# Combustion Analysis Target Operating Ranges
## (Residential Oil Burner)

| Parameter | Ideal Range | Accept-able | Action Required | Cause/Fix | |
|---|---|---|---|---|---|
| $O_2$ (%) | 3 – 5% | 2 – 6% | <2% or >8% | **Low**<br>**Causes:** Too little excess air, excessive draft<br>**Fix:** Increase air, adjust barometric damper | **High**<br>**Causes:** Too much excess air, insufficient draft<br>**Fix:** Reduce air, adjust barometric damper |
| $CO_2$ (%) | 12 – 13% | 11 – 13.0% | <10% or >13.5% | **Low**<br>**Causes:** Too much excess air, insufficient draft<br>**Fix:** Reduce air, adjust barometric damper | **High**<br>**Causes:** Too little excess air, excessive draft<br>**Fix:** Increase air, adjust barometric damper |
| CO (ppm) | 0 – 10 PPM | 10 – 50 PPM | CO >50 PPM | ***CO above acceptable levels can cause serious physical harm or death.***<br>**Causes:** Flame impingement, poor air/fuel mix, blocked heat exchanger, nozzle issues, draft problems, too little excess air, damaged burner head<br>**Fix:** Increase air, check nozzle, clean heat exchanger, verify draft, replace burner head | |
| Stack Temp (°F) | 350°F – 500°F | 300°F – 550°F | <300°F or >600°F | **Low**<br>**Causes:** Underfired<br>**Fix:** Verify firing rate & draft | **High**<br>**Causes:** Dirty heat exchanger, high excess air, overfired<br>Fix: Clean Heat exchanger, optimize air/nozzle |
| Draft Over Fire (in. w.c.) | -0.01 to -0.02 | -0.005 to -0.03 | Unstable | **Low**<br>**Causes:** Blocked heat exchanger, underfiring<br>**Fix:** Inspect/clean flue passes, set firing rate to manufacturers spec. | **High**<br>**Causes:** Mis-adjusted draft regulator<br>Fix: Adjust draft regulator |
| Draft Breech (in. w.c.) | -0.02 to -0.04 | -0.01 to -0.06 | <-0.01 or >-0.06 | **Low**<br>**Causes:** Leaky or undedrsized chimney, thimble, stack or breech, chimney obstruction, draft regulator adjustment<br>**Fix:** Seal leaks, clear chimney, adjust draft regulator to manufacturer's spec. | **High**<br>**Causes:** Oversize chimney, cold outdoor temp, miss-adjusted draft regulator, air entering combustion chamber<br>**Fix:** Adjust draft requlator, close/seal leaks in appliance |
| Smoke Number | 0 | 0-trace | #1 or higher | **High**<br>**Causes:** Insufficient air, poor fuel atomization, dirty burner, air in fuel<br>**Fix:** Increase air, check pump pressure/nozzle | |
| Efficiency (%) | 84 – 88% | 82 – 90% | <80% | | |

### Adjustment Procedure

1. Set burner to trace smoke
2. Check draft (over fire & breech)
3. Add air until $CO_2$ drops 1-1.5%
4. Verify CO (<25 ppm)
5. Confirm stack temp & efficiency
6. Document readings

**Smoke Test Video**

**Combustion Analyst Video**

**Learning & Resources Videos**

NORA Advancing Liquid Fuel Home Heating

LearningSupport@NORAweb.org
Learning.NORAweb.org

**Always follow manufacturer specifications for burner setup and operating limits.**
**The ranges provided are typical reference values only. Manufacturer-defined limits always take precedence.**

## $CO_2/O_2$ – Excess Air

*Typical operating ranges*
*$CO_2$: 11.5–13.0%*
*$O_2$: 4.0–5.3%*
*Excess air: 25–35%*

$CO_2$ and $O_2$ indicate the amount of excess air in the combustion process. Excess air is the additional air supplied beyond theoretical requirements to ensure stable, safe, and smoke-free combustion under real operating conditions.

As excess air increases, $O_2$ rises and $CO_2$ decreases. Measuring either $CO_2$ or $O_2$ allows the technician to evaluate the air–fuel balance.

Excess air provides a safety margin to compensate for variables such as draft, air and fuel temperature, burner settings, and system condition. Proper adjustment is a balance between combustion stability & efficiency.

**Too little excess air**
Incomplete combustion, smoke, soot, unstable flame.

**Too much excess air**
Higher stack temperature, reduced efficiency, flame cooling, possible CO increase, and flame detachment. Excessive excess air can lead to smoke, soot, control lockout, heat exchanger fouling, and burner head coking.

## Carbon monoxide (CO)

*Typical ranges:*
*In flue gas: Single digits to 30 ppm*
*Ambient: 0 – 5 PPM*

CO can be produced by both insufficient or too much combustion air. Mismatched fuel and air patterns and ratios as well as flame impingement can also lead to high CO production.

**Light off CO levels:**
CO levels at light off are typically higher, but quickly drop and stabilize. Unusually high CO levels may be an indication of rough or delayed ignition, warranting further investigation. CO readings should stabilize quickly and should never be rising during operation.

**Mechanical problems & CO:**
If the appliance being tested has sufficient combustion air and is still producing higher than acceptable CO levels, it could be a mechanical problem. Inspect the burner and appliance for cleanliness, proper firing assembly alignment and adjustment, missing burner covers, missing or damaged burner components, improper air adjust-ment or incorrect fuel pressures, defective or incorrect nozzle.

Check the appliance, inspect the combustion chamber for damage or excessive debris. Look for evidence of flame impingement, which occurs whenever the flame is hitting a surface.

**Initial start-up CO levels:**
When a new appliance is installed, manufacturing residue often causes temporarily elevated CO levels. These levels typically drop after approximately 15 minutes of operation.

## Stack Temperature

*Typical Net Range: 350°–500°F*

Flue gas temperature is the temperature of combustion gases leaving the appliance. It indicates how effectively the heat exchanger transfers heat from the combustion gases to the system. Stack temperature is influenced by burner adjustment, heat exchanger condition, and draft.

Measurements taken at the breech are “gross” readings.

To determine “net” flue gas temperature, subtract the burner inlet air temperature. Electronic analyzers calculate this automatically; wet kits require manual correction. In non-condensing, chimney-vented appliances, gross temperatures must remain above 350°F to prevent condensation.

**Common causes of high flue gas temperature**:
- Soot/carbon deposits reducing heat transfer
- Excess air from poor adjustment or air leaks
- Overfiring above rated input
- Excessive draft reducing heat transfer time

**Low flue gas temperature:**
Flue gas temperatures that are too low can cause condensation. Net stack temperature should typically be 270°–370°F, depending on chimney design. High-efficiency equipment may operate at the low end of this range; systems with draft regulators should operate toward the high end.

**Dew point:**
The dew point is the temperature at which water vapor in flue gas condenses. If chimney or vent temperatures fall below the dew point, condensation will occur.

## Draft

*Typical range: -.04” at breech.*
*.01” to -.02” over fire*

Draft is measured in inches of water column at two locations: over the fire (in the combustion zone) and at the breech in the flue pipe. The difference between these readings is called the draft drop. Always follow the appliance manufacturer’s recommended draft drop.

Excessive draft causes flue gases to move too quickly through the appliance, reducing efficiency and potentially pulling the flame away from the combustion head. High draft is usually corrected by adjusting the draft regulator.

Insufficient draft reduces combustion air, leading to incomplete combustion and possible smoke.

Low draft at the breech is commonly caused by air leaks in the chimney or breeching, chimney obstructions, or improper draft regulator adjustment.

Low draft over the fire is often caused by soot in the heat exchanger, overfiring, or underfiring.

Corrective action includes sealing leaks, clearing obstructions, cleaning heat exchanger surfaces, and setting the firing rate to manufacturer specifications.

**NOTE: Some appliances operate with positive draft over the fire. This is another reason to ALWAYS refer to the manufacturer’s instructions.**

## Smoke Number

*Target: Zero*

Smoke and soot are unburned carbon caused by improper burner adjustment, poor maintenance, or outdated equipment. Smoke is unacceptable because it reduces efficiency, increases service calls, and creates safety risks. Even a thin soot layer (1/8") can reduce heat transfer by more than 8% and may cause burner lockouts if it covers sensors or controls.

Modern burners are designed to operate at zero smoke. Any reading above zero indicates the need for adjustment, service or equipment upgrade.

**Common causes of smoke:**
- Poor fuel atomization (worn nozzle, incorrect pressure, cold fuel)
- Inadequate combustion air (restricted airflow, dirty components, poor draft, improper setup)
- Air in the fuel (afterburn or foaming under high vacuum)

Smoke is measured by comparing flue gas samples to a calibrated smoke scale.

NORA Advancing Liquid Fuel Home Heating
**LearningSupport@NORAweb.org**
**Learning.NORAweb.org**