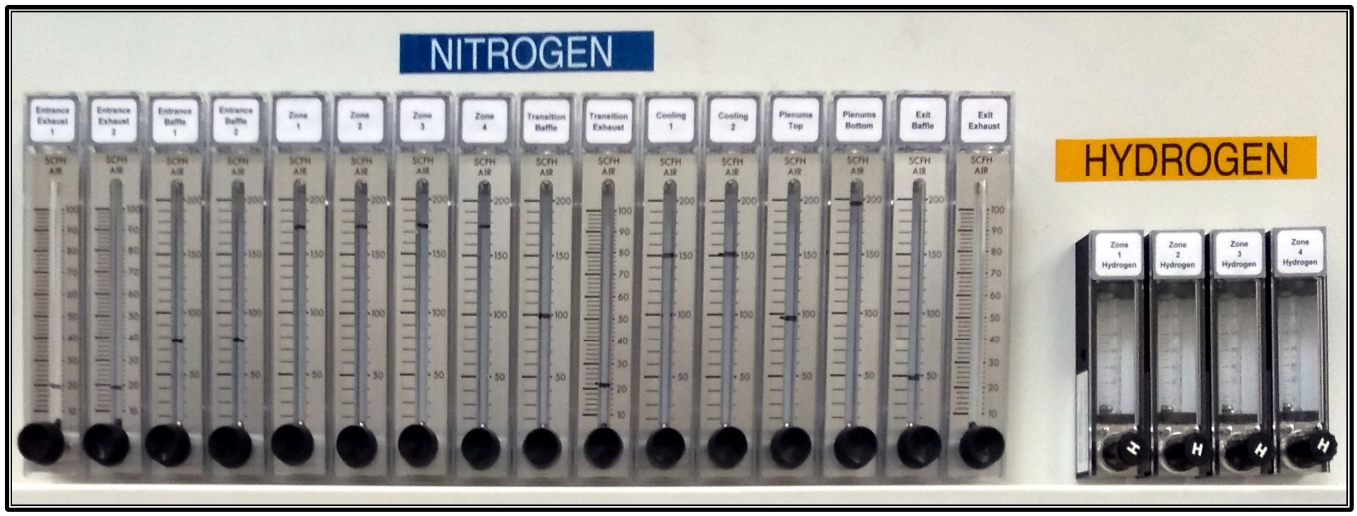
CONTINUOUS BELT IR FURNACE

Hydrogen Operation

Owner's Manual Supplement

Revision 0



This document is intended as a supplement to the Owner's Manual. It contains equipment description, safety warnings, standard settings, and operation instructions specifically tailored for use in operating the furnace with hydrogen process gas.

Do not operate the furnace using hydrogen gas until this manual has been read and understood and all equipment and operational pre-requisites have been satisfied.

Continuous Belt IR Furnace

Owner's Manual Supplement

Rev. 0

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Edited by: J. Clark, S. Barber

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Division of Lochaber Cornwall, Inc.
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949.218.4996
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10.1 Introduction

The Hydrogen Mode is designed to provide a means of introducing a reducing atmosphere into the furnace. Because hydrogen is an extremely flammable gas and presents numerous handling and control problems, connection of the furnace to hydrogen supply should not be attempted before this section is read and understood.

Typical features of a hydrogen furnace are depicted in Figure 10.1.1 Typical Hydrogen Furnace:

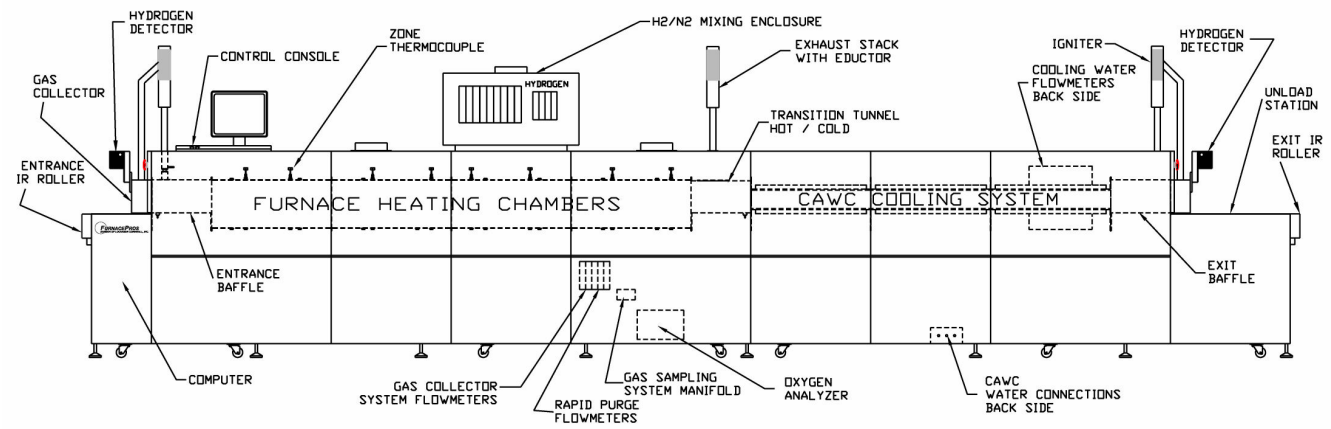

Figure 10.1.1 Typical Hydrogen Furnace

> WARNING: Do not permit hydrogen to be supplied to the furnace until this manual section has been read and understood by the equipment operator.

10.2 Alternate Nitrogen (only) Mode

This hydrogen furnace is equipped to operate in either Nitrogen or a Hydrogen Mode. In the Nitrogen mode, many of the safety features of the Hydrogen Mode are disabled to make the furnace easier and less expensive to operate. The Nitrogen Mode disables the gas selector popup, hydrogen detectors, gas collectors, rapid purge system, igniter system and gas permissive requirements. When operated in the Nitrogen Mode, the furnace will consume less nitrogen process gas. Since the igniter system is disabled in the Nitrogen Mode, the furnace will consume less power. Finally, the Nitrogen Mode can save time and manhours since it bypasses special operational steps including timed purges only required for safe operation with hydrogen. See paragraph *10.4 Setting System Modes* to enable/disable Hydrogen Mode of operation.

> WARNING: Make sure the hydrogen gas supply is safely locked out or disconnected before the Hydrogen Mode is disabled. Do not attempt to operate furnace in the Nitrogen Mode with hydrogen supply lines open to the furnace.

Except as expressly noted all parts of this section refer to operation of the furnace with the Hydrogen Mode enabled.

10.3 System Description

The Hydrogen Mode consists of the following systems to introduce hydrogen mixed with nitrogen in controlled concentrations into the furnace chamber:

1. Nitrogen furnace process gas plumbing,
2. Hydrogen/Nitrogen Mixing system
3. Control System Permissives,
4. Gas Sampling system (OSS),
5. Gas Collector system,
6. Rapid Purge system,
7. Combustion Gas Igniter system,
8. Combustible Gas Detector system,

The hydrogen gas first passes through a customer supplied manual shutoff valve into the hydrogen inlet manifold. The hydrogen manifold is equipped with a gas pressure switch to detect gas pressure above 55 psig. The hydrogen inlet manifold is plumbed to the hydrogen manifold which supplies gas to manual H2 Zone Control variable rate flowmeters. The hydrogen gas then mixes with nitrogen gas from the N2 Zone control variable rate flowmeters as the hydrogen/nitrogen mixture permeates the heating chamber porous ceramic fiber insulation. As it passes through the insulation the gas is preheated before it enters the process area.

Entrance and exit baffles located at each end of the furnace generate an inert gas curtain which prevents ambient air from entering the furnace and mixing with the hydrogen atmosphere. The heating and cooling sections of the furnace are separated by a transition tunnel which confines the hydrogen atmosphere to only the IR heating chambers. Venturi assisted exhaust stacks located in the entrance and exit baffles and transition tunnel draw off the used hydrogen and direct it into a burner assembly mounted in each exhaust stack where it is mixed with ambient air and ignited with a hot wire igniter.

Reference drawings: 801-101776 H2 Operation and 801-090674 H2 Process Gas P&ID.

10.3.1 Nitrogen System

The Nitrogen system operates as the default mode of the furnace. Nitrogen must be supplied to the nitrogen supply manifold to enable furnace operation. In either Nitrogen or Hydrogen Mode, if nitrogen pressure drops below the preset minimum, the software will provide audible and visible alarm.

After passing through the customer-supplied manual shutoff valve, nitrogen passes through the nitrogen manifold to the furnace heating zones, entrance and exit baffles, all stack eductors, transition tunnels, cooling sections and lamp plenums. Flow is controlled manually by variable rate flowmeters in the Nitrogen/Hydrogen mixing enclosure on top of the furnace.

In addition, nitrogen is supplied to the Gas Collector and Rapid Purge systems. Flow to the Gas Collectors is triggered by either selecting H2 Process Gas on the Gas Select popup screen or by start of the Rapid Purge system. Flow to the Rapid Purge system is activated by a timed sequence in the software via a normally open (NO) solenoid valve. Flow is controlled by flowmeters located in the lower middle of the furnace, front side (see Figure 10.1.1).

For the furnace to be operated with hydrogen gas, the following must be continuously detected:

1. Nitrogen pressure at the exhaust venturi, lamp and lamp plenums,
2. Nitrogen flow in the entrance and exit baffles and transition cooling tunnel (hot).
3. Nitrogen pressure at the N2 Zone Manifold and Rapid Purge system.

10.3.2 Hydrogen/Nitrogen Mixing System

Figure 10.3.1 H2/N2 Mixing System enclosure

The Hydrogen/Nitrogen Mixing system is located in a dedicated enclosure on top of the furnace (Figure 10.3.1). The enclosure contains the hydrogen and nitrogen supply manifolds and pilot operated solenoid for hydrogen supply gas.

The front of the enclosure provides controlled access to hydrogen and nitrogen variable rate flowmeters. Nitrogen flowmeters control nitrogen gas flow rates to the heating chambers, cooling chambers, transition tunnels and baffles, exhaust stacks and purge systems. Hydrogen flowmeters control hydrogen gas flow rates to the heating chambers only. All flowmeters are adjusted manually.

The H2/N2 Mixing enclosure contains a hydrogen detector and pressure and flow switches for certain controlled areas of the furnace (see Table 10-4 and Table 10-6 for sensing devices and settings).

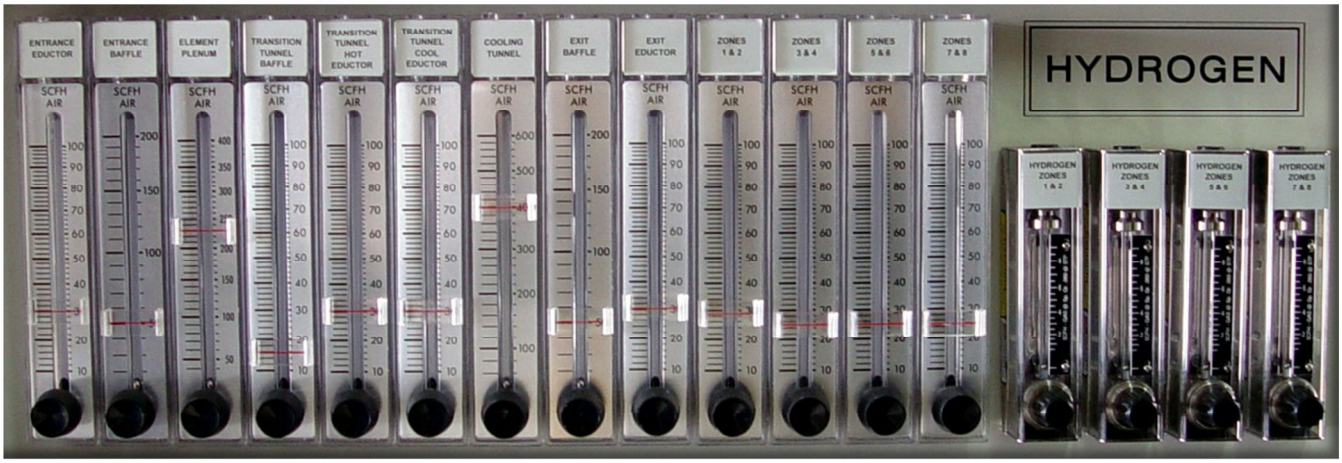

Figure 10.3.2 Nitrogen and Hydrogen Flowmeters

Whenever there is nitrogen supply pressure to the furnace and the nitrogen manual isolation valve is open, the nitrogen manifold is continuously supplied with nitrogen gas. Selecting hydrogen gas on the Gas Select popup opens the solenoid valve to allow hydrogen gas to flow to the hydrogen manifold and through the hydrogen flowmeters after all permissives have been satisfied and alarms cleared.

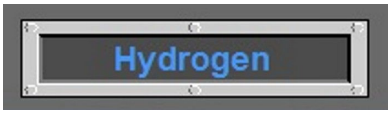

Figure 10.3.3 Gas Select window

Nitrogen and hydrogen flowmeters are adjusted separately to achieve desired ratios of hydrogen and nitrogen for each furnace control zone. See drawing *801-090674* for process plumbing details.

10.3.3 Control System Permissives

The hydrogen control system when enabled is designed to reduce the possibility of introducing a combustible mixture of hydrogen into the furnace. Before hydrogen can be introduced into the furnace heating chambers, software logic requires that the following conditions must be continuously met:

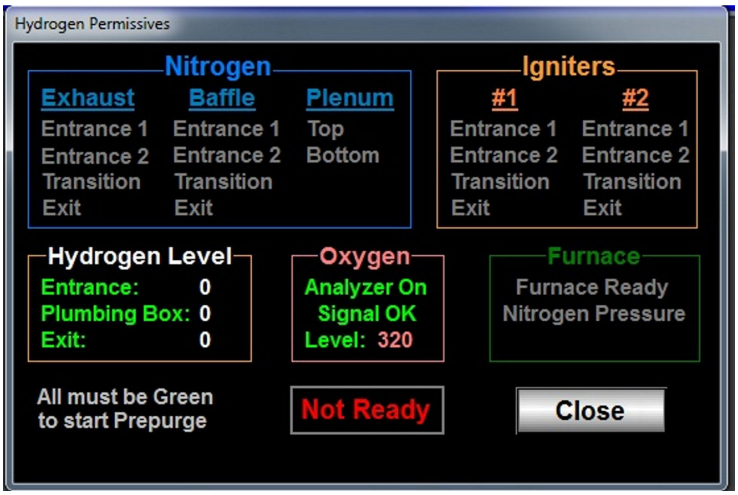

Figure 10.3.4 Combustion Gas Permissives screen

1. Nitrogen pressure detected at the exhaust venturi, lamp and lamp plenums,
2. Flow detected in the entrance and exit baffles and transition cooling tunnel (hot).
3. Pressure detected at the N2 Zone Manifold and Rapid Purge system
4. Hydrogen pressure detected at the hydrogen supply manifold.
5. All hydrogen detectors clear of combustible gas alarms.
6. The OSS oxygen monitoring system on and sampling, and the detected oxygen level below limits.
7. The Rapid Purge system has completed a purge cycle.

CAUTION: Even with the furnace safety features, use of hydrogen can be dangerous. It is the responsibility of the user to verify that the nitrogen and hydrogen zone control flowmeters are set in a ratio that assures that the concentration of hydrogen is less than the lower explosive limit (LEL). The LEL for hydrogen in air is 4.0% by volume in the presence of oxygen.

Alarm Interlocks

In additional to standard furnace alarms, the following hydrogen operation specific alarm interlocks are provided in the software.

Table 10-1 Hydrogen Operation Alarm Interlocks

Alarm	Audible	Visible	Cool Down
Low nitrogen supply pressure	X	X	X
Low hydrogen supply pressure	X	X	X
Low nitrogen flow to entrance baffle	X	X	X
Low nitrogen pressure to exhaust stack eductors	X	X	X
Low plenum pressure	X	X	X
Low nitrogen flow to exit baffle	X	X	X
Rapid Purge manifold low pressure fail	X	X	X
Hydrogen concentration high	X	X	X
Hydrogen sensor fail	X	X	X
Oxygen concentration high	X	X	X
Oxygen system OFF	X	X	X
Low igniter current or voltage	X	X	X

10.3.4 Gas Sampling System (OSS)

The Gas Sampling System samples and analyzes the process gas in the furnace to assure furnace concentrations of oxygen and/or moisture are below acceptable levels.

The system consists of analyzers, three (3) sample ports piped through a valve manifold. Source gas or reference gas is also piped to the valve manifold to allow operators to verify analyzer readings and source gas quality. A manual purge valve is provided to force pressurized source gas (Nitrogen) through the ports to remove moisture and oxygen. This valve must be in the Sampling (default) position for proper operation of the sampling system.

Figure 10.3.5 O_2 Sampling button

Active Process

The gas sampling system screen is accessed using the **OA Sample Select** button on the furnace software Process screen (*Figure 10.3.5*). The sampling pump and analyzers are turned ON or OFF by clicking on the radio buttons on the OA/MA Sampling screen (see *Figure 10.3.6*). Select either Source gas or one of the ports for sampling. Oxygen and/or Moisture concentrations are displayed on the Process Screen (*Figure 10.3.6*). Click **Exit** to return to the default Process screen.

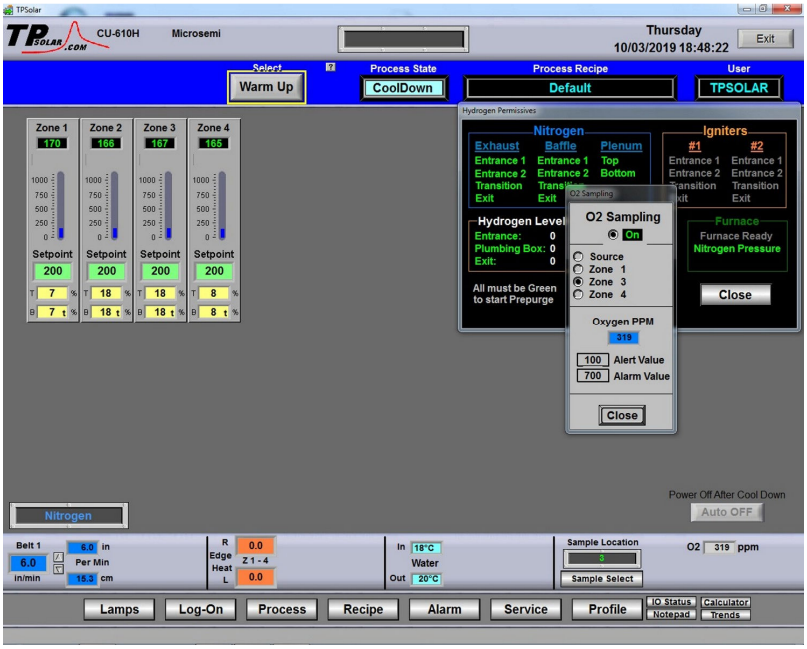

Figure 10.3.6 O2 Sampling window on Process screen

OSS in Recipes

OSS operation can also be determined and stored in recipes. Select Recipe button to access the Recipe Editor 1 screen (*Figure 10.3.7*). Enable or disable the Sampling system using the radio buttons on the right panel. Also select default sample port. Save Recipe to Disk to store on the furnace computer. Use Send to Furnace to activate recipe "from Editor" or "from Disk" in the furnace. When the program is closed and later reopened, the last recipe running will determine the ON/OFF state of the OSS.

Startup State

The moisture and oxygen system is setup to start automatically when the furnace is turned ON if a recipe is selected that requires its operation.

For reference, see drawing *801-090776 GAS SAMPLING SYSTEM* and separate operating manual section on the sample system (OSS), oxygen analyzer (OA) and optional moisture analyzer (MA).

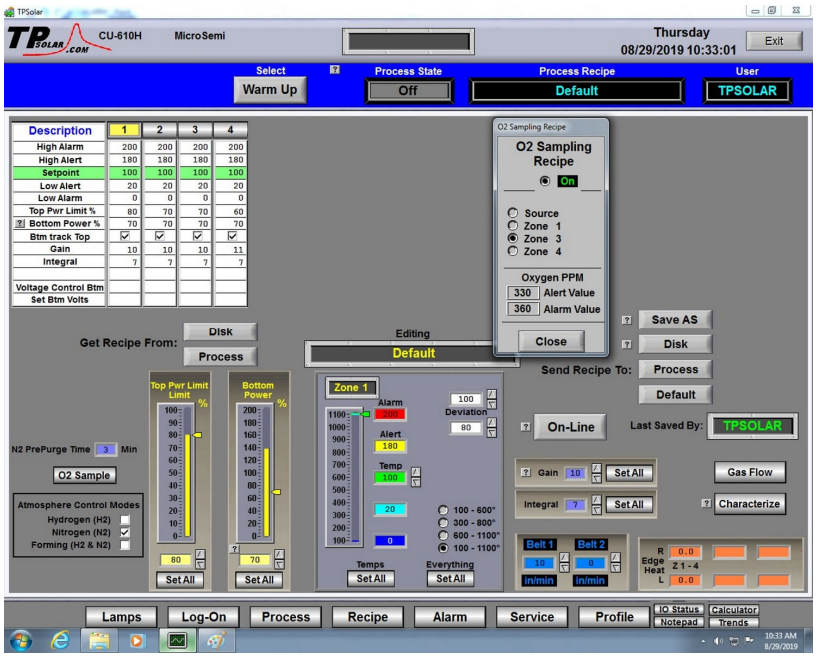

Figure 10.3.7 O2 Sampling on Recipe Editor screen

10.3.5 Gas Collector System

The gas collector system consists of two (2) enclosures, one at the entrance and one at the exit of the furnace. Nitrogen gas is fed to the collectors to provide a curtain of non-combustible gas at the product openings. The collectors vent to exhaust eductors which pull collected gas through the igniters before exhausting through the facility ventilation system. Nitrogen gas flow rate is controlled individually by manual variable rate flowmeters located near the Rapid Purge system manifold. See Figure 10.3.9 Nitrogen Pre-Purge.

Nitrogen gas is introduced to the collectors continuously during operation with H2 Process Gas (hydrogen gas supply valve is open). Nitrogen gas is also supplied to the collectors any time the Rapid Purge System is activated (hydrogen supply valve is closed, rapid purge valve is open).

Figure 10.3.8 Gas Collector at Exit

10.3.6 Nitrogen Pre-Purge System

The purpose of the Rapid Purge system is to quickly evacuate the furnace of process gas. The Rapid Purge system is initiated automatically when Hydrogen Process Gas is selected and when the hydrogen cycle is complete, either by user selection or by hydrogen system abort.

The Rapid purge system consists of additional piping a controlled supply of nitrogen gas to the following eductors. Cycle time and time rmaining appear in the Nitrogen Pre-Purge window (see *Figure 10.3.9*).

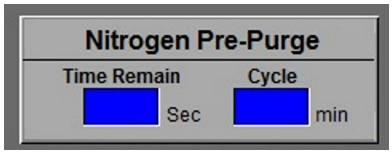

Figure 10.3.9 Nitrogen Pre-Purge Window

- Entrance Eductor
- Transition Tunnel (Hot) Eductor
- Exit Eductor

During initial start and shutdown of the Hydrogen Process gas cycle, the rapid purge valve is opened and nitrogen gas flows to the above devices to accelerate evacuation of combustion gas in the furnace for a timed duration. The duration can be set in the furnace control software by the engineer. During the Rapid Purge cycle the igniter system is activated to burn out any combustible concentrations of process gas.

10.3.7 Combustion Gas Igniter System

The igniter system starts when the hydrogen operation cycle is initiated, and runs continuously during the purge, fill, and steady state hydrogen operation.

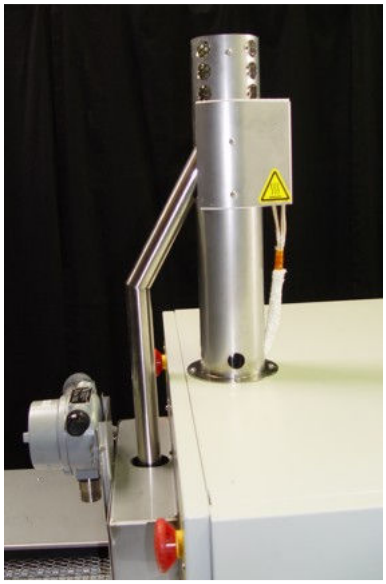

Figure 10.3.10 Igniter elements

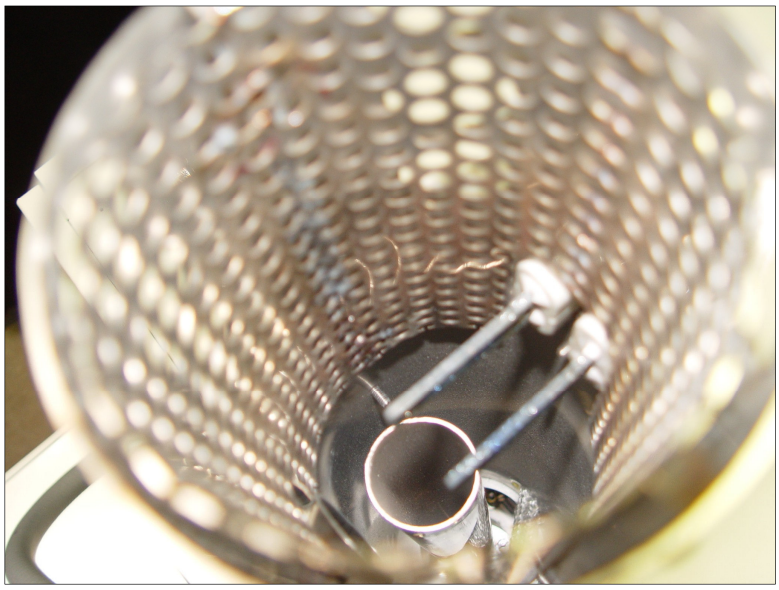

Figure 10.3.11 Igniter elements

The igniter system consists of redundant pairs of silicone carbide hot surface igniters located in each exhaust stack. The igniters are run by the power supplies located on the H2 Igniter panel. Sensors verify that the Igniter system is functioning properly.

If an igniter element fails, an audible alarm will sound and visual alarm will display the failed igniter number and position (top or bottom) in the furnace software. Igniter element pairs are numbered sequentially starting with “1” from the first stack at the entrance. If only one igniter fails in a single stack, the process in not aborted, but an alert occurs. If igniter failure is sensed and hydrogen operation aborted with alarm and display indication, a manual restart is required to reinitiate the hydrogen operation cycle.

10.3.8 Combustion Gas Detector System

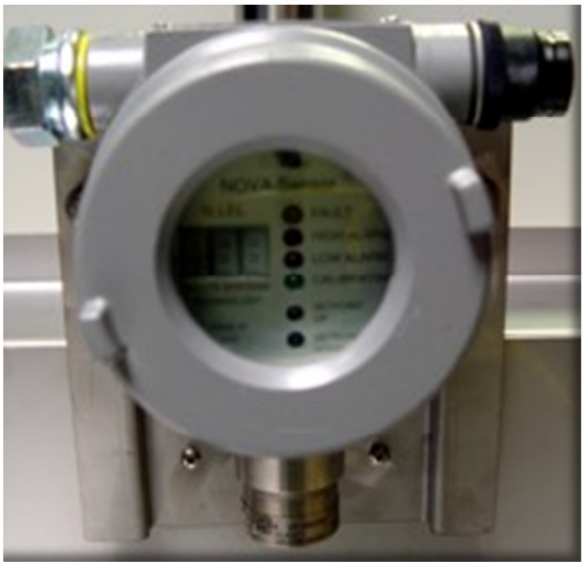

Figure 10.3.12 H2 Sensor

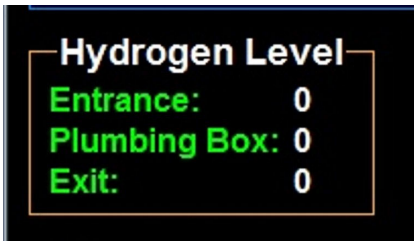

Figure 10.3.13 H2 Sensor Readings

The Combustion Gas Detector system consists of combustible gas sensors which monitor the furnace hydrogen levels at three locations: furnace entrance, furnace exit and in the hydrogen process gas mixing enclosure (Figure 10.3.12). The sensors provide a signal to the furnace program indicating volume percent lower explosive limit (%LEL) of combustible gas at each location. This signal shows on the sensor LED and on the furnace software Gas Select popup screen (Figure 10.3.13).

The combustible gas sensor is a self-contained device that measures and displays the concentration of combustible gas accumulated in and around the location of the sensor and transmits this information to the furnace controller and furnace computer. The sensors use the catalytic method of gas detection. Located inside a stainless steel flameproof housing, the sensing element is exposed to the detected gas through a sintered stainless steel flame arrestor. The actual detector consists of a matched pair of elements, each consisting of a fine platinum wire embedded in a bead of alumina material. Flammable gasses in low concentration will not burn by themselves, but when in contact with a suitable catalyst, it is possible to burn or oxidize any concentration of gas. One of the element pairs in the sensor is treated with such a catalyst, while the other element is protected with a similar, non-catalytic material. The platinum wires are heated by passing a suitable current through them. When the gas is oxidized on the surface of the catalyst, additional heat is released which causes a temperature rise on the catalytic surface. This change in temperature is measured and converted to determine the amount of combustible gas present. The sensor has been designed with a special poison resistant sensing material and provides accurate measurements in atmospheres where traces of silicone or other poisoning agents may be present. Readings are unaffected by humidity or carbon dioxide levels.

Detector RESET

The integral MODE push-button (black button on the upper right side of the sensor housing) can be used to clear any relays or alarms which have been latched when activated. Pressing the button for less than 3 seconds (0.5 second minimum) will cause the latched relays to clear and the alarm set points to be momentarily displayed.

Alarm Latch

The lower explosive limit for hydrogen is 4% by volume. The high alarm will latch when the sensor detects 50% LEL (2% Hydrogen). An alarm is sounded at the furnace software. Press the reset button for 0.5 to 3 seconds to release the high alarm latch. Then acknowledge the software alarm before restarting the furnace.

Operation

When power is first applied, the microcontroller in the sensor executes a startup test during which various internal components and parameters are checked. During the startup test, the indicator lights will be flashing. Upon successful completion of the startup test the sensor begins a 30 second countdown to allow time for proper temperature stabilization. The countdown is displayed on the digital readout. At the end of the countdown, the sensor displays its firmware revision code on the numerical readout and begins normal Protective Mode operation.

Protective Mode

In Protective Mode, the digital displays reads “000”. As a further verification that the unit is operating properly, the decimal points on the digital display slowly rotate from one digit to the next while displaying “000”. The sensor is now operating at the default calibration and alarm set points. After calibration, the most recent field calibration and alarm

set point information will be stored in the sensors non-volatile memory. This insures optimum performance even after power supply to the sensor has been temporarily interrupted.

Calibration

Each sensor has been calibrated at the factory. Each sensor should be recalibrated at regular intervals. The presence of clean air is essential to provide the electronics module with a reference point for 0% LEL gas concentration.

CAUTION: Do NOT use nitrogen to purge the sensor. False readings may result.

NOTE: Calibration gas with a concentration corresponding to 50% LEL of hydrogen is required for calibrating the sensors.

Calibration Procedure

Calibration is initiated by depressing the large MODE pushbutton located on the right side of the sensor enclosure and holding it for 6 to 10 seconds. The calibration sequence is as follows:

1. **Assure the sensor is exposed to clean air** to establish zero (air free of any combustion gas).
2. **Press the large MODE button on the outside of the sensor for 5 seconds**. The sensor acknowledges that the MODE button is pressed by lighting the three dots on the numerical display. The current gas concentration will also be displayed.
3. **Release the MODE button.** Once the MODE button is released, the numerical readout will flash "000" and "…" for about 10 seconds. During this time the sensor is storing the zero reference point based on clean air applied to the sensor.
4. **Apply 50%LEL test gas** as soon as the 15-second countdown begins (immediately after "000" stops flashing the sensor begins a 15-second countdown displaying the numbers "030" through "000". During this time the sensor is waiting for the calibration gas to be applied to the sensor.
5. **Allow the sensor to sample the gas.** "CAL" will be flashed and the CAL LED blinks as the gas for 3 seconds while the gas sample is quickly ramping up. As the sensor head reaches saturation, the current gas value is displayed every second. As soon as no more significant changes in gas concentration are detected, the sensor displays "050" and stores the calibration gas level as the new reference for the 50%LEL gas. At the same time the CAL LED changes from blinking to steady.
6. **Remove the test gas** immediately after the display stops flashing. The sensor begins normal operation once the gas level is safely below the LOW alarm set point (20% LEL)

During calibration the 4-20 mA signal to the furnace controller is set to minimum 2 mA and the relay outputs are suppressed. The sensor automatically returns to normal operation when calibration is complete.

Failed Calibrations

If calibration is aborted, the sensor will return to normal operation after a timeout period of 3.5 minutes. In this event, the sensor will use its original pre-calibration date. Correct deficiency and restart calibration if calibration fails.

Common causes for incomplete calibration include:

1. Turning the power off will also abort the calibration procedure.
2. Calibration gas concentration too low. The sensor will not accept calibration gas below 20%LEL. Low pressure will often be interpreted by the sensor as low concentration.
3. Gas applied at the wrong time. Gas applied during step 2 (too early during clean air sampling) will result in negative displays and inaccurate readings. If the gas is applied to late it may not reach significant levels before the 3.5 minute time-out and thus abort the calibration.

Correct deficiency and restart calibration if calibration fails.

10.4 Setting System Modes

This hydrogen furnace is equipped to operate in either Nitrogen or a Hydrogen Mode. In the Nitrogen mode, many of the safety features of the Hydrogen Mode are disabled to make the furnace easier to operate. The nitrogen mode disables the Gas Selector popup, Hydrogen Detectors, Igniter system, Gas Collectors, Rapid Purge system and gas permissive requirements.

> WARNING: Make sure the hydrogen gas supply is safely locked out or disconnected before the Hydrogen Mode is disabled. Do not operate furnace in the Nitrogen Mode with hydrogen supply lines open to the furnace.

10.4.1 Disabling Hydrogen Mode (Nitrogen only operation)

To take advantage of the cost savings of Nitrogen only operation, the furnace Hydrogen Mode must be disabled. To disable the Hydrogen mode perform the following steps in the order below:

1. Shut off manual valve on hydrogen gas supply line. Manually lock-out or disconnect the hydrogen gas supply line. The hydrogen supply must be securely disabled before the furnace system mode is changed.
2. Log on the furnace software as Engineer.
3. Go the Process screen and verify that the Gas Select popup screen is set to N2 (nitrogen gas).
4. Select the Maintenance screen.
5. Select the Calibrate screen (Figure 10.4.1)
6. Un-check the **Hydrogen Furnace** box.
7. Exit the calibrate screen

Figure 10.4.1 Enable/Disable Hydrogen Operation

The furnace is now in the Nitrogen Mode. Alarms related to nitrogen only operation will continue to function. However, all alarms and systems related to Hydrogen operation have been disabled.

10.4.2 Enabling Hydrogen Mode

To operate the furnace using hydrogen process gas, the Hydrogen Mode must be enabled. If the gas pop screen does not appear while in the Process screen, Hydrogen Mode has been disabled. To enable Hydrogen Mode, perform the following steps in the order below.

1. Log on to the furnace software as Engineer.
2. Select the Maintenance screen.
3. Select the Calibrate screen (Figure 10.4.1)
4. Check the **Hydrogen Furnace** box.
5. Exit the calibrate screen
6. Unlock or reconnect hydrogen process gas supply. Open hydrogen valve.

The furnace is now in the Hydrogen Mode. All alarms related to nitrogen only as well as alarms specific to operation with hydrogen gas are enabled.

With Hydrogen Mode enabled, the furnace can continue to be operated with nitrogen process gas alone. Gas Select popup screen and other features are available in the event operation with hydrogen gas is needed.

10.5 H2 Startup - Steps

The furnace Hydrogen Mode must be enabled to operate the furnace with hydrogen process gas. See *paragraph 10.4.2* to enable Hydrogen Mode.

In order to start using hydrogen gas the Hydrogen Operation Sequence is followed (*Figure 10.5.1*).

1. Verify that the Nitrogen and Hydrogen manual supply line valves are open.
2. In the furnace program, go to the process screen. Load or verify that the desired recipe is loaded. Select Warm Up to begin furnace stabilization.
3. Select the **O2 Monitor** button and turn O2 Sampling system ON. Select the port to be monitored.
4. Verify that the nitrogen flowmeters for the furnace zones, baffles, transition tunnels, lamp plenums, cooling system and exhausts eductors are properly set.
5. Hydrogen flowmeters should show zero. Set to off or verify that previous settings have not been changed (flowmeters can be locked out from operator access).
6. Go to the Process screen. After a few minutes, the **Gas Select** popup screen will appear. Select H2 for hydrogen process gas operation.
7. When the furnace temperatures stabilize, the system will:
    a. verify nitrogen is active and flowing above factory set points for the eductors, baffles, plenums.
    b. check to see if the Rapid Purge system has pressure.
    c. verify that hydrogen gas pressure is acceptable.
    d. verify that the O2 monitoring system is ON and sampling and that no O2 alarms are present.
8. The system will begin a nitrogen pre-purge cycle. The rapid purge system will turn ON for the operator set duration.
9. Hydrogen gas will flow into the H2/N2 Mixing system. The hydrogen flowmeters will open to previously set values.
10. Verify that the zone nitrogen and hydrogen gas flows are acceptable.
11. After the system has stabilized, product can be run.

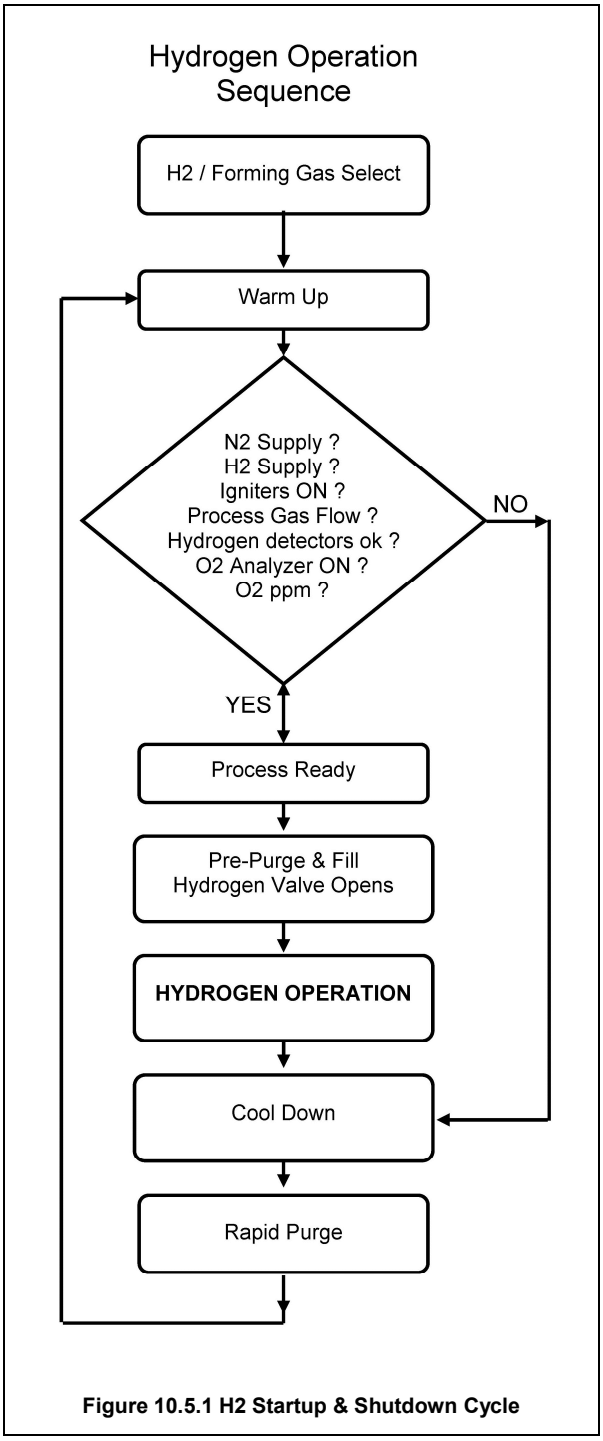

Figure 10.5.1 H2 Startup & Shutdown Cycle

10.6 Hydrogen Operation

After the system has completed the Hydrogen startup sequence (*Paragraph 10.5*) and stabilized, product can be run.

10.6.1 H2 Systems

During hydrogen operation the following systems related to hydrogen gas operation will be active:

1. Nitrogen supply pressure alarm.
2. Hydrogen supply pressure alarm.
3. Sampling System monitors oxygen and moisture levels in the furnace.
4. Minimum pressure/flow must be maintained in eductors, baffles, transition tunnels and lamp plenums. Verify that each of these is properly adjusted.
5. Verify that the nitrogen flowmeters for the furnace zones are properly set.
6. Once hydrogen gas flow has started, verify the hydrogen flowmeters for the furnace zones are properly set.

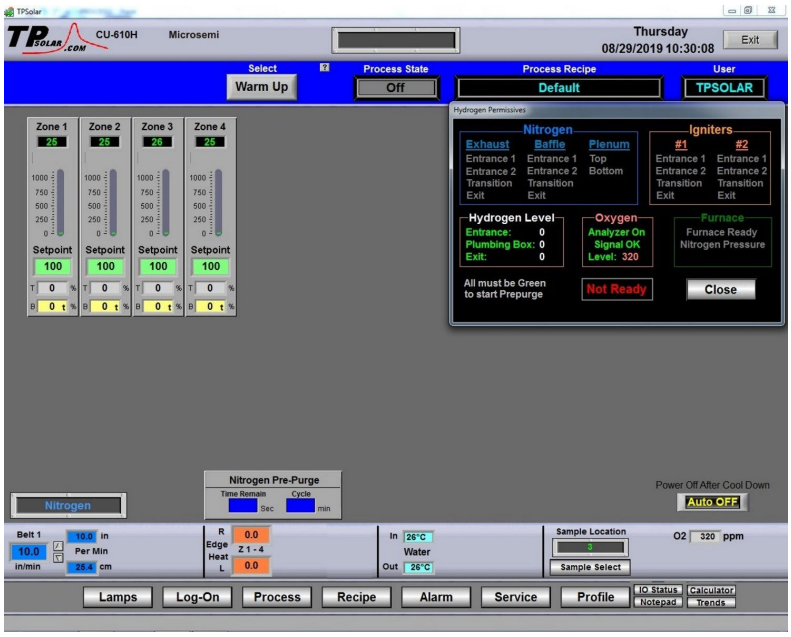

Figure 10.6.1 H2 Operation at Process Start

7. Hydrogen detector system will be actively monitoring for presence of combustible gas at the furnace entrance and exit and in the H2/N2 Mixing enclosure.
8. Hydrogen igniter system will be active at all exhaust stacks.
9. Gas collector system will provide gas flow to collectors.

10.6.2 H2 Operation - Steps

Hydrogen Atmosphere (option not supplied)

Figure 10.6.2 Gas Select

1. Go to the Process Screen and click on **H2 Process Gas** radio button on Gas Select screen (*Figure 10.6.2*).
2. Click on Warm Up.
3. Wait until the process start light is flashing. Then click on Process Start to start an automatic timed pre-purge with nitrogen that lasts from 5 to 30 minutes (set by user).
4. When the purge cycle is complete, click 

. Nitrogen supply will be shut off to the zone flowmeters and hydrogen will flow to the zone flowmeters. This action starts an automatic timed fill. Nitrogen flows to collector system. See *Figure 10.6.1.*
5. Adjust hydrogen zone flowmeters as required.

Hydrogen/Nitrogen (Forming Gas) Atmosphere (supplied option)

1. Go to the Process Screen. Click on **H2 Process Gas** or **Forming Process Gas** radio button on Gas Select screen (*Figure 10.6.2*).
2. Click on Warm Up.
3. Wait until the process start light is flashing. Then click on **Process Start**. to start an automatic timed pre-purge with nitrogen that lasts from 5 to 30 minutes (set by user).
4. When the purge cycle is complete, click 

and hydrogen gas will flow to the zone flowmeters to be mixed with the flow from the nitrogen flowmeters. This action starts an automatic timed fill. Nitrogen flows to collector system. See *Figure 10.6.1*.
5. Adjust nitrogen and hydrogen zone flowmeters as required.

NOTE: Fill is defined as the amount of time required for the combustion gas to enter and fill the chamber cavity. Fill time is factory preset for 5 minutes and can be changed by the user.

10.7 H2 Operation Cool Down and Termination

Cool Down

Any time the system is placed into **Cool Down**, the rapid purge system will be activated to force an additional volume of nitrogen gas to the gas collectors and to the stack eductors to quickly purge the furnace of combustible gas. The igniter system will remain active until the purge cycle is complete.

Terminate H2 Operation

To terminate operation using hydrogen gas, go to the Process screen and click **Cool Down**. The furnace will immediately begin the Rapid Purge sequence. Rapid purge performs a timed countdown during which period the Rapid Purge valve opens to flood the exhaust eductors with additional nitrogen gas to speed evacuation of combustible gas from the furnace.

Another way to terminate the current furnace process is to go to the Recipe Editor 1 screen and load a new recipe. The new recipe will require satisfaction of all items in the Hydrogen Startup sequence before operation with hydrogen gas can commence.

Any alarm, EMO disconnect or safety interlock disconnect will initiate the Cool Down / Rapid Purge cycle.

After the system has completed Cool Down, the hydrogen must be locked out before the furnace power can be shutoff.

10.8 Furnace Shutdown

To shut down the furnace, the system must complete Cool Down sequence.

After the system has completed Cool Down, the hydrogen supply line must be manually locked out before the furnace power can be shutoff. Since shutdown of the furnace disables the hydrogen detectors, igniters and other failsafe devices built into the furnace, it is imperative that lockout be complete before power is disconnected to the furnace.

10.9 Failsafe Design

The furnace has been designed to reduce the possibility of danger to employees, operators and production equipment and the facility in the event of an emergency such as a power failure, failure of the nitrogen gas supply or of a system on the furnace that disables the controls or computer.

Table 10-2 System and Device Failure Modes

Device	Normal condition	In the event of	
		Power Failure	Nitrogen gas failure
Nitrogen supply	Open to manifold (no valve)	Open for nitrogen purge	Furnace goes into Cool Down. H2 valve closes
Hydrogen supply pressure	NC pilot valve closed, pneumatic valve pressurized to open	H2 pilot and supply valve closes	H2 pilot and supply valve closes
Rapid Purge System	NC pilot valve open, pneumatic valve pressured to close	Solenoid open, pneumatic valve opens for nitrogen purge	Pneumatic valve open, but N2 not available.
Gas Collector System	Opens on H2 or RP System	Opens to supply nitrogen to collectors	Not applicable
Computer	Running	Shuts down, RAID recovery on startup	Alarms, goes to Cool Down
PLC	Running	Shuts down. download program from computer if necessary	Alarm, goes to Cool Down
Combustion Gas Detectors	ON in Hydrogen mode	Disabled. Furnace software alarm	Normal operation.
Igniters	ON when H2 Process Gas selected. Software alarm upon device failure.	Fails. Furnace software audible alarm and message.	Normal operation
Oxygen analyzer	Turn ON in software for Hydrogen operation.	Alarms if analyzer power fails	Alarms on high O2 concentration if analyzer power fails

10.10 Installation Requirements

10.10.1 Furnace Location

Adequate precautions must be taken to prevent the escape of hydrogen into the room air and to eliminate possible sources of ignition from the working environment.

The room containing the furnace must be arranged to prevent direct air drafts from hitting the furnace. A direct air draft at the entrance or exit end of the furnace can unbalance the can unbalance the gas curtains, cause hydrogen to escape into the room or oxygen to enter the furnace presenting a possible a danger of explosion. In addition, disruption of these air curtains can cause disturbances in the furnace profiles and introduce inconsistency in the furnace profile and performance.

The exhaust system above the furnace should be sufficient to collect hydrogen that may escape into the room and evacuate it safely.

A leak detection system should be installed in the room to indicate and alarm if combustible gas is present in the room.

10.10.2 Nitrogen Supply

Oil Free dry nitrogen is to be supplied to the furnace at a maximum dewpoint of 15°C through a customer supplied 3/4 inch minimum diameter customer supplied line connected to a ¾" FPT fitting on the furnace H2/N2 Mixing enclosure. In addition a customer supplied manual shutoff valve and pressure regulator suitable for nitrogen gas applications must be installed in the line before the furnace connection. The regulator should be adjusted to supply 70 psi pressure to the furnace.

Table 10-3 Recommended Nitrogen Composition

Oxygen (O2)	5 ppm max	Carbon Dioxide (CO2)	100 ppm max
Total Hydrocarbons	100 ppm max	Hydrogen (H2)	1000 ppm max
Moisture	20 ppm max	Other inert contaminants:	1000 ppm max

A minimum pressure of nitrogen gas must be detected continuously during furnace operation and during purge cycles. In the event of nitrogen supply failure, hydrogen is automatically shutoff and the hydrogen cycle is aborted with alarm and display indication. Only after nitrogen pressure is restored can the furnace be operated or the cycle be restarted.

Nitrogen supply is verified as follows:

Table 10-4 Nitrogen Supply Sensing Devices

		Factory Settings	
Nitrogen Permissives	**Device (Normally Open)**	**To close**	**To open**
Nitrogen manifold	Pressure (0-100 psi)	45 psi	40 psi
Rapid purge	Pressure (0-100 psi)	40 psi	35 psi
Entrance eductor	Pressure (0-15 psi)	14 scfh	10 scfh
Transition Tunnel (hot) eductor	Pressure (0-15 psi)	14 scfh	10 scfh
Transition Tunnel (cold) eductor	Pressure (0-15 psi)	14 scfh	10 scfh
Exit eductor	Pressure (0-15 psi)	14 scfh	10 scfh
Lamp Plenums	Pressure (0-15 psi)	70 scfh	50 scfh
Entrance baffle	Flow (10.8 scfh to close; 9 scfh to open)	14 scfh	10 scfh
Transition tunnel	Flow (10.8 scfh to close; 9 scfh to open)	14 scfh	10 scfh
Exit baffle	Flow (10.8 scfh to close; 9 scfh to open)	15 scfh	5 scfh

10.10.3 Hydrogen Supply

Hydrogen is to be supplied to the furnace at a maximum dewpoint of -17.8°C (0°F) through a customer supplied 3/8 inch minimum diameter customer supplied line connected to a ¾ inch FPT fitting on the furnace H2/N2 Mixing enclosure. In addition a customer supplied manual shutoff valve and pressure regulator suitable for hydrogen gas applications must be installed in the line before the furnace connection. The regulator should be adjusted to supply 70 psi pressure to the furnace.

Table 10-5 Recommended Hydrogen Composition			
Oxygen (O2)	10 ppm max	Carbon Dioxide (CO2)	100 ppm max
Total Hydrocarbons	100 ppm max	Nitrogen (N2)	1000 ppm max
Moisture	20 ppm max	Other inert contaminants:	1000 ppm max

A minimum pressure of hydrogen gas must be detected continuously during hydrogen operation and during purge cycles. In the event of hydrogen supply failure, a low pressure signal will abort hydrogen operation, hydrogen valve will close and nitrogen purge is initiated with an alarm and display indication. Only after hydrogen pressure is restored can the cycle be restarted.

Table 10-6 Hydrogen Supply Sensing Devices			
		Factory Settings	
Hydrogen Permissives	**Device (Normally Open)**	**To close**	**To open**
Hydrogen manifold	Pressure (0-100 psi)	60 psi	55 psi

WARNING: Hydrogen is a flammable gas and under certain conditions it can be explosive. The user of this equipment must take adequate precautions to prevent the escape of hydrogen into the room and to eliminate possible sources of ignition from the working environment. A common practice is to vent the upper part of the ceiling of the room containing the furnace and to install a hydrogen leak detector system in the room.

10.1 Functional Checkout

10.1.1 Checkout with Hydrogen

A functional checkout of the hydrogen system is recommended using helium gas for safety. If it is not practical to perform a functional checkout with helium, perform the system checkout in section 10.1.2 using a trace oxygen analyzer and combustion gas detector instead. If so equipped, use the oxygen sampling system and combustible gas monitoring system installed on the furnace for most of the test.

WARNING: The furnace has been designed and manufactured so that it can be safely and reliably operated on hydrogen. However if gas flows are not properly set, air can be drawn into the machine. Or the furnace atmosphere can be discharged out the entrance or exit product openings presenting possible fire hazard or explosion danger to employees and equipment.

10.1.2 Checkout with Helium

A functional checkout of the hydrogen system is recommended using helium gas for safety. During this activity a trace oxygen analyzer and helium detector be made available for the checkout.

1. Furnace System Functional Check

   First perform the recommended furnace system functional checkout. Correct any malfunctions as necessary before proceeding.

2. Helium Supply Gas

   Temporarily connect a source of helium gas to the hydrogen input line and adjust the input regulator to 50 psi (this corrects for 70 psi hydrogen). make sure that the hydrogen flowmeters are completely shut OFF at this time.

3. Turn Furnace ON

   Turn furnace ON and bring it up to a fully operational state using the suggested gas flow settings from the Owner's Manual to set the nitrogen and hydrogen flowmeters, except set the nitrogen flowmeters to zero.

4. Initiate the Hydrogen Operation Cycle

   Adjust each zone hydrogen flowmeter to the same flowrate as its respective zone nitrogen flowmeter setting.

5. Check Oxygen Concentration

   Check the oxygen concentration inside each zone of the furnace using a tract oxygen analyzer or the onboard sampling system and oxygen analyzer. The oxygen concentration can vary considerably, depending on flow settings; but as long as 100 ppm or less is maintained in the furnace, combustion will not occur during hydrogen operation. If the concentration of oxygen is above the 100 ppm limit, adjust the hydrogen zone control flowmeters to increase the flow of helium in small increments and retest the oxygen level. Allow several minutes between gas flow corrections and oxygen testing for the analyzer to stabilize.

6. Check for Escaping Gas

   Check each end of the furnace with a helium detector (or for H2 use the combustion monitors) to determine if any furnace gas is escaping. If furnace gas escapes, increase the flow to the appropriate eductor in small increments and retest.

NOTE: The eductor operates with a venturi assisted exhaust stack that produces a flow rate in a ratio of approximately ten to one (10:1). For each 1 SCFH of N2 gas to the eductor, the venturi will pull approximately 10 SCFH of gas from the furnace. In general the gas flows into the furnace chamber and baffles should be balanced by the gas flows out of the eductor stacks to assure the furnace is neither adding process gas to the room nor taking oxygen from the room.

7. Adjust for Hydrogen / Nitrogen Mixing

Selecting the hydrogen/nitrogen atmosphere (furnace in the hydrogen mode) will unbalance the ratio of input to exhaust gas. This happens because a second gas is introduced in addition to the volume that is already flowing to balanced furnace. Before pressing hydrogen operation, perform the following:

a) Determine the volume of helium (or hydrogen) flowing into the furnace when the machine is running in a balanced condition.

b) Decide what ratio of hydrogen to nitrogen is desired in each zone and the volume of each gas desired.

c) Select the nitrogen atmosphere mode to return the furnace to nitrogen operation.

d) Adjust the nitrogen volume to the values calculated in 2.12.6.6. Shut OFF the hydrogen flowmeters.

e) Select the hydrogen operation mode. Select the hydrogen mix mode before the purge cycle is complete.

f) Then adjust the hydrogen flowmeters. The machine should now be operating in a balanced condition with proper volume of nitrogen and hydrogen.

g) Check the oxygen level in the furnace. Check the ends of the furnace for helium (or combustible gas) and correct as necessary.

h) This completes functional checkout.

8. Connect Hydrogen Supply

This completes the functional checkout.

10.2 Gas Correction Factors

Flowmeters are calibrated to the indicated gas. If a different gas is used, the flowmeters must be corrected for the different gas density.

For example:

For helium: flowmeter reading x 2.69
For hydrogen: flowmeter reading x 3.78

If adjusting flowmeters calibrated for hydrogen using helium, adjust helium supply pressure to 50 psi

50 psi = (70 psi x 2.69 / 3.78)

Table 10-7 Gas Correction Factors

Gas	Symbol	Specific Gravity*
Air	…	1.000
Argon	Ar	1.378
Carbon dioxide	CO_2	1.517
Carbon monoxide	CO	0.967
Helium	He	1.380
Hydrogen	H_2	0.070
Hydrogen chloride	HCL	1.268
Hydrogen sulfide	H_2S	1.176
Methane	Me	0.554
Natural gas	…	0.665
Nitrogen	N_2	0.967
Nitrous oxide	N_2O	1.518
Oxygen	O_2	1.103
Propane	C_2H_2	1.550
Sulfur dioxide	SO_2	2.209
Butane-N	C4H10	2.400
Butane-ISO	C4H10	1.990
*20°C @ 1 atmosphere		