like fashion help reduce heat loss and minimize oxygen infiltration, and allow the parts to exit the furnace freely. The advantage of using flexible curtains is that the fibers tightly hug the processed parts and do not create a visible opening such as in the case of traditional tape curtain materials. A fiber curtain at the exit end also provides a physical barrier to gases escaping from the exit end and promotes the desired atmosphere flow towards the front end. Typically 80% of the gases should flow counter to the travel direction of the P/M parts. This helps to maximize the interaction of the reducing atmosphere with the part and enhance the forward sweeping action of the lubricant vapors in the de-lubing zone and moisture generated by the reduction of oxides in the sintering zone. The forward flow of atmosphere is essential to minimizing the problems of sooting, decarburization and oxidation. A detailed paper on trouble shooting techniques has been previously published^{4,8}.

Figure 3 below shows a steel plate exiting a roller hearth annealing furnace. It is important to ensure that the curtain extends all the way down to the part conveyor's level. A design variation is to lower the height of the curtain by using a screw down mechanism to ensure the curtain continues to touch the belt as the bottom edges gets worn out.



Figure3. A fiber cordage curtain at the exit end of furnace.

The further industrial improvement involves installation of a second set of curtains, further into the cooling section and introduction of an additional inlet of nitrogen gas between the two curtains. This double curtain design creates buffer zone increasing operational safety and thermo-chemical stabilization of the atmosphere in the entire furnace.

FLAME CURTAINS

It is not practical to install a physical fiber curtain at the front end of the furnace because of the high temperatures produced by burning of the hydrogen and lubricant vapors. A flame curtain is used instead which has been proven to effectively limit the ingress of air from the front end.

It is common practice to install a pipe with holes, below the belt to produce a lazy natural gas flame curtain coming up from below the belt. Such a flame curtain is not very efficient because as the part travels over the flame, it blocks the flame front and allows air to enter the furnace. A more effective design is to attach the flame curtain to the bottom of the door and let the flame shoot down to create a vertical plane that covers the full cross section of the front end. Additionally, using a ribbon burner design and compressed air will produce a stronger sheet of flame that can extend over several inches to the belt level. This will create a more effective barrier to the air ingress. A simple design consists of a slotted tube with several rows of corrugated ribbons as shown in figure 4. Several commercial versions are available with varying BTU capacities.

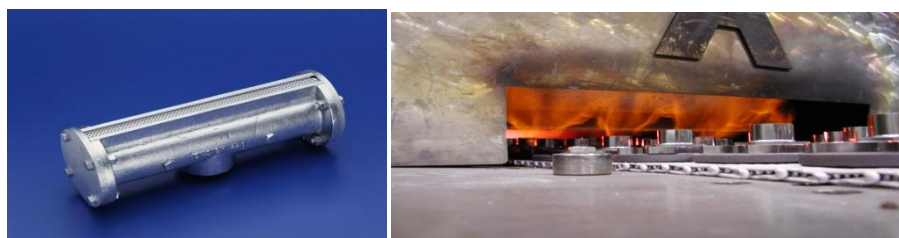


Figure 4. A ribbon burner and a traditional flame curtain.

The flame curtain also helps to burn the lubricant vapors as they exit the furnace and adds to the pre-heating of the P/M part which helps in the de-lubrication process. The flame front also acts as an important indicator of the atmosphere pressure and stability within the furnace. A flame front that blows out slightly indicates the desired

positive pressure within the furnace. A flame front that recedes into the furnace as shown in Figure 5 indicates insufficient total atmosphere flow and can lead to a condition known as frosted surfaces on the P/ M part. If the flame front fluctuates, then we have an unstable atmosphere which can result in non-uniform properties of the processed P/M parts.

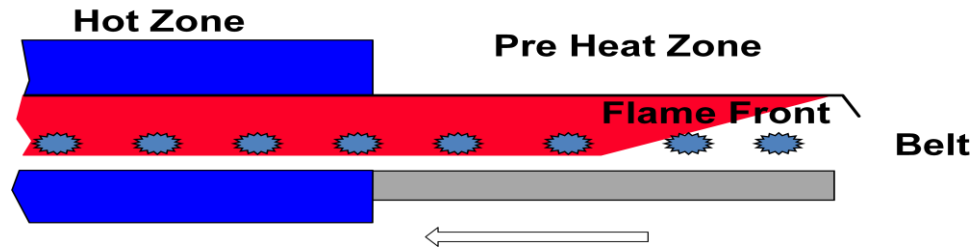
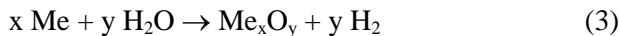
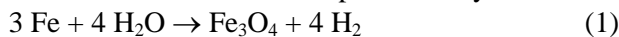


Figure 5. A flame front that is receding into the furnace.

INTERACTIVE ATMOSPHERE CONTROL

The incoming composition and flow rates of hydrogen and nitrogen into a sintering furnace are relatively stable assuming proper regulators and flow meters are used. The composition inside the furnace however can change significantly due to factors such as furnace integrity and muffle leaks, external room pressure changes, part geometry, door openings, lubricant decomposition and impurities in the powder compact. The reducing or oxidizing potential of the atmosphere inside a furnace is a function of temperature and the ratio of partial pressure of moisture to partial pressure of hydrogen present in the atmosphere.

The oxidation of iron and in general of any metal by the moisture forming in the atmosphere as a result of air ingress and O_2 - H_2 reaction can be represented by the following reactions:



where Me represents a metallic element.

These reactions are reversible and the direction is determined by the ratio of partial pressure of hydrogen to the partial pressure of moisture (K_p), as represented by the following expression, assuming that the activities of metal and oxide are unity.

$$K_p = p_{\text{H}_2}/p_{\text{H}_2\text{O}}$$

The oxidation/reduction potential determines the rate at which the surface oxides of the powder particles are reduced, which directly influences the sintering or bonding between the particles. The Ellingham diagram provides us the equilibrium conditions between metals and their oxides showing the effects of temperature, dew point/ H_2O content and $p_{\text{H}_2}/p_{\text{H}_2\text{O}}$ ratios.

It is also well known that any oxygen present in the furnace atmosphere is in equilibrium with hydrogen as per the following reaction:



Since the equilibrium constant (K) value for reaction (4) is known across temperature ranges, a zirconia-based oxygen probe may be used for controlling furnace atmosphere composition. Specifically the probe enables measurement of constant K_p and the moisture dew point according to the following equation:

$$K = \frac{p^2_{H_2} \cdot p_{O_2}}{p^2_{H_2O}} \quad (5)$$

or

$$K_p = p_{H_2O}/p_{H_2} \quad \text{and} \quad K_p = (p_{O_2}/K)^{1/2} \quad (6)$$

$$p_{H_2O} = p_{H_2} (p_{O_2}/K)^{1/2} \quad (7)$$

The interactive atmosphere control system⁷ consists of nitrogen and hydrogen gas flow panel, a dedicated oxygen probe and a PLC-based controller regulating flow rates of nitrogen and hydrogen introduced into a furnace (see Figure 6). The gas flow panel is also equipped with a flow meter to introduce an oxidizing component into certain sections of the furnace for operations that require maintaining a desired level of an oxidizing potential in the atmosphere such as in the pre-heat zone for de-lubrication. The oxygen probe is used to determine or calculate the value of K_p in the atmosphere present inside the furnace. Alternately a dew point monitoring system with a hydrogen analyzer can be used to determine the K_p value, or hydrogen analyzer and oxygen probe can determine the dew point level.

One of the more popular control algorithms involves adjustment of the flow rate of hydrogen and or the oxidizing component based on the measured oxidizing/reducing potential (K_p value) in order to maintain the required reducing or oxidizing potential in the each zone of the sintering furnace.

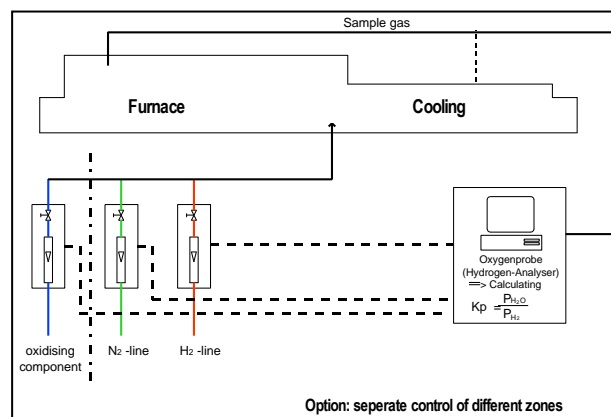
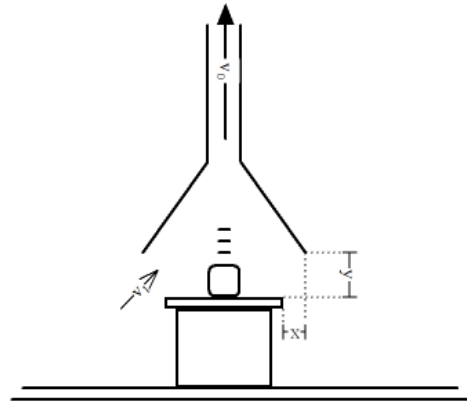


Figure 6. Schematic of the Advanced Atmosphere Monitoring and Control System.

EXHAUST HOOD DESIGNS

It is typical for most sintering furnaces to have an exhaust hood and vent piping system at the front or at either ends of the furnace. The function of these exhaust systems is to safely vent the atmosphere that exits the furnace. The exhausts at the front end also acts to extract some of the heat generated at the front end produced by the flame curtain and by products of lubricants that burn at the entrance. In many plants these exhaust hoods are extended down and connected to the furnace to become a continuous part of the furnace. Such a design may, sometimes, be problematic to the stability of the atmosphere because any up draft or down draft will cause a shift in the atmosphere profile within the furnace. It is likely to cause a preferential pull on the atmosphere enabling air infiltration into the furnace at the opposite end. More robust designs separate the hood from the furnace muffle so that some room air also goes up the vent along with the atmosphere. The atmosphere ideally should be such that it creates a slightly positive pressure within the furnace and that it is gently pushed out of the furnace and not pulled out. A separated hood design shown schematically in figure 7 will have a less pulling effect on the atmosphere inside the furnace.



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Figure 7. A well designed exhaust hood design.

Another effect to consider is that as the concentration of hydrogen is increased, the heat generated at the front end also increases causing an increase in the up draft of the atmosphere. This causes a negative pressure in the furnace causing an increase in air infiltration at the exit end. This can be compensated by re-balancing the atmosphere flows using the rotatable nitrogen injectors installed at the end of the cooling zones. This effect is represented schematically in figure 8.

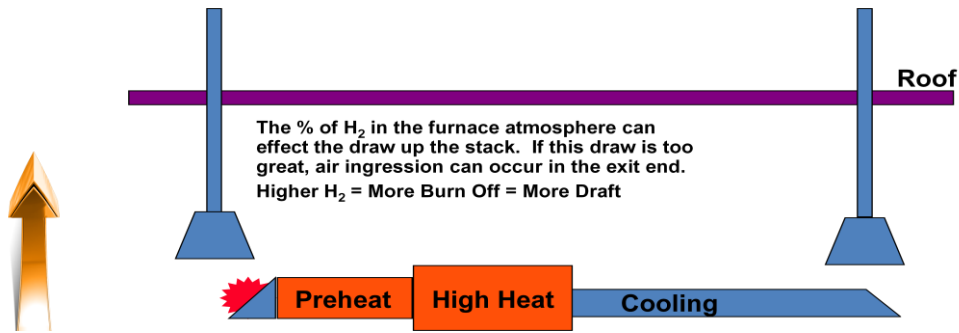


Figure 8. Differential pull on the atmosphere

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For more information,
please contact us at:

North America,
Corporate Headquarters
Air Products and Chemicals, Inc.
7201 Hamilton Boulevard
Allentown, PA 18195
Tel 800-654-4567 or 610-706-4730
Fax 800-272-4449
Email gigmrktg@airproducts.com

Asia
Air Products Asia Inc.
1001, 10/F, Sunning Plaza
10 Hysan Avenue, Causeway Bay Hong Kong
Tel 852-2527-1922
Fax 852-2527-1827
Email infoasia@airproducts.com

Europe
Air Products PLC
Hersham Place
Molesey Road
Walton-on-Thames
Surrey KT12 4RZ - UK
Tel +44 (0)1270 614314
Email apbulkuk@airproducts.com



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