Chapter 7

COMBUSTION

IN THIS CHAPTER

• Combustion theory
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Combustion theory
As a technician, you have an obligation to assure the equipment you are working on is operating at peak performance levels. Understanding combustion theory is the basis for adjusting oilburners for safe, clean, reliable, and economical operation.

Combustion is a controlled chemical reaction
Three things are needed to make a fire: oxygen, ignition, and fuel. When heating oil is burned, the chemical energy in the fuel is converted to heat.

The oxygen required for combustion comes from the air that is delivered by the oilburner fan. The spark delivered by the electrodes provides the heat needed to start the combustion process.

The heat from the spark vaporizes the oil droplets delivered by the nozzle then lights the vapor on fire. If the conditions for combustion are right, this process continues until all the droplets vaporize and burn completely and cleanly within the combustion zone.

Combustion is the rapid oxidation of any material that will combine readily with oxygen.

The resulting flame contains the hot gases produced when the hydrogen and carbon in the fuel react and combine with the oxygen in the air. This reaction creates light, and releases large quantities of heat. This heat from the combustion gases is extracted by the heat exchanger in the furnace, boiler, or water heater, and heats the air, water, or steam we use for space and domestic water heating.

Every gallon of oil contains about 140,000 Btus per gallon. A Btu is the energy required to raise one pound of water one degree Fahrenheit—about the amount of energy contained in a birthday candle flame. In a typical oil-fired appliance, every gallon of oil burned puts about 119,000 Btus into the building and about 21,000 Btus go up the chimney. Figure 7-1.

Heating oil is 85% carbon and 15% hydrogen. These fixed ratios of hydrogen and carbon in the fuel combine with a specific quantity of oxygen to form combustion gases. Therefore a precise

![Figure 7-1: Heat loads, heat loss]
quantity of combustion air is needed so all the fuel will burn completely. Too much air will lower efficiency, and too little air causes incomplete combustion and smoke.

During combustion, new chemical substances are created from the fuel and the air. These substances are called combustion gases. Most come from chemical combinations of the fuel and oxygen, but the gases can also include chemical combinations from the air alone.

When a hydrocarbon-based fuel (oil) burns, the exhaust gases include water (hydrogen + oxygen) and carbon dioxide (carbon + oxygen). Combustion gases can also include carbon monoxide (CO), oxides of nitrogen (NOx, nitrogen + oxygen) and since sulfur is present in the fuel, sulfuric oxide (sulfur + oxygen).

As the fuel and air are turned into combustion gases, heat is generated. Heat is required to start combustion and is itself a product of combustion. Once combustion gets started, we don’t have to continue to provide the heat source, because the heat produced by the combustion process will keep things going.

**What is air?**

Air is 20.9% oxygen, 78% nitrogen, and 1.1% other gases. For every one part of oxygen, we get four parts nitrogen, see Figure 7-2. Nitrogen is an inert gas and most of it goes through the combustion process unchanged. It cools the chemical reaction (burning temperature) and lowers the maximum heat content deliverable by the fuel. Therefore, it is impossible to achieve combustion efficiencies above 95% for most fuels, including natural gas, when air is used as the source of oxygen for the combustion process.

With flame retention burners, some of the nitrogen combines with the oxygen to form nitrogen oxide or NOx.
Combustion is a series of exact chemical reactions that create exact quantities of combustion gases. It takes 14.4 pounds of air to burn each pound of heating oil and we produce 15.4 pounds of combustion gases, Figure 7-3.

If we could achieve stoichiometric, or perfect combustion, each gallon of oil consumed would need 1,360 cubic feet of combustion air. The actual amount of air required will vary by the heat value of the fuel and the design of the burner. Heating oil contains about 19,500 BTUs per pound. Non-flame retention burners need at least 1,700 cubic feet of air to burn clean. Current burners need about 1,500 cubic feet.

Buildings today are so well insulated and weather-stripped that getting adequate combustion air to the burner is becoming a problem. When troubleshooting combustion problems, get into the habit of asking yourself, “Where is my combustion air coming from?” and “Do I have enough to burn all of my fuel?”

Oil burner flames produce various combustion gases in fixed quantities. With perfect combustion, every pound of oil burned will produce 3.2 pounds of carbon dioxide, 1.1 pound of water vapor, and 11.1 pounds of hot nitrogen. This constant ratio of combustion gases allows us to test the quality of a flame against this perfect standard to determine optimum adjustment.

**Heating oil atomization and vaporization**

Heating oil will not burn as a liquid. It must be converted to a vapor before the rapid reaction between the fuel and the air can produce a flame. The oil burner’s job is to convert the liquid fuel into a vapor so it can be burned.

The oil is pumped to the nozzle at high pressure (100 psi or more) where it is broken up into a mist of small droplets (atomized). The droplets evaporate quickly when exposed to the heat of the spark or flame, producing vapors that burn easily with the air supplied by the burner fan.

**Combustion air supply and air-oil mixing**

The better the air and the oil vapor are mixed, the better our combustion. Burner air parts, (including turbulators, spinners, end cones, and flame retention heads), are designed to give good mixing of the atomized fuel droplets and the combustion air. Good fuel and air mixing assures that all the fuel vapors contact enough oxygen for complete burning.

In high pressure atomizing burners, several factors control the quality of air-oil mixing. The spray pattern of the oil droplets must be similar to the air pattern created by the burner.

Flame retention burners have much better air/oil mixing capabilities than older burners. They use high speed burner...
motors (3,450 RPM) and air pattern shaping to create the high static air pressure needed to make the high velocity air swirl and the internal recirculation needed for clean, efficient combustion.

This recirculation is created by the drop in pressure in the center of the air swirl, like the eye of a tornado. This pulls some of the hot flame gases toward the burner head, the way the spray from a showerhead pulls in the shower curtain.

These hot gases add heat to the fuel droplets coming out of the nozzle speeding up their vaporization and burning rates, which gives us a nice clean, stable fire close to the burner head.

**New oilburners should not produce smoke**

Smoke and soot, which are nothing more than unburned carbon, are created by outdated burner designs and incorrect burner service and adjustment. Smoke production is unnecessary and must be eliminated, because it reduces efficiency, increases service calls, and is a nuisance to homeowners. It can be prevented using modern burners and by careful adjustment of burners using combustion test equipment.

Excessive smoke wastes fuel because it deposits soot on the heat exchanger surfaces, Figure 7-4. This insulates the heat exchanger, limiting its ability to extract the heat from the combustion gases. A layer of soot only 1/8” thick can reduce heat absorption by over 8%.

Efficiency loss caused by a smoky burner occurs as the soot slowly builds up. Soot also affects the reliable operation of the burner. If it builds up on the cad cell or the bimetal of the stack relay, it can act like a flame failure and cause the control to lock out on safety, creating an unnecessary service call.

**Overfiring can cause smoke:** If a unit is overfired, the burner will create heat faster than the heating system can distribute to the building. When this happens, the burner short cycles (goes on and off frequently for short periods of time). The problem is that older oilburners create smoke when they start and stop.

Up to two thirds of all the smoke produced by burners made before the year 2000 is produced on start up and shut down. Therefore, properly sized nozzles will produce less frequent burner cycling and less smoke.

**Sulfur**

Sulfur exists in varying degrees in all fossil fuels. The sulfur content of heating oil ranges from 0.5% to 0.05% by weight.

When burned, the sulfur mixes with oxygen to form sulfuric oxide (SOx). It reacts with the water vapor in the combustion gases to create sulfuric acid aerosol.
When the acid condenses (at about 150 to 200°F), it adheres to the flue pipe and heat exchanger surfaces in a film and reacts with the iron in the pipe and heat exchanger wall. This creates iron sulfates, the light yellow to rust colored crusty scale you find clinging to the heat exchanger.

Scale buildup downgrades efficiency by 1% to 4% over the year. It also blocks flue passages, restricting air flow and increasing smoke and soot. Sulfur levels in heating oil are gradually being reduced, so this will be less of a problem in the future.

**Carbon monoxide**

Carbon monoxide, or CO, is a toxic gas that can occur in homes and buildings where combustion by-products are generated, not properly vented and allowed to accumulate. CO is a colorless, odorless, tasteless poison. Carbon monoxide is readily absorbed in the body and can impair the oxygen-carrying capacity of the blood (hemoglobin).

Impairment of the body’s hemoglobin results in less oxygen to the brain, heart, and tissues. Even short-term over exposure to carbon monoxide can be critical or fatal to people with heart and lung diseases, and to the young or the elderly. It may also cause headaches and dizziness and other significant medical problems in healthy people. At low concentrations, CO can go undetected and contribute to nagging illnesses, and can compound pre-existing health problems. Figure 7-5.

Carbon Monoxide is a result of incomplete combustion due to unburned fuel. During combustion, carbon in the fuel oxidizes through a series of reactions to form carbon dioxide (CO₂). However, 100% conversion of carbon to CO₂ is rarely achieved under field conditions and some carbon only oxidizes to the intermediate step, carbon monoxide or CO. Carbon Monoxide is usually produced by insufficient combustion air. However, excess air and mismatched oil to air patterns and ratios can also reduce flame temperature to a point where CO is produced. So, adding too much air to clean up a smoky fire can create CO. When any part of the flame is reduced below 1,128°F, CO will be produced. Flame impingement also results in lower flame temperature and CO production.

**Ambient CO limits (Recommended)**

- **0 ppm.** This level is most desirable, but cannot always be achieved due to cigarettes, candles, and appliances such as gas stoves.
- **1-9 ppm.** Normal levels within the home.
- **10-35 ppm.** Advise occupants, check for symptoms (slight headache, tiredness, dizziness, and nausea or flu like symptoms), check all appliances, including the furnace, water heater and boiler, check for other sources including internal combustion engine operation in attached garages.
- **36-99 ppm.** Recommend fresh air, check for symptoms, ventilate the space, recommend medical attention.

**Carbon Monoxide (CO) Levels**

- **0 PPM.** Desirable Level
- **9 PPM.** Maximum Indoor Air Quality Level
- **50 PPM.** Maximum Concentration for Continuous Exposure in Any 8 Hour Period
- **400 PPM.** Frontal Headaches 1 to 2 Hours, Life Threatening After 3 Hours
- **800 PPM.** Nausea and Convulsions, Death Within 2 Hours
- **1600 PPM.** Nausea Within 20 Minutes, Death Within 1 Hour
- **12,800 PPM.** Death Within 1-3 Minutes
100+ ppm. Evacuate the home (including yourself!) and contact emergency medical services (911). Do not attempt to ventilate the space. Short-term exposure to these levels can cause permanent physical damage.

Carbon monoxide is released into homes by vent blockage, flue pipe damage, heat exchanger cracks, and restricted air supply into the house. This last problem is progressively getting worse as new homes become tighter in their construction, and many homeowners are weather stripping and insulating their older homes.

Most homes have a number of devices such as exhaust fans, clothes dryers, and fireplaces, that remove air from the home. This suction is often stronger than the suction of the heating system’s chimney or power vent. This back drafting causes the emissions from the heating system, the water heater, gas ovens, gas stoves, gas dryers, and wood stoves or fireplaces to enter the living area and elevate CO levels.

Oilheat’s CO warning signs
If you see smoke near the burner, dark smoke coming from the chimney, or smell a sharp raw oil smell, the burner is probably producing unacceptable levels of carbon monoxide. With insufficient combustion air, oil burners usually produce elevated smoke levels before high CO levels are reached. This smoke is a warning signal.

The result is that the danger from high CO levels is much lower from oil burners than any other hydrocarbon burner. However, if oil burners are operated with too much combustion air, it chills the flame and creates CO with no smoke! Improper nozzle to air patterning can also produce CO.

What to watch out for
CO is odorless and tasteless, therefore in order to detect its presence, we perform combustion tests and look for other clues for combustion or ventilation problems such as:

- Sharp gas or oil smell
- Stale or stuffy air
- Soot, rust, or scale build-up on or around appliances and vents
- Loose or disconnected chimney or vent connections
- Debris or soot falling from chimney, fireplace, or appliance
- Excessive moisture on the inside of windows or walls
- Chalky white powder forming on the chimney or vent
- Visible smoke in the living space

Light off CO levels: High CO levels at light off may be an indication of rough or delayed ignition, warranting further investigation. The CO readings will peak on startup, then dramatically drop. CO readings should stabilize within 10 minutes of operation and should never be rising during operation.

Mechanical problems and CO: If the appliance being tested has sufficient combustion air and is still producing higher than acceptable CO air-free levels, it could be a mechanical problem.

Inspect the burner for cleanliness, proper alignment, fuel pressures, and evidence of impingement. Impingement occurs when the flame hits an object that has sufficient mass to transfer enough heat from the flame to cause low flame temperatures and incomplete combustion. This can be as simple as a screw poking into the heat exchanger or as major as a collapsed refractory.

Missing burner covers, improper air band adjustment or oil pressures can also contribute to higher than normal CO levels.
CO ambient air testing
(Combustion air zone & living space)

Ambient CO levels should be checked and the equipment should be run through a complete cycle if you suspect any combustion problems.

If at any time ambient CO levels exceed 100 ppm, evacuate occupants and call emergency services.

The most common sources of CO are exhaust from a vehicle in an attached garage, and depressurization of the home resulting in insufficient air for combustion. If CO is detected, all possible sources of CO should be checked, including—but not limited to—water heaters, gas ovens and stoves, the furnace, (non-electric) space heaters, and vented or unvented appliances such as gas logs.

Combustion efficiency testing

Combustion efficiency testing is one of the most important things we do when servicing oilburners, Figure 7-6. The tests determine the quality of the combustion process and tell us if we have set up the burner correctly. In this section, we will explore how to use instruments to measure and improve efficiency, cleanliness, and safety of the unit. We will also cover the reasons for high and low efficiency, and how testing can pinpoint current and future problems.

It is imperative to perform a combustion analysis during routine service, or any time changes are made that will affect combustion. Combustion testing provides numerous benefits to the customer and service technician including:

- Saving money
- Saving time
- Avoiding callbacks
- Limiting liability
- Maintaining equipment warranty
- Providing confidence
- Providing increased comfort
- Providing increased safety
- Increasing energy efficiency
- Lowering environmental emissions

Modern burners require proper setup, making the use of instruments necessary. Using instruments assures low smoke and soot, improves your image, and increases customer comfort and satisfaction. Today’s burners are superior to the older models when set up correctly—but can be troublesome when setup incorrectly. You cannot see a #2 smoke, you also cannot feel a 350° stack, smell a 6% CO₂, or 100 ppm of carbon monoxide, yet if you leave the unit operating in any of these conditions, you will not be doing your job.

With the older units, you could observe the flame, see its shape and color, and determine to some extent how the burner was performing. However, even with the
older units, there is no way you can accurately determine whether the chemical reaction is complete by just observing the fire.

The most important setting you make on the burner is excess air. You cannot really do this without instruments. If you give testing a fair trial, you will find it will reduce the time required to accurately service, troubleshoot, and adjust a heating system.

**Principles of combustion testing**

Combustion test instruments measure the composition and temperature of flue gases as they leave the boiler or furnace. We use this information to calculate the amount of excess air and the combustion efficiency. We also measure the amount of smoke and draft produced in order to properly adjust the flame and identify problems.

**Combustion testing measurements:**

- Temperature of the flue gases
- Draft produced by the chimney, power-venter or venting system
- Smoke concentrations in the flue gases
- Composition of the flue gases (excess air, CO₂, O₂, and NOx)
- Carbon Monoxide concentrations in the flue gases

The three things we adjust that affect the combustion process are: fuel pressure, combustion air, and draft. Other factors can affect the combustion process, including impingement, excess air leaks into the heat exchanger, insufficient combustion air due to tight construction or improper ventilation, or an improperly installed venting system.

If you perform combustion testing prior to and after a tune up, you can calculate how much improvement you have made in the combustion efficiency, and how much money you have saved your customer.

**Combustion test equipment**

Combustion testing equipment can be separated into two groups: the manual instruments (Figure 7-7), and the continuous sampling digital electronic instruments, Figure 7-8. The manual equipment has been
used for many years and can produce reliable results if used and maintained properly.

The problem is, testing with the older manual equipment is time-consuming and only gives you a fuzzy snapshot of the burner performance. (Each squeeze of a wet kit bulb represents a different snapshot of the flue gas. A manual test blends all those snapshots together into one reading.)

The digital equipment is much quicker, and does efficiency calculations automatically. The best feature of the digital equipment is that they sample continuously, like using a video camera, so you can see the results change as you make the adjustments. It gives you a much better idea of what is going on.

**Holes for testing**

Measurements are taken through a three-eighths (3/8) inch hole drilled in the flue pipe near the boiler or furnace outlet (the breech), see Figure 7-9.

With electronic testers, the hole may have to be larger to accommodate the probe. The hole should not be in an elbow.

With the older test equipment, you will want to drill two holes to speed up the process. They should both be as close to the breeching (the place where the flue pipe connects to the furnace, boiler or water heater) as possible.

The holes should be at least 6” from the draft regulator on the furnace or boiler side of the regulator. There is no need to plug the holes in the stack, but we do suggest that you insert self-threading screws or snap caps in the holes.

You will also need a hole in the fire or observation door over the burner. Some new units do not have a door over the burner. If this is the case, check to see if the manufacturer has provided a special port for you to do your over-fire test. See Figure 7-6.
Manual combustion test equipment

To successfully adjust oilburners with the manual equipment, we need the following:

1. To test for draft, we need a draft gauge. (Figure 7-10).
2. To test for smoke, we need a smoke tester and a smoke scale. (Figure 7-11).
3. To test carbon dioxide ($CO_2$) we need an Orsat tester. (Figure 7-12).
4. A stack thermometer is used to measure the temperature of the flue gases. (Figure 7-13).
5. We need the combustion efficiency slide ruler to calculate efficiency.

While not needed to calculate efficiency, it is important to know if the oil pressure to the nozzle is correct, and to measure this we need a pressure gauge capable of reading up to at least 300 pounds pressure.

We also need a vacuum gauge to determine the condition of the oil delivery system. (See Chapter 4.)

Steady state

For accurate test results, measurements should be made after the unit has achieved steady state. Steady state is the point at which the stack temperature stops rising. At steady state there are no changes in the combustion gases, the unit has thoroughly warmed-up and will maintain constant conditions as long as the burner runs. This will require you to run the unit for 5 to 10 minutes, until the stack temperature reaches its highest point and levels off.

Stack temperature

The stack (flue gas) temperature is the temperature of the combustion gases leaving the appliance, and reflects the energy that did not transfer from the fuel to the heat exchanger. The lower the stack temperature, fine-tune the air to reach a zero smoke.

$CO_2$ or $O_2$: This is done last because if draft or smoke are wrong, it does not matter what $CO_2$ is—you cannot leave the unit that way.

Calculate Efficiency: Once the air is adjusted properly, take a final temperature reading, then compare the $CO_2$ reading and the net stack temperature using the slide ruler to get the combustion efficiency of the unit.

Important: Make a record of the results of each test on a Combustion Survey Form, which should show all before and after readings. Then you will know just how much improvement you are achieving.

Step-by-step testing procedure

The traditional order for taking these tests is:

**Stack Temperature**: With manual equipment, two holes will speed up testing and the thermometer should be placed into the unit on start and the rest of the testing done in the other hole when the temperature reading stabilizes.

**Draft**: Do draft second because the other tests will be affected by any increase or decrease of draft.

**Smoke**: To adjust for zero smoke number, you start by opening the burner air shutter or adjusting the head. Then
the more effective the heat exchanger design and heat transfer. Stack temperature is a measurement of the heat exchanger’s ability to draw the heat from the combustion gases. As the excess air goes up, so does the stack temperature, Figure 7-14. To understand why this happens, we must look at the heat exchanger. The longer the combustion gases are in the heat exchanger, the more the heat the exchanger can pull from them, and the lower the stack temperature will be. As the excess air increases so does the volume of combustion gases.

The volume of gases traveling through the heat exchanger determines how fast the gases must travel. The more air we put in, the faster it goes, and the less time the exchanger has to suck the heat out of the gases.

Therefore, as the excess air goes up, the stack temperature does too, even though the flame temperature is reduced. As stack temperatures go up, efficiency comes down, and our customers’ heating costs increase, see Figure 7-15.

The flue gas temperature and all other tests should be measured in the flue gas hot spot. This is the point in the center of the flue where the stack temperature and the CO₂ are at the highest level and the O₂ is at its lowest level.

The primary importance of stack temperature is to provide enough heat in the flue to prevent water formation. If the temperature is not high enough, water in the combustion gases can condense in the flue pipe or chimney. Condensing in non-condensing appliances can cause chimney
Deterioration, liner failure, and rusting of the appliance.

Take a gross stack temperature reading, subtract the temperature of air entering the burner (ambient air temperature) from the gross stack temperature to get the net stack temperature needed for calculating efficiency. The relationship between the percentage of excess air in the flue gases (CO₂ or O₂) and the net stack temperature is the combustion efficiency.

Causes of high stack temperature

- Soot Deposits: The insulating effect of soot deposits prevents good heat transfer through the heat exchanger. Inspect the heat exchanger, clean if necessary, and adjust the burner to a zero to trace smoke.

- Excess Air: Excess air cools the combustion gases and increases their volume. This results in lower heat exchanger efficiency. Excess air can be due to poor air-fuel mixing, poor burner adjustment (more air than needed to stop smoke), and air leaks into the heat exchanger.

- Overfiring: Firing a heating system at a higher GPH (gallons per hour) than it was designed for causes high rates of gas flow through the heat exchanger and results in high stack temperature.

Dew point temperature

The dew point temperature is the temperature below which the water vapor contained in the flue gas turns into a liquid. This change is often referred to as condensation. Below the dew point temperature, moisture exists; above the dew point temperature, vapor exists. If the chimney or venting material falls below the dew point temperature, condensation in the flue will occur.

To prevent condensation, the stack temperature should range from 270°F to 370°F above the ambient air temperature for non-condensing appliances. (With new high efficiency equipment that does not have a draft regulator, combustion gases can be on the low end of this range; if there is a draft regulator, they should be closer to the high end.)

With the new condensing appliances, the stack temperature will be close to the return air or water temperature from the heating system and usually below 125°F. The lower the heating system return air or water temperature, the higher the efficiency will be on a condensing appliance.

Using the dial type stack thermometer

Slide the holding clip out to the end of the thermometer stem. Insert the small tab into the top of sampling hole in the stack and push the thermometer in far enough so the tip is in the center of the flue pipe. Operate the burner until the thermometer reading is rising no faster than 3 degrees per minute and record the reading. If the stack temperature begins to approach 1,000 degrees, remove the thermometer, because readings above this temperature will damage it.

Draft

Draft is the flow of air and combustion gases through the burner, heating unit, and venting system. Draft is required to remove the flue gases from the heat exchanger.

If draft is too low, then the combustion
air flow will be reduced, causing excessive smoke. If the draft is too high, then too much excess air will be drawn into the unit and the combustion gases will be pulled through the heat exchanger too fast, lowering efficiency.

During steady state operating conditions, the draft should be stable. Over-fire drafts of -.01" to -.02"wc [water column, see below] are generally recommended for residential units. Measurement and adjustment of draft are important because draft affects all other burner adjustments.

Draft measurement
To measure draft, we use a manometer, a U-tube or a gauge. The U-tube is a glass tube bent into the shape of a U. The tube is filled with water up to a zero mark on a scale etched on the tube. A sampling tube is attached to the right leg of the tube, and it is inserted into the unit to be tested. The left leg is left open to atmospheric pressure.

The draft on the right leg causes a pressure drop on that side and pulls the water up in the tube, and the atmospheric pressure on the open side pushes the water down in the left leg.

The difference between the water levels in the two legs is the draft in inches of water column. The suction from draft is so slight the difference is only a few hundredths of an inch. One one-hundredth of an inch of draft is expressed as -.01"wc.

Since it is a vacuum and not a pressure, we call it negative draft. If the right leg measured a pressure higher than atmospheric the water would go up in the left leg and we would call it positive draft.

Our modern draft gauges (manometers) are the mechanical equivalent of the U-tube. An important thing to remember when using the draft gauge is you must “zero it out” before using it. Atmospheric pressure changes all the time, so we take this variable pressure out of the equation by adjusting the gauge reading to zero before we take each test.

To zero out the draft gauge place it on a level surface near where you are going to test and slide the lever on the side of the unit until the arrow points to zero. You should also be sure the gauge is functioning properly by spinning the rubber sample tube or blowing gently across the end of it to be sure the needle is not stuck. It should move smoothly and return to zero.

The most important draft reading on residential equipment is the over-the-fire draft. On most residential and light commercial negative draft units, this reading should be -.01" to -.02"wc. If upon reaching steady state you cannot obtain this reading, you should next check the draft at the breech, and adjust the draft regulator. If you still cannot achieve sufficient over-fire-draft, then you probably have one of the following problems.

Common causes of poor draft
- Chimney is too small for the load of the attached appliances
- Chimney is too large in diameter or cross-section
- Chimney too short or improperly constructed
- Leakage of air into chimney, thimble, stack, or breeching
Figure 7-16: Effects of leaving a unit operating with a 5 smoke

- Obstruction in chimney or at top of chimney
- Top of chimney is lower than the peak of the house
- Flue pipe diameter is too small. It should never be smaller than the breeching size
- Too many 90 degree elbows in the stack

- Flue pipe does not have sufficient pitch upward from breeching to thimble; it should be at least ¼" per running foot
- Flue pipe extends too far into the chimney flue
- Heat exchanger passages are clogged with soot and scale, too restricted, or too baffled
- Appliance is overfired; the volume of flame and combustion gases is too great for the heat exchanger design and are creating back pressure or a positive draft over the fire
- Unit is underfired, so that the chimney gases never get hot enough to create normal draft conditions
- Insufficient ventilation or combustion air in the appliance room, starving the flame for air and draft flow
- Improper adjustment of the draft regulator
- Differences between breeching and over-fire draft (draft drop): More than .05" difference between the two draft readings usually means trouble. Check for heavy soot deposits in the heat exchanger, particularly if the burner was found with a heavy smoke
- Little or no difference between the breeching and over-fire draft: If the stack temperature is high, baffling or heating unit replacement should be considered
- Over-fire CO₂ higher than breeching CO₂: Check for air leaks between top of combustion chamber and heat exchanger outlet (Breeching)
- Visible openings for air leakage: Study how the heating unit is put
together and check all joints for possible
leaks. If you suspect air leaks, but cannot
find them, temporarily set the draft
regulator to give maximum draft and run a
candle or lighted match around the joints to
see where the smoke is drawn in. Repair
the leaks and set the over-fire draft to -.01"
to -.02". Also, look for locations where
light from the flame can be observed
through cracks.

Smoke

After you have determined that draft
conditions are correct, the next step is to
adjust the burner to create a flame that will
not produce smoke.

Keeping smoke to a minimum is a must
if the heating system is to operate at peak
efficiency without further attention during
the entire heating season.

We measure smoke concentrations by
taking a sample of the flue gases with a
smoke tester and smoke scale, which
identify smoke numbers from zero (no
smoke) to a number 9 (heavy smoke). Any smoke
numbers above a number 2
cause rapid soot accumu-
lations on heat exchanger
surfaces. This causes flue
gas temperatures to rise and
efficiency to drop, Figure
7-16.

Excess combustion air is
needed to reduce smoke
centrations to a mini-
umum acceptable number
(less than a number 1).

As we have discussed,
this excess air must be held
to a minimum in order to
reach peak efficiency. Thus,
correct burner adjustment is
the proper balance between
smoke and combustion air.

To reach high efficiency,
we must adjust burners for
Zero Smoke and low excess
air while
maintaining a high
level of
CO₂ or a low level of O₂,
Figure 7-17.

The typical smoke
tester draws a total of
2,200 cubic centimeters
(ten full strokes of the
sampling pump illustra-
ted) of flue products
through a standard grade
filter paper. The color of
the resulting smoke stain
on the filter paper is
matched to the closest
shaded spot on the

Figure 7-17: Smoke vs. percent CO₂ curve

Figure 7-18: Smoke scale
standard graduated smoke scale, Figure 7-18. This scale has ten shaded spots with an equal difference between successive spots. Spot Number 0 is white, and represents smoke-free combustion. Spot Number 9 (darkest) represents the maximum smoke that typically will be produced.

An oily or yellow smoke spot on the filter paper is a sign of unburned fuel, indicating very poor combustion (and likely high emissions of carbon monoxide and unburned hydrocarbons). If too much excess combustion air is supplied, the combustion process will be chilled so much that some of the fuel cannot burn. The flame is actually being blown out. Further evidence is liquid fuel in the heat exchanger, white smoke (fuel vapor) and strong odors outside the home.

To adjust for a zero smoke, first adjust the burner for a trace smoke then open the air gate just a bit farther to go to zero smoke. By initially adjusting to a zero smoke you will be introducing an unknown amount of excess air which can lead to: lower CO\textsubscript{2}, cooler flame temperatures, higher stack temperatures, and possible elevated carbon monoxide production.

Remember that excess air cools the combustion products and increases their volume so that it is difficult for the heat exchanger to absorb the heat before it escapes to the breeching and up the chimney. Most new burners are designed to operate at zero smoke.

**Common causes of smoke and soot:**

- Poor fuel atomization: small fuel droplets vaporize quicker than large ones. Large droplets are caused by:
  - Damaged or worn nozzles
  - Low fuel pump pressure
  - Cold oil

- Inadequate combustion air is caused by:
  - The burner air control is not open far enough
  - Poor chimney draft
  - Build up of soot and scale in the heat exchanger
  - Accumulation of lint, hair, sawdust, and dirt on the air shutter and the burner fan
  - Restrictions of the air flow to the room the burner is in, and the operation of exhaust fans that de-pressurize the building

**Effects of insufficient combustion air**

For the proper operation and venting of gas or oil heating appliances, sufficient
outside air must be supplied to the structure to make up for the air lost from venting heating appliances, fireplaces, clothes dryers, exhaust fans and other building air losses.

Insufficient combustion air can cause major problems for proper draft and operation of both gas and oil heating systems.

For years it has been assumed that when a heating appliance was located in an unconfined area, there was sufficient air for both ventilation and combustion. Today, in most cases, that is not true! New construction standards, insulation, weather stripping, and energy efficient windows and doors have reduced the amount of air changes per hour.

The combustion and make up air requirements in the codes are based on 1/2 air changes per hour.

For newer homes and conversion of electrically heated homes, the air changes could be reduced to 1/3 or less air changes per hour. Air problems are most notable on the coldest days when heat loss is the greatest and there is a chance that windows or doors are closed for an extended period of time.

When installing new equipment or troubleshooting problem equipment, the first determination that needs to be made is whether the equipment is located in a confined or unconfined space. In accordance with NFPA 31 and NFPA 54, an unconfined space is defined as follows: Any space whose volume is equal to or greater than 50 cubic feet per 1,000 Btu (or 20 Btu/Cubic Foot). This is calculated on the sum of the total input ratings of all fuel burning appliances installed in that space. Only areas connected to the space that have no doors or with fully louvered doors can be considered part of the unconfined space.

Note: If the actual free area of the louvers is not known, wood louvers are assumed to have a 20% to 25% free opening. Metal louvers or grills are assumed to have 60% to 70% free opening.

### Calculating confined space

**Example:**

A room 20' by 30' with an 8' ceiling height and the heating appliance is 140,000 Btu. See Figure 7-19.

Determine the maximum total input firing rate allowable in a room without modification.

Example: Boiler room 20x30x8 = 4,800 cu ft.

4800 cu. ft. x 1000 Btu/50 cu. ft. = 96,000 Btu

96,000 Btu x 1 gph #2 fuel/140,000 Btu = 0.69 GPH

Result: If you fire greater than 0.69 GPH or 96,000 Btus, you will need additional combustion air.
To add air from an adjacent room, two openings between the room could be made 12 inches above the floor and 12 inches below the ceiling. The size of these openings is based on 1 square inch per 1,000 Btu input.

To add air directly from the outside of the structure, two openings could be made. The size of these openings is based on 1 square inch per 4,000 Btu input. The above requirements are based on guidelines in NFPA 31 or NFPA 54.

Alternately, if operating in a confined space, additional air may be added by a duct to the outside, sized on 1 square inch per 5,000 Btu input.

**Incomplete air-oil mixing**

Improper mixing creates fuel rich and fuel lean pockets in the combustion area and prevents complete burning. Some of the causes are:

- Mismatch of the fuel droplet spray and the burner air pattern
- Inadequate air swirl and turbulence caused by outdated burner design
- Improper burner head size
- Improper adjustment of air handling parts of the burner
- Irregular or unbalanced fuel spray caused by a partially plugged nozzle
- Off center installation of the nozzle
- Dirt or soot accumulation on burner air forming parts or air fan blades
- Defective or damaged burner parts such as the end cone, air tube, fan, and motor coupling
- Using a nozzle that is either too small or too large for the burner head and combustion area
- Fuel pump pressure set too low or too high
- Cold oil producing larger fuel droplets, and increasing the firing rate beyond the air setting
Flame impingement

The flame must not touch any solid surfaces of the burner, the end cone, the combustion chamber, or the heat exchanger. If this happens, the flame will be cooled and the unburned carbon atoms will turn to smoke and soot. Possible causes:

- Overfiring, too large a nozzle or excessive oil pump pressure
- Incorrect oil and/or air pattern
- Burner installed too high, too low, or off center
- Incorrect combustion chamber size or shape, or base of the chamber full of soot
- Partially plugged nozzle
- Cold oil

Smoky shut down

Check the cut-off valve by using a pressure gauge in the fuel pump nozzle port. See the nozzle and fuel unit chapters for causes of after drip. (Chapters 4 and 5).

<table>
<thead>
<tr>
<th>Correlation of Percent of CO₂, O₂ and Excess Air</th>
<th>Carbon Dioxide</th>
<th>Oxygen</th>
<th>Excess Air (Approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.4</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>15.0</td>
<td>0.6</td>
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<td></td>
</tr>
<tr>
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</tr>
<tr>
<td>10.0</td>
<td>7.4</td>
<td>50.0</td>
<td></td>
</tr>
</tbody>
</table>

The ranges that you will use most frequently are bold-faced and in color.

Excess air: CO₂ and O₂

As we add excess combustion air, the amount of nitrogen and unburned oxygen increase. The amount of water and carbon dioxide remain the same because we have already burned all the fuel; therefore the
percentage of CO₂ drops and the percentage of oxygen starts to increase. (Figure 7-20). By measuring either the percentage of CO₂ or the percentage of unused oxygen (O₂) we can determine the quantity of excess air. They are the opposite of each other. As the percent of O₂ increases the CO₂% decreases. (Figure 7-21).

Why we must control excess air

Properly adjusting the burner air shutter is a compromise between too little air, which produces smoke, and too much air, which lowers efficiency. See Figures 7-22 and 7-23.

Earlier we found that a fixed quantity of combustion air is required to burn each pound of oil. We call this the theoretical fuel-air ratio.

Oilburners require a controlled amount of excess air above the theoretical value to assure complete combustion and smoke free operation. This excess combustion air serves as a safety margin to prevent incomplete combustion and smoke.

The air pressure in the building is always changing, the temperature of the fuel changes, and the draft produced by the chimney is not constant. Excess air gives us the safety factor we need for all these variations.

While excess air is needed for reliable clean operation, it also reduces efficiency. When increasing air for more oxygen, excess nitrogen comes along for the ride. This dramatically increases the amount of combustion gases that must be vented. Heat exchangers need time to absorb the heat from the combustion gases. The more gases forced into a heat exchanger, the faster they travel through the heat exchanger. This gives the heat exchanger less time to pull out the heat so the stack temperature goes up, and the efficiency goes down.

Limiting the amount of excess air can increase efficiency and save our customers money.

We measure excess air by determining
the percentage of oxygen (O₂) in the combustion gases. For each 1% decrease in oxygen levels introduced into the combustion process, efficiency increases by up to 1%. While some excess air is needed for complete combustion, we must set the air to the manufacturer’s specifications to ensure maximum efficiency.

Another problem with excess air is that it cools the flame. This creates incomplete burning in the combustion area and carbon monoxide levels can rise. Therefore we must exactly control the amount of excess air we allow into the burner. The only way we can achieve this delicate compromise between smoke and efficiency is by using combustion test equipment. You cannot see flue gases; the only way you can be sure you are right is testing.

**CO₂ measurement**

The Orsat CO₂ analyzer, named for its inventor, uses chemicals that absorb CO₂ from a mixture of gases without absorbing any other gas. The chemical usually used is potassium hydroxide (KOH) because it has the capacity to absorb large amounts of CO₂. When it does so, it expands. By measuring how much it expands we can determine the amount of CO₂ in the gases.

**There are two main parts to this analyzer:**

1. **The sampling pump:**
   - A. The sample tube that is inserted into the stack gases, or replaced by a longer tube for over-fire sampling.
   - B. The yarn filter and water trap, which stops soot and water from entering the analyzer.
   - C. The sample pump, a rubber bulb with rubber flapper suction and discharge check valves that allow flow in only one direction into the analyzer.
   - D. The rubber connector, which seals the sampling pump system to the analyzer.

2. **The analyzer:**
   - A. A body, which has two cavities or “cups” at the top and the bottom, connected by a narrow tube with an adjustable scale alongside. (Figure 7-24).
   - B. A valve system that either seals the gases and liquid inside the analyzer, or else lets a sample be pumped into the top cavity while the narrow tube and the lower cavity are sealed off.
   - C. A diaphragm, or flexible disc in the bottom cavity, which prevents a vacuum from forming inside the analyzer and lets the liquid in the bottom cavity be drawn up into the narrow tube after CO₂ is absorbed.

**Using a CO₂ analyzer**

- A. Prime and “wet” the instrument by tipping it over and then back once, and allow the fluid to drain from the upper cavity while holding the instrument at a 45-degree angle. Next, hold upright and depress valve on top several times and release the valve. Loosen the lock nut on the sliding scale on the right side. Slide the scale until “0” lines up with top of fluid in the center tube. Tighten the locknut.

- B. Insert the sampling tube into the stack to draw the gases to be sampled through the sampling hole in the stack. This gives you a stack CO₂ reading.

However, under certain conditions, it is desirable to determine the over-fire CO₂. To do this you must replace the short metal sampling tube with a ¼” metal tube about 30” long. This must extend through the sampling hole in the fire door to a point above
Study the instruction manual and take the time to learn how your analyzer works before you expect it to perform for you. Be sure to follow the manufacturer’s recommended maintenance and service procedures.

Combustion efficiency calculations

Since it is not possible in the field to measure the temperature of the flame due to dilution of the gases and absorption of the heat by radiation to the surrounding areas, we use a combustion equation to determine the quality of the combustion process. The efficiency calculation is based upon the theoretical heat value of the fuel being burned minus the stack losses.

To calculate the combustion efficiency with older test equipment, you need to know:

1. The Net Stack Temperature: This is the measured or gross temperature as indicated by the stack thermometer, minus the ambient or intake air temperature.

2. The % CO₂ in the Stack Gases: Do not use the % CO₂ measured over the fire. This is for air leak checks only. Test the CO₂ at the breech.

To calculate the steady state efficiency, use combustion efficiency tables or the combustion efficiency slide ruler. Adjust the large slide to the right so that the net stack temperature appears in the small window in the upper right corner marked "Net Stack Temperature"; then move the small vertical slide until the arrow points to the CO₂ reading. Through the window in the arrow on this slide you now read the figures: combustion efficiency in black and on-cycle heat loss in red.

Electronic combustion test equipment

One drawback of manual combustion test instruments is the time required to use them properly. This is especially true when the tests must be repeated during oilburner fine-tuning. New digital electronic testing instruments have been developed in recent
years that can reduce the time needed for oil burner testing and adjustment.

Digital instruments are faster, more accurate, more reliable, and have a higher repeatability. Digital instruments stay in calibration, allow trending, allow more complex functions and save time.

Digital instruments allow data to be recorded and reported without human error, and provide reliable and accurate results for you and your customers. Data can be recorded much faster than any technician could ever do the calculations.

With the optional printer, the data can be recorded as an un-editable record, so the print out is what was measured at the jobsite. Permanent records allow the user to track system changes and determine if the system is operating within the design parameters or if changes have taken place.

Only digital analyzers allow you to take real time tests.

Study the instruction manual and take the time to learn how your analyzer works before you expect it to perform for you. Be sure to follow the manufacturer’s recommended maintenance and service procedures. Most manufacturers ask that you not expose the analyzer for extended periods of time to freezing temperatures, as this has an impact on sensor life. In the winter, do not leave the tester in a cold truck over night.

The electronic combustion analyzers use advanced methods of measuring flue gas composition and temperature through a single probe.

A pump within the electronic analyzer draws a flue gas sample through a series of sensors. These electronic analyzers are capable of measuring oxygen percentage ($O_2$), carbon monoxide (CO), carbon dioxide (CO$_2$ - calculated), excess air, draft, stack and ambient temperatures and many can even determine other gases like oxides of nitrogen (NO, NO$_2$, NOx) for advanced flue gas emissions level readings. The only thing they cannot measure is smoke.

Since the electronic analyzers are sensitive to carbon build-up, to extend the life of the sensors and instrument, take smoke tests with a smoke tester, and adjust for a low smoke reading before using the electronic analyzers.

The electronic analyzers eliminate the cumbersome work required by the manual test equipment and more importantly, they eliminate human error caused by varying interpretation of results we have with manual equipment. With the electronic analyzers, any two technicians will get identical results.

The use of these electronic instruments also indicates to customers that you are a professional equipped with the most up-to-date testing equipment. It adds to your image as an energy expert. This can assist with customer acceptance of energy conservation options, such as flame retention burners and new boilers and furnaces.

Some of the electronic instruments compute efficiency and display the results on a printed readout. This can be used to demonstrate to the homeowner the actual efficiency of their boiler or furnace. This information can serve as a sales tool to identify the fuel savings that are available by installing new equipment and can also provide a written record that everything was as you say it was when you left the job.
Measurement procedure

Connect the flue gas sampling probe assembly to analyzer per manufacturer’s instructions. Verify the condensate trap plug is properly seated in combustion analyzer, and that water trap and thermocouple are not touching the side of the probe assembly. Before inserting the probe into the unit, start the analyzer and allow it to do its start up procedure. This is called the zeroing process. Never allow the analyzer to zero in the stack unless manufacturer’s design allows this.

As with older test equipment, measurements must be made in the stack between the barometric damper (if equipped) and the breech. Allow burner to operate until stack temperature stabilizes before testing.

Observations to make before testing

With experience, you will be able to quickly pinpoint the likely problems in the heating unit by looking at the instrument results, and making a few quick observations.

- **Look at the flame.** Is it normally shaped? Is it lopsided? Is it striking the sides or floor of the combustion chamber? (Be sure the flame observation door is closed when you do your tests. The air flowing into the open door will lower the CO₂ readings and raise the stack temperature.)

- **Check the burner-operating period.** Burning periods of less than 5 minutes do not usually produce enough heat to give good results. Short burner operating periods can be caused by overfiring of unit, or by improper functioning of automatic electrical controls.

- **Watch the flame while the burner shuts down.** A flame that lasts more than two seconds after the burner shuts off may be due to a poor cut-off. The primary two causes are air in the oil or the cut off in the fuel unit is defective. Refer to the Fuel Units Chapter for testing pump cut off. (Chapter 4).

- **Test for air leaks** around the burner air tube, the combustion chamber and all access doors on the furnace. A common cause of low CO₂ readings is air leaks into the unit. To see if the problem is air leaks, take a CO₂ test over the fire. If it is higher
than the reading at the breech, you have air leaks into the heat exchanger. Because of leakage, air has been pulled into the heat exchanger passages by the negative draft within the unit, lowering system efficiency.

Keep a record of efficiency tests

They have a saying in the nursing profession, “If you didn’t write it, you didn’t do it.” Why go to all the trouble of taking these tests if you don’t brag about it? Create or buy an efficiency test report form, and use it to record the results of your efficiency tests. These reports are important for three reasons:

1. They serve as a starting point for diagnosis and service.
2. Efficiency test results can be valuable sales tools when trying to convince customers to upgrade their equipment.
3. Having a written record can help protect you if there is ever a future problem.

With most of the electronic combustion test equipment available today, a printer option is available. This gives you proof that you performed the test. Additionally, it provides time, date, and exact information as to burner performance when you left the unit. This can be invaluable when having to prove the burner operation at the time you made the adjustments.

Typical Combustion Test Readings

Non-flame retention burners:
Oxygen: 5 - 9%

Flame Retention Oxygen:
3 - 6%

Carbon Dioxide:
10–12.5%

Stack Temp:
60–79% Efficiency 400°F to 600°F

Stack Temp:
80+ Efficiency 330°F to 450°F

Stack Temp:
90+ Efficiency less than 125°F

Draft:
-0.02”wc Over fire

Draft (Stack):
-.04”wc to -.06”wc

Carbon Monoxide:
Less than 50 ppm (diluted)

Smoke spot:
Zero to #1

Always Follow Manufacturer’s Specifications

Report to the customer

Your report to the customer can be written or oral. A properly written report, including a conservative estimate of savings you anticipate from any changes you have made or suggested, can build customer good will and increase equipment sales.

Combustion air test

Modern buildings are much tighter than the old buildings; some do not allow enough air to leak into the building from the outdoors to replace the air going up the chimney. Winterization practices on older homes have sealed many of the openings that formerly provided combustion air.

If the building does not allow enough infiltration air in, provisions must be made to bring in the outdoor air to replace the air used in the combustion process. The following test will tell you if you have enough infiltration.
1. Visually inspect the venting system for proper size and horizontal pitch and be sure there is no blockage, restriction, leakage, corrosion, or other deficiencies that could cause an unsafe condition.

2. Shut off the unit and any other fuel-gas-burning appliance within the same room.

3. Inspect burners for blockage and corrosion.

4. Furnaces: Inspect the heat exchanger for cracks, openings, or excessive corrosion.

5. Boilers: Inspect for evidence of water or combustion product leaks.

6. Insofar as is practical, close all building doors and windows and all doors between the space in which the appliance is located and other spaces of the building. Turn on the clothes dryer. Turn on any exhaust fans, such as range hoods and bathroom exhausts, so they will operate at maximum speed. Close fireplace dampers.

7. Place the appliance being inspected in operation.

8. Determine that the burner ignition and operation is satisfactory.

9. Turn on all other fuel and gas-burning appliances within the same room.

10. Determine that all units are burning properly.

11. Use a monometer to test if the pressure in the room that the unit is in is less than the pressure outdoors.

12. Return doors, windows, exhaust fans, fireplace dampers, and any other fuel-gas-burning appliance to their previous conditions of use.

A combustion analyzer can be used for finding leaking cracks or holes in a furnace heat exchanger. The static pressure created by the system blower can overcome any positive pressure in the heat exchanger causing air to leak into the fire side of the exchanger rather than out.

Readings that change when the blower comes on after stabilization has taken place are indicative of a combustion air, venting, or mechanical problem such as a cracked heat exchanger. Furnaces can have cleanout doors leaking that will test positive for leakage. This is not a heat exchanger failure. Inspection door gaskets should be replaced and doors should be properly sealed.

**Procedure:**

1. Follow the manufacturer’s instructions to properly zero the combustion analyzer. Insert the combustion analyzer probe in the flue pipe.

2. Start the furnace and observe the oxygen reading for stability (1-3 minutes).

3. When the blower starts, watch for a change in the $O_2$ reading. If the $O_2$ reading goes up, there is a leak.

**Corrective action: Attempt to visually find the crack or hole.**

A. If you can find the defect, show it to the customer.

B. On the service invoice, write that your testing indicates a leak in the heat exchanger. (Do this even if you cannot find the leak.)

C. Inform the customer, in writing, that the heat exchanger has a defect and that the furnace should be replaced. You should not attempt to repair a heat exchanger.
Checking and caring for the instruments

1. Smoke tester
   A. Clamp a piece of filter paper in the smoke tester. Place a finger over the end of sample tube and try to pull the plunger handle out and then release. The handle should return by itself to approximately the original position. If it does not, the hose, paper holder, and plunger should be checked for leaks. If leakage is indicated, the hose in the sampling line may need replacement. Leakage may also occur if the surfaces of the filter paper holder are damaged. These areas (on the nylon inserts) should be inspected. The plunger can be removed for inspection if leakage is occurring across the plunger.

   B. A clean piece of filter paper should be clamped in the smoke tester and a 10 stroke sample of fresh air taken after very dark smoke readings have been observed. If the air sample does not give a clean spot, repeat until it does. In extreme cases, the tube, and possibly the pump, may have to be cleaned with soap and water.

   C. Sticky action of the plunger can be helped by coating the plunger cup with petroleum jelly (Vaseline) after wiping the cup and the bore of the body clean.

2. CO₂ analyzer
   A. After about 200 samples have been measured with the analyzer, the fluid will begin to lose its strength. This can be checked by measuring a sample in the normal manner, after the height of the fluid is measured on the % CO₂ scale, invert the instrument two more times, let it drain, and reread. If the % CO₂ reading changes more than ½ a number, the fluid is becoming weak and should be replaced.

   B. The sampling pump should be checked for leaks in the following manner:

   1. Place a finger over the end of the sampling tube and squeeze the rubber bulb. The bulb should stay collapsed. If it does not, an air leak exists between the bulb and the sampling tube, or the discharge valve in the rubber bulb is leaking, Figure 7-25.

   2. Place a finger over the rubber connector at the other end of the pump and seal off the hole tightly. Apply moderate pressure to the rubber bulb. If the bulb cannot hold pressure, a leak exists between the bulb and the rubber connector or the suction valve in the rubber bulb is leaking.

   C. Any evidence of fluid leakage from the analyzer should be checked. Such leakage is an indication of possible air leaks in the analyzer, which will give inaccurate CO₂ readings.
D. If the CO₂ scale will not slide low enough to adjust the zero setting, it may be necessary to add water or more KOH fluid to bring up the fluid level. Add 2 or 3 drops of tap water into the space around the valve in the top of the analyzer. Depress the valve and release it several times, allow the water to drain down, and then check fluid level. If the level is still too low, add 2 or 3 more drops and repeat. This should be used only as a stopgap procedure until you can obtain new potassium hydroxide (KOH) fluid.

E. If the fluid must be changed, refill kits are available and a spare should always be kept on hand. This kit includes fluid, gasket, screws, and filter yarn for the pump. To change the fluid:

1. Remove four screws in top of analyzer.
2. Remove top and discard fluid and rubber gasket (do not spill fluid, it is harmful to hands, paint, etc.)
3. Clean unit using soap and water.
4. Pour in full bottle of new fluid.
5. Install new rubber gasket cover, and new screws. Tighten screws evenly. The filter yarn in the sampling pump must also be changed. This filter yarn may be changed more often than the fluid to provide easy sampling pump operation.

F. The analyzer should be stored in an upright position with the valve on top to prevent any possible fluid leakage. When placing the analyzer in the carrying case, it should be placed with its valve toward the handle side of the case. Extensive storage in warm places such as car trunks during summer should be avoided. The fluid should be checked for strength following long storage periods.

3. Oxygen (O₂ analyzers)

Measuring the oxygen content of the surrounding air can check the accuracy of oxygen sensors. When fresh air is drawn through the instrument, a reading of 20.9 percent O₂ should be observed. The instrument should be adjusted to this value. If you cannot get a 20.9% reading, replace the oxygen sensor.

4. Stack temperature gauge

A. Other than checking for obvious damage, the only problem that might occur with a temperature gauge is a bent stem. The gauge will not read accurately with a bent stem.

B. Many manual and electronic temperature instruments can be checked in boiling water (212°F), and readjusted if needed.

5. Draft gauge

A. Check to be sure the indicator needle moves freely. This can be done by blowing lightly across, and then toward, the end of the sampling tube. The needle should move smoothly and return accurately to the zero setting position.

B. The draft gauge should be checked against an accurate manometer at least once a year.

6. Electronic analyzer calibration

All manufacturer instructions concerning equipment care and maintenance must be followed carefully. Oxygen cells, batteries, and calibration of the instrument must be done as needed to assure accurate readings. Electronic analyzers should be sent back to the manufacturer for calibration as required by the manufacturer. This will insure
<table>
<thead>
<tr>
<th>Problem</th>
<th>Possible Cause</th>
<th>Remedy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insufficient O₂ and/or excess carbon monoxide production</td>
<td>Insufficient combustion air</td>
<td>Adjust air band settings(s)</td>
</tr>
<tr>
<td></td>
<td>Burner over firing</td>
<td>Adjust fuel input</td>
</tr>
<tr>
<td></td>
<td>Low stack draft</td>
<td>Adjust/install barometric control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Check for restricted heat exchanger or vent system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Check for improperly sized or improperly constructed chimney or vent system</td>
</tr>
<tr>
<td>High O₂ reading</td>
<td>Excess combustion air</td>
<td>Adjust air band settings(s)</td>
</tr>
<tr>
<td></td>
<td>Burner under firing</td>
<td>Adjust fuel input</td>
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<tr>
<td></td>
<td>Loose cleanout ports, access doors, gasket missing in boiler sections</td>
<td>Repair</td>
</tr>
<tr>
<td></td>
<td>Excess stack draft</td>
<td>Adjust/install barometric control</td>
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<tr>
<td>Fluctuation in O₂ and/or carbon monoxide readings</td>
<td>Changing atmospheric conditions (i.e. wind speed)</td>
<td>Evaluate for barometric control</td>
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<td>Cracked Heat Exchanger</td>
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<td>Loose cleanout ports or gasket missing in boiler sections</td>
<td>Repair</td>
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<td>Excess stack temperature</td>
<td>Inadequate air flow across the heat exchanger</td>
<td>Check for dirty filter, blower and/or air conditioning coil</td>
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<tr>
<td></td>
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<td>Increase blow speed. Don’t over amp motor!</td>
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<td>Increase return or supply ducting if needed</td>
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<td>Insufficient stack temperature</td>
<td>Burner underfired</td>
<td>Adjust fuel input</td>
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<td></td>
<td>Excess air flow past heat exchanger</td>
<td>Check temperature rise per manufacturer</td>
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<tr>
<td>Low temperature rise</td>
<td>High fan speed</td>
<td>Decrease fan speed or baffle blower to reduce air flow</td>
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<td>Burner underfired</td>
<td>Adjust fuel input</td>
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<tr>
<td>Low stack draft</td>
<td>Improperly sized vent connector or chimney</td>
<td>Properly size system</td>
</tr>
<tr>
<td>*Less than -0.02 WC° in flue (gas)</td>
<td>Blocked vent system</td>
<td>Remove blockage</td>
</tr>
<tr>
<td>*Less than -0.04 WC° in flue (oil)</td>
<td>Excess elbows or long horizontal runs</td>
<td>Re-vent or move appliance to better location for venting</td>
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<tr>
<td>*Less than -0.02 WC° over fire with gas or oil power burners</td>
<td>Leakage in chimney or vent connections</td>
<td>Seal</td>
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<td>Improper vent termination</td>
<td>Re-vent</td>
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<td></td>
<td>Inadequate combustion air</td>
<td>Add combustion air</td>
</tr>
<tr>
<td></td>
<td>Improperly adjusted barometric control</td>
<td>Adjust</td>
</tr>
<tr>
<td>High stack draft</td>
<td>Improper vent system sizing</td>
<td>Properly size system</td>
</tr>
<tr>
<td>*Greater than 0.04 WC° in flue (gas)</td>
<td>Absence of or improperly adjusted barometric control</td>
<td>Install or adjust barometric control</td>
</tr>
<tr>
<td>*Greater than 0.06 WC° in flue (oil)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>