Heat treating processes are potentially dangerous, but they can be carried out with no risk to either humans or the environment by adhering strictly to published safety rules and applying a good dose of simple common sense.

Mircea Stefan Stanescu*
BOC Gases
Durham, N.C.

Paul F. Stratton**
BOC Gases
Holbrook, Sheffield, UK

** Member of ASM International and member, ASM Heat Treating Society
* Member ASM International

Heat treatment is widely used in the automotive, tooling, and many other industries that require components with specific shapes and metallurgical properties, and also is used for annealing semifinished products, such as wire, rod, strip, and tubing made of steels and other materials. Because heat treatments are carried out at temperatures ranging from 400 to over 1200°C (750 to over 2190°F) under atmospheres including flammable gases, such as hydrogen, and hydrocarbons including methane, propylene, propane, and natural gas, the processes are potentially dangerous. However, by adhering strictly to published safety rules and applying common sense, heat treatment processes can be carried out with no risk to either humans or the environment. This paper provides a timely reminder about safety issues and answers some of the common safety queries related to heat treatment.

** Keeping It Simple
Most of the frequently asked questions about safe working in heat treatment in both atmospheric and vacuum furnaces are related to the need to avoid the risk of explosion in flammable atmospheres. The official safety guidelines are contained in NFPA 86, Standard for Ovens and Furnaces, 2003 Edition, published by the National Fire Protection Association (NFPA; www.nfpa.org), an international organization that advocates fire prevention worldwide, and is an authoritative source on a wide range of public safety issues.

However, because these detailed guidelines can seem daunting to the nonexpert, BOC’s Controlled Atmospheres Technology (CAT) group publishes a range of safety information sheets of specific relevance to heat treaters. Many of safety queries received by the CAT group ask for general advice about the hazards associated with the wide range of atmospheres used in heat treatment. Following are answers to some of the most common questions received by the CAT group. For more detailed advice relevant to specific situations, it is important to seek further advice from a recognized safety expert in the relevant field of operations.

** Question: What are flammable special atmospheres?
Answer: These include all gases that are known to be flammable and predictably ignitable when mixed with air [1]. Hydrogen is a good example. Any air-hydrogen mixture between 4 vol% hydrogen’s lower explosive limit (LEL) and 75 vol% hydrogen’s upper explosive limit (UEL) at atmospheric pressure is flammable and explosive.

** Question: What are indeterminate special atmospheres?
Answer: Indeterminate special atmospheres are atmospheres that contain components that are flammable in their pure state, but are not reliably and predictably flammable in mixtures where they are diluted with nonflammable gases [2]. Examples include nitrogen atmospheres and 1 to 4% hydrogen atmospheres. When introducing or removing processing atmospheres made up of indeterminate special atmospheres, it is important to use inert gas purge procedures, rather than burn-in/burn-out methods [3].

** Question: When is it acceptable to introduce a flammable atmosphere into a continuous mesh belt furnace?
Answer: It is safe to introduce a flammable atmosphere, such as a 40% nitrogen + methanol atmosphere or an endothermic gas atmosphere, into a continuous mesh belt furnace—also known as a Type III furnace [4]—either after purging...
with an inert gas such as nitrogen or after burning-in.

During purging, it is important to ensure that there is a high enough nitrogen purge flow rate to maintain a positive pressure in all chambers of the continuous mesh belt furnace to prevent air infiltration\(^5\). In addition, at least one zone of the furnace must be hotter than 760°C (1400°F). The nitrogen purge must continue until the timed flow method indicates the purge is complete, or until two consecutive analyses indicate that the oxygen content is less than 1% O\(_2\) by volume\(^6\).

The burn-in procedure\(^7\) also requires that at least one zone of the furnace is at a temperature higher than 760°C. Both procedures require ignited pilots that remain lit in inert atmospheres stationed at both the charge and discharge ends of the furnace. When flame appears at both of these ends, the introduction of the flammable atmosphere is complete. It is also important to install a full range of protective safety equipment\(^8\) and follow all the standard safety procedures to prevent explosions.

**Question:** What is the influence of temperature on the explosion limits of hydrogen/air mixtures at atmospheric pressure?

**Answer:** Experiments carried out to investigate the temperature influence on the explosion limits of hydrogen/air mixtures at atmospheric pressure show (Table 1) that the explosion range becomes wider with increasing temperature for temperatures in the range of 20 to 400°C (68 to 750°F)\(^{9-13}\). However, the experiments also indicate that at temperatures in excess of 550°C (1020°F), nonexplosive oxidation drastically reduces the effective flammable limits\(^{14}\). Because furnaces containing these atmospheres always operate at temperatures above 550°C, the discussion of flammable limits to assess hazard becomes meaningless in the heat treatment context. An air leak into a hydrogen/nitrogen mixture would rapidly consume hydrogen to form either water without flames, or an explosion risk. The oxygen would not accumulate until

### Table 1 — Influence of Temperature on the Explosive Limits of Hydrogen/Air Mixtures\(^a\)

<table>
<thead>
<tr>
<th>Temperature, °C (°F)</th>
<th>Lower explosion limit (LEL), vol%</th>
<th>Upper explosion limit (UEL), vol%</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 (70)</td>
<td>3.9</td>
<td>75.2(^{9, 10})</td>
</tr>
<tr>
<td>25 (80)</td>
<td>4.0</td>
<td>75.0(^{11-13})</td>
</tr>
<tr>
<td>100 (210)</td>
<td>3.4</td>
<td>77.6(^{9, 10})</td>
</tr>
<tr>
<td>200 (390)</td>
<td>2.9</td>
<td>81.3(^{9, 10})</td>
</tr>
<tr>
<td>300 (570)</td>
<td>2.1</td>
<td>83.9(^{9, 10})</td>
</tr>
<tr>
<td>400 (750)</td>
<td>1.5</td>
<td>87.6(^{9, 10})</td>
</tr>
</tbody>
</table>

\(^a\) Measured at atmospheric pressure according to DIN 51649-1
a locally explosive mixture was formed.

**Question:** How can I safely remove hydrogen from furnaces without exposing downstream equipment and control devices on the piping line to cryogenic temperatures?

**Answer:** The standard recommendation is to install a device to prevent the flow rate of gas from exceeding the vaporizer capacity. If the vaporizer capacity is exceeded, the downstream equipment or control devices could be damaged by exposure to cryogenic fluids. However, when an atmospheric vaporizer is used, visual and audible alarms can be used instead of a flow-limiting device to indicate that the temperature of the vaporizer outlet gas has fallen a minimum level, indicating a potential to exceed vaporizer capacity. This option requires operators to be present and alert during the purging operation. Additionally, your industrial gas supplier should always be informed of any changes to the plant that could materially increase the consumption rate of inert gases, such as nitrogen, so that vaporizer and storage capacity can be resized for the revised requirements.

**Question:** What is proper procedure for introduction of 100% hydrogen atmosphere into a bell type furnace used in annealing of steel strip coils?

**Answer:** To avoid an explosion, hydrogen inside the inner bell (Type VIII furnace) should be purged using nitrogen before the inner bell is removed. The detailed procedure of hydrogen removal from the inner bell is given in the standard. It is important to ensure (among other things) that the hydrogen gas safety shutoff valve is closed, and that the nitrogen purge flow rate is sufficient to maintain a positive pressure in the inner bell to prevent air infiltration. It is also important to keep the circulation fan working until the end of purging to avoid hydrogen stratification, or the formation of a pocket of hydrogen, on the top of the inner bell. The nitrogen purge must continue until the purge is completed as verified either by the timed flow method, or until two consecutive analyses indicate that the oxygen content is less than 50 vol% of lower explosive limit (LEL) of hydrogen in air, which is 2 vol% H₂.

After more than five inner volume changes by nitrogen purging, and after removing the inner bell from the base, a flame torch should be used to make sure that no hydrogen is left on the top of the inner bell. And no welding should be carried out while the inner bell is anchored and sitting on the base in a vertical position.

**Question:** What is proper procedure for removal of 100% hydrogen atmosphere from a bell type furnace used in annealing of steel strip coils?

**Answer:** To avoid an explosion, hydrogen inside the inner bell (Type VIII furnace) should be purged using nitrogen before the inner bell is removed. The detailed procedure of hydrogen removal from the inner bell is given in the standard. It is important to ensure (among other things) that the hydrogen gas safety shutoff valve is closed, and that the nitrogen purge flow rate is sufficient to maintain a positive pressure in the inner bell to prevent air infiltration. It is also important to keep the circulation fan working until the end of purging to avoid hydrogen stratification, or the formation of a pocket of hydrogen, on the top of the inner bell. The nitrogen purge must continue until the purge is completed as verified either by the timed flow method, or until two consecutive analyses indicate that the oxygen content is less than 50 vol% of lower explosive limit (LEL) of hydrogen in air, which is 2 vol% H₂.

Protective safety equipment listed in should be installed and procedures followed to prevent explosion.

**References**

1. NFPA 86, Standard for Ovens and Furnaces, 2003 Edition, Sect. 3.3.62.2
2. ibid., Sect. 3.3.62.4
3. ibid., Sect. 11.2.1
4. ibid., Sect. 11.4.2.2
5. ibid., Sect. 11.4.2.2.1
6. ibid., Sect. 11.7
7. ibid., Sect. 11.4.2.2.2
8. ibid., Sect. 11.4.4
15. NFPA 86, Sect.: 11.1.5.2.5
16. ibid., Sect. 11.1.5.2.3
17. ibid., Sect. 11.6.2.3
18. ibid., Sect. 11.6.2.4

For more information: Mircea Stefan Stanescu, BOC Gases, 4204 Five Oaks Dr., Durham, NC 27707-5229; tel/fax: 919-402-9439; e-mail: stefan.stanescu@boc.com; Paul Stratton, manager of the Controlled Atmospheres Technologies group, Global Technical Solutions, BOC Gases, Holbrook, Sheffield, UK; e-mail: paul.stratton@boc.com; Internet: www.catweb.boc.com (dedicated heat treat web site).