Purging of Furnaces: Is It Safe?

The Doctor decided to take a break the other evening and watch a movie. After rummaging through a sea of Beta (yes, Beta) tapes, VHS tapes, laser discs, and DVDs, Marathon Man was in hand. The movie stars Dustin Hoffman as a young man pursued by a manicual Sir Laurence Olivier who keeps asking the question, "Is it safe?" He's referring to his stash of diamonds and keeps torturing Hoffman (there is a memorable scene in a dental chair) who knows nothing about them. For some strange reason, the movie got the Doctor to thinking about...

**Furnace purges**: Over the years, a heat treating industry rule of thumb has developed that says five volume changes per hour are required to purge a batch-type furnace or other closed vessel (like a retort) of one gas (or mixture of gases) with another gas (or mixture of gases). We typically purge a furnace with nitrogen to remove air prior to introducing a combustible gas, or to remove a combustible gas prior to shutting the furnace down. The question becomes, "Is it safe?"

**Automatic systems available**

A good example might be the copper or nickel brazing of stainless steel assemblies in a dry hydrogen atmosphere using a bell-type furnace with an alloy inner cover (Fig. 1). At the start of the cycle, the initial room air must be purged from the inner cover by flowing nitrogen, and then the flow must be switched from nitrogen to hydrogen before placing the hot furnace bell over the inner cover. In other words, elimination of an explosion hazard requires that the inner cover contain no initial mixture of air with hydrogen when it is first subjected to heating and a source of ignition. Today, automatic systems in combination with an oxygen analyzer or vacuum pump ensure it is safe.

NFPA 86C, "Standard for Industrial Furnaces Using a Special Processing Atmosphere," defines purging as "the replacement of a flammable or high-oxygen-bearing atmosphere with an inert atmosphere to a nonflammable state, that is, 50% of the lower explosive limit (LEL) or <1% oxygen." Procedures currently used for confirming that a vessel has been purged involve sampling of the inner cover atmosphere with an oxygen analyzer and continuing to purge with inert gas until two consecutive readings indicate that the oxygen content is below 1 vol%. A vacuum purge is an acceptable alternative if the initial room air within the inner cover is pumped out with a mechanical pump to a vacuum generally in the range of 100 microns (0.1 torr or 0.1 mm Hg).

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**Fig. 1** — Carbottom bell furnace. Two movable cars are located at the left and right of the unit. A retort is at right, foreground. The furnace heater is in the raised position. Courtesy Lindberg, Unit of SPX Corp., Waukegan, Wis. ([www.heat-treat.com](http://www.heat-treat.com)).
But rule of thumb still used

Despite the use of automatic systems many older furnaces still rely on a timed purge sequence or the five-volume-changes-per-hour rule. In these instances, it is assumed that the rule of thumb is correct. But is it? Let's find out by performing a calculation. Yes, we're going to do some math, and although these calculations may seem strange to some heat treaters, the purpose in presenting them is to demonstrate that there is a scientific way to calculate how to purge a heat treating furnace.

Disregarding the possible effect of stratification from differing specific gravities of initial and purge gases or mixtures, or whether the furnace or vessel has internal fan recirculation, the degree of purging at various numbers of "volume changes" can be theoretically calculated.

Here we go: If we let \( F \) = the flow rate of the purge gas mixture, in ft\(^3\)/h; \( t \) = the elapsed time, in hours, from the start of purging; \( V_i \) = the volume of the initial gas or mixture still remaining at time \( t \); and \( V_{vo} \) = the volume of the initial gas or mixture at time \( t = 0 \), in ft\(^3\) (which is the total furnace or vessel volume), then a differential equation can be set up as shown in Equation 1:

\[
\frac{dV_i}{dt} = -\frac{F \cdot V_i}{V_{vo}}
\]

(Integrating this equation gives:

\[
V_i = V_{vo} \cdot e^{-n}
\]

where \( n = \frac{F \cdot t}{V_{vo}} \), or the number of volume changes. Then, the percent of the initial gas or mixture remaining at time \( t \) equals

\[
\frac{V_i}{V_{vo}} \cdot 100 = 100 \cdot \frac{V_{vo} \cdot e^{-n}}{V_{vo}}
\]

Simplifying gives:

\[
\frac{V_i}{V_{vo}} \cdot 100 = 100 \cdot e^{-n}
\]

Solving Eq. 4 for fractions of a volume change and whole volume changes gives percentages of the initial gas, or mixture of gases, still remaining. Data are listed in Table 1 and plotted in Fig. 2.

What this purely theoretical calculation shows is that the rule of thumb of five volume changes per hour is safe to use. The concentration of the initial gas or mixture of gases is reduced to less than 1% — below the level that could result in an explosion hazard in most applications.

Remember, if you want to purge a batch-type furnace or closed vessel in 30 minutes rather than an hour, then you need twice the flow of purge gas. A 15 minute purge requires four times the flow of purge gas; and so on.

Also bear in mind that all rules of thumb are designed to get you "in the ballpark." The use of an oxygen analyzer or vacuum pumping system is the only sure way to confirm that the furnace has been properly purged.

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**Table 1 — Effect of volume changes on percent initial gas or mixture remaining**

<table>
<thead>
<tr>
<th>No. of volume changes</th>
<th>% initial gas remaining in vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>90.48</td>
</tr>
<tr>
<td>0.2</td>
<td>81.87</td>
</tr>
<tr>
<td>0.3</td>
<td>74.08</td>
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<tr>
<td>0.5</td>
<td>60.65</td>
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<tr>
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<td>36.79</td>
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<tr>
<td>2.0</td>
<td>13.53</td>
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<tr>
<td>3.0</td>
<td>4.98</td>
</tr>
<tr>
<td>4.0</td>
<td>1.83</td>
</tr>
<tr>
<td>5.0</td>
<td>0.67</td>
</tr>
</tbody>
</table>

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Fig. 2 — Theoretical purge-down curve. Data show that the rule of thumb of five volume changes per hour is safe to use — the concentration of the initial gas or mixture of gases is reduced to less than 1%, or below the level that could produce an explosion hazard.

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How useful did you find the information presented in this column?

**Very useful, Circle 270**

**Of general interest, Circle 271**

**Not useful, Circle 272**

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