Chapter 4

4 Thermal Processing

4.1 Heating Concepts

4.1.1 Infrared Heating

Infrared (IR) heating is electromagnetic radiation emitted from the surface of IR lamps or emitters. Thermal radiation is generated when heat from the movement of charged particles within atoms is converted to electromagnetic radiation. In the furnace, radiant heating from IR lamps provides heat directly to objects without first heating the surrounding air. IR waves excite molecules within a substance (product) thus generating heat, but pass generally undisturbed through the surrounding atmosphere. Other substances such as glass, ceramics and some organic materials are also transparent to IR waves. Objects suspended in these media can, therefore, be heated directly by IR waves without directly heating the supporting media.

Not all heating in the furnaces occurs via direct IR radiation. The belt and air inside the furnace are heated via the IR lamps. Also edge heaters (resistance heaters installed along the furnace length) can introduce heat into the furnace. Your product also acquires heat from the edge heaters, conveyor belt and surrounding heated gas in the chamber via **conduction**.

The amount of direct heating via IR radiation is determined by three factors:

1) The level of IR radiation emitted from the heat lamps.
2) The amount of IR absorbed by a product.
3) The level of edge heat introduced into the furnace

4.2 Furnace Construction

The heating chamber technology allows for rapid heat-up and cool-down times. Stable temperatures of up to 1000ºC can often be reached in less than 20 minutes. Radiant heating allows for rapid startups and profile changes and system stabilization.

The heating chambers consist of an outer metallic shell fabricated from either aluminum or stainless steel, lined with a refractory-ceramic-fiber (RCF) insulation. Controlled atmosphere heated sections allow process gas to pass through the RCF insulation.

4.2.1 Modules

The furnace is constructed from a number of basic modules which make up the furnace length.

For example:

> *Figure 3-8: Furnace* Layout *on p.14 shows a furnace with 7 modules*
>
> *Module 1 – Loading Station*
> *Module 2 – Entrance Baffle*
> *Module 3 – 3-Zone Heating Chamber Module*
> *Module 4 – Transition Tunnel*
> *Module 5 – Controlled Atmosphere Cooling Module*
> *Module 6 – Exit Baffle*
> *Module 7 – Unloading Station*
>
> *In some applications, longer cooling sections are required. Additional controlled atmosphere cooling modules, a water cooling system, or a forced air cooling module after the exit baffle may be added.*
>
> *Another application may call for a longer heating section with an additional 4-Zone heating chamber module.*

Every furnace heating chamber is constructed with 30-in. (76-cm) modules. Depending upon application requirements, the furnace can be configured for any size up to 16 zones. Each furnace is a custom arrangement from standard design modules, the layout and overall design is completed prior to the start of fabrication.

4.2.2 Throat

The throat of the furnace describes the maximum height of any product allowable through the process section. Depending upon configuration, throat clearance can range from 0.75 to 4 inches. The throat height has a significant impact on the thermal process profile as gas flow between chambers is significantly increased as the throat is increased.

Warning: Feeding items trough the furnace that exceed the throat clearance will damage furnace zone separators and may reduce furnace performance.

4.3 Heating Chamber Design

4.3.1 Zones

The heating chambers are divided into individually controlled **zones**. Each 30" chamber module can be divided into 1, 2, 3 or 4 zones. If the furnace requires more than 4 zones, additional heating chamber modules must be added. The zone configuration of your furnace depends on the type of processes your furnace will be running and is part of the project furnace design specification.

4.3.2 Infrared Heating Chamber

The chamber is insulated with a porous material and if the furnace is used in a controlled atmosphere application, pressurized process-gas entering **plenums** at the top and bottom diffuses through the porous insulation and enters the process area. The gas enters in high volume and with low velocity. As the gas diffuses, it becomes heated to the bulk temperature of the zone.

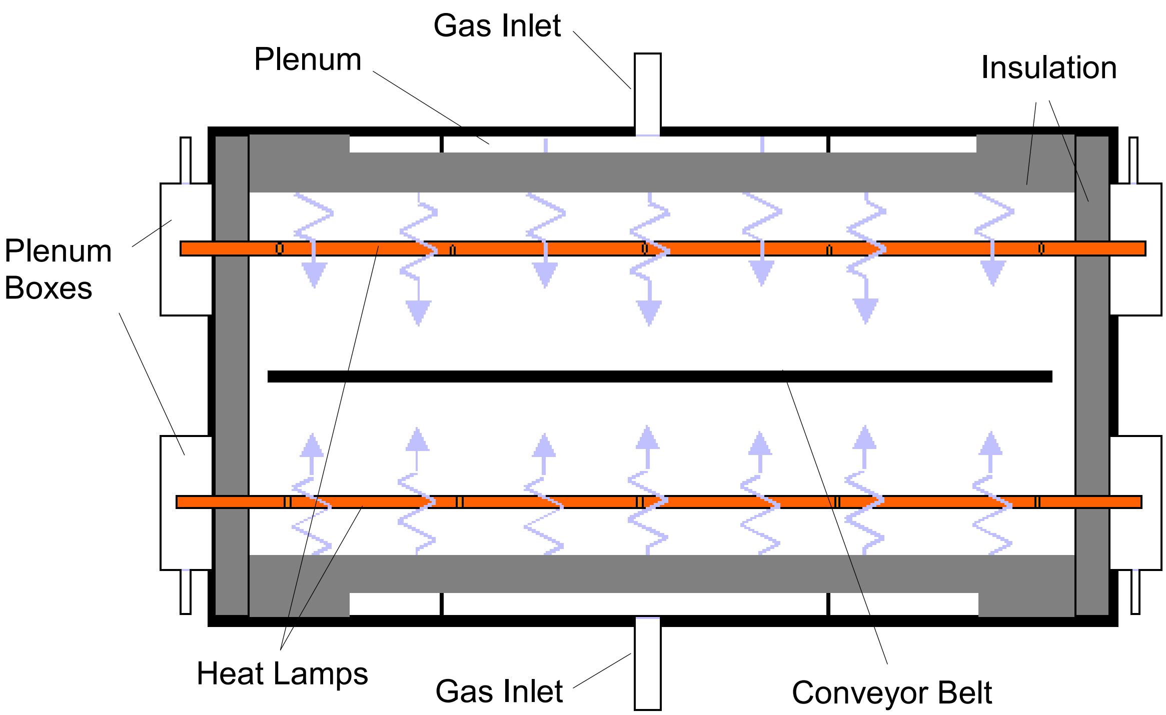

Figure 4-19: Heating Chamber Construction. End view

Plenum boxes may be specified and included as part of the hermetic seal option, which allows a light positive pressure to be applied to the ends of the heat lamps forming a highly controlled atmosphere condition.

Correctly balancing the airflow contributes greatly to the cleanliness of the chamber. When properly balanced, a high volume gas-flow is present from both top and bottom of the chamber. Effluents released from your product are swept along the centerline of the chamber to the exhaust ports, and do not rise to contact the upper surfaces or fall to contaminate lower surfaces.

Incoming process gas introduced through a large displacement area provides rapid purge times and low contamination levels. Typically, a process environment atmosphere of less than 10 parts Oxygen in 1,000,000 parts Nitrogen (<10ppm O_2) can be achieved within about 10 minutes. Rapid purge times also allow for quick process environment replenishments as well as fast cool-down times.

4.3.3 Dryer Heating Chamber

An IR Dryer heating chamber is designed the same as an IR Furnace heating chamber except that the heat lamps are only installed above the belt. Other features remain the same except thinner insulation is used for lower temperature applications.

4.4 Heating Lamps

Warning: Whenever handling furnace heat lamps, special care must be taken not to touch the surface of the lamp. Leftover salt from handling the lamps can cause hot spots which can reduce lamp performance or cause failure.

If the cleanliness of a heat lamp is suspect, clean the lamp with isopropyl alcohol and wipe with a lint-free cloth prior to use.

4.4.1 Placement

Lamp configuration within each zone is determined at the time of purchase to achieve optimal power consumption based on the type of processes specified by the owner operator. Heat lamps can be packed closely together where high temperatures need to be reached quickly. For Holding Zones where rapid rises to high temperatures are not required, lamps are usually spaced further apart.

4.4.2 Wiring

Heating lamps are wired differently for each furnace. The actual amount of power available to each lamp is based upon the heat lamp wiring configuration and the AC input voltage. Lamps may be wired in parallel providing the highest available power to the individual lamp or in series, splitting the power with other lamps. Most systems are wired in a series-parallel configuration to optimize the use of available voltage and minimize current flow. Refer to the wiring diagram in the Operating Manual for heat lamp wiring details for a specific furnace.

4.5 Controlled Atmosphere (Option ❐)

A controlled atmosphere inside the furnace isolates the product from possible negative effects during chamber heating.

4.5.1 General Flow Control

By creating a balanced flow within the process section, ambient air is prohibited from entering the process section and any contaminants within the chamber are contained inside the furnace.

Operators Please Note: When changing recipes, flow meters must be adjusted according to the levels outlined in the applied recipe.

4.5.2 Flow Rate Monitors

To control the level of gas flow inside the process section, different types of flow rate control devices are installed. Depending upon the specified application requirements, the number and type of flow monitors will vary.

Flow Meters

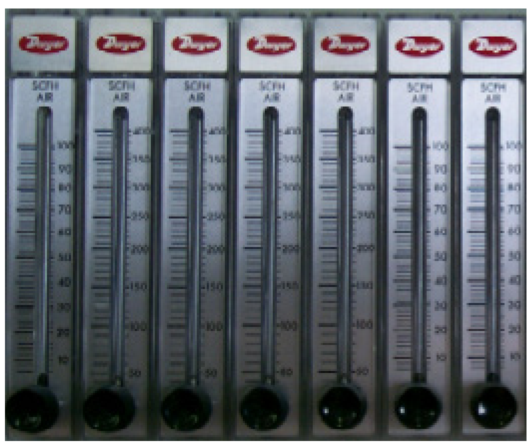

Figure 4-20: Flow Meters

Volumetric flow meters are installed with most controlled atmosphere furnaces. Manually configured, the flow meter rates need to be checked by the operator each time a recipe is changed as each thermal process may require a different replenishment time or flow rate. When the furnace is used for one process only, flow meter settings can generally be left alone once the proper flow rates have been set.

4.6 Cooling Section (Option ❐)

Furnace cooling modules can be either **forced air** or **controlled atmosphere** types. The cooling rate is outlined by the process engineer to avoid thermal shock to the process product.

Forced-air cooling has the advantage of cooling product quickly and evenly. Air removes heat from all surfaces of a product thus ensuring even cooling. This system is important where uneven cooling can cause thermal stresses and damage the product.

Controlled-Atmosphere cooling is employed when oxygen cannot be tolerated in the cooling chamber, and sometimes when slower cooling rates are needed. Most heat is slowly removed by conduction through the conveyor belt.

4.6.1 Forced Air Cooling

Forced air cooling can bring large or high speed product to a low temperature very quickly. In all forced air cooling modules, powerful fans are utilized and are controlled by knobs typically located at the control panel.

CMB30 or CMB45 Fan-driven Air Cooling (Option ❐)

This open air cooling module is either 30 or 45 inches (76 or 114 cm) long. Axial cross-flow fans located above the belt force filtered ambient air in a downward laminar flow over the entire surface area of the cooling module. This laminar gas flow is then collected and exhausted from below the belt via an impeller powered exhaust duct. The top axial cross-flow fans and bottom impeller blowers are manually adjustable from the control panel

4.6.2 Controlled Atmosphere Cooling

Where controlled atmospheres are required (typically because oxygen cannot be tolerated around the cooling product), controlled atmosphere cooling modules are necessary.

These cooling chambers can be either water-cooled or heavily finned and air-cooled. Water or airflow to the cooling chamber is regulated to optimize the chamber’s cooling characteristics.

WC Cold-wall Water Cooling (Option ❐)

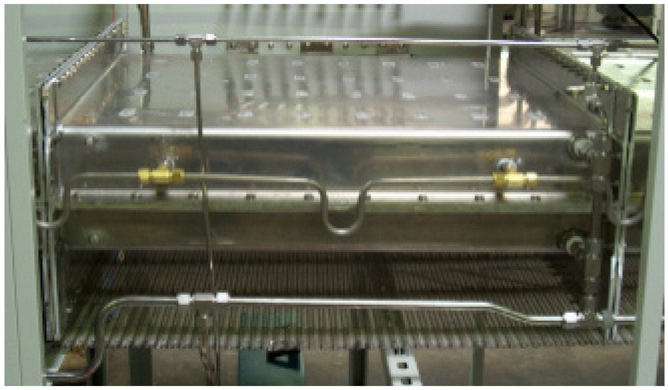

Figure 4-21: Water Cooled Controlled Atmosphere Cooling Module

Water cooling is used to ensure high rates of heat transfer while the product advances through the tunnel. The water cooled module is 20 inches long and has cold walls above and below the belt. Water plumbing lines are wrapped in insulation to prevent condensation. Water temperature at inlet source and at discharge is monitored as is water flow rate through the section. A separate flow meter (0-400 SCFH) controls the flow of gas through the air knife inside the section and, therefore, controls the cooling rate.

Owner supplied water must meet the following conditions:

Average Flow Rate:	5 gpm
Average Flow Pressure:	50 psig max.
Maximum Inlet Temperature:	30°C or lower
Water Quality:	Facility supply

Warning: Using supply water different from the suggested parameters may reduce furnace performance characteristics and increase maintenance requirements or require the replacement of system components.

Water flow is controlled via flow meters next to the cooling chamber. The adjustable water regulator valve, in the base enclosure, should be set for the pressure (psig) specified in the installation diagram or facility drawing in the Owner's Manual.

CACT Closed Atmosphere Cooling Tunnel (Option ❒)

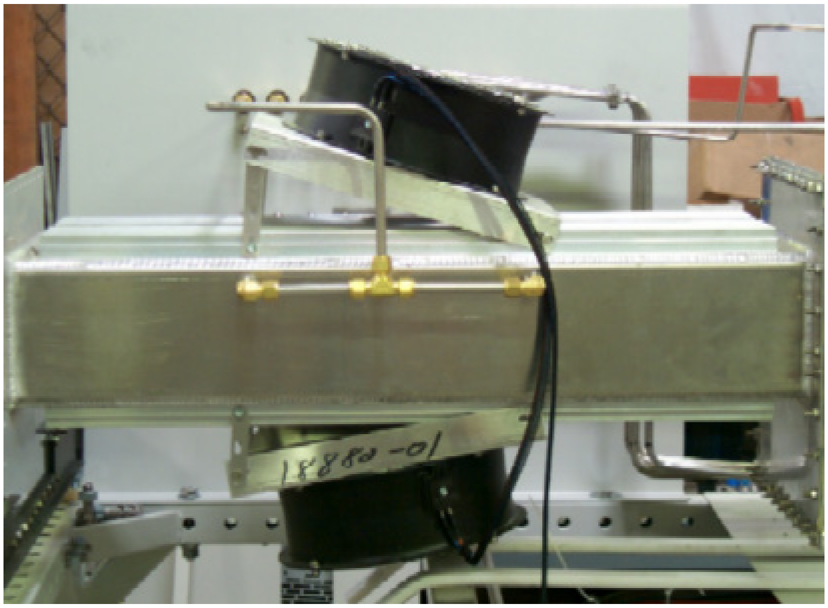

Figure 4-22: Controlled Atmosphere Air Cooled Module

Heavily finned aluminum heatsinks are attached to the outside of the cooling module which is not insulated to promote rapid heat loss. Hanging baffle gates and an air rake effectively isolate the high temperature furnace section from the controlled atmosphere cooling section. Adjustable rate fans direct air past the heat sink to remove heat transfer from the chamber. High-volume air knives inside the controlled atmosphere process section blow process gas around the parts inside to speed the cooling.

4.7 Heating Chamber Options

4.7.1 Air Filter (Option ❒)

Figure 4-23: Pre-filter/Regulator Shown

This option provides a filter, regulator and trap to clean and control incoming process air. The pre-filter/regulator unit includes a 0.5 µm impregnated fiber filtering element, manual drain, pressure gauge and regulator. The after filter is a 0.5 µm coalescing filter for water/oil removal with automatic drain. This combination unit reduces downstream oil contamination to 0.5 ppm wt maximum.

4.7.2 Air Purification System (Option ❐)

This option provides an air dryer and filtering system, which removes moisture, oil and particulate contamination from air or nitrogen. The system alternates between two large, approximately 6 ft. (1.83 m), storage tanks, constantly replenishing the gas in one while dispensing gas from the other. When pressure drops in the supply tank, each tank switches to the opposite supply or replenishing mode respectively.

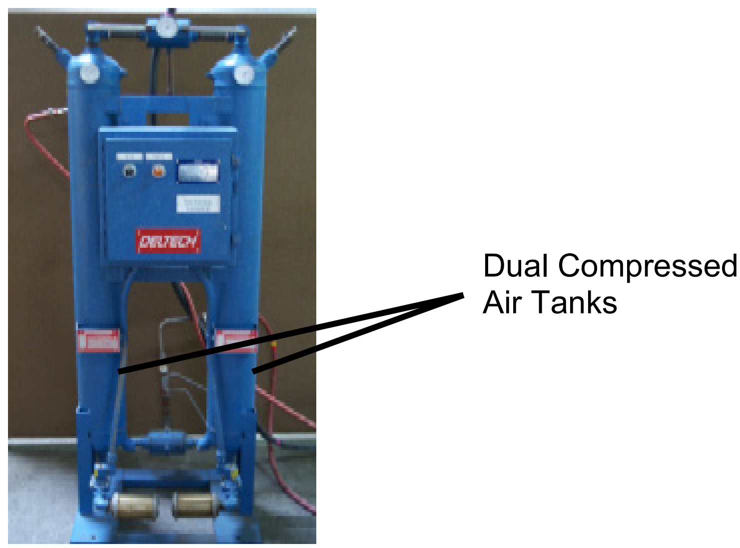

Figure 4-24: Typical Air Purification Tanks

Air Purification System Performance	
Particulate	Removes particles > 1 µm
Oil	Reduces oil and hydrocarbons to a level below 1 ppm
Water Removal	
Standard:	will dry 35 scfm to a dewpoint of -73°C (-100°F)
High Capacity:	will dry 56 scfm to a dewpoint of -73°C (-100°F)

NOTE: Using flow rates higher than specified will reduce performance.

4.7.3 Edge Heat

Edge heaters may be added to a furnace to provide more control over temperature uniformity across-the-belt inside the heating chamber. **In critical applications, especially in furnaces greater than 14 inches wide, properly adjusted edge heaters can enable greater use of the furnace width because they make possible a flatter temperature profile across the width of the furnace.**

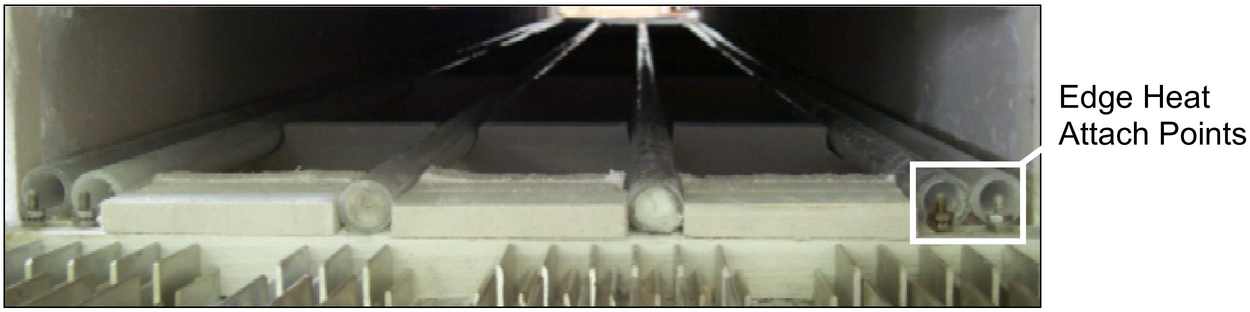

Figure 4-25: Edge Heaters

Carefully tuned nickel chromium resistance wires passed through quartz tubes inside the heating section increase the temperature at the edge of the conveyor belt. Left and right edge heaters are individually adjusted by the operator to reduce furnace delta T (temp deviation) and tune furnace performance. Edge heaters are a fine tuning device to be used in conjunction with the gas flow introduced through the chamber walls. Edge heaters are not designed to react to changes in chamber temperature and, therefore, should not be adjusted to dominate the temperature profile in any zone.

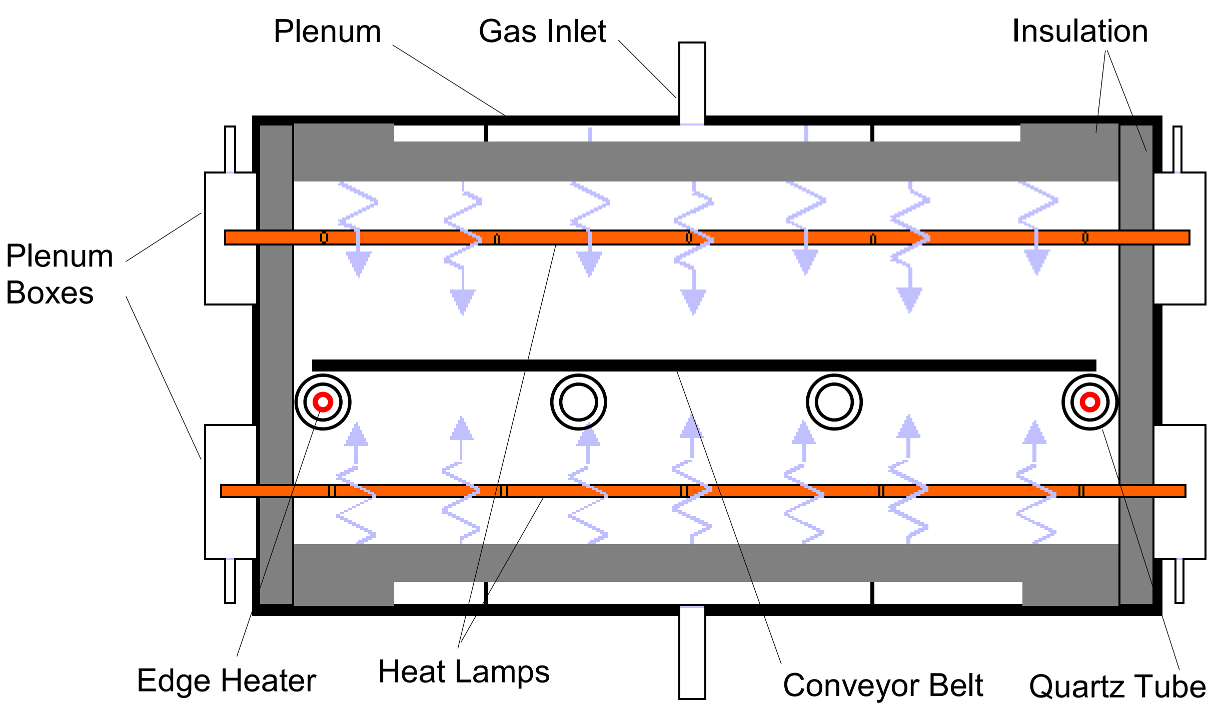

Figure 4-26: Cross Section of Furnace showing Edge Heaters

4.7.4 Element Monitor (Option ❐)

A special network is used to monitor each heat lamp circuit. Return power from the lamps is passed through an inductive circuit which transmits a signal when current is lost. The signal is relayed to the furnace PLC controller which then signals an alert. Lamp failure is designed to not immediately shut-down the process. Until the zone temperature falls outside the alarm conditions set in the recipe, the furnace will continue to operate. However, the operator is alerted to an element (lamp) failure.

The Element Monitor Window is added furnace control software that provides active element status. Element Monitor software interface is not available to Operator level. It is described in more detail in Section 7.3.2 on p.70.

Note: The Element Monitor circuit does not function at power levels below 10% which is under the threshold of the sensor circuit. So any elements operating in this range are reported as "OK" regardless of their status.

4.7.5 Hermetic Seal (Option ❐)

The hermetic seal option provides a positive pressure gas flow to the outside of the ends of the lamps on each chamber to ensure that unwanted process offgas does not collect around the lamps or inside the process section. A plenum box surrounds the ends of the lamps and acts to duct controlled atmosphere gas to this area. An added benefit to this option is the protection of the ends of the lamps from overheating. By allowing process gas to flow around the ends of the heat lamps, heat is carried away from each lamp.

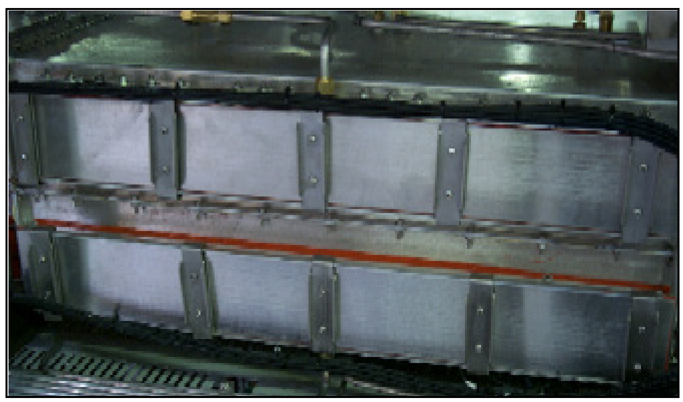

Figure 4-27: Plenum Box

4.7.6 Over Temp. Monitor (Option ❐)

This option provides an independent zone temperature watchdog that monitors each zone and responds to set boundary conditions. A secondary thermocouple installed in each zone provides temperature sensor monitor and control redundancy. If an Over Temp condition is detected, the system is designed to automatically shut down the heat lamps, even if multiple components fail. The process engineer selects the maximum/minimum temperature. The system will shut down the heating elements if sensors detect that the temperature extends outside the predetermined range. The system factory default is set as an over-temperature alarm for 50°C above the maximum rated temperature of the furnace.

4.7.7 Oxygen Analyzer (Option ❐)

Oxygen analyzers are regularly installed in controlled atmosphere furnaces to assist in monitoring O_2 levels at various points of the Furnace. Four sensors are installed: one to monitor the incoming source gas and three in the specified zones. O_2 levels are reported in parts per million (PPM) on the Process Screen.

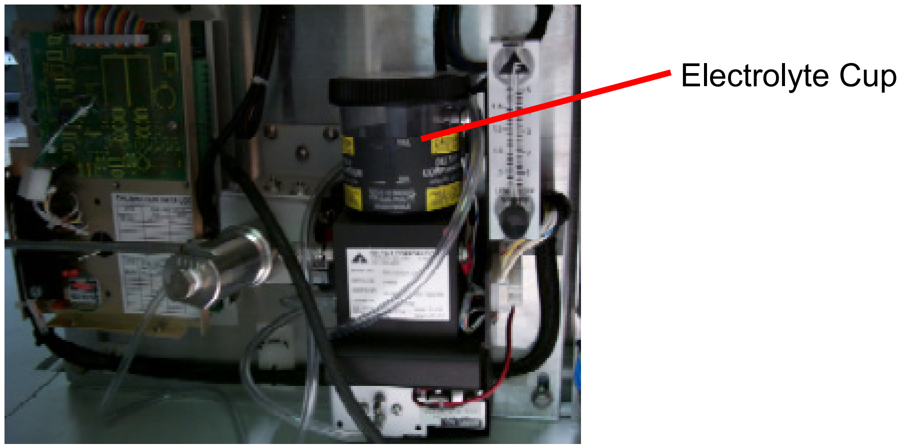

Figure 4-28: Oxygen Analyzer

Software Control (Oxygen Analyzer)

To select the sampling port:

From the Process Screen, click on the **O2 / MA Sampling** button.

From the Recipe Screen, click on the **O2 Sampling Port** button.

The following window will appear.

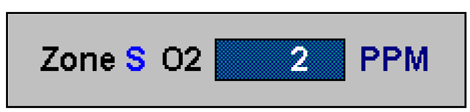

Figure 4-29: Oxygen Analyzer

Click the appropriate selector button to see the oxygen content at various positions within the furnace chamber. If the selector button for the Source is selected, the analyzer will sample the incoming gas.

Note: When switching between sampling ports, several seconds must pass to clear the sampling line and establish an accurate reading. Furthermore, upon system startup, the oxygen analyzer lines must be purged of residual air that is in the system prior to gas hook-up. Initial readings may take as long as a minute but will not occur again unless the oxygen supply is disconnected.

4.7.8 Moisture Analyzer (Option ❒)

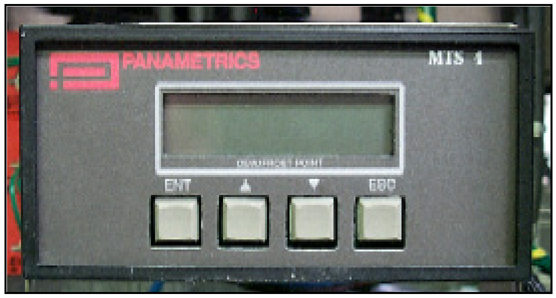

Figure 4-30: Moisture Analyzer

The moisture analyzer provides accurate moisture readings at four locations in the supplied process gas. Typically, a source and three heating chamber process gas supply lines are sampled.

Note: Moisture analyzer saturation can cause false readings until the sensor is dry. The drying process may take as long as 45 minutes. Avoid allowing high levels of moisture into the process air supply lines.