Retrofitting Infrared Reflow Furnaces

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Introduction

Cost reduction has always been an important goal for most corporations. It is essential that companies find ways to cut capital spending and save money, especially in today's highly competitive economic climate. Purchasing new manufacturing equipment can be one of the most capital-intensive projects a company undertakes. Rather than purchase new machines, more and more companies are modifying older existing equipment to keep up with technological advances.

One industry where this is especially true is in electronics packaging. Previous research has shown that using inert gases as the soldering atmosphere in the manufacture of printed circuit boards (PCBs) significantly enhances the process and final product. PCBs manufactured using infrared (IR) reflow and wave soldering have been shown to have improved characteristics when soldered under an inert gas.[1] Advanced processing materials, like low-residue solder pastes, are more efficient when processed under inert atmospheres, allowing for the implementation of no-clean soldering. Unfortunately, a significant number of soldering units were not manufactured to allow for inert atmosphere use. The conversion of soldering machines from air to nitrogen is therefore becoming quite popular. In-house retrofits typically cost a fraction of a new nitrogen-compatible machine and take only a couple of days to bring fully on-line, minimizing system downtime.

An inert atmosphere retrofit system for IR reflow furnaces has been developed, aided by the use of computer models as well as beta site testing. This paper describes the development of the retrofit from the identification of the need for retrofits through the completion of a second-generation system. Customer inputs and concerns have been addressed in order to make the system as user-friendly as possible.

The Benefits of Using Inert Gas Soldering

Nitrogen is the most widely used industrial gas for inert atmosphere reflow soldering. Its popularity has come about based mostly on the following factors:

1. **Availability**—Production capacity of nitrogen in the U.S. is over 35,000 tons per day.
2. **Cost**—Nitrogen is the least expensive of the cryogenically produced inert atmospheric gases. For example, argon, the next most plentiful atmospheric gas after oxygen and nitrogen, costs about five times as much as nitrogen.
3. **Ease of Use**—Only typical storage and delivery systems are needed when working with nitrogen, unlike potentially hazardous gases like hydrogen or hydrogen blends that require additional safety devices.
4. **Purity**—The oxygen purity specification for standard industrial grade nitrogen is 10 parts per million (ppm) with typical impurity levels around 3 ppm. High-purity nitrogen is available with oxygen contamination at merely 0.1 ppm.

Nitrogen has proven to be effective at displacing oxygen in IR furnaces, allowing PCB soldering to take place in a nonoxidizing atmosphere. The benefits of reducing the oxygen content in the soldering gas are numerable and well documented. One study discovered that by converting an air atmosphere IR furnace to nitrogen a 75% reduction in soldering defects could be experienced.[2] Nitrogen has also proven to provide a cleaner processing atmosphere than air, low in oxygen content and free of contaminants such as dust and dirt. As a result joint surfaces are oxide-free, shinier, smoother, have better fillets and are easier to inspect.[3,4] Other works observed a reduction in board discoloration, demonstrating that the onset of discoloration is retarded by at least 20°C under nitrogen.[5,6] Better wetting under nitrogen is cited as a major factor in improving solder joint reliability.[7]

Currently, one of the most important benefits of using nitrogen for soldering is that it allows for the implementation of a no-clean soldering system. No-clean soldering has become an important issue in recent years due to international mandates, such as the Montreal Protocol, that limit the current and future use of ozone-depleting chemicals such as chlorofluorocarbons (CFCs). CFCs, such as Freon 113 and 1, 1, 1 trichloroethane, have been popular for cleaning electronic assemblies in the past.

Research has been conducted in recent years dealing with no-clean reflow soldering. Several companies have developed a "no-clean" soldering system employing a specially formulated solder paste. A recent survey of available solder pastes in the industry disclosed that of twenty vendors, fifteen offered pastes classified as no-clean.[8] In many cases it is recommended or required that the paste be reflowed in an inert atmosphere to achieve optimum results.[9] A controlled inert atmosphere reflow process has been shown to produce very little benign residue when a low-residue solder paste was used. This is especially true with today's improvement in solder paste chemistry, which can allow for a total no-clean surface mount assembly operation.[10] In one study, a no-clean paste showed marked improvement in cleanliness when reflowed in nitrogen,[11] while in another nitrogen played a major role in reducing post-soldering residue when a no-clean flux was used.[12]

No-clean soldering is possible through the use of less aggressive fluxes in solder pastes. The purpose for using flux is twofold: (1) to chemically remove solder oxides, and (2) to protect the alloy from reoxidation during reflow. The presence of solder oxides hinders the wetting of the molten alloy, thereby affecting solderability. Air has been shown to oxidize molten tin/lead alloys, within the time-temperature regime of reflow soldering, forming predomi¬nantly tin oxides.[13] Elimination of atmospheric oxygen by displacement with an inert nitrogen atmosphere complements low-residue, no-clean solder paste flux by protecting the molten solder from oxidation.[14] This allows solder paste manufacturers to employ less aggressive flux in low-residue solder paste systems.

In order to fully experience the benefits of a no-clean system, furnace soldering equipment will have to be capable of using inert gases. Electronics packaging companies will be forced to obtain new soldering equipment or convert their current machines to inert atmospheres.

Furnace Amenability for IR Retrofits

The interest in inert reflow soldering in the electronics packaging industry has increased greatly in the past several years. More and more companies are becoming involved with inert IR soldering. Figure 1 shows how nitrogen sales to IR users have increased for Air Products and Chemicals over the course of fiscal year 1989 through fiscal year 1992. This chart shows a significant increase in the number of companies using nitrogen for inert IR soldering. This fact is further supported by the large number of technical papers dealing with inert IR soldering pre¬sented at national trade conferences like NEPCON, Surface Mount International, and ISHM.

Although there is a growing availability of inert soldering equipment, a large base of noninert atmosphere compatible IR soldering machines still exists. Fortunately, many models of IR furnaces can be converted easily through the use of retrofits, usually over the course of two to three days. Costs of $10,000–$15,000 are also relatively inexpensive, especially when compared to the cost of new nitrogen-capable IR equipment.

IR furnace designs can be placed into one of two categories, open interior access and closed interior access. Open interior access units are those that "open up" to allow inspection of the furnace's belt and/or conveyor system and heating panels or lamps. They are also known as clamshell furnace designs and are fairly well sealed when closed. Open interior IR furnaces are the most simple units to retrofit. Closed interior access furnaces are sealed from the outside, not allowing open inspection of the inside of the furnace. Furnaces with sealed hermetic chambers and muffles fall into this category. These units are not easily amenable to a furnace retrofit without significant muffle modification.

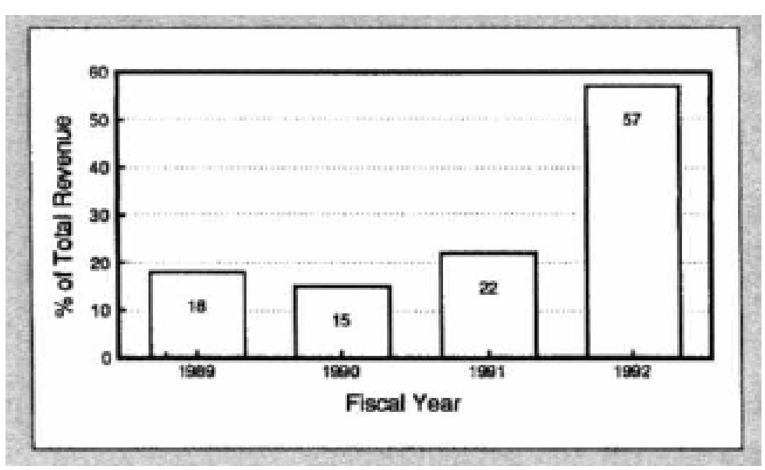
The Development of an IR Furnace Retrofit—Generation I

Air Products first installed an IR retrofit at a customer site in the late 1980's. In a joint development effort, a nitrogen delivery system was designed, tested and installed in a clamshell, open access furnace. The results of this work have been presented at a previous technical conference's and resulted in a first-generation retrofit package described below.

The customer's need for converting to nitrogen from air for IR soldering was brought about by high soldering defect levels in air. The beta site customer was experiencing problems with poor wetting which contributed to many of the soldering defects, including insufficient solder joints, open solder joints and solder bridges.

A system was devised whereby a large IR furnace, with a total heated length around 12.5 feet, was fitted with several perforated stainless steel tubes. A typical tube was 1/4"

Figure 1: Sales from Nitrogen IR Accounts

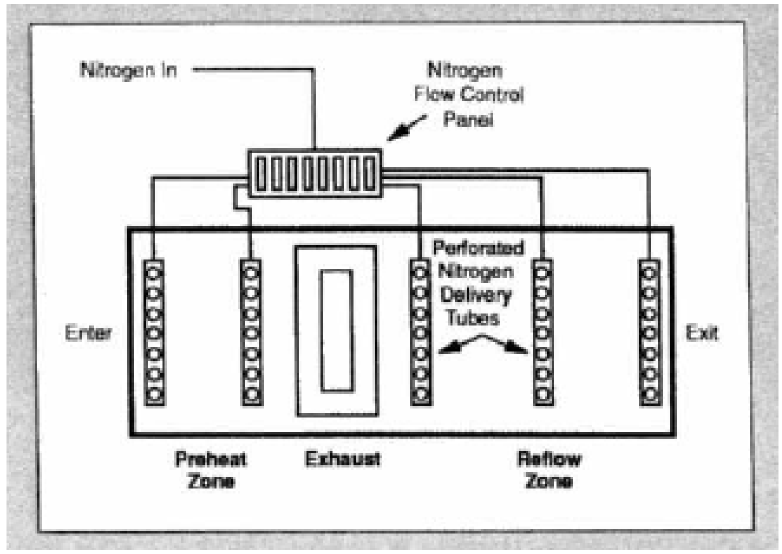


in diameter and had a single row of 1/32" diameter holes across its length. Tubes were placed perpendicularly above the furnace belt as illustrated in Figure 2.

The tubes were installed by drilling a guide hole through the furnace lid and inserting the tube into the furnace. Nitrogen entered the tube from one end and was dispersed along the length of the tube. Locations for tubes were determined through process expertise and a thorough analysis of the system. A nitrogen flow control system was also installed that allowed for individual control of nitrogen to an entrance and exit curtain, the preheat zone and the reflow zone. During testing, a temporary liquid nitrogen source was set up near the furnace. Initial results with this system showed promise, with oxygen levels in the furnace being reduced to 1,800 ppm–5,800 ppm from air levels of 210,000 ppm. Total nitrogen flow was 1,855 standard cubic feet per hour (scfh) at about 50 pounds per square inch (psi) pressure.

The first-generation retrofit system did experience some problems. The temperature profile of the furnace was depressed by approximately 5°C near the end of the reflow stage. This was due to a combination of the gas entering the furnace at a cool temperature (less than 10°C) and a high flowrate. The cool temperature of the gas was due to the fact that the liquid nitrogen was stored near the furnace in portable liquid cylinders called dewars. There was insufficient time for the vaporized cold gas to warm up to ambient temperatures due to the close proximity of the liquid source to the furnace. The flowrate problem was magnified by the fact that the perforations on the stainless steel tube delivery system were facing downward, forcing the nitrogen to flow directly onto the, circuit board. Another problem experienced was the shifting of components on PCBs

Figure 2: Generation I IR Furnace Retrofit



as they exited the reflow zone and passed under the exit curtain. At this point the solder was still molten and was just beginning to solidify. The high flowrate from the exit curtain caused this problem.

Both issues were addressed by optimizing the nitrogen flow to the furnace, providing lower oxygen levels and a uniform temperature profile (equivalent to that in air) at an efficient nitrogen consumption rate. Proper vaporization of the nitrogen to ambient temperature was ensured by add¬ing vaporization capacity to the delivery system. Eventually a permanent liquid nitrogen storage/vaporization system was installed on-site.

Upon further evaluation of the furnace, it was determined that oxygen levels could be further reduced by using a high-temperature silicone rubber gasketing material to form a uniform seal between the furnace base and hinged furnace lid. Locations where the gasketing material was placed are shown in Figure 3.

Oxygen levels dropped to 700 ppm–1,200 ppm at a reduced nitrogen flowrate of 1,255 scfh after optimization.

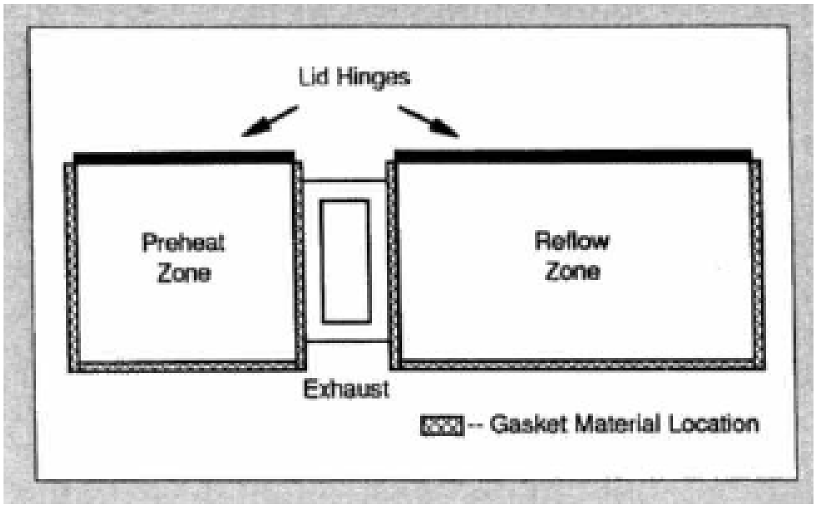
Computer-aided modeling was also implemented in the Generation I system. FLUENT, a software program for fluid flow, modeling, was used to exemplify the flow pattern of gas in the furnace. This analysis was based on the location and orientation of the nitrogen tubes and the nitrogen flowrate. This model has been described in detail in other research work.[16] The program is useful because it allows a wide variety of parameters to be used to determine such items as optimal nitrogen tube placement in a furnace.

As noted earlier, this beta site customer experienced a reduction in soldering-related defects of 75%, related mostly to improved solder wetting under nitrogen. Savings to the company in reduced rework and other factors added up to over $38,000 per month, easily justifying the retrofit cost. The retrofit system has since been installed on two other IR soldering lines.

Improvement Issues for the Generation II IR Retrofit

Although the Generation I system was successful, several observations were made that left room for improvement. The following items were identified as areas for possible system

Figure 3: Gasket Locations for IR Retrofit



modifications:

1. The perforated nitrogen delivery tubes could cause shifting of parts because of high gas velocity.

2. Nitrogen gas was delivered to the tube from one end only. Through field testing of the system, it was discovered that under some conditions, uneven gas distribu¬tion was possible across the length of the tube with this delivery option.

3. The nitrogen delivery tubes as installed were permanent. They could not be moved in order to test possible placements that could provide more optimal results.

4. The system did not provide a means of preheating the nitrogen gas before it entered the furnace. Preheated nitrogen would ensure that the gas was at least room temperature before entering the furnace.

5. High gas flow for the curtains at the ends of the furnace was required to ensure that outside air did not infiltrate the inert furnace atmosphere.

The second-generation retrofit is concerned with ad¬dressing these user issues.

Gas Velocity

In the Generation I retrofit, nitrogen was delivered to the furnace through the use of perforated tubes. As discussed previously, the gas velocity exiting from the tubes was high enough to cause component shifting in some cases. This high velocity also contributed to the infiltration of oxygen into the processing atmosphere by creating turbulent eddies and drawing air in through the entrance and exit furnace openings.

This problem was addressed by implementing a porous metal diffuser to replace the perforated nitrogen tubes. The diffuser is constructed of sintered stainless steel and can be obtained in a variety of porosities. Field testing of the porous diffuser demonstrated that gas distribution through the diffuser was much less turbulent than through a perforated tube. Higher flowrates could be used with the porous diffuser without the detrimental effects of exces¬sively high gas velocities on the soldering process.

Gas Flow Distribution

The porous diffuser also assisted in solving gas distribution problems experienced with the perforated gas delivery tube. The perforated tube used in the Generation I retrofit resulted in an uneven gas distribution as described above. According to published design methods,[17] sparging tubes similar to the Generation I nitrogen tubes cannot be expected to yield good flow distribution unless there is a balance between the kinetic and momentum forces of the incoming gas, the friction losses along the tube and the pressure drop across the perforated holes. This system can be difficult to model in order to achieve the proper balance. In addition, the gas flowrates in the retrofit system likely cause the kinetic and momentum forces of the incoming gas to overpower the other balancing factors. The porous diffuser alleviated the need for concerns on these issues by promoting a uniform gas flow pattern across the entire length of the diffuser by employing thousands of tiny holes with diameters measuring in the tens of microns.

In order to further ensure proper gas distribution in the furnace, the method of gas delivery to the porous diffuser was also modified. Instead of entering the diffuser from one end, as in the Generation I design, nitrogen en¬ters from both ends of the diffuser assembly in the Gen¬eration II system as shown in Figure 4.

Diffuser Movement/ Removal

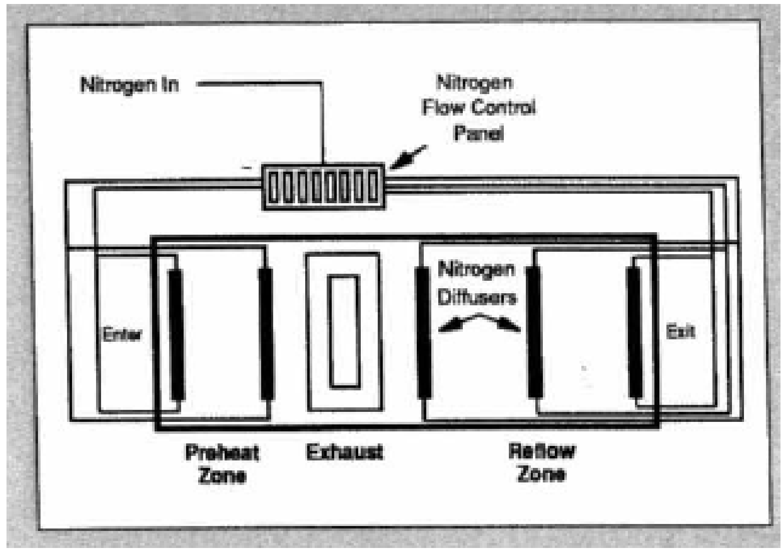
In the Generation I retrofit the nitrogen delivery tubes were immobile because guide holes were drilled directly into the furnace lid. This was determined to be undesirable for two reasons. First, the permanent state of the tubes meant that fine-tuning adjustments to the nitrogen inlet location could not easily occur after mounting the tubes. Second, the installation of the Generation I retrofit perma¬nently altered the interior of the furnace with the drilling of guide holes through the furnace lid.

The diffuser assemblies used in the Generation II retrofit are movable and removable. The diffuser assembly is a freestanding apparatus. The diffuser itself is supported by two vertical lengths of stainless steel tubing and by two horizontal runs of stainless steel tubing. The dimensions of the diffuser assembly are such that they straddle the belt or conveyor and fall within the height restrictions of the inside of the furnace. Several standard assembly sizes have been devel-oped to fit a wide variety of furnace schemes.

The horizontal lengths of stainless steel tubing connect the diffuser as-sembly in the furnace to a bulkhead fitting outside the exit or entrance tunnel of the furnace. There are two bulkheads for each diffuser assembly, supplying nitrogen to each end of the diffuser. Gas flow to each diffuser is controlled through an independent flowmeter.

The design of the diffuser assembly allows it to be moved about during installation of the retrofit. Once the location for the diffuser is determined, through furnace optimization, the dif-fuser is put in place by bolting down the stainless steel tubing to the bulk-head fitting. Many nonnitrogen-ready furnaces have small internal oxygen leaks that may be unavoidable. Such leaks may be more prevalent when an inert atmosphere is introduced which can create areas of turbulence. This turbulence may aspirate atmospheric air into the furnace. Through testing various positions of the diffusers, it is possible to place diffusers so that they can most efficiently combat this prob-lem. Such flexibility is not possible with permanent tube placement.

Figure 4: Generation II IR Furnace Retrofit



Although the diffuser assemblies are eventually bolted down, they can still be moved or even removed without damage to the interior of the furnace. The tubing that supplies the diffuser assembly can be disconnected from the bulkhead fitting, allowing for adjustment of the diffuser location. In the same manner the assembly can be removed from the furnace altogether.

Nitrogen Preheating

As described earlier, cold nitrogen en-tering a furnace can have a profound effect on the furnace's temperature profile if the gas is not warmed to am-bient temperature first. This problem is especially prevalent when using a portable liquid nitrogen source, such as dewars, to supply gas to the furnace because the liquid tank is in close proximity to the point of use. In this case the system does not have suf-ficient time and vaporization capac-ity to heat up the gas from cryogenic temperatures of nearly -200°C to am-bient. When the gas is at least room temperature, tem¬perature profiles in nitrogen should remain the same as in air at equivalent gas flows.

In order to avoid this potential prob-lem, it is important to ensure that gas entering the furnace atmosphere is at least at ambient temperature. The Generation II retrofit accounts for this by preheatng the nitrogen as it flows through the hot furnace to the diffusers. Heat from the furnace is exchanged with the gas in the stain-less steel tubing that supplies each diffuser. This method of introducing nitrogen into the furnace ensures stable temper¬ature profiles.

Entrance and Exit Nitrogen Curtains

During the early development phases of the Generation II retrofit, perforated nitrogen tubes were used as curtains on the ends of the furnace. Further testing showed that porous diffus-ers could be more effectively used for this purpose. Benefits of using the diffusers were slightly lower nitrogen flowrates and a reduction of gas veloc-ity. This was especially important at the exit of the furnace where compo-nents on molten solder could shift and misalign.

Performance Results of the Generation II Retrofit

Changes in design considerations did produce signifi¬cantly better performance results in the Generation II retrofit. In smaller furnaces, with total heated lengths of 5.7 feet, oxygen levels under 100 ppm in the reflow zone have been achieved with total nitrogen consumption around 950 scfh. In addition, oxygen levels under 1,000 ppm were still obtained when the nitrogen flowrate was reduced to 525 scfh. For larger furnaces, with total heated lengths of 12.5 feet, oxygen levels under 500 ppm have been achieved with flowrates of 1,600 scfh.

System Description of the Generation H Retrofit

The Generation II IR retrofit is shown schematically in Figure 4. To summarize, the system consists mainly of the following components:

1. **Nitrogen Source**—The preferred method of supplying nitrogen to an IR retrofit is through the use of a liquid storage tank and vaporizing system. Large volumes of liquefied gas can easily handle the supply of high flowrates without loss of houseline pressure. They also ensure that the nitrogen will be provided to the use point at the proper temperature.

2. **Main Flow Control Panel**—Houseline nitrogen is piped into the flow control panel where pressure is regulated down to the retrofit operating pressure of about 50 psi. Gas then flows to individual flowmeters, one for each diffuser assembly in the furnace.

3. **Diffuser Assemblies**—Several diffuser assemblies are placed within the furnace preheat and reflow zones. After optimizing their positions, they are bolted down to the furnace exterior with a bulkhead fitting. Nitrogen lines coming from the main flow control panel are then attached to the diffuser supply tubes.

4. **Gasketing**—As in the Generation I retrofit, a high-temperature gasketing material is used to seal the interface between the furnace lid and the furnace base.

After installation of the retrofit, a typical start-up consists of the following:

Day 1

–Clean furnace interior.

–Install gasketing.

–Install main flow control panel.

–Install diffuser assemblies.

Day 2

–Complete component installation.

–Furnace atmosphere optimization.

Day 3

–Furnace atmosphere optimization.

Following the above installation scenario, several retrofits have been installed in the U.S. and Canada. Currently numerous systems are either installed and operating or are pending.

Generation Ill Retrofit and Beyond

Future plans for the retrofit include a Generation III design, currently under evaluation. The most significant change for the Generation III package is in the design of the entrance and exit nitrogen curtains.

Future goals of the IR retrofit are to have the capability to achieve oxygen levels under 100 ppm throughout the furnace, with nitrogen flow rates under 1,000 scfh for all models of IR furnaces that are retrofittable.

Conclusion

IR furnace retrofits have proven to be effective at lowering oxygen levels in PCB soldering atmospheres. Figure 5 shows the performance comparison for Generation I and Il retrofits along with future expectations for the Generation Ill design.

The low oxygen content atmosphere in IR furnaces after retrofitting allows for the implementation of many advanced reflow processes, including no-clean soldering. The IR retrofit is a viable low-cost alternative to investment in high-cost nitrogen-ready reflow equipment.

Figure 5: Retrofit Performance Comparisons

Generation	I* (unopt.)	I* (opt.)	II**	III**
Oxygen Level (ppm)	1,800–5,800	700–1,200	100–500	<100
Nitrogen Consumption (scfh)	1,855	1,255	950–1,600	<1,000

* Large furnace models only
** All furnace models

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