

Oxyfire-LT Modular Oxygen Sensor

Installation / Operation Manual

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For the safe use of this equipment***Sensor Handling***

The cell (sensor) at the tip of the detector is made of ceramic (zirconia element). Do not drop the detector or subject it to pressure stress.

- Do NOT allow the sensor (probe tip) to make contact with anything when installing the detector.
- Avoid any direct water drop on the probe (sensor) of the detector when installing it.
- Check the verification gas piping before introducing the gas to ensure there is no leakage of the gas. If there is any leakage of the gas, the moisture drawn from the measuring gas can damage the sensor.
- The detector (especially at the tip) becomes very hot. Be sure to handle it with gloves.
- Oxyfire-LT may be heavy. Handle it with care. Do not drop it. Handle safely to avoid injury.

Sensor Heater

Only qualified personnel with knowledge of electrical equipment and safety procedures involving electrical equipment should be allowed to work on this equipment. Connect the power supply for the heater only after confirming that the supply power is switched off. Insure that heater voltage supply and current matches the rating of this equipment.

Process Gas

Some process gases are dangerous to people. When removing this equipment from the protection tube and mounting flange protect yourself from potential poisoning by using a protective mask or ventilating the area well.

1 INTRODUCTION

1.1 GENERAL

The Oxyfire-LT In-Situ Zirconia Oxygen Sensor has been designed to measure excess oxygen in a wide variety of low temperature combustion processes. It is an outstanding unit for monitoring oxygen concentrations in combustion gas of large or small boilers, industrial furnaces and combustion processes or for the control of low percent oxygen combustion.

The analyzer consists of a detector and converter. Optional accessories, such as electronics, reference air units, verification units, mounting assemblies, and protection tubes may be selected to enhance installation. The complete installation provides system care, minimizes maintenance and provides automated or manual verification. An optimal control system can be realized if the appropriate supplemental equipment is selected.

The Oxyfire-LT utilizes high performance Oxyfire-LT Probe technology to provide cost-effective and reliable oxygen sensing and control in low process temperature applications.

1.2 OVERVIEW

The Oxyfire-LT is a self-heated device that is mounted into the process flue with a flange interface. The probe is internally heated to operate at a temperature of 600°C with the application 120V AC power. Sensor is used to monitor and control the excess oxygen concentration in combustion gases of boilers, incinerators and other industrial furnaces.

A low temperature sensor sampling gases from 500°F (300°C) up to 1100°F (600°C) is inserted into the process gas stream via a flange, threaded adaptor, or sealable opening. The sensor may be installed vertically or horizontally, depending on application specifics such as temperature, gas flow, etc. The atmosphere around the sensor tip should be moving and not stagnant. For optimum results, the sensor should be protected from direct flame contact and located at a point where combustion is complete.

1.3 THEORY OF OPERATION

Yttria stabilized zirconia conducts oxygen ions at temperatures above 1000°F (540°C). The driving force of the ion migration is the difference in the oxygen concentration between the process gas and the supplied reference air. Partial pressure laws of gases state that oxygen molecules will travel from higher to lower concentrations. Platinum electrodes, located on both the inside and the outside of the zirconia, detect the voltage produced by the flow of these ions. This millivolt signal is a function of the difference in oxygen concentration. Knowing the process temperature, reference gas oxygen concentration (20.9%) and the millivolt signal, the Nernst equation is used to calculate the percent oxygen.

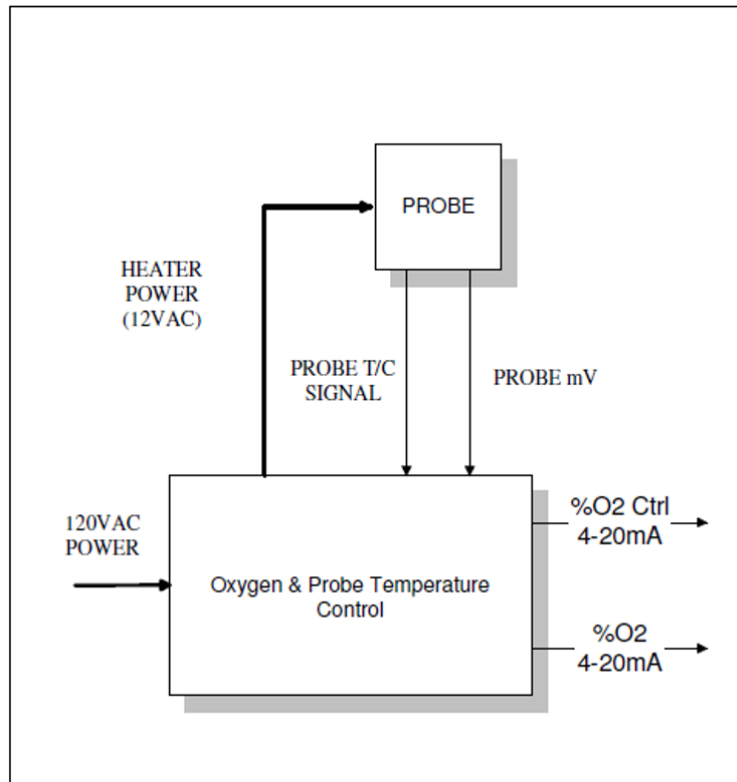
The Nernst Equation is as follows:

$$E := \left(0.0215 \frac{\text{mV}}{\text{K}} \right) \cdot T \cdot \ln \left(\frac{\%O_2_{\text{reference}}}{\%O_2_{\text{process}}} \right)$$

E = Sensor Output in Millivolts
 T = Sensor Temperature in degrees Kelvin (degrees C + 273)
 $\%O_{2_reference}$ = Oxygen concentration on the inside of the zirconia substrate (20.9%)
 $\%O_{2_process}$ = Oxygen concentration on the outside of the zirconia substrate (unknown)
 ln() = Natural log

1.4 SYSTEM CONFIGURATION

The basic system consists of a sensor, electronics and reference air unit.



1.5 STANDARD SPECIFICATIONS

Measurement Method	Zirconium Oxide
Net O ₂ Range	PPM to 20.9%
Accuracy	± 1.5% of observed process variable or 0.5% O ₂ , whichever is greater
Response Time	Less than 1 second for 98% of final value
Stability	Less than 1% deviation in signal output over the life of the sensor
Operating Temp of Heater	1112°F (600°C)
Maximum Process Temp	1292°F (700°C)
Temp Limit Terminal Head	150°F (65°C) max.
Mounting	Vertical or horizontal.
Construction	
Inner Tube	Zirconia
Outer Sheath	Alumina, TSR
Terminal Head	6061-T6 aluminum
Heater	Ceramic material (replaceable)
Integral Thermocouple	Type "K"
Gas Calibration	Not required. Verification of sensor possible.

Insertion Rate	1 inch (25mm) per 5 minutes during a hot installation
Sensor Outputs	Two millivolt output signals (electrolyte and type K thermocouple)
Interconnecting Cable	Sensor to electronics 2-conductor twisted pair shielded Belden #6341PC cable K T/C version: 1 cable, 2 conductor, solid extension grade wire

Warning

The oxygen sensor is heated to 600°C (1112°F) with 110VAC / 200VA mains power. The heater power is a potential source of ignition and should only be energized in a non-explosive atmosphere or when the atmosphere is safe from explosion. An interlock is provided in the sensor control system to shut off the heater power when conditions are not safe. *Never apply power to the heater in an explosive atmosphere.*

Oxyfire-LT Mechanical Information

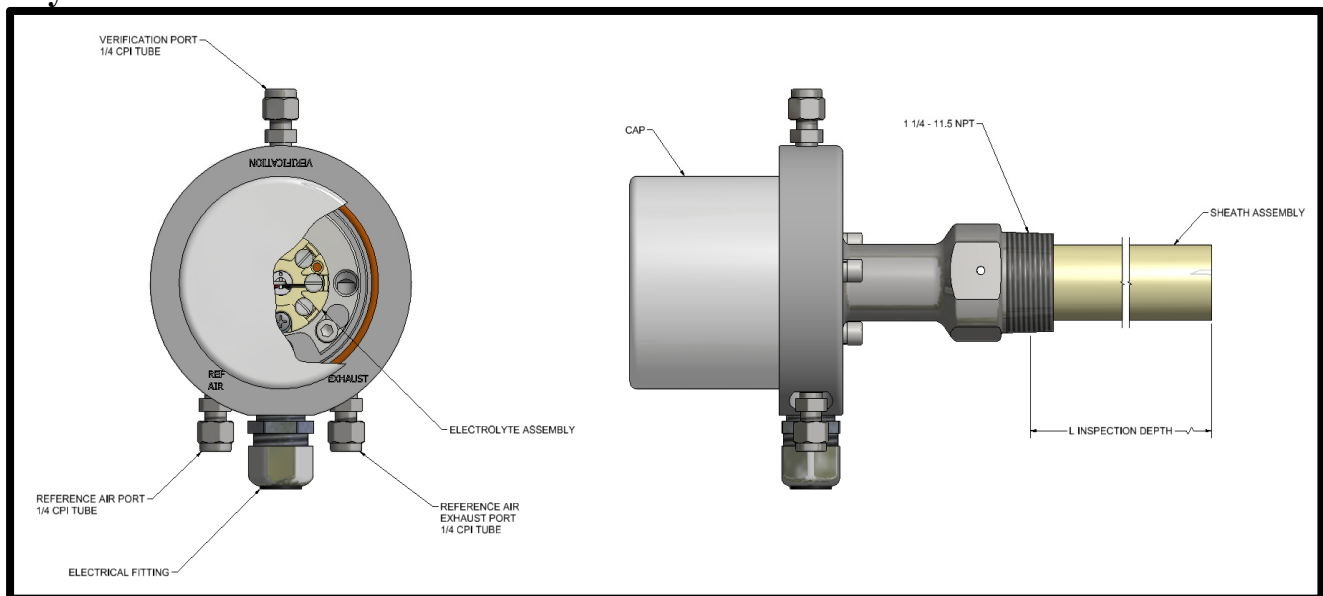


Figure 1 Sensor Parts Identification

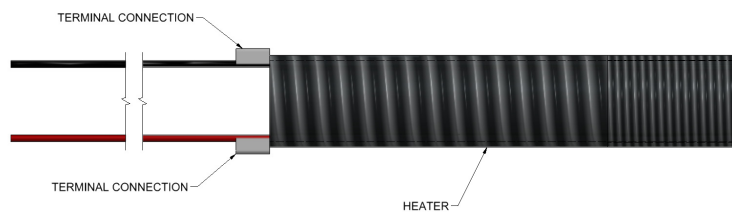


Figure 2 Heat Assembly

Table 1 Standard Part Numbers

Part #: FOI X -YYYY -Z

Sheath Style X				
Alumina Open End	5			
Alumina Closed End	6			
SS 316 Closed End	7			
Insertion Length YYYY				
in	mm			
12	304.8			1200
18	457.2			1800
24	609.6			2400
30	762			3000
36	914.4			3600
TC Type Z		K		

2 INSTALLATION

2.1 APPLICATION CONFIRMATION

Call your local MMI Representative or MMI directly when planning your sensor installation. The sensor location and depth of insertion are critical factors to consider and vary with different applications. MMI Application Engineers are equipped to help with such information in many applications.

2.2 ITEMS REQUIRED

To perform a sensor installation, you will need the following items:

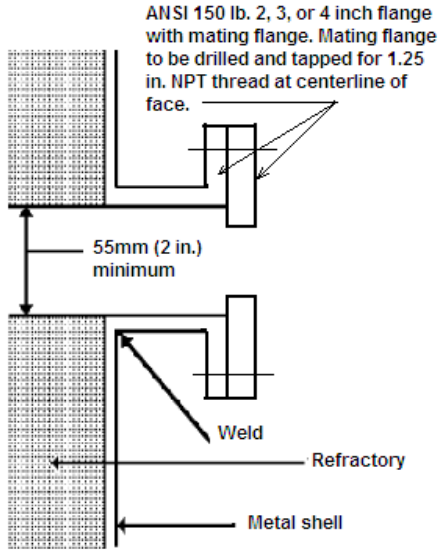
- Supplied with standard Oxyfire models:
 1. K T/C models: 2-conductor solid extension wires
 2. Polyvinyl coated copper wire, two conductor, stranded, 18 gauge, twisted pair, shielded – Belden #6341PC
- Ceramic fiber blanket insulation and/or refractory cement.
- Sensor Reference Air: Clean, dry continuous air source – approximately 2 psi at 50 to 150cc/minute
- Cooling Air: If the temperature of the sensor terminal head will exceed 300°F (148°C), air should be blown across it to reduce the temp. The cooling air should be directed to flow perpendicular across the sensor head.

2.3 SENSOR HOLE SIZE

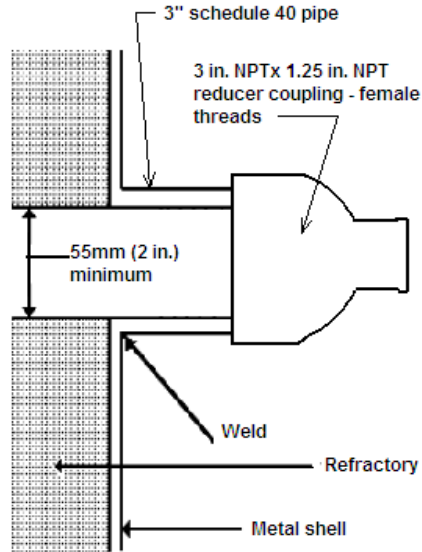
The installation hole, through the refractory of the crown or wall, should be a minimum of 2 inches (50mm) in diameter. The hole should always be straight, clean, and perpendicular to the wall or crown. **It is advised to always verify the hole size required for your application and sensor. MMI Application Engineers can help with this matter.**

2.4 INSTALLATION PORTS

The ports can be of different designs – open hole, threaded, and flanged. Applications with exterior metal shells should use threaded or flanged type ports. Thread is 1.25” NPT size for standard Oxyfire models. Applications with ceramic exterior shells may use the open hole, threaded, or flanged connection ports. The flange or pipe will be cemented in to the refractory.



FLANGE MOUNTING METHOD

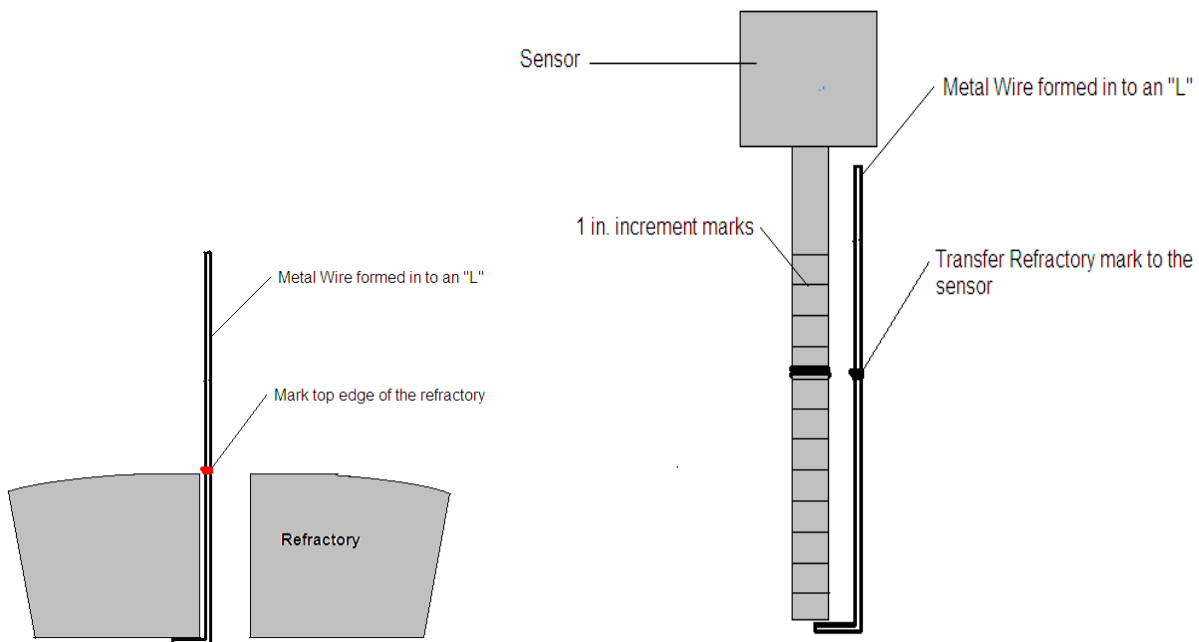


PIPE COUPLING MOUNTING METHOD

The methods above may be used on boilers and furnaces with refractory lined metal shells. Installations are good for temperatures up to 1600 deg. C.

2.5 WALL THICKNESS

Verify the exact thickness of the refractory in the crown or wall. A length of high temperature metal wire, formed like an "L", should be inserted into the refractory hole. Hook the lengths of wire against the inside face of the refractory and mark the outside face of the furnace on the wire. Check the dimension at several points around the circumference of the hole. This will indicate possible erosion or build-up. Transfer this mark to the sensor sheath. Next mark 1 inch (25mm) increments along the length of the sensor sheath starting at the tip.



2.6 COOL INSTALLATION (100 ° F or lower)

If the installation is cool

- Apply Teflon tape or thread sealant to the sensor threads before installing.
- Insert the entire sensor at once and seal or tighten the port connection to avoid any air in-leakage.
- Carefully hand-tighten the sensor.
- Using a wrench to tighten one-quarter turn. ***Over tightening the sensor can cause breakage.***
- Connect the reference air supply to reference air fitting (1/4" tube CPI) on sensor.
- Verify that the cap on the verification fitting is tight.

2.7 HOT INSTALLATION

Before inserting the sensor, verify the presence of a flame exiting the port & apply Teflon tape or thread sealant to the sensor threads before installing.

If a flame is not observed, follow these installation procedures:

- Insert the first 4 to 6 inches (100 to 150mm) of the sensor in to the port. This dimension should not exceed one half of the refractory thickness.
- Then begin the slow insertion rate of 1 inch (25mm) per 5 minutes to prevent thermal shock to the sensor. Keep the sensor supported during the insertion process.
- Carefully hand tighten the sensor once completely installed.
- Use a wrench to tighten one-quarter turn. Over tightening the sensor can cause damage to the sheath.
- If the threaded connection is not used, carefully seal the hole around the sensor with insulation and/or cement. Connect the reference air supply to the reference air fitting (1/4" tube CPI) on sensor.
- Verify that the cap on the verification fitting is tight.



Warning

An insertion rate faster than specified can cause irreparable damage to the sensor.

If a flame is observed exiting the installation port, contact MMI engineers before starting sensor insertion.

2.8 ELECTRICAL CONNECTIONS:

- Wire the sensor to the electronics via an MMI approved cable.
- Each sensor is supplied with approximately 8 feet (2.4 meters) of cable (or cable assembly). The cable is connected to the appropriate terminals in the sensor terminal head. The opposite cable end should be connected to a similar type cable leading to the electronics. The connection between the two cables shall be made inside of an approved electrical junction box. The cable shield wires should be maintained with system extension cables and only be attached at a suitable ground point in the electronics enclosure.

- Both of the sensor output signals, TC and millivolt, are low voltage with no current flow.
- Do not physically pull on any of the wires in the terminal head. The wires are delicate and any extra force can cause them to break or connections to become loose. It is not recommended to remove the terminal cover.
- If required for installation, it is possible to replace the supplied cord grip fitting and grommet with a ½” conduit fitting. Extreme care should be taken to remove the cable connections and reconnect them through the conduit fitting.

Sensor cable insulation color **Oxyfire-LT models**

WIRE INSULATION COLOR	ELECTRICAL CONNECTION	
RED (red shield)	SENSOR (+)	
BLACK (red shield)	SENSOR (-)	
BLACK (green shield)	HEATER (+)	
WHITE (green shield)	HEATER (-)	
RED		THERMOCOUPLE (-)
YELLOW		THERMOCOUPLE (+)

- *Connection TIP:* Resistance between the heater wires is approximately 25 ohms. Resistance between the mV signal wires is a virtual open.

3 REFERENCE AIR

3.1 Clean, Dry Air Supply

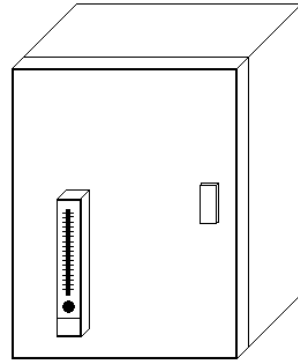
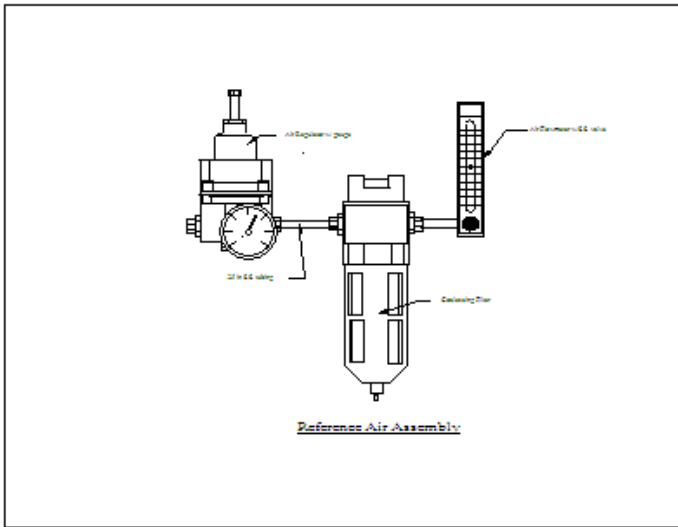
The sensor requires a supply of clean, dry air at a flow rate of 50 to 150cc/min. at a pressure of approximately 2 psi. Sources for the air supply are regulated, clean plant instrument air or atmospheric air from a small pump.

Each Oxyfire-LT sensor has a reference air inlet and outlet port. If necessary, but not required, the reference air outlet can be vented to a specified location. The reference air exhaust must not create back pressure nor can it be plugged.

3.2 Suitable Reference Air Units

- Part #F005010 – Reference Air Assembly – Includes regulator, filter, flow meter, and interconnecting stainless steel tubing and fittings. For use with customer plant instrument air supply. May be used for multiple sensors.
- Part #F005026 – Reference Air Panel – Includes pre-wired and plumbed enclosure with atmospheric pump and flow meter. For use when plant instrument air is not available. One reference air panel per sensor. Requires 120 VAC power supplied by customer.

- Suitable 1/4" tubing for the application, such as poly/teflon, copper, aluminum, or stainless steel should be run from the reference air supply to the sensor.



Reference Air Panel with Pump

4 VERIFICATION

The oxygen sensor does not require calibration with a certified calibration gas. The Oxyfire-LT includes a port and fitting for verification of the oxygen measurement and operation of the cell. There are two common methods used in the verification process.

4.1 Method #1

Inject a certified gas into the verification port and compare the sensor reading to the cal gas. The verification gas should be regulated to 5 psi maximum and a flow rate not to exceed 2 scfh. The gas will need to exceed the process gas flow and pressure. The gas will disperse the process gas contained inside the sensor's outer sheath and allow the cell to measure the oxygen content of the verification gas. If the gas flow does not disperse the process gas completely, there will be a slight blending of process and cal gases at the cell. This can cause the sensor's readings to vary slightly from the actual oxygen level in the verification gas. It is recommended to start the cal gas flow at 2 psi and slowly increase to a maximum of 5 psi if required.

4.2 Method #2

Method #2 is to use a portable extractive oxygen analyzer to extract a gas sample from the sensor's verification port and compare the portable reading to the sensor reading. Care should be taken to make sure the portable analyzer is calibrated and accurate. After completing this process, remember to replace the cap on the verification fitting and tighten to prevent any in-leakage

5 OXYFIRE-LT REPLACEMENT COMPONENTS

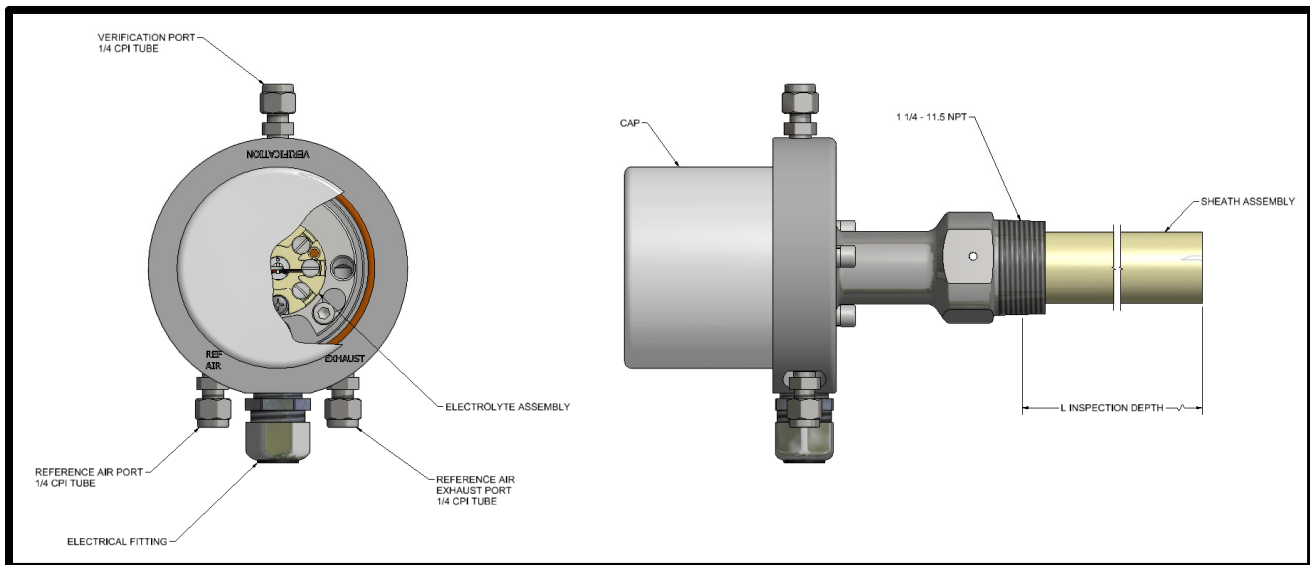
Warning

Disconnect the heater power before removing the sensor head cover. The mains voltage of this supply is exposed when the cover is removed and is a potential shock hazard to maintenance personnel.

The Oxyfire-LT is designed for modularity and quick replacement of critical components. The sensor has three key components that can be purchased separately for replacement on-site.

- Sheath Assembly - this contains the protective sheath and stainless steel mount fitting
- Electrolyte Assembly - this contains the electrolyte, thermocouple, and terminal block
- Head Assembly - this is the manifold base with fittings and cap

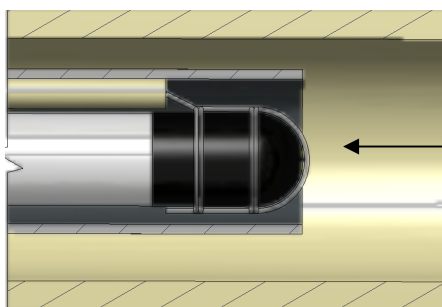
For assistance with replacement component purchasing please contact MMI



5.1 REPLACEMENT PRECAUTIONS

DO NOT REPLACE HOT COMPONENTS. The sensor must be removed from the process before any disassembly is accomplished. Please follow these instructions before replacing any component on the Oxyfire-LT

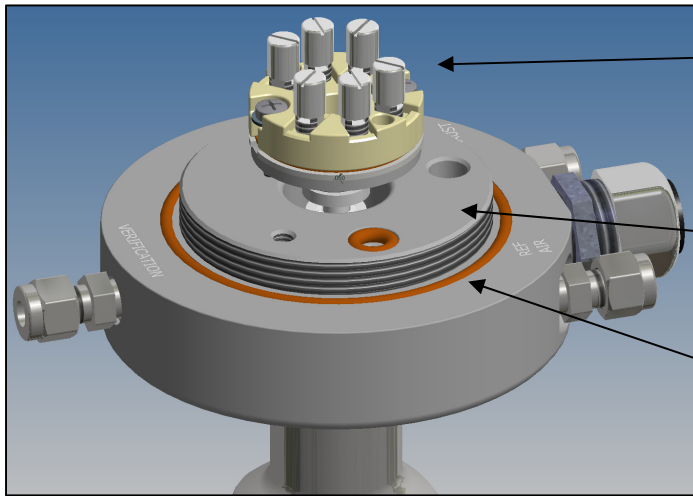
- The sheath must be inspected for sagging before replacing the Electrolyte Assembly. Severe sagging will cause concentricity interference issues with the electrolyte assembly installation. If the electrolyte assembly tip is contacting the sheath after installation, then the sheath assembly must be replaced as well.



Electrolyte and heater must not contact the sheath after installation. Clean out any debris before replacing the Electrolyte Assembly. If necessary, you may have to use 0.005" shims under the busing in order to align the zirconia tube.

Do not attempt to replace the electrolyte assembly unless you have been properly trained by MMI personnel.

- The sheath must be free of debris on the inside before any new components are installed. Please clean out the sheath before installing a new electrolyte assembly.
- The head mounting surface must be clean and free of debris. do not install a new electrolyte assembly on a dirty surface because this may cause concentricity issues with the electrolyte assembly
- Inspect all of the sealing O-rings on the head before replacing the electrolyte. If the gaskets are beyond use, please replace accordingly
- Inspect screw on terminals for connection integrity. Crimp on new terminals accordingly.
- Inspect terminals for connection integrity on heater. Crimp on new terminals accordingly.

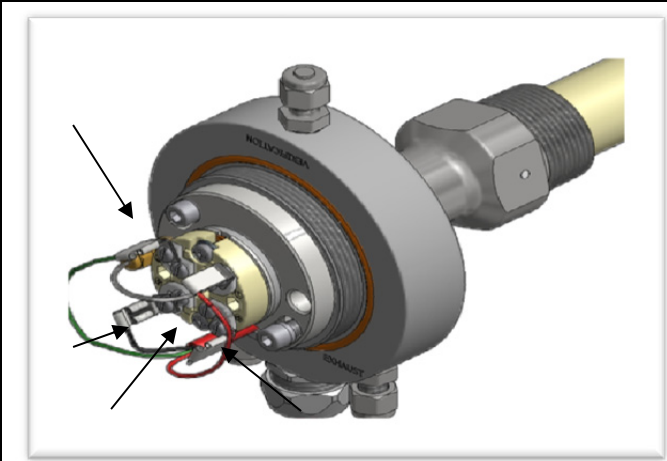


Inspect screw on terminals and replace accordingly

Mounting surface

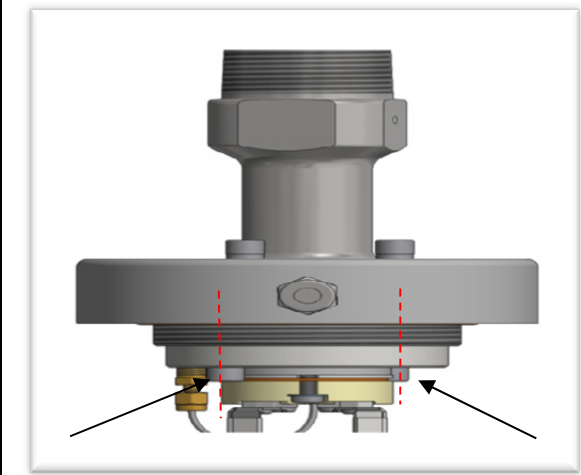
Inspect all O-rings for integrity

5.2 ELECTROLYTE REPLACEMENT

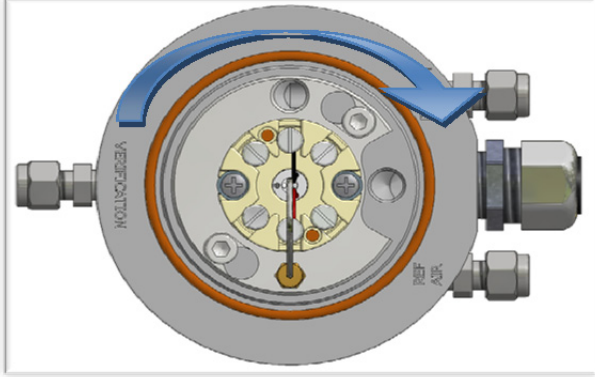
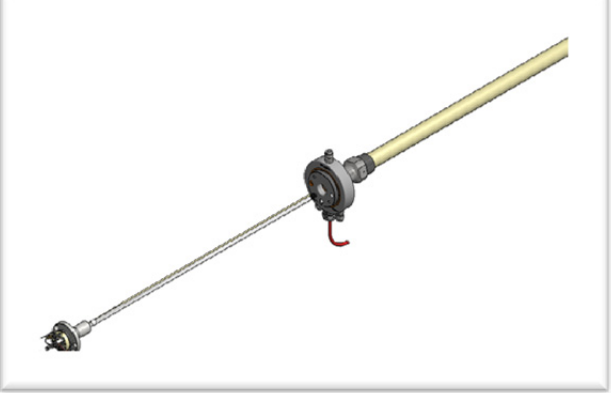


1. Remove the cap and inspect the threads on the Cap and on the Manifold base.

2. Disconnect the six screw-on terminals.



3. Using a 3/16" Allen Wrench, Unscrew the two stainless steel socket head cap screws enough to clear the electrolyte Assembly head thickness. You DO NOT need to completely remove the screws, just unscrew enough for clearance.

	<p>4. Rotate the assembly aligning the two SHCS in the clearance holes.</p>
	<p>5. Remove the assembly from the body.</p> <p>Clean out any debris before replacing the Electrolyte Assembly, inspect heater assembly to insure proper connection. If necessary, you may have to use 0.005" shims under the busing in order to align the zirconia tube.</p> <p>Do not attempt to replace the electrolyte assembly unless you have been properly trained by UPC personnel.</p>

6 TROUBLESHOOTING

6.1 ITEMS REQUIRED

The following items are required to troubleshoot the Oxyfire sensor.

- A digital multimeter (with DC millivolt ranges)
- Blade and Phillips screwdrivers
- Needle-nose pliers
- Verification gas or portable oxygen analyzer
- Oxygen/Temp/Millivolt Chart (See Appendix)
- Sensor wiring schematic (See Appendix)

6.2 SIGNAL TROUBLESHOOTING

- a. Sensor must be in the process at normal operation and heater is in operation with sensor temperature above 1000°F (550°C).
- b. Use a portable analyzer or verification gas to verify sensor reading. If sensor does not verify or the verification cannot be performed, proceed to **step c**.
- c. Verify that the reference air tubing is connected to the correct port on the sensor.
- d. Verify that the verification port on the sensor is capped tightly to prevent any air in-leakage.
- e. Check sensor reference air for proper flow and pressure. Verify air is reaching sensor port by disconnecting the supply tubing at the sensor and place the tubing in a cup of water. If you see no bubbles or a very slow flow of bubbles, increase the reference air flow at the supply until a steady flow of bubbles is achieved.
- f. Dry and reconnect the air tubing to the sensor port and proceed to **step g**. A higher than normal oxygen reading may be observed if the reference air flow is low. A lower than normal reading may be observed if the pressure and flow is too high.
- g. The sensor is supplied with a cable approximately 8 feet long. It is attached to the terminal screws inside the terminal head of the sensor. If the cable has not been removed then follow these steps:
 - i. Isolate the sensor from the rest of the system by disconnecting the sensor cable.
 - ii. At the sensor cable, measure and note the cell millivolts across the (+) wire and the (-) wire. This measurement should fluctuate. Next, measure and note the thermocouple millivolts across the (+) wire and the (-) wire. This measurement should be fairly stable
 - iii. Using the charts in the appendix, look up the temperature and oxygen. Compare the readings to what you were seeing in the electronics. They should match. If the readings do not match, reconnect the wires to the cable running to the electronics. Measure the same millivolt readings at the terminals on the electronics. They should match. If not, trace all wires and connections to see if they are crossed or connected in error. The shield wire should only be connected at the electronics ground. If everything checks out, then disconnect the shield to see if a ground loop or interference is involved. If everything checks out OK and the readings are still incorrect, call Marathon Monitors Inc. for further assistance.
- h. If the factory cable has been removed:
 - i. Remove the terminal cover from the sensor and verify that all connections are correct. See Appendix.
 - ii. Isolate the sensor from the rest of the system by disconnecting the cable from the terminal connections inside the sensor terminal head. Make note of wiring connections before disconnecting. Do not disconnect the sensor's internal wires or damage to the sensor may occur.
 - iii. Measure and note the cell millivolts across the internal (+) wire and the (-) wire. This measurement should fluctuate. Next, measure and note the thermocouple millivolts across the

- (+) wire and the (-) wire. This measurement should be fairly stable (see diagram on page 13 for wire color and location).
- iv. Using the charts in the appendix, look up the temperature and oxygen. Compare the readings to what you were seeing in the electronics. They should match. If the readings do not match, reconnect the cable running to the electronics. Measure the same millivolt readings at the terminals on the electronics. They should match. If not, trace all wires and connections to see if they are crossed or connected in error. The shield wire should only be connected at the electronics. If everything checks out, then disconnect the shield to see if a ground loop or interference is involved. If everything checks out OK and the readings are still incorrect, call Marathon Monitors Inc. for further assistance.



Disconnect the heater power before removing the sensor head cover. The mains voltage of this supply is exposed when the cover is removed and is a potential shock hazard to maintenance personnel.

6.3 HEATER TROUBLESHOOTING

- a. Disconnect power from the sensor heater circuit.
- b. Confirm correct connection from the supplied cable and wiring diagram
- c. At the sensor cable measure the resistances across the heater(+) and heater (-). This measurement should be between 25 – 30 ohm. If no resistance is measured, trace wires and connection to see if they are crossed or connected in error. If everything checks out OK and the readings are still incorrect, call Marathon Monitors Inc. for further assistance.
- d. If the resistance is correct, apply power to the heater circuit.
- e. Verify that 110 ~ 120VAC is applied across the heater connections. If no voltage is indicated check the heater fuse and the incoming power.

7 APPENDIX

7.1 OXYGEN CALCULATION

A natural phenomenon occurs when zirconia oxide is heated above 550° C. and a reference gas is on one side and an unknown atmosphere containing the same component as the reference gas is on the other side. As long as these two atmospheres are kept separate, ions of the reference gas will transfer across the zirconia boundaries, going from area of greatest concentration to area of least concentration.

Electrodes of various materials are used to measure the ion electrons (+/-) flowing through the zirconia oxide. This signal (millivolts) is generated as long as a reference gas is continuously supplied. In the area of combustion control, the reference gas is typically air (20% Oxygen and 80% Nitrogen).

Knowing that there is Oxygen present in the combustion process, allows the in-situ oxygen sensor (it's substrate being made of zirconia oxide) to measure the oxygen ion transfer across the substrate, and thus give a millivolt signal that is inversely proportional to the amount of Oxygen present in the combustion zone. Walther Hermann Nernst, the German physical chemist is credited with developing the "Theory of Solutions". This theory explains the voltages developed by electrochemical batteries. This universally accepted equation can be applied to the sensing of Oxygen using a zirconia oxide cell. MMI's oxygen sensors and their electrical interfaces conform to the Nernst Equation in combustion environments. In most combustion applications, the level of excess Oxygen range from 0.001ppm to 21% oxygen. The equation allows the computation and display of the oxygen concentration in the combustion gas stream. The sensors and electronics are virtually maintenance free, needing no calibration and no maintenance of sample tubing.

The Nernst Equation is as follows:

$$E := \left(0.0215 \frac{\text{mV}}{\text{K}} \right) \cdot T \cdot \ln \left(\frac{\%O_2_{\text{reference}}}{\%O_2_{\text{process}}} \right)$$

E = Sensor Output in Millivolts

T = Sensor Temperature in degrees Kelvin (degrees C + 273)

%O₂_Reference = Oxygen concentration on the inside of the zirconia substrate (20.9%)

%O₂_Process = Oxygen concentration on the outside of the zirconia substrate (unknown)

ln() = Natural log

Sample Solution:

T = 1273K E = 80mV

80 = (0.0215)(T)(ln (20.9/Ln X))

80 = (0.0653)(T) – (0.0215)(T)(ln X)

80 = 83.13 - (0.0215)(1273)(ln X)

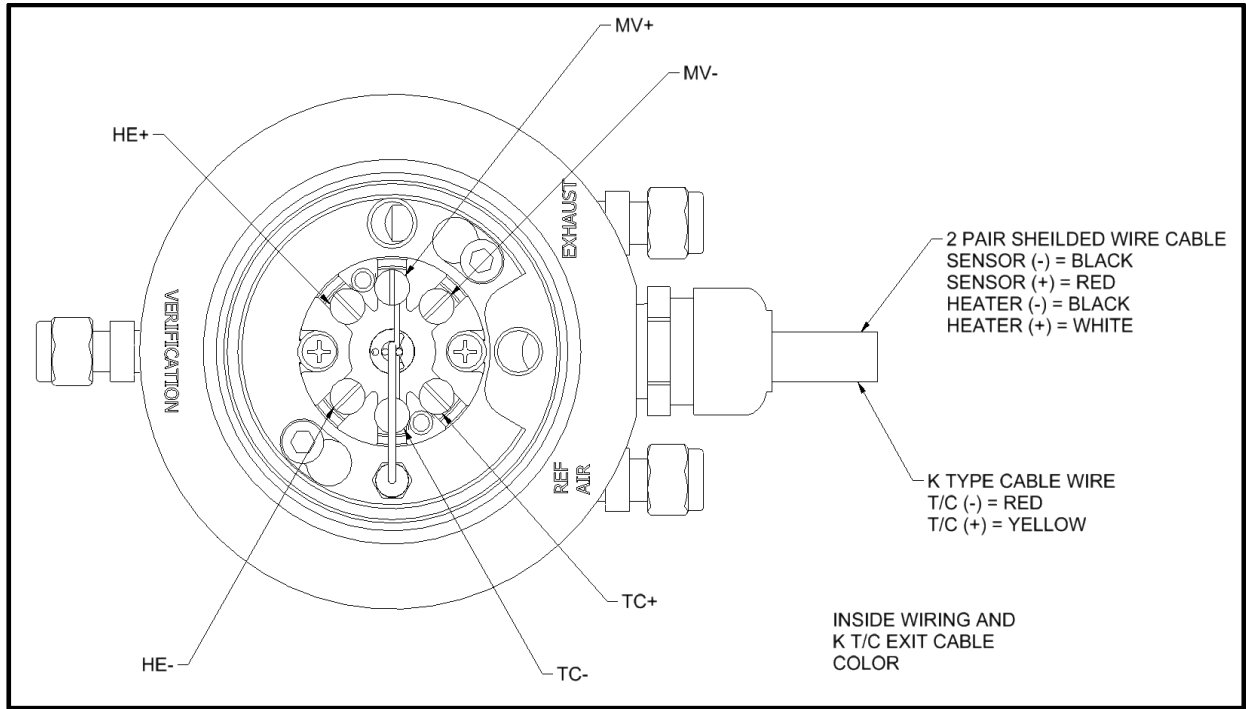
(27.37)(ln X) = 83.13 – 80

ln X = 3.13/27.37

ln X = 0.114

X = 1.12% oxygen

7.2 STANDARD OXYFIRE SENSOR WIRING CONNECTIONS



7.3 OXYGEN/TEMPERATURE/ MILLIVOLT CHART

Oxygen Chart								
Deg C	500	520	540	560	580	600	620	640
Deg F	932	968	1004	1040	1076	1112	1148	1184
MV								
0	20.95%	20.95%	20.95%	20.95%	20.95%	20.95%	20.95%	20.95%
2	18.58%	18.63%	18.69%	18.74%	18.79%	18.83%	18.88%	18.92%
4	16.47%	16.57%	16.67%	16.76%	16.85%	16.93%	17.01%	17.09%
6	14.60%	14.74%	14.86%	14.99%	15.11%	15.22%	15.33%	15.43%
8	12.95%	13.11%	13.26%	13.40%	13.54%	13.68%	13.81%	13.94%
10	11.48%	11.65%	11.82%	11.99%	12.15%	12.30%	12.45%	12.59%
12	10.18%	10.37%	10.55%	10.72%	10.89%	11.06%	11.21%	11.37%
14	9.02%	9.22%	9.41%	9.59%	9.77%	9.94%	10.11%	10.27%
16	8.00%	8.20%	8.39%	8.58%	8.76%	8.93%	9.11%	9.27%
18	7.09%	7.29%	7.48%	7.67%	7.85%	8.03%	8.21%	8.38%
20	6.29%	6.48%	6.67%	6.86%	7.04%	7.22%	7.39%	7.56%
22	5.58%	5.77%	5.95%	6.13%	6.31%	6.49%	6.66%	6.83%
24	4.94%	5.13%	5.31%	5.49%	5.66%	5.83%	6.00%	6.17%
26	4.38%	4.56%	4.73%	4.91%	5.08%	5.24%	5.41%	5.57%
28	3.89%	4.06%	4.22%	4.39%	4.55%	4.71%	4.87%	5.03%
30	3.45%	3.61%	3.77%	3.92%	4.08%	4.24%	4.39%	4.55%
32	3.06%	3.21%	3.36%	3.51%	3.66%	3.81%	3.96%	4.11%
34	2.71%	2.85%	3.00%	3.14%	3.28%	3.42%	3.57%	3.71%
36	2.40%	2.54%	2.67%	2.81%	2.94%	3.08%	3.21%	3.35%
38	2.13%	2.26%	2.38%	2.51%	2.64%	2.77%	2.90%	3.02%
40	1.89%	2.01%	2.13%	2.25%	2.37%	2.49%	2.61%	2.73%
42	1.67%	1.78%	1.90%	2.01%	2.12%	2.24%	2.35%	2.47%
44	1.48%	1.59%	1.69%	1.80%	1.90%	2.01%	2.12%	2.23%
46	1.32%	1.41%	1.51%	1.61%	1.71%	1.81%	1.91%	2.01%
48	1.17%	1.26%	1.35%	1.44%	1.53%	1.62%	1.72%	1.82%
50	1.03%	1.12%	1.20%	1.29%	1.37%	1.46%	1.55%	1.64%
52	0.92%	0.99%	1.07%	1.15%	1.23%	1.31%	1.40%	1.48%
54	0.81%	0.88%	0.95%	1.03%	1.10%	1.18%	1.26%	1.34%
56	0.72%	0.79%	0.85%	0.92%	0.99%	1.06%	1.13%	1.21%
58	0.64%	0.70%	0.76%	0.82%	0.89%	0.95%	1.02%	1.09%
60	0.57%	0.62%	0.68%	0.74%	0.80%	0.86%	0.92%	0.99%
62	0.50%	0.55%	0.60%	0.66%	0.71%	0.77%	0.83%	0.89%
64	0.45%	0.49%	0.54%	0.59%	0.64%	0.69%	0.75%	0.80%
66	0.40%	0.44%	0.48%	0.53%	0.57%	0.62%	0.67%	0.73%
68	0.35%	0.39%	0.43%	0.47%	0.51%	0.56%	0.61%	0.66%
70	0.31%	0.35%	0.38%	0.42%	0.46%	0.50%	0.55%	0.59%
72	0.28%	0.31%	0.34%	0.38%	0.41%	0.45%	0.49%	0.54%
74	0.24%	0.27%	0.30%	0.34%	0.37%	0.41%	0.44%	0.48%
76	0.22%	0.24%	0.27%	0.30%	0.33%	0.37%	0.40%	0.44%
78	0.19%	0.22%	0.24%	0.27%	0.30%	0.33%	0.36%	0.39%
80	0.17%	0.19%	0.22%	0.24%	0.27%	0.30%	0.32%	0.36%

7.4 USEFUL FORMULAS

- a. Fahrenheit to Celsius

$$C = (5/9) \times (F - 32)$$

Example: $F = 100$

$$C = 0.56 \times 68 = 38$$

- b. Celsius to Fahrenheit

$$F = (C \times 9/5) + 32$$

Example: $C = 100$

$$F = 100 \times 1.8 + 32 = 212$$

- c. Celsius to Kelvin

$$K = C + 273$$

Example: $C = 100$

$$100 + 273 = 373$$

NOTES

Reach us at www.group-upc.com

United Process Controls brings together leading brands to the heat treating industry including Waukee Engineering, Furnace Control, Marathon Monitors and Process-Electronic.

We provide prime control solutions through our worldwide sales and services network with easy-to-access local support.

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