EAGLE

COMBUSTION ANALYZERS™

Owners Manual

You'll love this STUFF

OWNERS MANUAL & MAINTENANCE

SAFETY NOTES

Before using this meter, read all safety information carefully. In this manual the word “WARNING” is used to indicate conditions or actions that may pose physical hazards to the user. The word “CAUTION” is used to indicate conditions or actions that may damage this instrument.

WARNING!
This analyzer extracts combustion gases that may be toxic in relatively low concentrations. These gases are exhausted from the back of the instrument. This instrument must only be used in well-ventilated locations. It must only be used by trained and competent persons after due consideration of all the potential hazards.

PREFLIGHT CHECKLIST

- Clean particle filter
- Water trap and probe line are empty of water
- Power on and zero
- All hose and thermocouple connections are properly secured
- Flue gas probe is sampling ambient FRESH air
- Water trap is fitted correctly to the instrument
- Flue temperature plug is connected
- Inlet temperature probe is connected if required

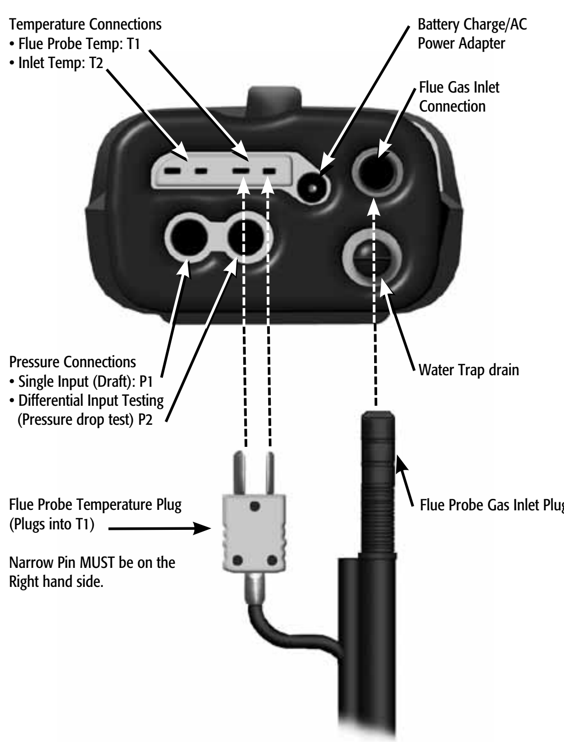
- Setting Inlet Temperature
  - Turn on and zero the analyzer with out the flue probe connected to use ambient temperature
  - Connect flue probe thermocouple to T1 during zero countdown to store probe tip temperature as inlet (ducted system)

ANALYZER CONNECTIONS

NOTE: Take care when inserting the temperature probes as the pins are polarized. Insert with the smaller pin (+) to the right. See diagram to right.

WARNING!
Turning the pump off while the probe is in the flue will leave toxic gases inside the analyzer. Once data has been printed or copied it is advisable to purge the unit with fresh air as soon as possible. To do this, with the probe removed from the flue, turn ON the pump. Always allow the readings to return to zero (20.9 for O2) prior to shutting the unit off. The meter will not switch off until the CO reading is below 20 ppm.

WARNING!
The probe will be hot from flue gases. Remove the probe from the flue and allow it to cool naturally. Do not immerse the probe in water, as this will be drawn into the analyzer and damage the pump and sensors. Once the probe is removed from the flue and the readings have returned to ambient levels hold down “On/Off” and switch off the analyzer. The instrument will count down from 30 to switch off. If you pressed “On/Off“ by mistake, pressing “Send“ will return you to normal operation.



POST FLIGHT

- Remove the probe from the flue and allow the analyzer to purge with fresh air until readings return to zero.
  - O2 to 20.9%, CO to Zero ***(Be careful as the probe tip will be HOT)***
- Drain water trap
- Check particle filter

EAGLE COMBUSTION ANALYZER™ OVERVIEW

GENERAL MAINTENANCE

- Calibrate your instrument annually to ensure it meets original performance specifications
- Keep your instrument dry. If it gets wet, wipe dry immediately. Liquids can degrade electronic circuits
- Whenever practical, keep the instrument away from dust and dirt that can cause premature wear
- Although your instrument is built to withstand the rigors of daily use, it can be damaged by severe impacts. Use reasonable caution when using and storing the meter

PERIODIC SERVICE

WARNING!
Repair and service of this instrument is to be performed by qualified personnel only. Improper repair or service could result in physical degradation of the instrument. This could alter the protection from personal injury this meter provides to the operator. Perform only those maintenance tasks that you are qualified to do.

ANNUAL RE-CALIBRATION

While the sensor has an expected life of more than two years in normal use it is recommended that the analyzer is re-calibrated at least annually, This is so that long-term drift on the sensor and electronics can be eliminated. Local regulations may require more frequent re-calibration and users should check with appropriate authorities to ensure the comply with relevant guidelines.

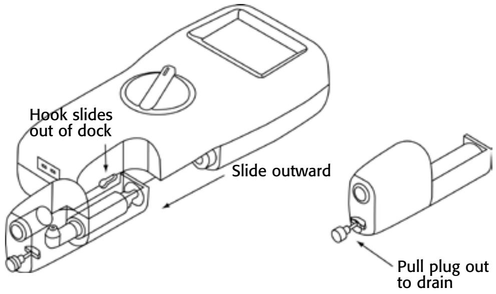
CLEANING

Periodically clean your instruments case using a damp cloth. DO NOT use abrasive, flammable liquids, cleaning solvents, or strong detergents as they may damage the finish, impair safety, or affect the reliability of the structural components.

EMPTYING & CLEANING THE IN-LINE WATER TRAP

The in-line water trap should be checked and emptied on a regular basis. Water vapor will condense in the probe line, which may cause the water trap to fill suddenly if the probe is moved. Care should be taken at all times.

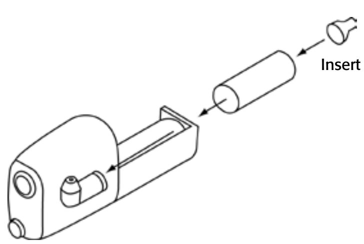
Carefully remove the rubber plug from the bottom of the water-trap housing. Dispose of the condensate in a suitable drain, care must be taken as it could be acidic. If condensate spills onto the skin or clothing, clean off immediately using fresh water, seek medical advice if problems occur. Ensure plug is replaced before performing combustion tests. Note: O2 reading will be high if the Water Trap Plug is not in place.



CHANGING THE PARTICLE FILTER

This is a very important part of the analyzer and should be changed regularly. It prevents dust and dirt particles from entering the pump and sensors that will cause damage. The filter MUST be changed when it appears discolored on the inner surface.

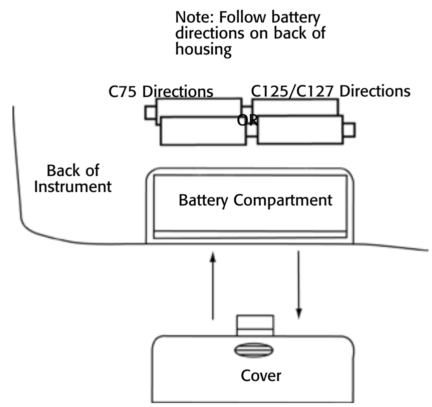
Remove water-trap assembly from the analyzer as shown above. Remove the filter and plastic holder from the housing. Discard the filter element but keep the holder to fit to the new filter. Clean the inside of the filter housing with a suitable soft cloth. Fit the holder onto the new filter element and then insert into the housing. Refit the housing onto the analyzer.



BATTERIES REPLACEMENT

This meter has been designed for use with both alkaline and rechargeable Nickel Metal Hydride (NiMH) batteries. No other types are recommended. The analyzer is supplied with 4 “AA” size alkaline batteries.

These should be installed into the instrument as shown in the diagram to the right and indicated on the back of the unit.



CAUTION!
Take great care when installing the batteries to observe correct polarity. Always check the meter for operation immediately after installing new batteries.

USING RE-CHARGEABLE BATTERIES

The battery charger must only be used when NiMH batteries are fitted. Alkaline batteries ***are not*** re-chargeable. Attempting to recharge alkaline batteries may result in damage to the product and may create a fire risk.

BATTERY CHARGING

Ensure that you use the correct charger. This unit uses a 9V DC regulated charger.

Ensure that the batteries are fitted in the correct manner, and then charge for at least 16 hours. Subsequent charges should be overnight. NiMH batteries may be charged at any time, even for short periods to conduct testing.

WARNING!
Under NO circumstance should you expose batteries to extreme heat or fire as they may explode and cause injury. Always dispose of old batteries promptly in a manner consistent with local disposal regulations.

ELECTROMAGNETIC COMPATIBILITY (EMC)

This product has been tested for compliance with the following generic standards:
EN 50081-1, EN 50082-1 and is certified to be compliant.

The European Council Directive 89/336/EEC requires that electronic equipment does not generate electromagnetic disturbances that exceed defined levels and has an adequate level of immunity to enable it to be operated as intended.

Since there are many electrical products in use that pre-date this Directive and may emit electromagnetic radiation in excess of the standards defined in the Directive there may be occasions where it would be appropriate to check the analyzer prior to use. The following procedure should be adopted.

- Go through the normal start up sequence in the location where the equipment is to be used
- Switch on all localized electrical equipment that might be capable of causing interference
- Check that all readings are as expected (a level of disturbance in the readings is acceptable)
- If not, adjust the position of the instrument to minimize interference or switch off, if possible, the offending equipment for the duration of the test

At the time of writing this manual (July 2006) UEi is not aware of any field based situation where such interference has ever occurred and this advice is only given to satisfy the requirements of the Directive.

WHY TEST WITH EAGLE COMBUSTION ANALYZERS™

VERIFY PROPER OPERATION OF COMBUSTION EQUIPMENT

- To verify that equipment is operating as the manufacture designed it to work. This includes installation tests for CO, CO2, O2, Excess Air and stack temperatures
  - A properly tuned combustion appliance will perform better, and reduce the likelihood of call-backs for no-heat
- To verify that the maintenance work performed has corrected the problem
  - A print-out documents the before-after improvement in performance
- To detect any defects early – possibly at installation
  - Higher efficiency equipment is running at peak only when properly adjusted. As the complexity of a system increases, so does the importance of proper adjustment of the combustion process.
- Improperly adjusted equipment not only fails to meet expected performance but could lead to future failures
  - High CO readings throughout the burner operation could be from a burner that isn't aligned or a flame impingement problem
- To check that the equipment is supplied with enough combustion air, make-up air and has proper venting to exhaust the combustion by-products
- To determine if emissions are within acceptable levels. Governing organizations such as the AGA have various requirements such as a 400 ppm CO Air Free reading on gas range oven vents
- To check heat exchangers for cracks.
  - A breach in the heat exchange may result in CO, O2 and Excess Air values that change after the blower turns on. This is due to an introduction of additional fresh air into the stack gases from the positive pressure pushing fresh air into the flue. The Eagle II and III have a test procedure programmed into the instrument that allow you to capture these values and printout a comparison of the before and after levels. A change in these values warrants a further look into the problem
- To monitor the operation during start-up and shutdown.
  - Many problems with burners may show an increase in CO at these points earlier than when the equipment is at operating temperature. A slight rise in CO during these times may be typical, but anything over 400 would indicate a problem.
- To establish a base-line of desired performance
  - By tracking the performance over time you are able to see changes before they lead to equipment failure.

VERIFY SAFE OPERATION OF COMBUSTION EQUIPMENT

- Equipment that is not properly adjusted, or that has insufficient draft to vent combustion gases could produce carbon monoxide in deadly quantities. The UEi Eagle Series test both flue gas and ambient levels of carbon monoxide. A specific test is programmed into the Eagle II and Eagle III to measure CO levels over a 30-minute period, and provides a printout to document your test results.
- When customers complain about fumes it is usually an indication of improper operation. CO is a colorless, odorless gas so the fumes are not the CO, but an indication that a problem may exist.

IMPROVE YOUR PRODUCTIVITY & PROFIT

- The UEi Eagle combustion analyzers give a quick, continuous readout of the combustion process. Readings change in real-time as adjustments are made to help zero in on the proper setting. Compare this to spot tests or other methods, and you will see your productivity rise.
- Proper testing with documented results will help you provide the proper service or equipment replacement recommendations, and have the data to support this. Sales will increase because you are no longer guessing, and the work provided is proper for the needs of the customer.
- Customers on a service contract will be provided excellent service, and you will quickly diagnose failures and help keep the equipment up for the season.

IMPROVE CUSTOMER PERCEPTION OF YOUR SERVICES

- Provide your customers documented results of the performance of their equipment
- Reduce your customers energy expense by properly adjusting and maintaining their equipment
- Increase your confidence in the work performed and remember

IF YOU DON'T TEST, YOU DON'T KNOW

WHAT RESULTS ARE GENERALLY ACCEPTABLE

ATMOSPHERIC GAS FIRED BURNERS

- ***Oxygen*** .... 7 to 9% O_2
- ***Stack Temperature*** .... 325 to 500°F
- ***Draft*** (Water Column Inches).................................... -.02 to -.04wc”
- ***Carbon Monoxide*** (parts per million) .... <100ppm

GAS FIRED POWER BURNERS

- ***Oxygen*** .... 3 to 6% O_2
- ***Stack Temperature*** .... 275 to 500°F
- ***Stack Draft*** (Water Column Inches) .... -.02 to -.04wc”
- ***Overfire Draft*** (Water Column Inches) .... -.02wc”
- ***Carbon Monoxide*** (parts per million) .... <100ppm

OIL FIRED BURNERS (#2 OIL FUEL)

- ***Oxygen*** .... 4 to 7% O_2
- ***Stack Temperature*** .... 325 to 600°F
- ***Stack Draft*** (Water Column Inches) .... -.04 to -.06wc”
- ***Overfire Draft*** (Water Column Inches) .... -.02wc”
- ***Carbon Monoxide*** (parts per million) .... <100ppm
- ***Smoke*** .... 0 (or manufacturer’s recommendation)

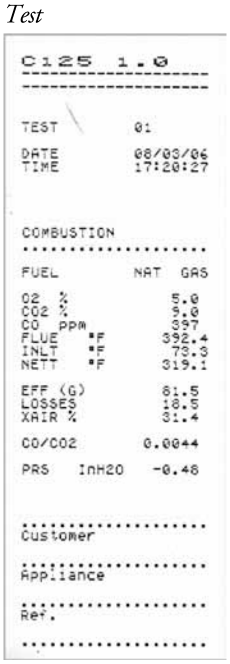
POSITIVE OVERFIRE GAS & OIL

- ***Oxygen*** .... 3 to 9% O_2
- ***Stack Draft*** (Water Column Inches) .... -.02 to -.04wc”
- ***Overfire Draft*** (Water Column Inches) .... +0.4 to +0.6wc”
- ***Carbon Monoxide*** (parts per million) .... <100ppm

NOTE: Follow manufacture guidelines for the specific equipment being serviced.

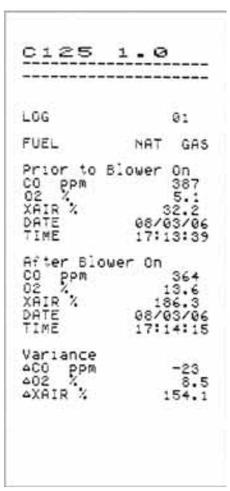
SAMPLE PRINT OUTS / REPORTS

Combustion Test



```
C125 1.0
--------------------
--------------------

TEST          01

DATE          08/03/06
TIME          17:20:27


COMBUSTION
....................

FUEL          NAT  GAS

O2  %             5.0
CO2 %             9.0
CO  ppm           397
FLUE   °F       392.4
INLT   °F        73.3
NETT   °F       319.1

EFF (G)          81.5
LOSSES           18.5
XAIR %           31.4

CO/CO2         0.0044

PRS   InH20     -0.48


....................
Customer
....................
Appliance
....................
Ref.
....................
```

Heat Exchanger Test



```
C125 1.0
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LOG               01

FUEL        NAT  GAS

Prior to Blower On
CO  ppm          387
O2  %            5.1
XAIR %          32.2
DATE        08/03/06
TIME        17:13:39

After Blower On
CO  ppm          364
O2  %           13.6
XAIR %         186.3
DATE        08/03/06
TIME        17:14:15

Variance
ΔCO  ppm         -23
ΔO2  %           8.5
ΔXAIR %        154.1
```
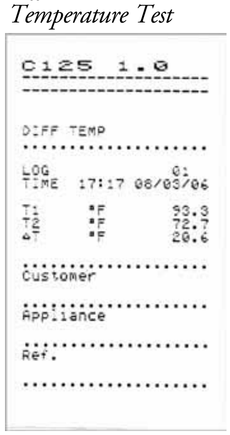

Differential Temperature Test



```
C125 1.0
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DIFF TEMP
....................

LOG               01
TIME  17:17 08/03/06

T1     °F       93.3
T2     °F       72.7
ΔT     °F       20.6

....................
Customer
....................
Appliance
....................
Ref.
....................
```
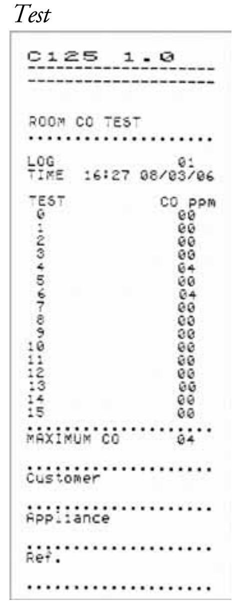

Manometer Draft/ Pressure Test

```
C125 1.0
--------------------
--------------------

PRESSURE
....................

LOG               01
TIME  17:19 08/03/06

PRS   InH20    -0.43

....................
Customer
....................
Appliance
....................
Ref.
....................
```

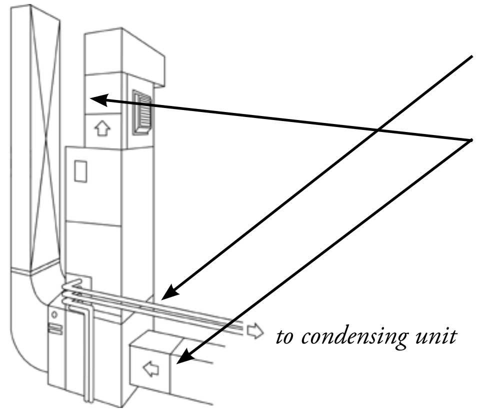
Room CO Test



```
C125 1.0
--------------------
--------------------

ROOM CO TEST
....................

LOG               01
TIME  16:27 08/03/06

TEST          CO ppm
 0                00
 1                00
 2                00
 3                00
 4                04
 5                00
 6                04
 7                00
 8                00
 9                00
10                00
11                00
12                00
13                00
14                00
15                00
....................
MAXIMUM CO        04

....................
Customer
....................
Appliance
....................
Ref.
....................
```

Where To Test

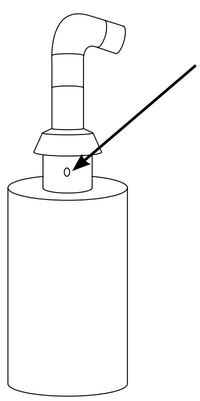
Air Conditioning / Heat Pump



Suction Line:
- *Temperature*

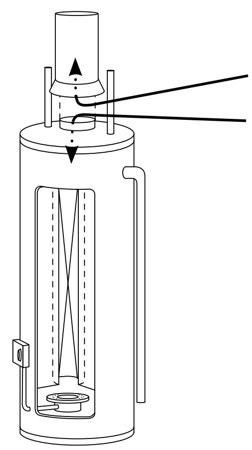
Verify proper:
- *Static Duct Pressures*
- *Temperature Differential*
- *Static Pressure Drop Across Coils*

Boiler & Water Heaters



Boiler

Verify proper combustion:
- *O2*
- *CO Air Free*
- *Stack Temp*
- *Stack Draft*
- *SSE*

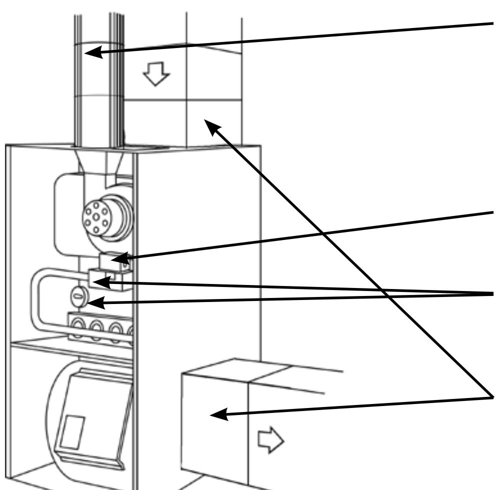


Water Heater

Draft

Verify proper combustion:
- *O2*
- *CO*
- *Stack Temp*
- *Efficiency*

Furnaces: 80%



80% Furnace

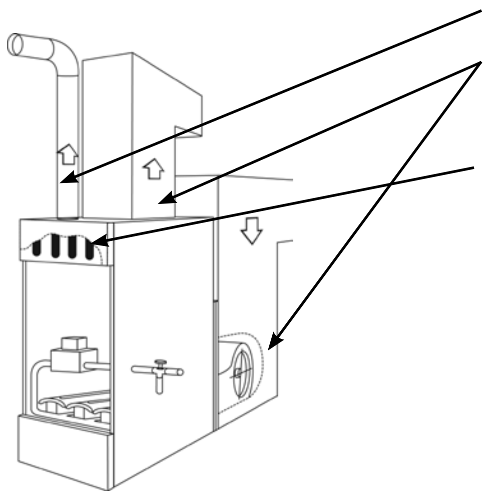
Verify proper combustion:
- *O2*
- *CO*
- *Stack Temp*
- *Vent Pressure*
- *Efficiency*

Set Up
- *Gas Pressure*

Test
- *Limit Switch*
- *Pressure Switch*

Verify proper combustion:
- *Static Duct Pressure*
- *Temperature Rise*
- *AC side Static Pressure Drop across coils*

Furnaces (continued): Atmospheric, Gas & Oil

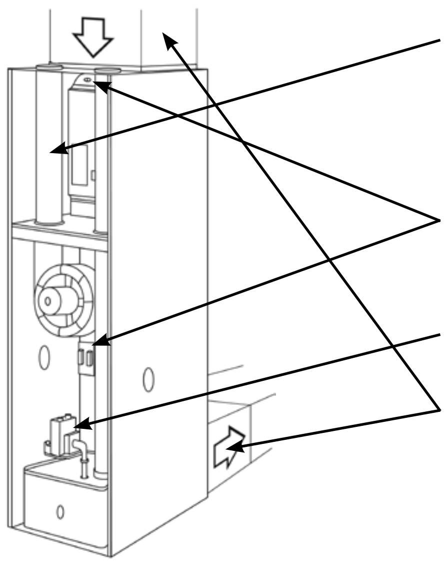


Atmospheric Furnace

Draft

Verify proper
- *Temperature Rise*
- *AC side Static Pressure Drop across coils*

Verify proper combustion:
- *O2*
- *CO*
- *Stack Temp*
- *Efficiency*



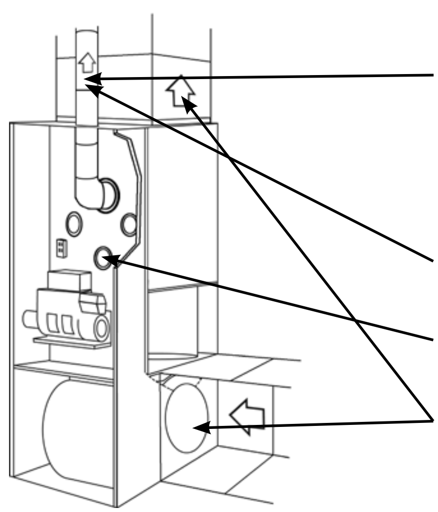
Gas Furnace

Verify proper combustion:
- *O2*
- *CO*
- *Stack Temp*
- *Vent Pressure*
- *Efficiency*

Test
- *Limit Switch*
- *Pressure Switch*

Set Up
- *Gas Pressure*

Verify proper:
- *Static Duct Pressure*
- *Temperature Rise*
- *AC side Static Pressure Drop across coils*



Oil Furnace

Verify proper combustion:
- *O2*
- *CO*
- *Stack Temp*
- *Stack Draft*
- *Efficiency*

Test:
- *Smoke*

Set Up
- *Over Fire Draft*

Verify proper
- *Static Duct Pressure*
- *Temperature Rise*
- *AC side Static Pressure Drop across coils*

IMPORTANT CO INFORMATION

CO NUMBERS TO REMEMBER

Although there are several sources causing CO over-exposure conditions, there are a few common problems related to combustion, such as inadequate ventilation, tight buildings, and fuels releasing CO.

PPM CO	Time	Symptoms
9 PPM -	24 hour	National ambient air quality limit for CO (EPA's outdoor) (ASHRAE indoor) CO "Action" level for many public safety organizations.
35 PPM	8 hours	Maximum 8 hr workplace exposure (OSHA)
200 PPM	3 hours	Mild headache, fatigue, nausea and dizziness.
400 PPM	2 hours	Serious headache, dizziness, and nausea. Life threatening after 3 hours.
800 PPM	45 min	Dizziness, nausea, convulsions, and unconsciousness. Death within 2-3 hrs.
3200 PPM	5-10 min	Dizziness, nausea, convulsions, and unconsciousness. Death within 25-30 min.
6400 PPM	1-2 min	Death within 10-15 minutes.
12,800 PPM	30 sec	Death within 1-3 minutes.

The above information has been compiled from a number of sources listed below, and is intended as non-technical reference related to Carbon Monoxide poisoning within a work environment as it relates to the Combustion Analyzers and/or CO detectors being used. Such equipment being operated in these conditions are intended to be used by qualified professionals or under the supervision of one. UEi strongly urges all technicians to follow state and local guidelines and safety regulations. The above information is provided in good faith and is believed to be correct as of the date compiled. It is expected that individuals receiving the information will exercise their independent judgment in determining its appropriateness for a particular purpose. Accordingly, UEi will not be responsible for damages of any kind resulting from the use of this information or updates of data post printing.

American Conference of Governmental Industrial Hygienist ***(ACGIH)***
Occupational Safety & Health Administration ***(OSHA)***
National Institute for Occupational Safety and Health ***(NIOSH)***
American Society of Heating, Refrigeration & Air-Conditioning Engineers ***(ASHRAE)***
American Industrial Hygiene Association ***(AIHA)***

HOW DOES CO AFFECT US

When victims inhale CO, the toxic gas enters the bloodstream and replaces the oxygen molecules found on the critical blood component, hemoglobin, depriving the heart and brain of the oxygen necessary to function.

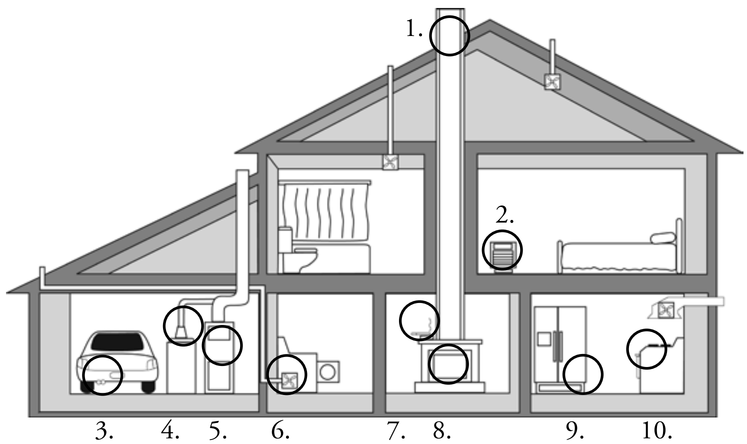
Carbon Monoxide Poisoning Symptoms

- Mild exposure:
  - Often described as flu-like symptoms, including slight headache, nausea, vomiting, fatigue.
- Medium exposure:
  - Severe throbbing headache, drowsiness, confusion, fast heart rate.
- Extreme exposure:
  - Unconsciousness, convulsions, cardiorespiratory failure, death.

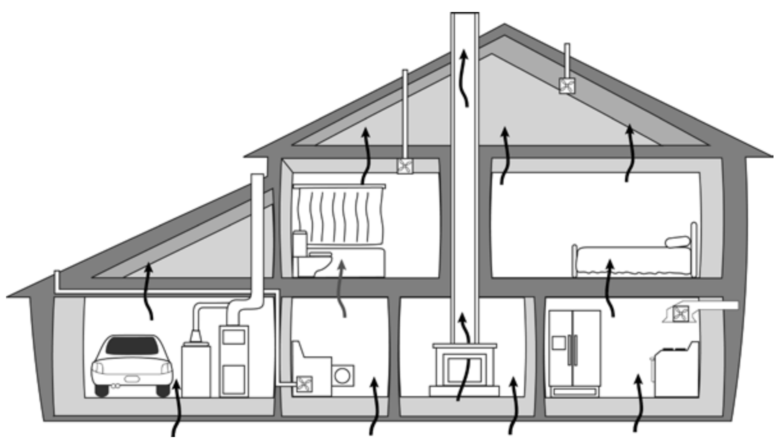
CO poisoning victims may initially suffer flu-like symptoms including nausea, fatigue, headaches, dizziness, confusion and breathing difficulty. Because CO poisoning often causes a victim's blood pressure to rise, the victim's skin may become pink and flushed. Many cases of reported carbon monoxide poisoning indicate that while victims are aware they are not well, they become so disoriented, that they are unable to save themselves by either exiting the building or calling for assistance.

RESIDENTIAL SOURCES OF CO

1. Chimney
2. Space Heaters
3. Vehicle exhaust
4. Water Heater
5. Furnace
6. Improperly vented appliances
7. Tobacco products
8. Fireplace (Gas or wood burning)
9. & 10. Gas appliances

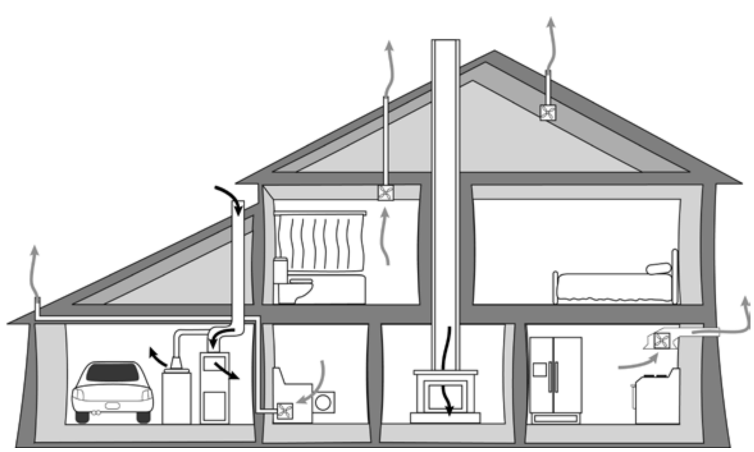


STACK EFFECT & NEGATIVE PRESSURE



Stack Effect

When air escapes through openings in the upper part of a building and is replaced with outside air entering through vents or cracks lower down. As air warms it expands and becomes less dense than the surrounding air, it rises and escapes through small gaps at the top of the house. This also draws fresh cold air through similar gaps or vents at the bottom of the house. The vacuum created by escaping warm air is called the stack effect. When carefully controlled, stack effect can produce a low and effective level of natural ventilation.



Negative Pressure

A tightly sealed house will indicate a reduction of draft when venting equipment (clothes dryer, kitchen hood, bathroom vent) is turned on during a draft test. If the air pressure outside is greater than the pressure within the house, a vacuum, or negative pressure is created. This difference in air pressure will pull air through any available openings in building walls, ceilings, floors, doors, windows, and air circulation systems. If this vacuum is strong enough it can reverse exhaust ventilation systems pulling harmful gases in to the house.

COMBUSTION BASICS

INTRODUCTION

UEi combustion analyzers provide real time data that provides information on the condition of the combustion process of your equipment. This information is needed for proper setup and maintenance to verify proper operation. Benefits of combustion analysis are to increase efficiency thus reducing fuel costs, verification of proper combustion to reduce future problems, and to check for safe operation. A combustion process out of balance can increase maintenance needs, create excess emissions, lead to safety concerns or waste fuel and money. By checking for proper operation you are able to confirm a job well done.

- This overview will explain some of the common terms used in combustion testing
  - The combustion process – (a small amount of chemistry)
  - Ideal combustion – you may have heard the term Stoichiometric (or not)
  - Relationship between CO2, CO and O2
- The analyzer and display
  - Various text and icons used on the front housing, in the display and on the printout
  - What will the readings do when adjustments are made
  - Where are you on the combustion curves from these readings

THE COMBUSTION PROCESS

What is really going on during combustion? Most of us know it as a fire that is generating heat and possibly smoke. We know that paper or wood can burn when lit, and continue to burn – but what is really happening?

Combustion is a continuous chemical reaction that occurs when a certain temperature is reached, and there is the presence of both fuel and an oxidizer. The most common fuels are hydrogen and carbon, and the typical oxidizer is O2 present in the air we breathe. Once the reaction is started it will continue as long as it is being fed fuel and oxygen, and the temperature is sufficient.

IDEAL COMBUSTION PROCESS

If a perfect condition could exist for combustion it would be the burning of pure hydrogen (H2) in pure oxygen (O2). This would give us heat and water, and be the easiest to maintain. Two hydrogen (H2), combine with one O2 molecule gives us two water molecules plus heat. The reaction would be something like figure 1. It is great in theory that we would have a very efficient system with only some heat losses from the water vapor, but it isn't very practical. Pure hydrogen and oxygen are expensive to create, and difficult to handle compared to other fuels already available.

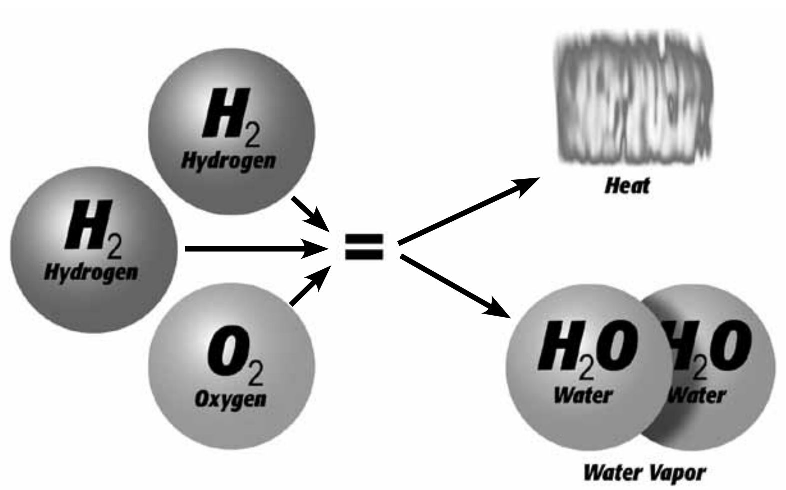


figure 1

NEAR IDEAL COMBUSTION

When we burn pure hydrogen in the air. Our atmosphere is 20.9% oxygen with the remaining 79.1% nitrogen.

This is nearly as desirable as the example for ideal combustion with the only added loss being the heat that is carried away from your target with the nitrogen. Because nitrogen isn't part of the combustion process, it enters the combustion chamber at the inlet temperature and leaves with some of the heat created by the combustion. If this isn't recovered at the heat exchanger it is lost up the flue.

The main problem with this example is again the availability and cost of pure hydrogen.

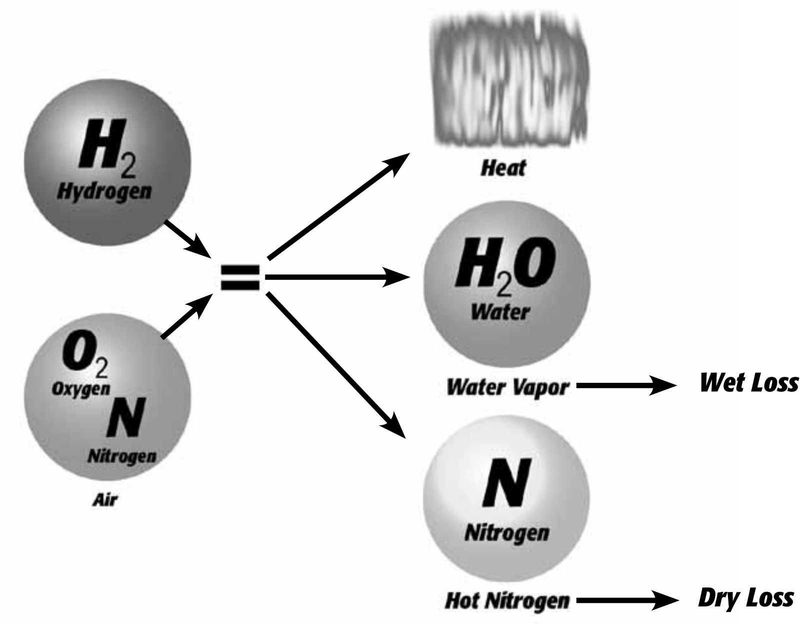


figure 2

BEST OF THE REAL WORLD

Natural gas is a readily available fuel, and our atmosphere contains sufficient oxygen. When this is used as a fuel we get the reaction; shown in figure 3. Now the other added byproducts are CO2 and hot nitrogen compared to the Ideal World situation. In addition to this we have added the byproduct Excess Air.

Excess Air is exactly what the name implies, air that is in excess of what is needed to burn all of the fuel. The reason for this is more related to the ability to mix all of the fuel and O2 for complete combustion. Without some amount of excess air not all of the fuel would burn completely, and this leads to the formation of CO instead of CO2.

Other fuels all contain the basic ingredients for combustion, but also may include other components such as sulfur, fuel bound nitrogen, soot and ash and water. These either react with the oxygen to form other pollutants or contribute to additional losses.

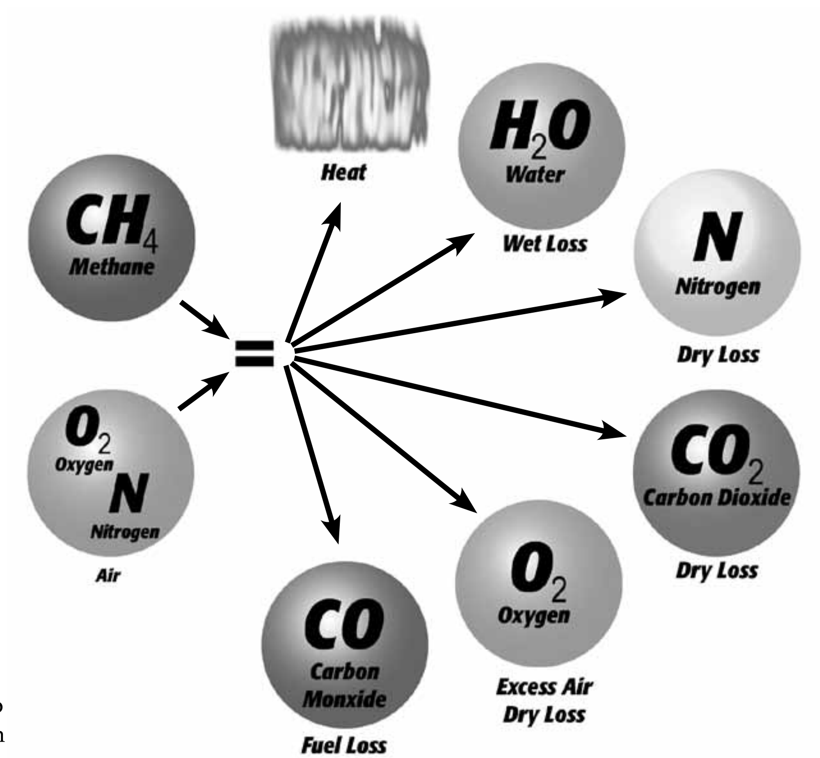


figure 3

***Carbon Monoxide** is formed from incomplete combustion (partial oxidation of carbon in the fuel). Typical causes are incomplete mixing of fuel and air, low combustion temperatures, or not enough excess air.*

Perfect Combustion

The term perfect combustion is also called stoichiometric combustion. This is the point where all of the fuel is burned with all the oxygen, leaving no undesirable byproducts. At this point all of the hydrogen in the fuel ($H2$) would combine with oxygen to form $H2O$, all of the carbon (C) would combine to form $CO2$, and all of the sulfur (S) would form $SO2$. There would be no additional air to carry heat away from the fire, and no undesirable byproducts would be created. In practice this isn't possible due to the inability to completely mix the fuel and air, so an additional amount of air is used to completely burn the fuel.

The chart in figure 4 illustrates the relationship between the main flue gas components that provide and indication of the performance of the combustion process.

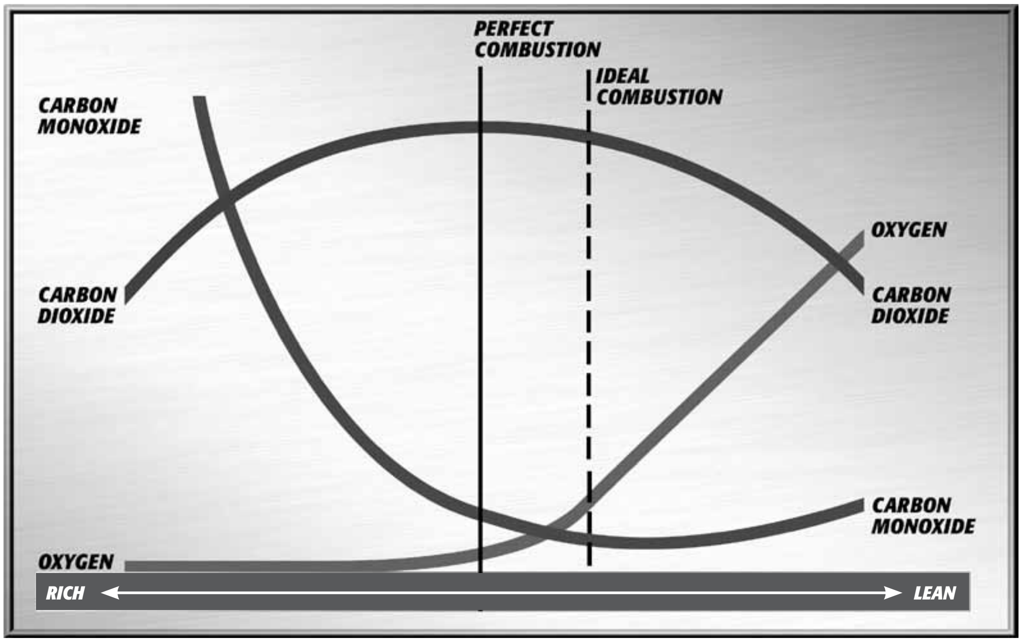


figure 4

As you move left to right you are going from a rich to lean condition. The term Air rich is equivalent to fuel lean, and simply indicates a situation where the excess air is much higher.

To adjust the combustion process you are given the best overall picture of the condition my measuring all three parameters. Each of the parameters performs differently as you move through the adjustment of a combustion process

1. $CO2$ – This is the gas that was most commonly used for adjusting combustion equipment. A tool called an Orstat, or wet chemical kit would give you a snapshot of the $CO2$ value. As you can see by the graph, $CO2$ is maximized when the process is running at perfect combustion. Because this isn't possible, the goal has always been to maximize $CO2$. The trouble is that this can occur at two places in the graph, once on the fuel rich side, and once on the fuel lean side. In the past a smoke test was used to first place you on the right side of the graph, and then $CO2$ was maximized to reach the highest value possible.

2. $O2$ is the next gas that is measured. At perfect combustion all of the $O2$ in the atmosphere is consume so very little remains in the flue gases. If you adjust with this gas you are more certain to be on the correct side of perfect combustion, but you may still be creating carbon monoxide (CO) due to insufficient levels of $O2$ to completely burn the carbon in the fuel. This may lead to sooty buildup, reducing efficiency, but you are also not extracting all of the energy the fuel has to offer.

3. Carbon Monoxide (CO) is the last gas listed. As you can see on the left side of the chart CO production is the highest. At ideal combustion this level is the lowest possible, but if the other gases are not available you may be adding too much excess air leading to losses in efficiency. Also if the amount of air being fed to the combustion process is increased too high it may start cooling the combustion chamber down and begin creating CO. Once you are at this point without measuring $O2$ or $CO2$, you may instinctively add more $O2$ to reduce the CO level and end up creating more.

OTHER IMPORTANT FACTORS RELATING TO COMBUSTION

- The three T's of combustion
  – Time
- Amount of time that the fuel and oxygen are together in the combustion chamber
  – Temperature
- How high the temperature is determines the rate of oxidation, or speed of the combustion
  – Turbulence
- How well the fuel and air are mixed

- These three factors are all interrelated, and will move your results along the combustion curves.

COMBUSTION MEASUREMENT TERMS

Other parameters measured include net temperature, draft and efficiency.

Net Temperature

Net temperature is the difference between the combustion air entering the combustion chamber and the flue gas temperature past the heat exchange. This is used to determine how efficient the system is extracting heat from the combustion process in addition to the performance of the combustion process. On sealed systems that have ducted inlet air for combustion air, the net temperature must compare this air stream temperature with the flue gases. If the appliance simply uses room air for the combustion air, our analyzers have an internal temperature sensor in the handset, so it will use this temperature when calculating net temperature.

The most accurate results for efficiency are obtained when measuring flue gases at the point where flue temperature (not flame temperature) is the highest.

Draft

Draft is the difference between the ambient pressure level and the pressure level in the flue. This is created either by the natural buoyancy of the hot gases created in combustion lifting, or by an inducer fan that assists the flow of flue gases up the stack. Most combustion equipment will specify the amount of draft that is required for proper operation.

Draft helps draw combustion air into the combustion chamber, and also helps in mixing the fuel and oxygen. Without proper draft, the combustion process can spill poisonous byproducts into the space where the appliance is located. This can be a risk to those in the area, or create a danger to residents or employees working near the combustion equipment.

Efficiency

Efficiency is a measure of how well the fuel is burned to create heat, and how well the generated heat is captured for the intended use.

The information used to create this value are based on the fuels heating value, the heat lost up the flue and the gas components in the flue gas. The original method to determine efficiency included many manual methods and look-up charts. As an example you would measure the CO2 level and the stack temperature and then reference a slide scale that would give you the relative efficiency number. UEi's electronic combustion analyzers perform the measurements on a continuous basis, and can calculate the efficiency as adjustments are being made. Combine this with a printout and you are able to provide a before and after comparison of the combustion equipment in relatively little time as part of normal servicing.

COMBUSTION EFFICIENCY CALCULATIONS

This identifies three sources of loss associated with fuel burning:

- Losses due to flue gasses:
  - Dry Flue gas loss, Moisture and hydrogen,
  - Sensible heat of water vapor, Unburned gas
- Losses due to refuse:
  - Combustible in ash, riddling and dust
- Other losses:
  - Radiation, convection, conduction other unmeasured losses

Net efficiency calculations assume that the energy contained in the water vapor (formed as a product of combustion and from wet fuel) is recovered and the wet loss term is zero. Gross efficiency calculations assume that the energy contained in the water vapor is not recovered. Since the fuel air mixture is never consistent there is the possibility of unburned/partially unburned fuel passing through the flue. This is represented by the unburned carbon loss. Losses due to combustible matter in ashes, riddling, dust and grit, radiation, convection and conduction are not included.

Efficiency Calculation:

- Known Data Fuel:
  - Qgr = Gross Calorific Value (kJ/kg)
  - Qnet = Net Calorific Value (kJ/kg)
  - K1 = Constant based on Gross or Net Calorific • •
- Known Data Value:
  - K1g = (255 x %Carbon in fuel)/Qgr
  - K1n = (255 x %Carbon in fuel)/Qnet
  - K2 = % max theoretical CO2 (dry basis)
  - K3 = % Wet Loss
  - H2 = % Hydrogen
  - H2O = % Water
- Measured Data:
  - -Tf = Flue Temperature
  - -Ti = Inlet Temperature
  - -O2m = % Oxygen in flue gas
  - -O2r = Oxygen reference %
- Calculated data:
  - - Tnet = Net Temperature
  - - % CO2 content in flue gas
  - -% Dry Flue Gas losses
  - -% Wet losses
  - -% Unburned carbon loss
  - -% Efficiency
- Tnet = Flue Temperature - Inlet Temperature (or ambient)
- Dry flue gas loss %
  = 20.9 x K1 x (Tnet) / K2 x (20.9 - O2m)
- Wet loss %
  = 9 x H2 + H2O / Qgr x [2488 + 2.1Tf - 4.2 Ti]
- Simplified
  = [(9 x H2 + H2O) / Qgr] x 2425 x [1 + 0.001 Tnet]
- Wet loss %
  = K3(1+0.001xTnet)
- Where K3
  = [(9 x H2 + H2O) / Qgr] x 2425
- Net Efficiency %
  = 100 - dry flue gas losses
  = 100 - 20.9 x K1n x (Tnet) / K2 x (20.9 -O2m)
- Gross Efficiency %
  = 100 - {dry flue gas losses + wet losses}
  = 100 – {[20.9 x K1g x (Tnet) / K2 x (20.9 - O2m)]+ [K3 x (1 + 0.001 x Tnet)]}
- Excess Air
  = [20.9 / (20.9 - O2m) - 1] x 100
- CO2%
  = [(20.9 - O2m) x K2 / 20.9]
- Unburned
  = K4 x CO / (CO + CO2)
  Note: CO scaled in % fuel Loss %

- Where K4
  = 70 for coke
  = 65 for anthracite
  = 63 for Bituminous coal
  = 62 for coal tar fuel
  = 48 for liquid petroleum fuel
  = 32 for natural gas

The formula for K4 is based on the gross calorific value Qgr. To obtain the loss based on net calorific value multiply by Qgr/Qnet. Since this loss is usually small this conversion has been ignored. This loss is subtracted from the efficiency.

CO AIR FREE

Certain standards (ANSI Z21.1) for Carbon Monoxide are stated in terms of air-free. Air-free refers to the concentration of CO in combustion gases undiluted with flue, or other gases containing little CO. This value is computed using an equation that takes into account the O2 concentration of the flue gas.

- If 5% O2 is measured (O2m) in the flue then the CO gas value will be recalculated as if 0% were measured. The equation for air-free is as follows:
  - COaf = CO PPM x [(20.9) / (20.9 - O2m)]
- In our example if a reading of 325 PPM were measured then the air-free value would be calculated as follows:
  - COaf = 325 PPM x [(20.9) / (20.9 - 5)] COaf = 325 PPM x [(20.9) / (15.9)] COaf = 427

We may be given a limit on our gas range by the local authority, which stated that we must not emit more than 400-PPM Carbon Monoxide air-free. In the example we would be breaking the limit and corrective action should be taken to reduce the level of CO. Air-free values prevent false readings being submitted, e.g. allowing more air into the boiler will increase the oxygen level in the flue and dilute any toxic gas reading. Air-free referencing gives readings as if they were undiluted.

INFORMATION ON EXCESS AIR

- Excess Air
  - Theoretically perfect combustion would have the exact amount of O2 to combine with all of the fuel, resulting in no excess air.
    - If perfect combustion were possible, there would be 0% excess air
    - Because perfect combustion is not possible, you will always have some excess air
    - Too high excess air will reduce the time fuel and oxygen are together in the combustion chamber, and lower the temperature – two of the T's of combustion
    - Too little excess air, and all of the fuel will not be burnt
      - Carbon will form CO instead of CO2

- Typical Excess Air Level

	O2% (measured)	**Excess Air %**
Natural gas	3%	16.7%
Light Oil	5%	31%
Coal	8%	62%

Excess Air is also one method that can be used to determine heat exchanger integrity

- Before the blower starts the pressure is higher on the combustion side of exchange (see figure 5)
  – Small amounts of CO may leak into the living space side
  – Flue gas measurements will be stabilizing as the combustion chamber heats up.

- After the blower starts the pressure on the primary side will be higher (See figure 6)
  – Blower forcing air through the heat system
  – Fresh air may now enter the flue through the breach in the heat exchange
- Observe the flue gas levels and check the following;
  - Excess Air, 02 level and CO in ppm for drastic changes.

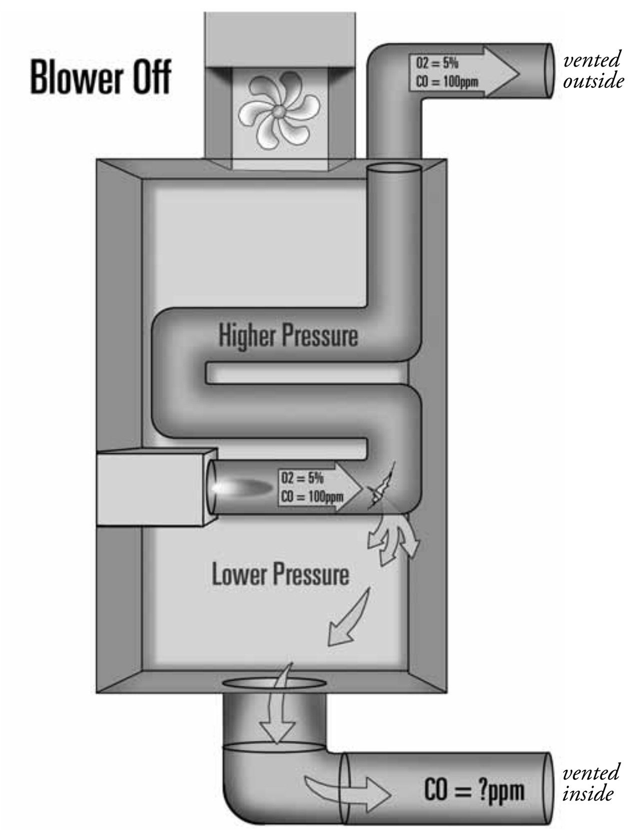


figure 5

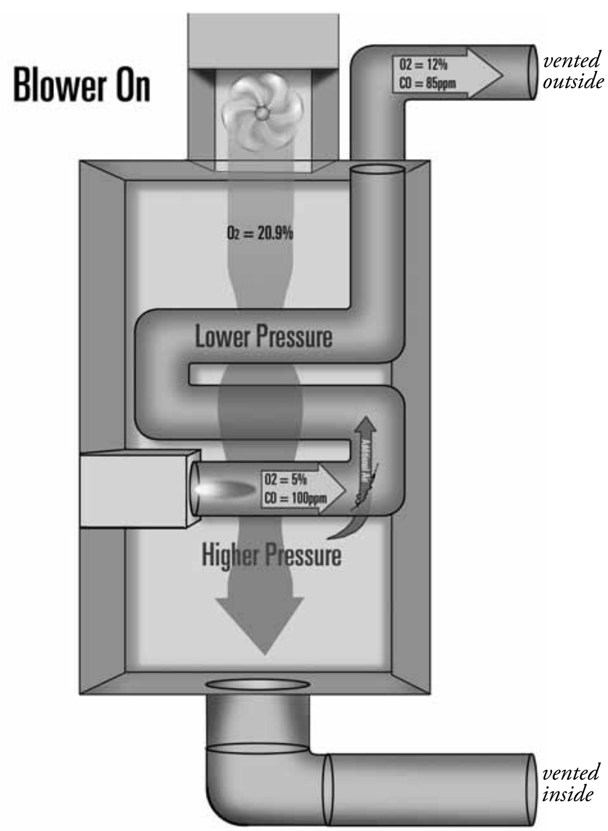


figure 6

GLOSSARY

DISPLAY PARAMETERS ON UEi COMBUSTION ANALYZERS

- ***TF*** (Flue Temperature) Used to calculate net temperature in Fahrenheit or Centigrade. Will show ambient temperature after fresh air calibration and '– OC –' if the flue probe is disconnected.
- **Δ*T*** (Net Temperature)Indicated by ΔT (Greek letter delta for difference)
  - Differential of flue temperature minus ambient (or inlet if set) temperature
  - Differential of T1 - T2 on C125 and C127
- ***O2*** (Oxygen) Direct reading of oxygen from the O_2 sensor reading in percentage (%)
- ***CO*** Carbon Monoxide reading displayed in ppm (parts per million). '- - - -' or '- OC -' is displayed if there is a fault with the CO sensor or the instrument has not set to zero correctly, switch off instrument and try again.
- ***CO2*** Calculated from the fuel selected and the measured O_2 level
  - Will display "----" or "-O>-" if the oxygen level is too high to calculate CO_2
  - Only displays a reading during combustion test. '- - - -' or '- O > -' is displayed while in fresh air.
- ***X-Air*** (Excess Air)
  - Indicated by _ (Greek small case lambda) or ' X ' on screen
  - Indicated by XAIR % on the printout
  - Excess air is a calculation of the percentage of oxygen above what is theoretically required for complete combustion
  - Is required to completely burn all of the fuel due to poor mixing and to assist in venting flue gases
  - Only displays a reading during combustion test. '- - - -' or '- O > -' is displayed while in fresh air.
- ***Eff*** (Efficiency)
  - Indicated by _ (Greek letter eta) followed by G for gross, N for net or C for condensing on the screen if the analyzer has these options
  - Indicated by Eff (G) on the printout if set to Gross (used in the States)
  - Eff (N) or Eff (C) for the other scales (based on standards for that location)
  - Is calculated based on gas readings, net temperature and fuel selected.
  - This value is combustion efficiency, not appliance efficiency
- ***Loss*** (Δ in the display)
  - Total losses calculated from Combustion Theory. This is the summation of the next three param-
eters
    - Dry %: Calculated heat lost turning the Carbon in the fuel to Carbon Dioxide (CO_2)
    - Wet %: Calculated heat lost turning the Hydrogen in the fuel into water (H20)
    - CO Loss %: Calculated loss due to partially burnt Carbon. Any Carbon Monoxide (CO)in the flue has the potential to be turned into Carbon Dioxide and release more heat, thus this heat is lost up the flue
- ***CO AF*** (Carbon Monoxide Air-Free) Reading referenced to an oxygen level of 0%. Do not confuse this reading with the actual CO reading as detailed above. See the Combustion Efficiency Calculation sections for more details.
- ***AMB*** Air INLET temperature used to calculate the NET temperature.
- ***CO/CO2*** (CO/CO_2 Ratio) The ratio of measured CO divided by calculated CO_2.
  - It gives an indication of:
    - How good a gas sample the instrument is reading.
    - How clean the boiler is running.
  - For example: A new or clean domestic boiler will display a ratio of less than 0.004, a unit in need of cleaning 0.004-0.008 and a unit in need of major overhaul will show greater than 0.008.
  - Only displays a reading during combustion test. '- - - -' is displayed while in fresh air.

EAGLE SPECIFICATIONS

Features	C75	C125	C127
Worklight		✔	✔
Low battery indicator		✔	✔
Individual print-out reports		✔	✔
Rotary selector	✔	✔	✔
Memory positions (various tests)	20	179	179
Infrared printer port	✔	✔	✔
Backlit display	2 Lines	4 Lines	4 Lines
Boot with integral magnet	✔	✔	✔
User programmable headers	✔	✔	✔
Time & date stamp	✔	✔	✔

Temp Measurement		
Flue Temp Range (T1 C125/C127)	32 ~ 1112˚F / 0 ~ 600˚C	20 ~ 2400˚F / -29 ~ 1315˚C
Inlet Temp Range:Probe (T2 C125/C127)	-	
Inlet Temp Range: Ambient	32 ~ 112˚F / 0 ~ 50˚C	32 ~ 112˚F / 0 ~ 50˚C
Net Temp (ΔT)**	32 ~ 1112˚F / 0 ~ 600˚C	20 ~ 2400˚F / -29 ~ 1315˚C
Resolution	1˚F/˚C	0.1˚F/˚C
Flue (T1, Inlet T2, & Net ΔT) Accuracy	±[0.3% rdg +5˚F(3˚C)]	±[0.3% rdg +3.6˚F(2˚C)]
Inlet Temp Ambient Accuracy	±[0.3% rdg +1˚F(1˚C)]	±[0.3% rdg +1.8˚F(1˚C)]

Gas Measurement			
Oxygen	0 ~ 21%	0 ~ 21%	0 ~ 21%
O_2 Resolution/Accuracy	0.1% / ±0.2%*	0.1% / ±0.2%*	0.1% / ±0.2%*
Carbon Monoxide	0 ~ 1000 ppm	0 ~ 4000 ppm	0 ~ 4000 ppm
CO Resolution/Accuracy	1 ppm/±10 ppm < 100 ppm* ±5% reading	1 ppm/±10 ppm < 100 ppm* ±5% reading	1 ppm/±10 ppm < 100 ppm* ±5% reading
Carbon Dioxide**	0 ~ 30%	0 ~ 30%	0 ~ 30%
CO_2 Resolution/Accuracy	1.0%/±0.3% reading	1.0%/±0.3% reading	1.0%/±0.3% reading
Efficiency**	0 ~ 99.9%	0 ~ 99.9%	0 ~ 99.9%
Efficiency Resolution/Accuracy	0.1%/±1.0% reading	0.1%/±1.0% reading	0.1%/±1.0% reading
Excess Air**	0 ~ 250%	0 ~ 250%	0 ~ 250%
Excess Air Resolution/Accuracy	0.1%/±0.2% reading	0.1%/±0.2% reading	0.1%/±0.2% reading
CO/CO_2**	-	0 ~ 0.999%	0 ~ 0.999%
CO/CO_2 Resolution/Accuracy	-	0.0001%/±5% reading	0.0001%/±5% reading
Nitric Oxide	-	-	1 ppm/±2 ppm < 30 ppm*
Nitric Oxide Resolution/Accuracy	-	-	±5 ppm > 30 ppm

Pressure (Differential)			
	Range ±0.2mBar 0.08"wg	0.001mBar/±0.005mBar ±0.002"wg	0.001mBar/±0.005mBar ±0.002"wg
	Range ±1mBar 0.4"wg	0.001mBar/±0.03mBar ±0.01"wg	0.001mBar/±0.03mBar ±0.01"wg
	Range ±80mBar 32"wg	0.01mBar/±3% reading	0.01mBar/±3% reading

Eagle Dimensions	
Weight	2.2lbs. with boot
Handset	7.9 x 1.8 x 3.5"
Probe	11.8 x 0.25 x 9.4" stainless steel shaft, type K thermocouple (9' hose)
Operating temp	0 to 40˚C/10% to 90% Relative Humidity non-condensing
Battery	x4 "AA" cells / 12 hour life typical with Alkaline "AA" cells
Warranty	3 year limited warranty (2 year sensor warranty)

Pre-Programmed Fuels
Natural Gas, Propane, Butane, LPG, Light Oil

*Measures **Calculates

EAGLE COMBUSTION ANALYZERS™ LIMITED WARRANTY

The Eagle Combustion Analyzers (C75/C125/C127) is warranted to be free from defects in materials and workmanship for a period of three years (two years on sensors) from the date of purchase. If within the warranty period your instrument should become inoperative from such defects, the unit will be repaired or replaced at UEi's option. This warranty covers normal use and does not cover damage which occurs in shipment or failure which results from alteration, tampering, accident, misuse, abuse, neglect or improper maintenance. Batteries and consequential damage resulting from failed batteries are not covered by warranty.

Any implied warranties, including but not limited to implied warranties of merchantability and fitness for a particular purpose, are limited to the express warranty. UEi shall not be liable for loss of use of the instrument or other incidental or consequential damages, expenses, or economic loss, or for any claim or claims for such damage, expenses or economic loss. A purchase receipt or other proof of original purchase date will be required before warranty repairs will be rendered. Instruments out of warranty will be repaired (when repairable) for a service charge. Return the unit postage paid and insured to:

1-800-547-5740 • FAX: (503) 643-6322
www.ueitest.com • Email: info@ueitest.com

This warranty gives you specific legal rights. You may also have other rights which vary from state to state.

USA: *1.800.547.5740 • Fax: 503.643.6322*
CANADA: *1-877-475-0648 • Fax: 604.278.8299*
WWW.UEiTEST.COM