

## 9.1 Infrared Heating

Infrared waves form part of the electromagnetic spectrum. Electromagnetic waves with wavelengths from  $0.78\ \mu\text{m}$  to  $1000\ \mu\text{m}$  are called infrared waves. You are already familiar with electromagnetic waves of different wavelengths. Microwaves, X-rays, radio waves and visible light are all electromagnetic waves. Infrared waves produced inside the furnace lie predominately in the near and medium infrared range with wavelengths ranging between  $0.5$  and  $3.0\text{-}\mu\text{m}$ .

When using infrared lamps, higher heat-lamp temperatures emit higher radiant energy. This elevated energy translates to a shorter electromagnetic wavelength of emitted IR radiation. While the IR waves of a heat lamp come from a continuous range of wavelengths, the **dominant wavelength** ( $\lambda_{\text{dom}}$ ) as given by Plank's distribution principle is the wavelength transmitted with the highest occurrence. So for a given temperature, only one  $\lambda_{\text{dom}}$  exists. See Figure 9-1 below.

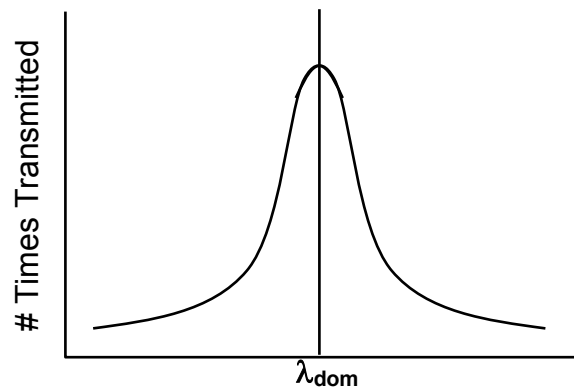


Figure 9-1: Dominant Wavelength Graph

## Chapter 9

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The relationship between heat-lamp filament temperature **T** and  $\lambda_{\text{dom}}$  is given by the fixed relationship:

$$\lambda_{\text{dom}} \mu\text{m} = \frac{2897 \mu\text{m}\cdot\text{K}}{\text{T K}}$$

To convert from degrees Celsius (°C) to Kelvin (K) add 273 to the Celsius temperature value.

*Example:*

*At 1000°C the respective material dominant wavelength is:*

$$\text{T} = 1000^{\circ}\text{C} + 273$$

$$\text{T} = 1273 \text{ K}$$

*Substituting back into the given equation:*

$$\lambda_{\text{dom}} = 2897 \mu\text{m}\cdot\text{K} / 1273 \text{ K}$$

$$\lambda_{\text{dom}} = 2.28 \mu\text{m}$$

Table 9-1 shows dominant wavelengths for some common temperatures.

Furnace Setpoint (°C)	Dominant Wavelength (μm)
1000	2.3
900	2.5
800	2.7
700	3.0
600	3.3
500	3.7
400	4.3
300	5.1
200	6.1
100	7.8

**Table 9-1: Dominant Wavelength vs. Temperature**

If you know the **resonant frequency** of a particular substance, matching the furnace dominant wavelength the product resonant frequency ensures maximum energy transfer via IR radiation. In most cases, rapid product heating can be achieved more efficiently through frequency matching rather than with temperature increases.

## Advantages of IR Heating

Heating via conduction and convection operates by transferring heat to object surfaces. Heat is then transferred from the surface to the layers beneath. Heat transfer, however, is not uniform, causing temperature differences and unequal expansion across an object. The unequal expansion due to the uneven heating is called thermal stress and can cause objects to fracture called thermal shock.

IR radiation heats molecules below an object's surface and allows for more uniform heat distribution than can be provided by conduction and convection heating alone.

Rapid heat up time is also achieved with IR technology due to the high energy-transfer rate of IR waves. The speed of conduction and convection heating is proportional to the temperature difference between the object and heating environment, whereas the speed of IR heating is proportional to the difference between the fourth powers of the object and environment temperatures.

*For example:*

*Suppose the temperatures of an object were 100°C.*

*If a convection heating furnace were heated to 500°C, the proportional difference would be*

$$500 - 100 = 400$$

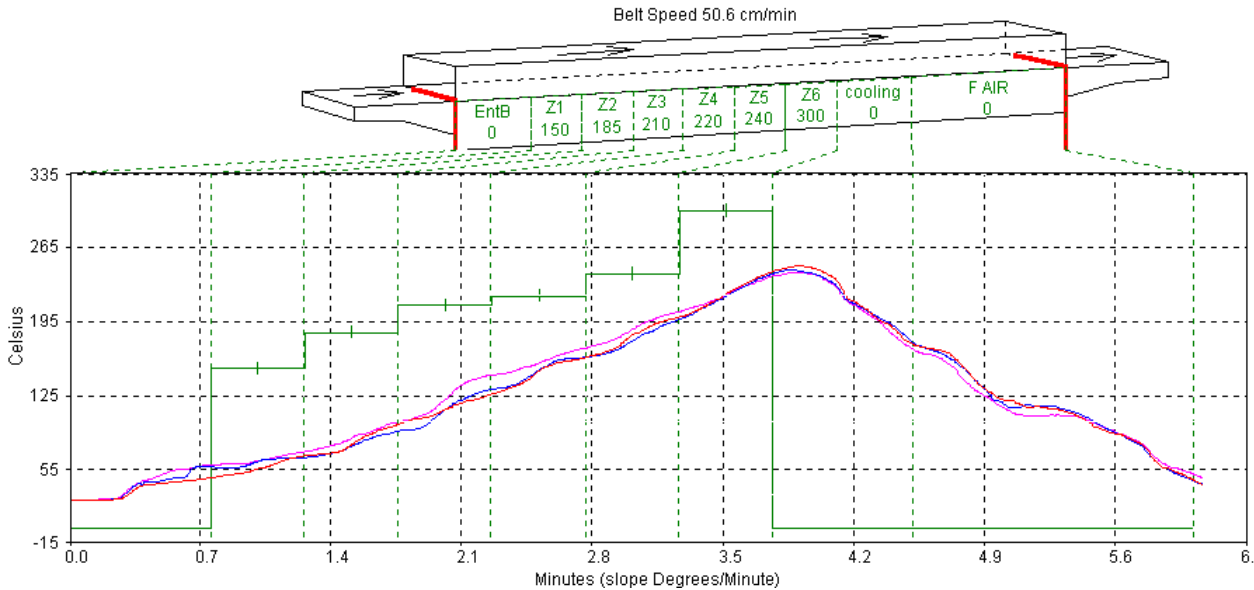
*If an IR furnace were heated to 500°C, the proportional difference would be*

$$500^4 - 100^4 = 6.25 \text{ E}^{10} - 1.00 \text{ E}^8 = 6.24 \text{ E}^{10}$$

Other factors such as the emissivity of objects are taken into account when calculating energy transfer rates.

# 9.2 Temperature Profiling

As discussed previously in Section 3.3 “Thermal Process”, product passing through the furnace go through a set of temperatures known as a temperature profile. The process engineer must configure the furnace to achieve the temperature profile with the product. To do this, the engineer must have an idea of what the cycle of the product must look like. Looking again at the temperature profile from Chapter 3, six zones are visible labeled Z1 – Z6 (See Figure 9-2 below). Depending upon the configuration of the furnace, more zones may be present.



**Figure 9-2: Temperature Profile**

Initially, temperature profiles must be recorded from inside the furnace. To get to the point of taking a temperature profile, the following list of topics will be covered.

- Profile Specifications
- Basic Variables
- Type of Profiles
- Examples of Profiling

## 9.2.1 Profile Specifications

In general, the temperature profile is defined by the following parameters:

- a. Heating Rate: The rate of increase of temperature from room temperature.
- b. Dwell/Hold Time: The time the product remains above a certain temperature or a range of temperatures.
- c. Second Heating Rate: The rate of increase of temperature from the temperature reached during the hold time, as required.
- d. Peak Temperature: The maximum temperature reached with a +/- range.
- e. Second Hold Time: Dwell/Hold time for 2<sup>nd</sup> heating.
- f. Cooling Rate: The rate of decrease of temperature to a lower/critical temperature.
- g. Product Exit Temperature: As required.

When a conveyor belt speed range is requested for a desired product speed the above specifications are met within the specified speed range. In general, the speed range depends on the size and type of furnace. However, many sets of belt speeds and temperature settings can meet a given set of profile specifications. Furthermore, higher belt speeds result in greater temperature deviations and lower consistency from the desired temperature profile.

## 9.2.2 Basic Variables

The two most influential and basic variables in setting up a temperature profile are:

- Conveyor Speed: The time required to pass through the process section.
- Temperature Setpoints: The energy level in each zone.

The combination of the time-temperature exposure of the product determines the temperature profile. The temperature settings in each zone set the heating rate and hold times of the product.

A third and less influential factor in the temperature profile is:

- Flow Meter Settings: The rate of gas flow through the process section.

If the furnace is equipped for a controlled atmosphere, this will be an important factor to consider. Gas flow and flow meter settings will be addressed in detail later in Section 9.6 on p.108.

### 9.2.3 Types of Profiles

In most processes, two kinds of temperature profiles exist:

Equilibrium (flat) profile applications:

- Hybrid thick film and PTF firing
- Glass or metal/solder sealing of IC packages
- Die-attachment processes
- Drying/Curing of polymeric products

Non-Equilibrium (peaked/spiked) profile applications:

- Solder reflow attachment
- Cerdip lead-frame attachment
- Solar cell firing processes

Most microelectronic and semiconductor thermal processes fall into one of the above categories, or some combination of the two. Set the furnace parameters according to the type of process that will be used with the furnace.

### 9.2.4 Examples of Profiling

To create a temperature profile, the following components are needed:

Thermocouple Wires

K-Type thermocouples are recommended.

Depending upon operational temperatures, use a properly rated thermocouple for accurate readings. For temperatures above 300°C, we recommend the use ceramic or ultra-high-temperature plastic connectors and Inconel sheath material with MgO insulation.

Use one thermocouple for centerline profiling or three for across-the-belt profiling.

Temperature recording device

Chart recorder

OSP – On Screen Profiling option

KIC temperature profiling software kit

MOLE/SuperMOLE type of datalogger

DATAPAQ Data Logger

Below temperatures of 300°C, the thermocouple can be taped with Kapton tape to a test specimen.

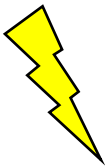
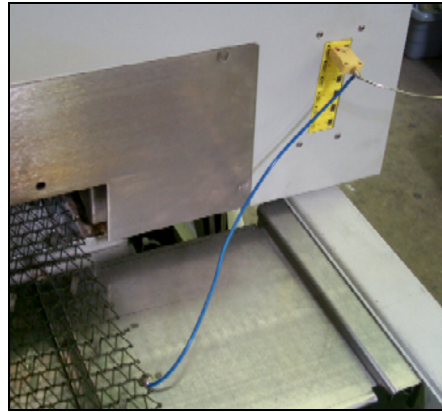
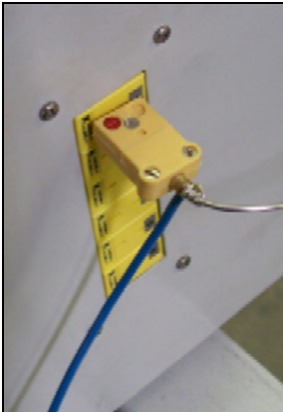
**Note: Repeat testing may require new tape for accurate results.**

Above 300°C, the thermocouple sensor must be cemented onto a test specimen. In cases where the product of interest is not readily available, The thermocouple may be placed inside a small length of ceramic tube called a bead.

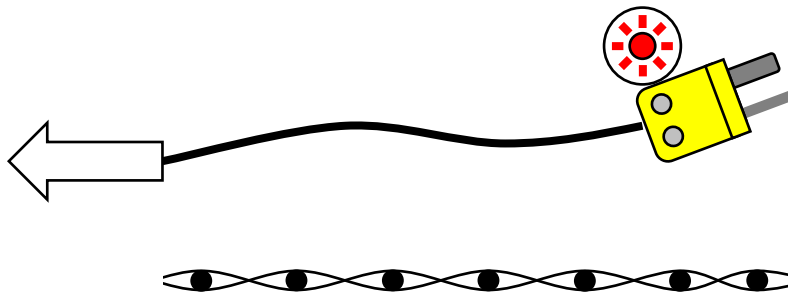


**Safety**

**DANGER:** When using metal shielded thermocouple wires inside a furnace, electrostatic energy may collect on the wires. Properly ground the shielding material to the furnace chamber by wrapping a wire around the sheath and attaching one end to an unpainted portion of the furnace cabinet



**DANGER:** Extreme caution must be taken when pulling thermocouple wires through the process section. Connectors may bounce inside the chamber and break a lamp exposing the handler to high voltage and current, which could cause serious injury or death.



## Equilibrium Profiles

For equilibrium profiles (flat temperatures profiles), set a belt speed that will result in at least a 6-10 minute dwell time inside the heating chamber. The following table shows some belt speeds for various heating chamber lengths.

Heating Chamber Length		Dwell Time			
(in.)	(cm)	6 minutes		10 minutes	
		(in./min)	(cm/min.)	(in./min)	(cm/min)
30	76	5	12.7	3	7.6
60	152	10	25.4	6	15.2
90	229	15	38.1	9	22.9
120	304	20	50.8	12	30.4

Table 9-2: Equilibrium Belt Speed Recommendations

**For across-the-belt temperature profiles**, set the belt speed to a minimum. The slow rate of the conveyor belt will result in a larger number of recorded temperature readings. A slower rate increases the resolution of the temperature profile and can reveal more information about temperature uniformity and consistency.

Set all zone temperatures to the desired peak temperature plus 5°C.

**If edge heaters are installed**, a setpoint of 30% power is a good starting point. Also, for edge heat, allow a few minutes to pass between setting adjustments, as the nickel chromium edge heat wires do not respond as quickly as the IR heat lamps.

**If faster heating rate** is desired with a longer dwell time at the peak temperature, increase the first 1-2 zone temperature setpoints by about 10-20% of the peak temperature. The heating rate will be higher at the start, while the remaining zones will maintain the temperature of the product at the peak temperature.

A slow belt speed will allow the temperature to reach the peak temperature within the first 1-2 zones. The rest of the heating chamber will hold the temperature for the remainder of the profile.

- Record the temperature and observe the results.



**If the desired temperature and hold time is not achieved**, begin tuning the belt speed and zone setpoint temperature variables. The following are some guidelines:

For faster initial heating rates, try one of the following:

- Lower the belt speed
- Raise the first 1-2 zone temperature setpoints

For slower initial heating rates:

- Raise the belt speed
- Lower the first 1-2 zone temperature setpoints

For faster belt speeds:

- Raise the belt speed 5%
- Increase zone 1-2 setpoint temperatures by 7%

For slower belt speeds:

- Lower the belt speed 5%
- Decrease zone 1-2 setpoint temperatures by 7%

- Record a new temperature profile
- Go back and retune as necessary until the desired temperature profile is achieved.



## Non-Equilibrium Profiles

For non-equilibrium (peaked or spiked) temperature profiles, if the type of profile requires no hold time temperatures, try the following.

- Start with a high belt speed that will result in a 2-4 minute dwell time through the heating chamber.

Heating Chamber Length		Dwell Time			
(in.)	(cm)	2 minutes		4 minutes	
		(in./min)	(cm/min.)	(in./min)	(cm/min)
30	76	15	38.1	7.5	19.0
60	152	30	76.2	15.0	38.1
90	229	45	114.3	22.5	57.2
120	304	60	152.4	30.0	76.2

**Table 9-3: Non-Equilibrium Belt Speed Recommendations**

- Record the temperature and observe the results.

**If the desired peak temperature is not achieved**, begin tuning the belt speed and zone setpoint temperature variables. The following are some guidelines:

- Lower the belt speed
- Increase zone temperatures
- Repeat the profiling until the desired temperature peak is achieved.

**If the profile requires an initial hold time**, follow the procedures listed under “Equilibrium Profiles” for the necessary hold time with the following modification:

- Increase the final zone temperature to about 30-50°C above the desired peak temperature.
- Record the temperature and observe the results.

**If the desired peak temperature is not achieved**, begin tuning the belt speed and zone setpoint temperature variables. The following are some guidelines:

- Lower the belt speed
- Increase the final zone temperature
- Repeat the profiling until the desired temperature peak is achieved.

## 9.3 Creating a Recipe

For the furnace to operate, temperature setpoints, control parameters and alarm conditions must be entered. Once the best parameters have been established, they can be stored in a recipe which can be used by the operator to run the furnace under those conditions.

### 9.3.1 Recipe Editor

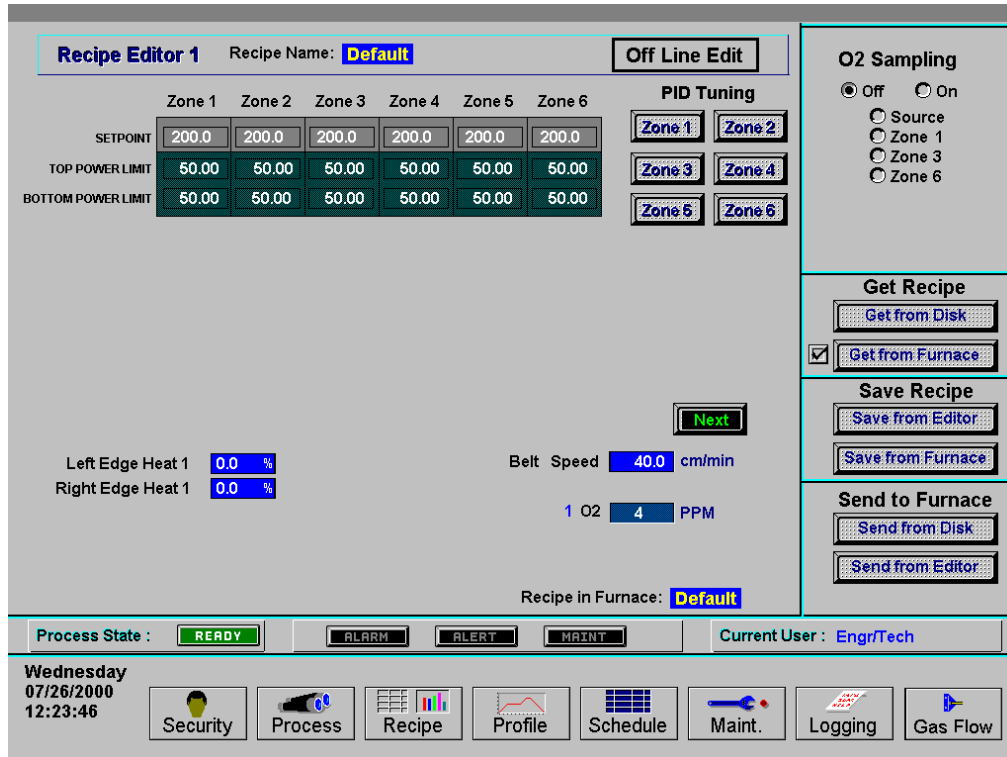


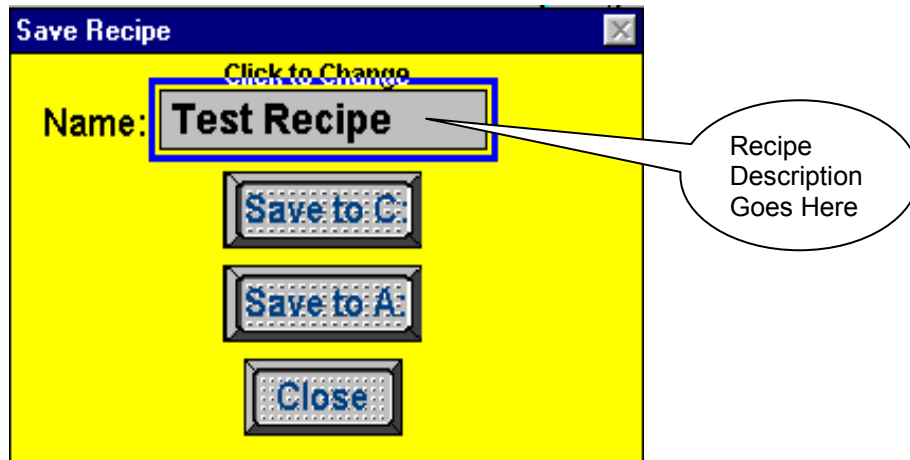
Figure 9-3: Recipe Editor screen

### 9.3.2 Recipe Handling

Recipes are handled in nearly the same way as described previously in the Saving and Retrieving Recipes Section under 5.5.3 on p.47.

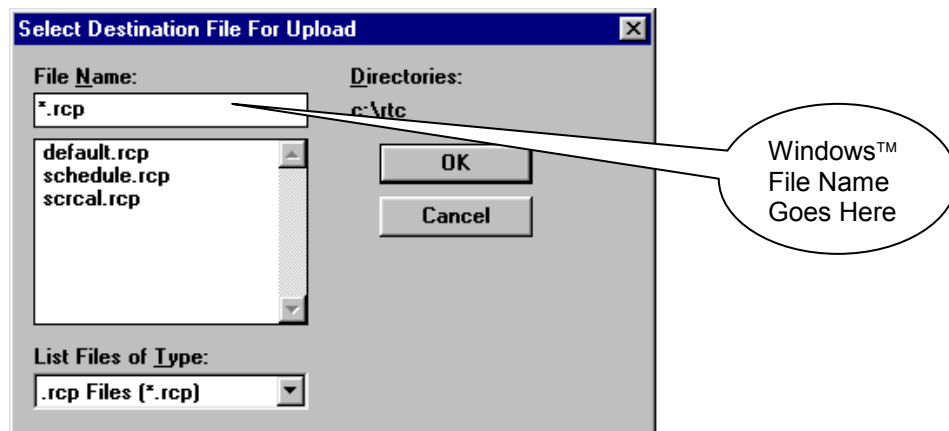
## Recipe Names

The **Recipe Name** in the **Save Recipe** dialog box is not the same as the **Windows™ file name**. When saving a recipe to disk, a dialog box appears asking for the recipe name. This dialog box can be used for a recipe description. The description can be long and descriptive or the same as the Windows™ filename.



Once a recipe description has been entered in the [Save Recipe](#) dialog box, the recipe can be saved to disk.

Click on either [Save to C:](#) or [Save to A:](#) The following dialog box appears:



It is a good idea to save all your recipes to a diskette or USB removable media as well as to the hard drive. Recipe files can be copied using Windows Explorer or saved to a diskette or removable media by selecting the [Save to A:](#) command button in the [Save Recipe](#) dialog box.

### 9.3.3 PID Tuning

When the furnace is in operation, the power supplied to the lamps is under constant control. A special performance control is used to maintain consistent zone temperatures by adjusting the current allowed to reach the heat lamps. The control is referred to as a PID control loop. The name PID stands for **P**roportional + **I**ntegral + **D**erivative and represents the three terms used in the control loop.

When in PID tuning mode, any changes that are made are sent directly to the PLC controller. This method of tuning the furnace allows the engineer to precisely control the temperature profile inside the furnace.

A complete understanding of how a PID loop works and how to tune it will greatly benefit the owner operator and product results.

In general, the PID equation takes on the following form:

$$CO = G \cdot \left\{ (S - T) + \frac{1}{I} \int_0^{1\text{sec}} T \cdot dt + D \cdot \frac{dT}{dt} \right\}$$

Where:

$T$  = Temperature

$t$  = Time

$G$  = Gain Term Value

$S$  = Setpoint Temperature

$I$  = Integral Term Value

$D$  = Derivative Term Value

The output from the three terms, the proportional, the integral and the derivative terms are summed to calculate the output of the PID controller. The following sections review and explain the three components of the PID equation.

### Gain

The proportional band is adjusted according to the following equation

$$PB \text{ } ^\circ\text{C} = 100 \text{ } ^\circ\text{C} / \text{Gain}$$

The higher the gain, the narrower the proportional band; the lower the gain, the wider the proportional band.

The gain value multiplies the difference between the setpoint and actual temperature. The difference between these two values is referred to as the **error**. (This does not mean that anything is wrong). The error is measured continuously, about once a second. When this difference is large, power to the heat lamps will be increased, or decreased, accordingly. When the error is small, power to the heat

lamps will be maintained at present levels. Gain values greater than 1 amplify the controller's response to error (differences between temperature and setpoint).

Setting the gain too high will result in temperature over and under shoots. It is possible that the temperature will never reach a stable state. The temperature might oscillate around the setpoint.

Setting the gain too low will result in a slow response to temperature changes. The furnace will take longer to reach operating temperatures and will be slower to recover from temperature drops as the product soaks up heat.

A default value of **9** is suitable for many processes.

Note: Since the gain value is a multiplier, it should not be set to zero.

## Integral

With only gain operating, and no value set for integral and derivative, the controller acts somewhat like a thermostat. When the difference between temperature and setpoint (error) is zero, power to the heat lamps is maintained at current levels. When the temperature drops below the setpoint, power is increased until the temperature returns to the setpoint. This PID setting results in a operating condition where the measured temperature is often inappropriately far from the temperature setpoint.

The integral value is used to rapidly converge on the set point.

The **integral value** refers to the integer value entered in the recipe screen. The **integral term** is calculated automatically by the PLC controller. The integral value multiplies the integral term.

The Integral term in the PID equation represents the average error (temperature difference) over a time interval of about one second and is updated continuously, accumulating error as a function of time.

The integral product (**integral value** multiplied by **integral term**) is added to the error. This integral product can make a significant difference to the PID control output signal especially if the current error is small.

Think of it this way: The difference between temperature and setpoint at any given time could be zero, but the average difference between temperature and setpoint over the length of time represented by the integral term is never likely to be zero. With an integral value of zero, power will be maintained at its current level even though the temperature is about to decrease. With an integral value greater than zero, multiplying the integral term, power will be increased slightly and the impending temperature drop will be not be as profound.

With a Gain and an Integral value entered in a recipe, the PID equation will always be adjusting the controller's output unless the both the **current difference** and **average difference** between temperature and setpoint is zero.

Larger integral values generate smaller responses from the controller. A value of 1, for instance, will use the entire average difference between temperature and setpoint for the correction value. A value of 2 will use half the average difference for the calculation. Entering very large integer values will have the same effect as entering zero.

For many processes, start with an initial value of **45** for the integral.

### Derivative

The derivative term of the PID equation is a value representing the rate of change of the temperature setpoint deviation. If, for example, the temperature deviation is accelerating away from the setpoint, the derivative term attempts to predict what the deviation will be some short time in the future. This behavior allows the derivative to sense a change in load early and attempt to counteract its effect ahead of time.

Suppose, for example, that the zone temperature is deviating downwards from the setpoint at 10°C/second. At the next measurement, the temperature is deviating downwards at a rate of 20°C/second. The derivative term will sense this acceleration away from the setpoint and counteract it by increasing the PID signal to the controller. The larger the derivative value entered in the recipe screen, the larger the correction.

A zero value is appropriate for many processes with constant furnace loading (a continuous stream of similar parts entering the furnace).

**For processes where furnace loading is uneven**, such as when parts arrive from screen printers or non-buffered processes in an automated line, a non-zero derivative term may help the furnace respond more quickly when parts suddenly enter the heating zones.

In such uneven loading situations, a derivative term of **2** is a good initial value.

Care must be taken when entering derivative terms higher than 2 due to the fast response of the IR furnace.

**Detecting an accelerating deviation from setpoint** requires at least three temperature measurements. Therefore, at least two seconds elapse before a correction can be made. Heat lamps are very responsive and very little amplification is needed to correct the lamp output. The derivative can show a downwards accelerating temperature deviation even though the temperature may have started increasing. This condition can result in an over correction.

**If furnace loading is constant**, Gain and Integral values are generally sufficient to counteract temperature deviations and the Derivative may be set to **zero**.



To begin a PID tuning sequence, click on one of the Zone # buttons in the Recipe Screen. The following pop-up box will appear (Figure 9-4). Remember, this data is pulled directly from the furnace and may not be the same as what is seen in the Recipe Screen. Any adjustments while in the PID Tuning screen occur real-time. The programmed values are sent directly to the controller and immediately affect controller values.

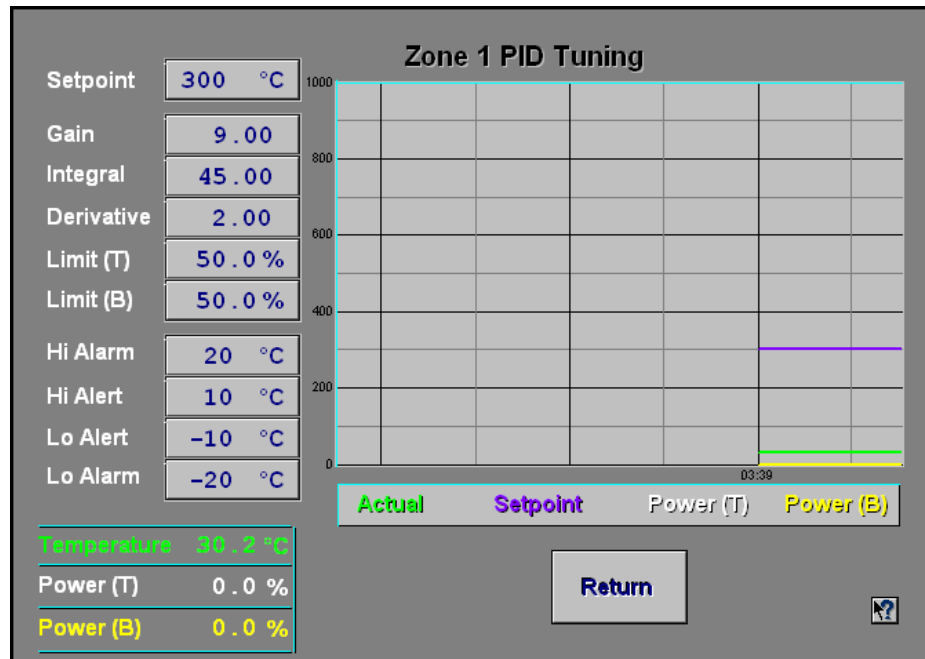


Figure 9-4: PID Tuning screen

The values in the boxes on the left show the setpoints that are currently loaded in the furnace. The values on the bottom left reflect the numerical values of temperature in the zone as read by the thermocouple and the level of power being applied to the heat lamps in that zone as regulated by the controller and SCR. The graph on the right records these values as the graph scrolls from right to left. This screen should give the viewer a clear picture of the interaction of the level of power being applied to the heat lamps as the temperature deviates from the setpoint.

## Power Limits

Top and bottom power limits can be set in the PID tuning screen. This value limits the amount of current that can be drawn by heat lamps. Reducing this value might increase the furnace warm-up time. A modest saving in operating costs might, however, be achieved with lower limits.

# 9.4 Gas Flow

## 9.4.1 Gas Flow Basics

The most important factor in creating a safe and efficient process environment is gas-flow balance. The volume of process gas entering the system should be equal to the volume of exhaust gas leaving the system.

Gas flow entering the oven is controlled by **flow meters**. The flow meter arrangement is different for every furnace. A flow meter can be installed to supply gas for each individual zone or for various combinations of zones.

All furnaces are equipped with gas power exhausts. Compressed gas (usually air or nitrogen) is forced through a small hole in a small tube creating a venturi effect inside the exhaust stack. The forced high-speed gas flow drags the furnace atmosphere out with it. To regulate the rate of exhaust, each venturi is supplied by its own flow meter.

Correct gas flow through the venturi is a critical factor in achieving stable temperature profiles. For this reason, exhaust stacks cannot be connected to facilities ducting. Changes in facilities-ducting pressure would change exhaust pressure that would in turn change the gas flow within the furnace. The condition will lead to alterations in the thermal process profile.

Disruptions in gas flow in the process section can be caused by the following influencers:

- Close proximity of doors
- Close proximity fans
- Placing a furnace through a wall between rooms
- Attaching facility exhaust ducts directly to the furnace exhaust stack

## 9.4.2 Process Gas

Various forms of process gas can be utilized inside furnaces. Users may want to operate a pure  $N_2$ ,  $O_2$  or  $H_2$  environment. Others will only need clean dry air (CDA). Whatever the case, the furnace can be factory configured in different ways to meet specific requirements. The following are some possible process gases.

### Nitrogen

Many processes require the process environment be free, or almost free, of oxygen as the products would either burn or oxidize. Removing oxygen involves forcing the oxygen out by pumping in another gas. A relatively inert gas such as nitrogen is normally used for this purpose.

### Hydrogen

Other gasses having a beneficial effect on a process can also be introduced into the process environment. Hydrogen, for example, is commonly used in reflow soldering processes to facilitate solder flow.

### Forming Gas

Forming gas is the term used to describe any mixture of  $N_2$  and  $H_2$  gas.

All processes with concentrations of  $H_2$  higher than 4% mass percent require all  $H_2$  automated safety features. When the concentration of  $H_2$  gas required for the process falls below 4%,  $H_2$  levels will not reach an explosive concentration inside a furnace.

## 9.5 Creating an Optimum Process Environment

To establish a process environment, the engineer will need to start with the number of times the air surrounding the product will need to be replenished. This figure depends very much on the process requirements and costs. Some processes give off large quantities of volatiles that will need to be removed, requiring higher gas flow rates than other, cleaner processes. The cost of the process gas will also need to be taken into account, as quick replenishment times will use significant volumes of gas. For new processes, it may be safest to start with a high gas flow rate that can be adjusted downwards until the test product stops coming out clean.

The first step in calculating the flow rates will be to calculate the internal volume of the furnace chamber and multiply the answer by the number of times per hour that the atmosphere needs replenishing. The result is the total gas flow per hour for the chamber.

### Calculate the Internal Volume of the Furnace Chamber

*Example 1:*

*The process engineer determines the thermal process **replenish time** is 60 seconds.*

**Given:** Replenishment Requirement: 60 seconds / replenish  
Belt Width: 24 in.

**Process Section Dimensions** (Not including Open Air cooling modules)  
*The better the estimate of internal volume, the less tuning required.*

#### Entrance Baffle

**Height, H:** 6 in.

**Width, W:** 25 in.

**Length, L:** 15 in.

**Volume, V** =  $H \times W \times L = 6 \times 25 \times 15 = 2250 \text{ in}^3$

#### Heating Chamber

**Height, H:** 12 in. ← Includes top and bottom insulation because gas passes through this

**Width, W:** 25 in.

**Length, L:** 30 in.

**Volume, V** =  $H \times W \times L = 12 \times 25 \times 30 = 9000 \text{ in}^3$

#### Transition Tunnel

**Height, H:** 6 in.

**Width, W:** 25 in.

**Length, L:** 15 in.

**Volume, V** =  $H \times W \times L = 6 \times 25 \times 15 = 2250 \text{ in}^3$

Controlled Atmosphere Cooling Module

**Height:** 6 in.  
**Width:** 25 in.  
**Length:** 30 in.      $H \times W \times L = 6 \times 25 \times 30 = 4500 \text{ in}^3$

Exit Baffle

**Height, H:** 6 in.  
**Width, W:** 25 in.  
**Length, L:** 15 in.  
**Volume, V = H x W x L = 6 x 25 x 15 = 2250 in<sup>3</sup>**

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**Total Internal Volume:** 20250 in<sup>3</sup>

### Calculate Replenish Rate

Convert furnace Volume from cubic inches to cubic feet:

$$20250 \text{ in} \times \text{in} \times \text{in} / [(12 \text{ in} / \text{ft}) \times (12 \text{ in} / \text{ft}) \times (12 \text{ in} / \text{ft})]$$

$$= 11.72 \text{ ft}^3 / \text{replenish}$$

Convert to CFH

1 hour = 3600 seconds

3600 seconds / (60 seconds / replenish) = 60 replenishes / hr

(60 replenishes / hr) x (11.72 ft<sup>3</sup> / replenish) = 703.1 ft<sup>3</sup> / hr

Balancing Gas Flow, Q = 703.1 CFH (actual cubic feet per hour)

From these calculations you can balance the furnace environment with a total gas flow of 703.1 CFH.

Note: although the above result is not true SCFH, it can be used to balance the furnace. The flowmeter scales are labeled in SCFH, but are not corrected for actual conditions. To calculate true SCFH, convert using Boyles law:

*Correct for temperature and pressure to convert from CFH to standard cubic feet per hour (SCFH), assuming the inside of the furnace is at 1 atmosphere:*

$$\text{SCFH} = \text{ACFH} \times \frac{(\text{Std Temperature} \times \text{Actual Pressure})}{(\text{Act Temperature} \times \text{Std Pressure})}$$

Actual Furnace Temperature, T<sub>1</sub> = 100F + 460 = 560 K

Actual Pressure, P<sub>1</sub> = 0 psig + 14.7 = 14.7 psia

Standard Temperature, T<sub>s</sub> = 70F + 460 = 530 K

Standard Pressure, P<sub>s</sub> = 14.7 psia

$$\text{SCFH} = 703.1 \times \frac{(530 \text{ K} \times 14.7 \text{ psia})}{(560 \text{ K} \times 14.7)}$$

True Standard Gas Flow, Q<sub>s</sub> = 665.4 SCFH

True SCFH can be used to determine plant compressed air requirements.

### 9.6 Balancing Gas Flow

Once the total gas flow has been determined for the process, the process engineer can then determine the balance of the gas flow.

Balanced gas flow means that the same volume of gas enters the chamber as exits.

- ❶ First to determine the quantity of gas that should be introduced to the each heating chamber: Divide the Balancing Gas Flow among each of the heating chamber zones and baffles for which the furnace has control.
- ❷ To determine the total gas flow to the eductors, divide the Balancing Gas Flow by 10. The approximate volume of air drawn out by the venturi created by the eductor is 10 times the flow rate.
- ❸ Divide the total eductor gas flow among the available eductors.
- ❹ The sum of the eductor gas flow and the Balancing Gas Flow is the gas consumed by the furnace.

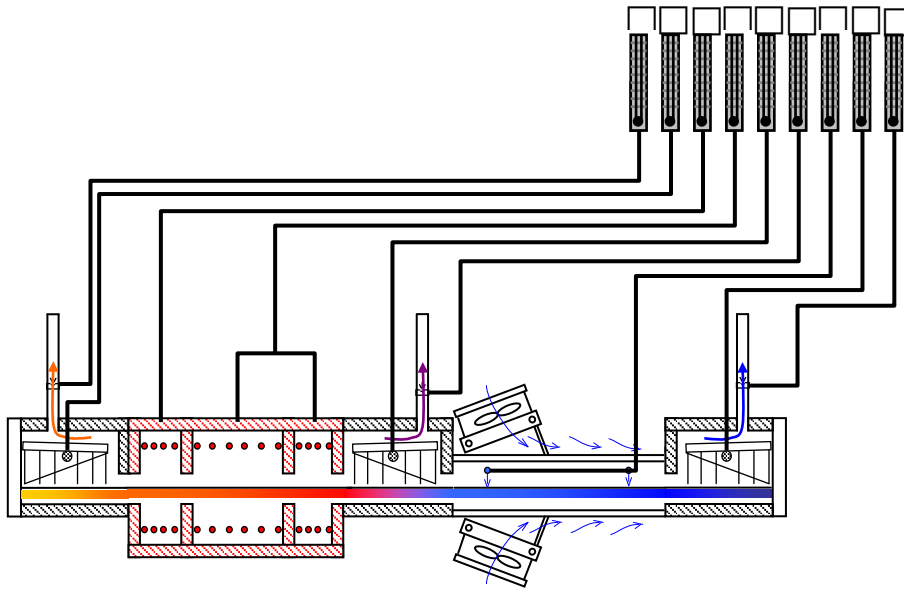
Refer to Example 2 example shown on the following page.

**Note: A balanced gas flow does not guarantee the best or most economical environment for your process. After following this procedure, gas flow may still need adjusting to achieve an optimum and safe environment.**

The following are guidelines for some common processes performed in furnaces.

1. If faster cooling is required – increase flow to the entrance eductor while reducing flow to the transition or exit eductor. This will prevent hot air from the heating chamber from carrying over into the cooling section.
2. For equilibrium profiles – set the flow to the zones at about the same rate. This will assist in keeping a steady flow of process gas around the product during heating.
3. For peaked or non-equilibrium profiles (i.e. solder reflow or solar cell firing) – increase flow to the middle zones and reduce flow at the beginning and ending zones, also increase flow to cooling sections. This will help the product achieve high temperature under IR radiation and allow for quick cooling.
4. In a long steady peak profile – increase flow to exit or transition eductor while reducing flow to the entrance eductor. This will draw the air to the end of the heating chamber using convection heating to assist in raising the product to its final temperature.

Example 2:



- Entrance Eductor
- Entrance Baffle
- Zone 1
- Zone 2-3
- Transition Baffle
- Transition Eductor
- Cooling Section
- Exit Baffle
- Exit Eductor

**Gas Entering Zones**

<i>Entrance Baffle</i>	50 SCFH	} ①
<i>Zones 1</i>	150 SCFH	
<i>Zones 2 &amp; 3</i>	200 SCFH	
<i>Transition Tunnel</i>	50 SCFH	
<i>Ctrl. Atm. Cooling Module</i>	153 SCFH	
<i>Exit Baffle</i>	+ 50 SCFH	
<b>Total Gas Flow =</b>	<b>703 SCFH</b>	
<i>Eductor Flow Divider</i>	÷ 10	← ②
<b>Total Eductor Gas Flow =</b>	<b>70.3 SCFH</b>	
<i>Entrance Eductor</i>	25 SCFH	} ③
<i>Transition Tunnel Eductor</i>	22 SCFH	
<i>Exit Eductor</i>	23 SCFH	
<b>Gas Consumption</b>	<b>773.3 SCFH</b>	← ④

This method provides a good starting point for balancing the gas flow in your furnace. It is, however, an approximate method so additional tuning will be required.

## 9.7 Hydrogen Operation (Option □)

If the furnace is not equipped for hydrogen operation, skip to "Check for an Escaping Environment" Section 9.8 p.117.



**DANGER: If the furnace is equipped for H<sub>2</sub> operation, Ozone, or another hazardous process gas, balancing gas flow is extremely important to the safety of any one working near the furnace.**

### 9.7.1 Introduction

The hydrogen operation option 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, do not attempt to connect hydrogen to the machine until this section is read and understood.

### 9.7.2 Description

The hydrogen operation system uses existing furnace plumbing and an additional gas flow control system to introduce hydrogen into the furnace chamber. The hydrogen is introduced into the furnace by allowing it to permeate through the porous ceramic fiber insulation, which preheats the gas before it enters the process area.

Entrance and exit baffles, located at each end of the furnace chambers, generate an inert gas curtain which effectively keeps ambient air from entering the furnace chamber and mixing with the hydrogen atmosphere. Venturi assisted exhaust stacks, located in the entrance baffle or in both entrance and exit baffles, draw off the excess hydrogen and direct it into a burner assembly. The excess hydrogen, which is drawn through the exhaust stack, is directed into the burner where it is mixed with ambient air and ignited with a hot wire igniter.

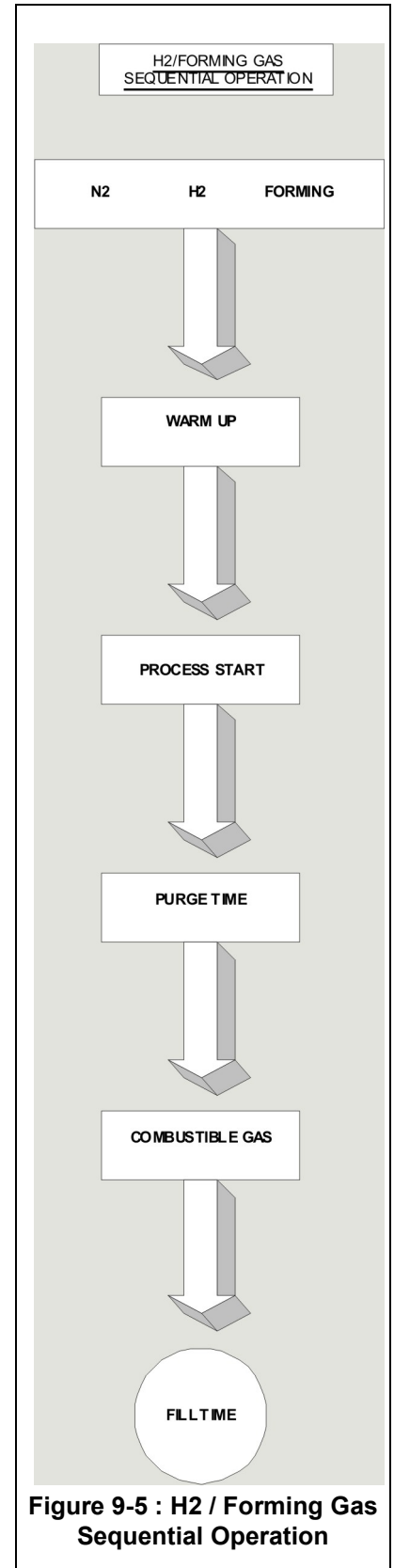


Figure 9-5 : H2 / Forming Gas Sequential Operation



### 9.7.3 Control System

The hydrogen control system is designed to prevent the possibility of introducing a combustible mixture of hydrogen into the furnace chamber. The furnace software control logic requires that nitrogen be run continuously in the exhaust venturi, entrance/exit baffles, furnace chamber, and in the transition tunnel/cooling muffle, if so equipped. The hydrogen control logic provides an user configurable automatic timed purge of from 5 to 30 minutes, with nitrogen, before hydrogen is allowed to enter the furnace. Nitrogen and hydrogen pressure switches, together with additional control logic, enhance the safety of the system by requiring that the following conditions be met.

#### Nitrogen Pressure

Nitrogen pressure must be present at all times during the purge cycle, as well as during straight hydrogen operation. In the event of nitrogen failure, hydrogen is automatically shut off, and the hydrogen cycle is aborted with alarm and display indication. Only after nitrogen pressure is restored can the cycle be restarted.

#### Hydrogen Pressure

Hydrogen pressure must be present during the purge cycle and during straight hydrogen operation. In the event of hydrogen failure, the cycle is aborted and nitrogen flow is initiated with an alarm and display indication. Only after hydrogen pressure is restored can the cycle be restarted.

#### Igniter

The hydrogen Igniter element(s) must start when the hydrogen burn-off operation is initiated, and run continuously during the delay cycle, as well as in the steady state. The furnace is manufactured with dual (2) igniters per stack. If both igniters in a single stack fail, the cycle is aborted with alarm and display indication. Manual restart is required to reinitiate the cycle. If only one igniter fails, the process is not aborted, but an alert occurs.

#### Seal or Plenum Pressure

Sensing a lack of seal pressure parts puts the machine into heat shut down with alarm and display indication.

### 9.7.4 Gas Flow Control

Gas flow control is accomplished manually with Variable Area Flowmeters. To start system open valve slowly to avoid possible damage. Control valves are turned clockwise to reduce flow and counter-clockwise to increase flow.

The standard technique for reading a Variable Area Flowmeter is to locate the highest point of greatest diameter on the float, and then align that with the theoretical center of the scale graduation. In the event the float is not aligned with a grad, extrapolation of the float location must be made by the operator as to its location between the two closest grads.

The furnace flowmeters are calibrated to operate at standard conditions:

Standard pressure,  $P_s = 14.7$  psia (101.3 kPa)

Standard temperature,  $T_s = 70^\circ\text{F}$  (21.1°C)

Deviation from standard conditions will require correction for the calibration to be valid. In practice, the reading taken from the flowmeter scale must be corrected to standard conditions to be used with the scale units. The correct location to measure the actual pressure and temperature is at the exit of the flowmeter. The equation to correct the flowmeter observed reading to standard flow,  $Q_s$  in SCFH.

$$Q_s = Q_a \times \text{SQRT} [(P_a \times T_s) / (P_s \times T_a)]$$

Where:

$P_s$  = Standard Pressure = 14.7 psia

$T_s$  = Standard Temperature =  $70^\circ\text{F} + 460 = 530$  R

$Q_a$  = Observed flowmeter graduation reading

$P_a$  = Pressure at exit of flowmeter, (Gage pressure + 14.7 psia)

$T_a$  = Temperature at exit of flowmeter (use  $100^\circ\text{F} + 460 = 560$  R)

Example 1: An Exhaust Stack flowmeter with a scale of 10-200 SCFH Air. The float is sitting at the 100 grad on the flowmeter scale. Assume at the exit of the flowmeter that the pressure is -2.0 inches H<sub>2</sub>O and temperature is 100F.

$$P_a = 14.7 \text{ psia} + (-2 \text{ in. H}_2\text{O} / 27.68 \text{ in./psi}) = 14.6 \text{ psia}$$

$$Q_a = 100 \text{ grad} \times \text{SQRT} [(14.6 \times 530) / 14.7 \times (100+460)] = 96.95 \text{ SCFH}$$

Example 2: An Zone flowmeter with a scale of 10-400 SCFH Air. The float is sitting at the 200 grad on the flowmeter scale. Assume at the exit of the flowmeter that the pressure is 55 psig and temperature is 100F.

$$P_a = 14.7 + 55 \text{ psig} = 69.7 \text{ psia}$$

$$Q_a = 200 \text{ grad} \times \text{SQRT} [(69.7 \times 530) / 14.7 \times (100 + 460)] = 897.5 \text{ SCFH}$$

**Caution: Do not completely unscrew valve stem. Removal while in service will allow gas or liquid to flow from the front of the valve body and could result in serious personal injury.**

## 9.7.5 Installation Requirements

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 air 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.

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 will unbalance the gas curtains and could cause hydrogen to escape into the room, or create an explosive mixture of air and hydrogen inside the furnace.

**DANGER: The flow meters installed in the control panel are rated for 70 psi maximum; operating beyond 70 psi exposes the operator to possible injury.**

## 9.7.6 Operating Instructions, Furnace Software & Control

### Process Screen Controls (H<sub>2</sub>)

Go to Process screen and click on [H2](#) Button. Click on [Warm-Up](#). Wait until the process start light is flashing, and click on [Process Start](#). This starts an automatic timed purge with nitrogen and lasts from 5 to 30 minutes. When the purge cycle is complete, click on [Combustible Gas On](#). Nitrogen will be shut off and hydrogen will be turned on.

### Hydrogen/Nitrogen (Forming Gas)

Go to Process screen. Click on [Forming](#) button. Click on [Warm-Up](#). Wait until the process start light is flashing, and click on [Process Start](#). This starts an automatic timed purge with nitrogen and lasts from 5 to 30 minutes.

When the purge cycle is complete, click on [Combustible Gas On](#) and hydrogen will be turned on. This starts an automatic timed fill (manual set).

**NOTE:** Fill is defined as the amount of time required for the combustible gas to enter and fill the chamber cavity. Fill time is factory preset for 5 minutes, and can be user altered.

### Terminate

Click on [Cooldown](#) (this returns the furnace to nitrogen operation), or go to Recipe Screen and load a new recipe.

### Nitrogen or Manifold Pressure, Low

Low nitrogen pressure is indicated with a message and an audible alarm. The hydrogen operation cycle is aborted, and the machine goes into a heat shut down mode. The cycle cannot be restarted until nitrogen pressure is restored.

### Hydrogen Pressure, Low

Low hydrogen pressure is indicated with a message and an audible alarm. The hydrogen operation cycle is aborted, and cannot be restarted until hydrogen pressure is restored.

### Plenum Pressure, Low

Low seal pressure is indicated with a message and an audible alarm. The machine goes into a heat shut down mode and the hydrogen cycle is terminated.

**Warning: Low plenum pressure can cause damage to the heating lamps. Do not continue to operate the machine with low plenum pressure indication. In the event of low plenum pressure indication, the machine should be shut down until the problem is found and corrected.**

### Igniter Failure

Igniter failure is indicated with a message and an audible alarm. If both igniters in a single stack fail, the hydrogen operation cycle is aborted and cannot be restarted until the igniters are repaired. If only one igniter fails in a single stack, the process is not aborted, but an alert occurs.

## 9.7.7 Hydrogen Flowmeters

Each of the hydrogen flowmeters is identified with a label as to specific function, and is adjustable from zero flow to full scale by means of an integral control valve.

### Control Knob

Turning this knob clockwise decreases the flow; counterclockwise increases the flow.

## 9.7.8 Functional Checkout with Helium

We recommend that a functional checkout of the hydrogen system be made using helium gas for safety. It is further recommended that a trace oxygen analyzer and helium detector be made available for the checkout.

The furnace is designed so that it can be safely and reliably operated on hydrogen. However, if the 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, causing a fire hazard. If it is not possible to perform a functional checkout with helium, we recommend, as a minimum, a trace oxygen analyzer and combustible gas monitor be used to guide final process settings.

### Furnace System Functional Check

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

### Helium Supply Gas

Temporarily connect a supply of helium gas to the hydrogen input line and adjust the input regulator to 50-psi. Make sure that the hydrogen flow meters are completely shut off at this time.

### Turn On Furnace

Turn on the furnace and bring it up to a fully operational state using the suggested gas flow settings from your operation manual.

### Initiate the Hydrogen Operation Cycle

Adjust the hydrogen flow meters to the same flow rates that the equivalent nitrogen flow meters were set at.

### Check Oxygen Concentration

Check the oxygen concentration inside each zone of the furnace, using a trace 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. If the concentration of oxygen is above the 100 PPM limit, 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.

### Check for Escaping Gas

Check each end of the furnace with a helium detector to see if any furnace gas is escaping. If furnace gas escapes, increase the flow to the appropriate eductor in small increments and retest.

### 9.7.9 Nitrogen/Hydrogen Mixing

Selecting the nitrogen/hydrogen atmosphere, with the furnace in the hydrogen mode will unbalance the ratio of input to exhaust gas. This happens because nitrogen is introduced in addition to the volume of hydrogen that is already flowing into the furnace. Before pressing nitrogen/hydrogen mixing, perform the following:

1. Calculate the volume of helium flowing into the furnace when the machine is running in a balanced condition.
2. Decide what ratio of helium to nitrogen is to be run and the volume of each gas required.
3. Select the nitrogen atmosphere mode to return the furnace to nitrogen operation.
4. Adjust the nitrogen volume to the values calculated above. Shut off the hydrogen flow meters.
5. Select the hydrogen atmosphere mode, and select the nitrogen/hydrogen mix mode before the purge cycle is complete.
6. Then adjust the hydrogen flow meters. The machine should now be operating in a balanced condition, with the proper volume of nitrogen/hydrogen.
7. Check the oxygen level in the furnace and ends of the furnace for helium, and correct as necessary.

This completes the functional checkout.

<u>GAS</u>	<u>SP.G</u>
Argon (A)	1.38
Carbon Monoxide (CO)	.966
Carbon Dioxide (CO <sub>2</sub> )	1.51
Helium (He)	1.38
Hydrogen (H <sub>2</sub> )	.070
Hydrogen Chloride (H <sub>2</sub> Cl)	1.59
Hydrogen Sulphide (H <sub>2</sub> S)	1.39
Methane (Me)	.553
Natural Gas	.55-.66
Nitrogen (N <sub>2</sub> )	.966
Nitrous Oxide (N <sub>2</sub> O)	1.52
Oxygen (O <sub>2</sub> )	1.103
Propane (C <sub>2</sub> H <sub>2</sub> )	1.56-1.99
Sodium Dioxide (SO <sub>2</sub> )	2.2-2.26
Butane-N	2.4
Butane-ISO	1.99

**Table 9-4: Gas Correction Factors**

## 9.8 Check for an Escaping Environment

If your furnace is equipped for a controlled atmosphere, the oxygen analyzer option is probably also installed and should be used to assist in establishing if a balanced gas flow has been reached. The following are some basic tests that users can apply to check for safe and healthy furnace environments.

- ◆ Check the **bezels** (exit and entrance guards) for signs of burning. If the bezels are turning brown, furnace atmosphere is probably escaping.
- ◆ Smoke exiting from either end of the furnace is an obvious sign of an escaping environment. Strong fumes in the vicinity of the bezels indicate likewise.
- ◆ A small smoke source close to the furnace entrance or exit will indicate if air is being drawn in, or forced out of the furnace. Smoke rising vertically indicates that gas flow is balanced. A small piece of tissue paper or light thread taped to a pencil will also work.

## 9.9 Plenum Gas Flow

The IR-heat lamps do not make an airtight seal with the sides of the heat chamber. For this reason, nitrogen or clean dry air (**CDA**) is pumped into the plenums where it penetrates the heat-lamp seals and enters the chamber. This technique prevents process gas escaping through the heat-lamp seals. The volume of gas entering the chamber via the plenums is minimal, and does not affect general gas-flow calculations.

### 9.10 Gas Flow Screen

Once gas flow has been determined by the process engineer, the values should be stored with the recipe. This provides a record of the correct process settings which can be applied when the recipe is retrieved by the operator.



Select the [Gas Flow](#) button.

The gas-flow screen can be used to record gas-flow settings for a recipe.

**Note: If the furnace does not include a Mass Flow Control, the controls in this screen have no effect on the actual gas flow. With a Mass Flow Controller, the flow can be controlled through the software from this screen.**

Adjust the slide indicators until the screen flow meters match the actual flow meters on the outside of the furnace. Select the [Save Settings](#) button.

A pop-up window appears, prompting the user for a recipe name. Select a recipe name you wish to associate and select [Save to C](#).


These settings are now attached to that recipe. When the operator recalls the recipe, the settings for the flow meters will be available and should be adjusted when the recipe is loaded.



## 9.11 Mass Flow Controller (Option □)

In some furnaces, optional electronic mass flow control valves may be installed to allow the operator or engineer to directly control the gas flow rates in the heating chamber.



Notice the  indicator box located above the flow meters installed with this option.

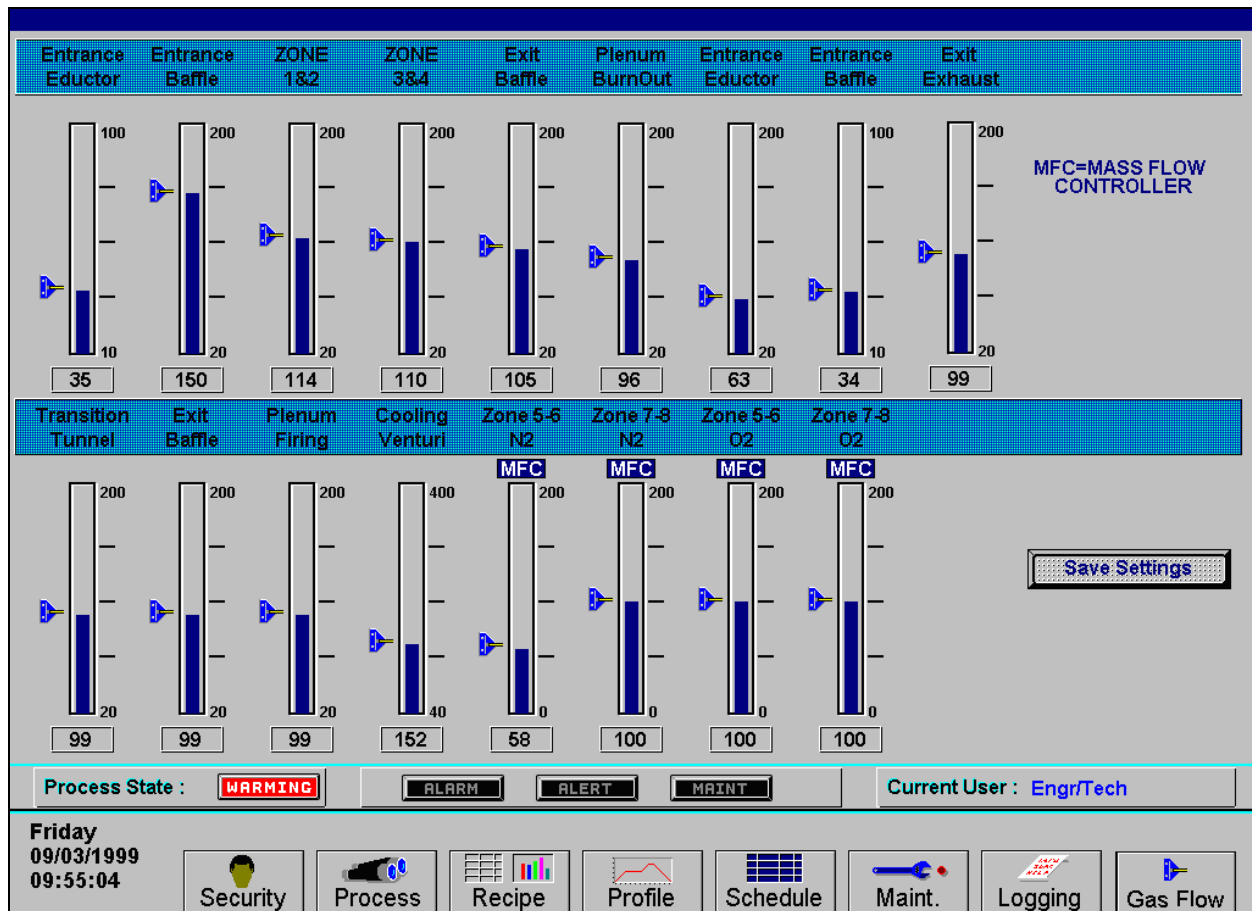


Figure 9-6: Mass Flow Control Valve Settings Screen

## 9.12 PC Anywhere

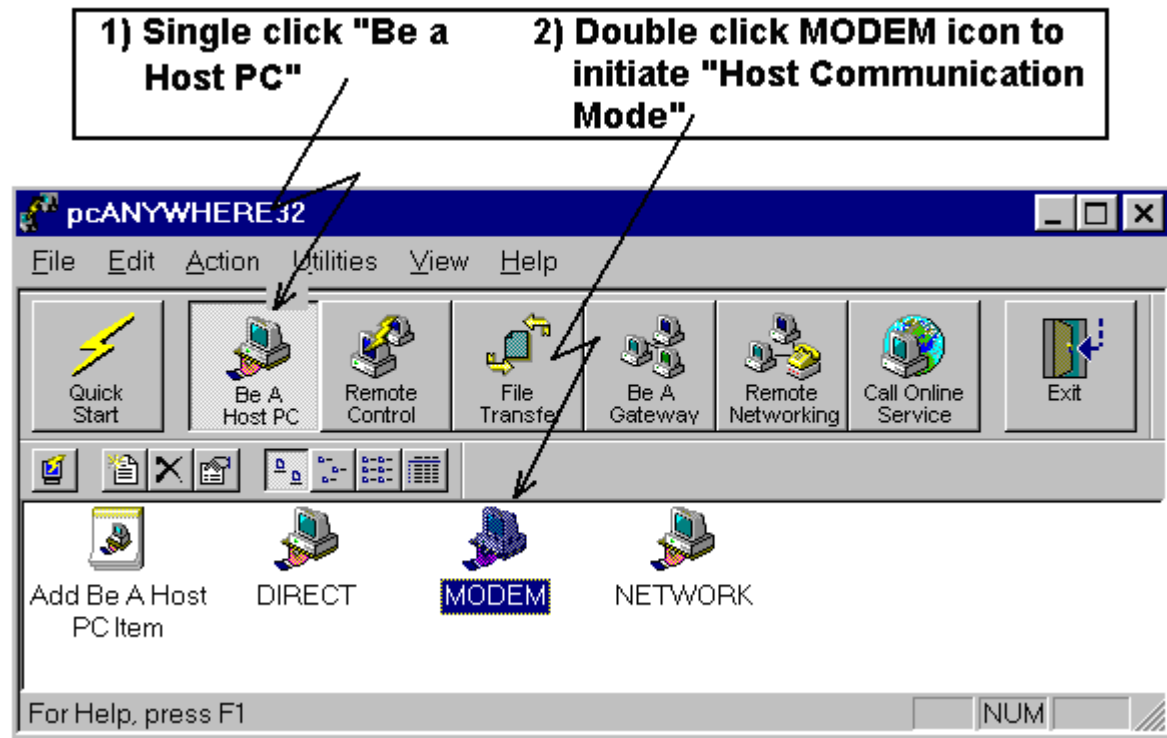
If it is necessary for the manufacturer to access the furnace-PC for diagnostic and maintenance purposes, before your machine can be accessed, you need to run the **pcANYWHERE™** software.



Double click the **pcANYWHERE™** icon from the Windows desktop.

Or the quick-launch button  or from the Windows Start Menu.

After the application opens, Select the [Be A Host PC](#) button.



Connect a phone line from the RJ11 phone jack on the furnace to a direct- line phone jack. Make sure the accessing party knows the direct dial number for this jack.