Burn Baby Burn: The Art and Science of Making Flames Behave

A Practical Guide to Combustion, Burner Tuning, and Avoiding Explosions

By Craig Prescott

Foreword: Why This Book Exists

This book is about **making flames behave.**

It's not a fluffy theory textbook, and it's not an ultra-dry engineering manual that makes you want to throw it into a furnace (although, technically, that would be a combustion reaction). Instead, this is a **real-world guide**—a mix of **science, troubleshooting, and practical wisdom** from someone who's spent years getting flames to do what they're supposed to do.

Why? Because combustion is an **art** as much as a science. Sure, the equations are important, but **numbers don't light flames—people do.**

So, whether you're a **newbie**, a **seasoned engineer**, or just someone who likes fire a little too much, this book is for you. We'll cover **burner tuning, flame behaviours, troubleshooting, and myths that refuse to die**. And we'll do it without making you fall asleep.

Chapter 1: How Not to Blow Yourself Up

Combustion: A Love Story (with Occasional Explosions)

At its core, **combustion is simple**:

- **Fuel + Oxygen + Heat = Fire.**
- Remove any of those, and you have **nothing**.
- Mess up the balance, and you have **CO, soot, efficiency losses, or an explosion.**

The Fire Triangle & The Fire Tetrahedron

If you've ever seen a safety poster, you know about the **fire triangle**:

Fuel (Gas, oil, coal, biomass, hydrogen, etc.)

Oxygen (Usually from air)

Heat (Ignition source)

But real-world combustion isn't that simple. Enter the **Fire Tetrahedron**:

1. **Fuel** (Same as before)
2. **Oxygen** (Air supply, including excess air)
3. **Heat** (Pilot, spark, or hot surface ignition)
4. **Mixing & Turbulence** (The part most people ignore, and why their flames suck)

Without proper **mixing**, you get **rich pockets (CO formation) or lean pockets (flame instability and NOx spikes)**. You need turbulence for **even mixing and complete combustion**.

So yes, a flame is just a chemical reaction—but **getting it right is the tricky part.**

The Perfect Flame is a Lie

Some people chase the idea of a **perfect** flame. Here's a reality check:

There is no such thing as a perfect flame.

There is only an optimal flame for your system.

And that flame changes depending on load, fuel, air, and process conditions.

What does that mean in practice? **Stop chasing perfection—chase optimization.**

A well-tuned burner isn't just about getting a blue flame or hitting a magic O_2 number on your analyser. It's about making sure the flame:

Is stable (No pulsing, lift-off, or oscillations)

Is burning all the fuel (No CO spikes, no unburnt hydrocarbons)

Is transferring heat efficiently (No excess heat loss, no impingement)

Isn't destroying the burner itself (Yes, that's a thing)

A perfect number on your flue gas analyser **doesn't mean jack** if your flame is unstable or impinging on your refractory.

Why Your Burner Hates You (And How to Fix It)

If your burner trips, sputters, or misbehaves, it's **trying to tell you something.**

Common burner complaints and their meanings:

1. **It trips on flame failure.** → Either it didn't light properly, or it's losing stability.
2. **It makes weird noises.** → It's either **starving** (lean flame) or **getting too much air/fuel too fast** (high momentum flame).

3. **The flame is lifting off.** → Air velocity is too high, or your swirler settings are wrong.
4. **It keeps tripping on high CO.** → Either it's too rich OR it has too much over-air stripping the fuel away before it can burn.
5. **It won't light consistently.** → Ignition source is weak, fuel isn't atomizing properly, or pre-purge settings aren't right.

Burners aren't **just** equipment. They have **personalities**—some are easy to work with, others fight you every step of the way. Your job is to figure out **what it needs** to run properly.

Combustion's Greatest Myths (That Refuse to Die)

Now, before we go further, let's kill some **common combustion myths**:

"More excess air is always good."

False. Too much air cools the flame, reduces efficiency, and can even cause CO formation due to over-air momentum.

"CO only happens when you're running rich."

False. Over-air flames with high velocity can strip fuel before it fully burns, creating CO.

"Blue flames are always perfect."

False. You can have a blue flame that's making CO. You need actual gas analysis.

"Just set it once and forget it."

False. Changes in load, temperature, humidity, and fuel composition mean you need to check and re-tune regularly.

"Flue gas analysis tells you everything."

False. It tells you **a lot**, but if you ignore flame shape, impingement, and heat transfer, you're missing the full picture.

Flame Behaviour 101

A happy flame is:

Steady, not flickering wildly.

Well-anchored, not lifting off or snuffing out.

Not roaring like a jet engine unless it's supposed to.

Not slamming into the process equipment.

If your flame **is misbehaving, it's trying to tell you something.** Your job is to figure out **what** and adjust accordingly.

Final Thoughts: Welcome to the Fire Club

If you've made it this far, congratulations. You now know more about combustion than most people. And you've learned that:

Flames have personalities.

Burners can be jerks.

Tuning is an art as much as a science.

This book won't solve all your combustion problems—but it'll make you laugh while you fix them. And if all else fails? **Turn it off and try again.**

Chapter 2: Dancing with Fire – The Art of Flame Tuning

Tuning a burner is like tuning a guitar—if guitars ran on pressurized fuel and could explode.

The Art vs. The Science of Tuning

If combustion were purely a science, we'd just plug in a few numbers, press a button, and get the perfect flame every time. But in reality, tuning a burner is **part science, part art, and part sheer stubbornness.**

A **good burner technician** listens, watches, and adjusts **based on what the flame is telling them**—because burners, like musicians, each have their own quirks.

Some **light smoothly** and run flawlessly.

Others **sputter, lift off, make weird noises, and throw CO tantrums** for no apparent reason.

And some just flat-out refuse to behave unless you tweak every setting manually.

The secret? **Knowing what to change and why.**

What Actually Affects Flame Shape?

Your flame shape is controlled by **four key factors:**

1. **Fuel Pressure** – Higher pressure means more velocity, which changes flame length and stability.
2. **Airflow (Primary & Secondary Air)** – Controls the mixing, anchoring, and turbulence.
3. **Swirl** – The rotation of air and fuel in the burner throat (affects flame width and stability).
4. **Burner Tile & Furnace Pressure** – Confinement and backpressure change how the flame behaves.

The **goal of tuning** is to balance these four forces, so the flame is:

Stable (No lifting, snuffing out, or flashbacks)

Efficient (Burning completely with minimal CO and NOx)

Transferring heat properly (Not too long, too short, or impinging on anything)

Flame Tuning Cheat Sheet

Issue	Cause	Fix
Flame lifting off burner	Too much air velocity, poor anchoring	Reduce excess air, adjust swirl, increase fuel pressure slightly
Flame impingement (hitting walls/tubes)	Flame is too long or unstable	Increase swirl, reduce fuel pressure, check furnace pressure
Pulsing or unstable flame	Poor mixing, wrong air-fuel ratio, fluctuating conditions	Stabilize air supply, check dampers, adjust fuel valve response time
CO emissions too high	Incomplete combustion (either too much or too little air)	Fine-tune excess air, improve mixing, reduce over-air stripping
Excessive NOx	Too high flame temp, excessive excess air	Reduce peak temps with flue gas recirculation, lower excess air slightly
Delayed ignition or misfire	Poor fuel atomization, weak ignition source	Check igniter, adjust fuel pressure, verify purge sequence

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Tuning by the Numbers: Flue Gas Analysis

You can't tune a burner **by eye alone**—you need to check your **flue gas composition.**

Ideal Combustion Targets (Natural Gas):

- **O_2:** 2%–4% (Lower means more efficiency, but too low risks CO)
- **CO:** <50 ppm (Higher means incomplete combustion)
- **CO_2:** 8%–10% (More CO_2 = more efficiency, but only if CO is low)
- **NOx:** <30 ppm (Lower is better, but depends on burner type and regulations)

Why O_2 Isn't Everything

Many operators **only** look at the O_2 reading and think that's the whole story. But:

- High O_2 **doesn't always mean complete combustion**—excess air momentum can cause **CO formation.**
- Low O_2 **doesn't always mean rich combustion**—flame quenching from improper mixing can cause CO even at low air levels.

You need to check **O_2, CO, and flame stability together.**

Swirl: The Secret Sauce of Burner Tuning

What Does Swirl Actually Do?

Swirl controls **flame shape, stability, and anchoring.**

- **No Swirl (Axial Flow)** → Long, thin, unstable flame.
- **Low Swirl** → Controlled, moderate length, stable flame.
- **High Swirl** → Short, wide flame with better anchoring.

How Swirl Fixes Common Problems

- If your **flame is too long**, **increase swirl**.
- If your **flame is unstable**, **increase swirl slightly** to improve mixing.
- If your **flame is lifting off**, **reduce swirl and check primary air.**

Rule of Thumb: More swirl = better mixing, but too much can **disrupt anchoring** and cause CO spikes.

How Not to Over-Tune Your Burner

One of the biggest mistakes in combustion tuning is **chasing a "perfect" number instead of a stable process.**

Signs You've Over-Tuned:

O_2 is low, but CO is high → You've pushed too far, incomplete combustion is happening.
Flame is unstable, even though flue gas looks okay → You've sacrificed stability for efficiency.
Burner trips on small load changes → Your settings are too tight for real-world operation.
Combustion isn't about hitting a single magic number—it's about making the flame stable and efficient.

Flame Stability: The Silent Killer of Efficiency

Some burners LOOK like they're running fine—until you check their stability.

How to Spot an Unstable Flame:

Flickering excessively at the base (poor anchoring)
Pulsing (air/fuel ratio is fluctuating)
Sudden CO spikes at steady load (mixing issues)

Rule of Thumb: If your CO is fluctuating, your flame is unstable. And if your flame is unstable, your efficiency is garbage.

The best way to fix it? **Adjust air distribution, fuel pressure, and swirl until the flame STAYS PUT.**

Final Thoughts: Tuning is a Dance, not a Science Experiment

Tuning a burner isn't just about **hitting the right O_2 number** or **turning random knobs**—it's a **dance.**

- **If you push too much air, the flame lifts off.**
- **If you pull too much air, CO spikes.**
- **If you add too much swirl, the flame widens and shortens.**
- **If you ignore swirl, the flame gets lazy and inefficient.**

A good tuner doesn't just adjust blindly—they **watch, listen, and react** to what the flame is doing.
And that's why combustion tuning is an **art** just as much as a science.

Chapter 3: The Myth of "Perfect Combustion"

Spoiler: There's no such thing, and anyone who tells you otherwise hasn't tuned a burner in real life.

Why "Perfect" Doesn't Exist

If I had a dollar for every time someone asked for **"perfect combustion,"** I'd be rich enough to buy a yacht, set it on fire, and analyse the flue gas just for fun.

Here's the truth:

Perfect combustion is a myth.

What we actually chase is optimal combustion.

And optimal changes depending on your process, fuel, and operating conditions.

What works beautifully in one system **might be completely wrong for another.** And yet, people still obsess over the idea that there's a magic **air-to-fuel ratio that makes everything perfect.**

Let me save you some time:

- **Stoichiometric combustion** (where every molecule of fuel reacts with exactly the right amount of oxygen) **is theoretical.**
- In the real world, we run with **excess air or excess fuel** to ensure stability.
- The more stable and efficient your flame, the **closer you are to "perfect" combustion**—but you'll never hit a single fixed number.

Why Stoichiometry is Just a Starting Point

What is the "Perfect" Air-to-Fuel Ratio?

Technically, the **stoichiometric ratio** is:

Natural Gas (CH_4) Combustion Equation:

CH4+2O2→CO2+2H2OCH_4 + 2O_2 → CO_2 + 2H_2OCH4+2O2→CO2+2H2O

In this ideal reaction, **every molecule of methane reacts with oxygen to form only CO_2 and water, with zero CO or unburnt hydrocarbons.**

The problem?

- **Real-world burners don't mix fuel and air perfectly.**
- **Combustion occurs in zones**, not in a perfectly uniform mixture.
- **Load fluctuations constantly change the ratio.**

That's why we use **excess air**—to make sure we burn all the fuel, even in areas with poor mixing.

Why Excess Air is Necessary (But Too Much is Bad)

Excess Air %	What Happens?
0% (Stoichiometric)	Theoretical only—CO will form due to local rich pockets.
5-10%	Very efficient, but borderline unstable. Risk of CO spikes.
10-15%	Normal range for most burners—good efficiency with stable combustion.
20-30%	Safe but wasteful—excess air carries heat up the stack.
30%+	Too much air cools the flame, NOx rises, efficiency drops.

Chasing the "Magic O_2 Number" is a Trap

Every combustion manual has **an O_2 target**—but if you chase that number **without understanding flame stability**, you're asking for trouble.

Why You Can't Tune on O_2 Alone:

1. **Low O_2 ≠ Good Combustion** – If O_2 is too low, you're at risk of CO formation and unstable flames.
2. **High O_2 ≠ Bad Combustion** – But too much excess air reduces efficiency and increases NOx.
3. **Mixing Matters More Than O_2** – Even with a "perfect" O_2 number, poor mixing will create **rich pockets, CO formation, and wasted fuel.**

Real-World Example:

I've seen burners running at **2% O_2 with massive CO spikes** because of flame quenching. The operator thought **low O_2 meant efficiency,** but the flame was unstable and stripping fuel before it could fully burn. The result? **CO alarms, efficiency losses, and lots of swearing.**

What's "Optimal" for Your Process?

Instead of chasing a mythical "perfect" setting, you should aim for **the best trade-off between efficiency, stability, and emissions.**

What Actually Matters in Tuning?

Stable flame shape and anchoring – No lifting, no impingement, no pulsing.

CO levels consistently low – A sign that combustion is complete.

Flue gas temperatures within target range – Not wasting heat up the stack.

Minimal NOx without killing efficiency – (Lower excess air where possible).

How Different Applications Have Different "Perfect" Settings

Application	Target O_2 (%)	Notes
Kiln/Furnace	3-5%	Needs controlled heat transfer, flame stability is key.
Industrial Boiler	2-4%	Higher excess air for safety, but lower O_2 = better efficiency.
Power Plant Boiler	3-6%	NOx control needed, often tuned with flue gas recirculation.
Process Heater	1.5-3%	More aggressive tuning possible with good burner design.

Moral of the Story:

- You don't run a kiln the same way you run a boiler.
- You don't run a process heater the same way you run a refinery furnace.
- And **you don't tune for an O_2 number—you tune for stable, efficient combustion.**

Common Mistakes When Chasing "Perfect" Combustion

Mistake #1: "We Just Need to Get O_2 Lower"

If you keep lowering O_2 to chase efficiency, you'll eventually hit CO formation or unstable combustion.

Mistake #2: "More Air is Always Better"

Too much excess air **reduces flame temperature, kills efficiency, and increases NOx.**

Mistake #3: "We'll Just Set It and Forget It"

Load conditions change, ambient air conditions change, and **tuning needs to be checked regularly.**

Mistake #4: "The Analyzer Says It's Fine, So It Must Be Fine"

Analysers give you numbers, but **if your flame is unstable, your process is suffering even if the numbers look good.**

The Real Goal: Smart, Adaptive Combustion Tuning

Instead of chasing a mythical perfect flame, a **good burner tech** does the following:

✓ **Tunes for lowest stable O_2 without CO formation.**

✓ **Balances air/fuel ratio to maintain good flame shape and heat transfer.**

✓ **Adjusts settings based on load, process conditions, and real-world behaviours.**

✓ **Looks beyond just O_2 and checks CO, NOx, flame shape, and stability.**

At the end of the day, the **best combustion setting is the one that works best for your specific system.**

Final Thoughts: Burners Are Like People—Some Are Just Jerks

Some burners light easily, hold a steady flame, and make your job easy. Others trip out at the slightest change, make weird noises, and refuse to behave no matter what you do.

But the best way to handle them is to **stop chasing a magic number and start reading what the flame is telling you.**

If you take one thing from this chapter, let it be this:

There's no perfect number. There's only the best setting for your system.

And that's what real combustion tuning is all about.

Chapter 4: CO – The Silent Killer That Won't Just Go Away

Why CO is a problem, why it's not just about excess fuel, and why your analyser doesn't tell the whole story.

CO: Not Just a "Too Much Fuel" Problem

If you ask most people why CO forms in combustion, they'll say, **"Too much fuel, not enough air."**
And they're **half right.**

Carbon monoxide (CO) **is the result of incomplete combustion**, meaning the fuel didn't fully oxidize into CO_2. But the **cause** isn't always just **too much fuel.** In fact, many CO problems are caused by **too much air, poor mixing, or flame instability.**

Yes, you read that right. **You can make CO with excess air.**

Key takeaway: If you're chasing CO problems by only adjusting fuel flow, you're **only solving half the problem.**

Why CO Formation is a Bigger Deal Than People Think

Carbon monoxide isn't just **a regulatory headache**—it's a **direct sign that your combustion process is wasting fuel.** If CO is forming, it means fuel molecules are **partially combusting instead of fully converting into CO_2**, meaning you're losing:

- **Efficiency (wasted fuel = wasted money)**
- **Heat energy (CO is an incomplete combustion product, meaning you didn't extract all the energy from the fuel)**
- **Process stability (high CO often means fluctuating or unstable combustion)**

And let's not forget the **safety** risks. CO is:

Toxic – Binds to haemoglobin in your blood, reducing oxygen transport.

Odourless – You won't know it's there unless you measure it.

A sign of burner problems – Even low levels in flue gas mean something isn't right.

CO Formation: It's All About Reaction Time and Mixing

CO forms when fuel molecules don't fully react with oxygen before leaving the flame zone. There are **three major reasons this happens:**

1. Too Much Fuel (Rich Combustion)

What happens?

- Not enough oxygen to fully oxidize the carbon → CO forms instead of CO_2.
- More common in **poorly tuned gas burners, oil burners with bad atomization, and coal combustion.**

🔧 **How to fix it?**

Increase air slightly (but not too much).

Improve burner mixing.

Check for localized fuel-rich zones in the flame.

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2. Too Much Air Momentum (Over-Air Combustion)

What happens?

- If air velocity is too high, it **strips** fuel molecules out of the high-temperature flame zone before they can fully combust.
- Creates **localized cooling**, leading to CO formation.
- This is a major issue in **high-swirl burners, high-velocity systems, and improperly tuned air registers.**

How to fix it?

Reduce excess air slightly.

Improve mixing patterns to ensure the fuel stays in the flame zone longer.

Adjust swirl and air registers to balance velocity.

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3. Poor Mixing or Flame Quenching

What happens?

- If fuel and air **aren't evenly mixed**, some areas go **fuel-rich** while others go **too lean.**
- Incomplete combustion happens in rich pockets.

- Lean zones **quench the flame** before full oxidation occurs, trapping CO before it turns into CO_2.
- This often happens in **poorly tuned staged combustion burners, under-fired burners, or burners operating at turndown.**

How to fix it?
Optimize **fuel/air mixing** by adjusting swirl and fuel jet positions.
Increase burner temperature to avoid premature quenching.
Improve burner flame pattern to avoid dead zones.

Flame Quenching – The Sneaky CO Problem No One Talks About
Most combustion engineers focus on **air-to-fuel ratios**, but they ignore **flame quenching**—one of the most common CO formation mechanisms.
What is flame quenching?
When combustion gases cool too quickly, the reaction stops before CO can fully convert to CO_2.
Why does this happen?

- **Cold furnace walls** pulling heat away too fast.
- **Too much air causing excessive cooling.**
- **Poor burner placement leading to bad flame interaction with walls.**

What does it look like?

- High CO even with normal excess air.
- CO spikes when load changes suddenly.
- Poor flame stability, flickering, or snuffing out.

How to fix it?

- Ensure flame **stays hot enough** to allow full oxidation.
- Reduce **over-airing** that cools the flame prematurely.
- Check **flame shape**—avoid impingement or excessive cooling.

Why Your CO Analyzer is Lying to You
You might think, **"I'll just check the CO reading on my flue gas analyser, and if it's low, I'm fine." Wrong.**
CO analysers measure **what's making it to the stack**, not what's happening inside the burner. Here's why that matters:

1. **CO Can Form in the Flame and Burn Out Before It Hits the Stack**
   - If your combustion chamber is **long enough**, CO might have time to finish converting to CO_2.
   - You'll never see it on the analyser, but it's still **stealing efficiency inside the burner.**
2. **CO Can "Disappear" Due to Secondary Air or Air Leaks**
   - Some furnaces have **secondary air or leaks** that introduce extra oxygen after combustion, making it look like CO is lower than it really was at the flame.
3. **CO Spikes Might Only Last a Few Seconds**
   - If your analyser isn't **fast-response**, it might miss **short-duration CO spikes**, especially during load changes.

Solution? Don't just trust your flue gas readings. **Watch the flame behaviours, look for CO spikes during transitions, and consider in-flame measurements when possible.**

CO and Load Changes: Why It Spikes When You Least Expect It
Ever notice CO spikes **right after a load change**? That's because burners take time to respond to new fuel/air settings.
Why it happens:

- **Fuel valve moves faster than air control**, creating a temporary fuel-rich condition.
- **Sudden shifts in burner pressure** cause turbulence and poor mixing.
- **Flame momentarily destabilizes**, creating incomplete combustion pockets.

How to reduce CO spikes?
Ensure your fuel and air controls **move at the same rate** during transitions.
Use **ramp rates** to avoid sudden swings in combustion conditions.
Check for **control system deadband**—small delays in feedback loops can cause temporary CO excursions.

Final Thoughts: CO is a Symptom, Not the Disease

T**he Big Takeaways:**

✓ CO isn't just from too much fuel—it's from poor mixing, over-air, and flame quenching.

✓ You can't trust a single analyser reading—watch for **transients and flame behaviours.**

✓ Tuning is more than O_2—good combustion needs **stable flames, proper mixing, and controlled velocity.**

So next time someone says, **"We just need to add more air to fix the CO problem,"** you'll know to respond with:

"Are you sure about that?"

Chapter 5: Why Your Burner Hates You (And How to Fix It)

Burner tripping? Pulsing flames? Random failures? It's trying to tell you something—if you know how to listen.

Burners Have Personalities (And Some Are Jerks)

If you've worked with combustion long enough, you know **some burners just don't want to behave.**

- Some light instantly, hold a stable flame, and make life easy.
- Others **trip, pulse, scream, lift off, or randomly fail—just to mess with you.**
- And then there are those that **work fine for weeks, then suddenly refuse to light for no reason.**

Why? Because Burners Are Like People.

They need the right conditions to function. If something is off—fuel pressure, air supply, mixing—they **throw a tantrum.**

Your job? **Figure out what's making your burner mad and fix it.**

The Burner Troubleshooting Cheat Sheet

Before we get into details, here's a quick **troubleshooting reference**:

Problem	Likely Cause	Fix
Flame won't light	Low ignition energy, poor air/fuel ratio, bad atomization (for oil)	Check spark/pilot, adjust purge, verify fuel pressure
Burner lights but trips on flame failure	Weak flame signal, unstable flame, incorrect fuel pressure	Adjust air/fuel ratio, check flame scanner, verify swirler settings
Flame lifting off burner	High air velocity, poor anchoring	Reduce excess air, adjust swirl, increase fuel pressure slightly
Flame impingement (hitting tubes/walls)	Long flame, poor distribution	Increase swirl, adjust fuel pressure, check furnace pressure
Pulsing or unstable flame	Poor mixing, wrong air-fuel ratio, fluctuating conditions	Stabilize air supply, check dampers, adjust fuel valve response
CO emissions too high	Incomplete combustion, bad mixing, excess air stripping fuel	Fine-tune excess air, improve mixing, reduce over-air stripping
Excessive NOx	High flame temp, excessive excess air	Reduce peak temps with flue gas recirculation, lower excess air slightly
Delayed ignition or misfire	Poor atomization (for oil), weak ignition source, bad air/fuel ratio	Check igniter, adjust fuel pressure, verify purge sequence

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Why Your Burner Keeps Tripping (And Making You Look Bad)

Nothing is more frustrating than a burner that randomly trips out for no obvious reason.

If your burner keeps failing, one of these things is happening:

1. Flame Is Weak or Unstable

If the burner lights but then **trips on flame failure**, the flame might be too weak for the sensor to see.

Causes:

- **Excess air too high** – Weakens flame intensity.
- **Flame scanner misaligned** – It can't "see" the flame properly.

- **Swirl too high** – Flame is too short and unstable.
- **Low fuel pressure** – Not enough heat release for stable combustion.

Fixes:
Reduce excess air slightly (without creating CO).
Adjust scanner alignment and sensitivity.
Reduce swirl (if flame is too short).
Increase fuel pressure slightly to improve flame stability.

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2. Ignition Issues (Delayed or No Light-Off)
Does your burner **hesitate before lighting**, or **fail to light at all**? That's an ignition problem.
Causes:

- Weak or misfiring spark/pilot.
- Poor atomization (for oil burners).
- Incorrect purge timing (too much or too little).
- Incorrect air/fuel ratio at startup.

Fixes:
Check pilot flame—if it's weak, main burner won't light.
Verify atomization—poorly atomized fuel won't ignite.
Optimize purge settings—too much air before ignition makes lighting harder.
Check igniter spark—weak or intermittent sparks = unreliable light-off.

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3. Airflow Issues (Flame Lift-Off or Sudden Extinction)
Flame lift-off happens when air velocity is **too high**, stripping fuel away before it can fully burn.
Causes:

- Too much excess air.
- High furnace pressure reducing flame anchoring.
- Improper swirler settings.
- Sudden air damper movements disrupting the flame.

Fixes:
Reduce excess air slightly.
Check furnace pressure—ensure it's stable.
Adjust swirl to improve flame anchoring.
Smooth out air damper adjustments to avoid sudden changes.
Rule of Thumb: If your flame is **lifting**, air velocity is too high. If it's **lazy**, you need more velocity.

Why Some Burners Act Fine… Until the Load Changes
Ever had a burner that works perfectly **until the process load changes**? That's because **load changes affect everything**:

- **Fuel pressure** (valves and regulators take time to adjust).
- **Airflow distribution** (fans and dampers react at different speeds).
- **Flame stability** (heat transfer shifts as loads change).

If your burner trips **right after a load change**, here's what to check:
Causes:

- Fuel control valve reacts faster than air control, creating a temporary rich condition.
- Fan or damper response is slow, leading to excess air swings.
- Poor control loop tuning (deadband issues, slow response time).
- Flame momentarily destabilizes and scanner loses sight.

Fixes:
Make sure **fuel and air controls move at the same rate**.
Add ramp rates to avoid sudden swings in fuel/air flow.
Check control loop tuning—reduce deadband if needed.
Adjust scanner sensitivity to tolerate brief transitions.

Pulsing Flames and Why Your Furnace Sounds Like a Jet Engine
Flames should be **steady and smooth.** If your burner **pulses, rumbles, or makes weird sounds**, something is wrong.

Causes:

- **Poor mixing** → Uneven combustion zones, leading to oscillations.
- **Improper fuel pressure** → Too high or too low causes instability.
- **Airflow not steady** → Sudden changes in fan/damper position.
- **Burner throat resonance** → Air/fuel interaction causing pulsation.

Fixes:

Improve mixing—adjust swirl or diffuser settings.
Stabilize fuel pressure—ensure regulators are functioning correctly.
Smooth out airflow adjustments—no sudden damper jumps.
Adjust burner throat geometry (for resonant issues).
If your burner sounds like a helicopter, it's trying to tell you something.

When In Doubt, Look at the Flame
Your burner is always giving you clues.
A well-tuned flame should be:
Stable (not flickering wildly or pulsing)
Anchored (not lifting off or snuffing out)
Consistent (not changing colour or shape randomly)
If something looks off, **don't just rely on the analyser—watch the flame itself.**
Rule of Thumb: If CO is fluctuating, your flame is unstable. And if your flame is unstable, your efficiency is garbage.

Final Thoughts: Stop Fighting Your Burner—Start Listening to It
Most burner problems **aren't random**—they're a reaction to bad conditions.

✓ If your burner **trips**, figure out why.
✓ If your flame **pulses**, check your mixing and airflow.
✓ If your CO **spikes**, look at flame shape and stability.
✓ If your ignition **fails**, look at pilot, purge, and atomization.

Burners don't hate you. **They just don't work well when they're not treated right.**

Chapter 6: Flame Colours – A Mood Ring for Your Process

What your flame colour is telling you about efficiency, combustion quality, and potential disasters.

Why Flame Colour Matters
Flames aren't just pretty—they're **giving you real-time feedback** on how your combustion process is working.

✓ A **blue flame** means one thing.
✓ A **yellow flame** means another.
✓ A **green or purple flame** means something is **seriously wrong** (or you're burning something weird).

If you know what to look for, your flame is telling you:

- Whether your **air-to-fuel ratio** is correct.
- If you're **forming CO or NOx**.
- If you have **contaminants in your fuel**.
- Whether your burner is about to **go wrong in a spectacular way.**

Flame Colour Cheat Sheet: What's Normal and What's Not

Flame Colour	**What It Means**	**Good or Bad?**
Blue (Almost Invisible)	Very lean combustion, potentially excess air	**Too much air = efficiency loss**
Bright Blue with Orange Tips	Good fuel/air mix, efficient combustion	**This is what you want**
Yellow or Orange	Incomplete combustion, possible CO formation	**Check fuel/air ratio**
Red or Dark Orange	Carbon deposits burning off or excess fuel	**Rich combustion—watch for soot**

Flame Colour	What It Means	Good or Bad?
Green	Presence of copper, organics, or chemicals	**Contaminated fuel—check sources**
Purple or Violet	Burning alcohols, potassium, or sodium	**Monitor for impurities**
White or Gray	High levels of unburnt hydrocarbons, possible refractory damage	**Not good—investigate immediately**

Blue Flame: The Gold Standard (Mostly)
A **blue flame** means you have **enough oxygen to fully combust the fuel**, with little excess carbon or impurities. This is what we aim for in most combustion processes.
However, …
Not all blue flames are created equal.
Too Much Air (Over-Airing the Flame)
A **light blue, almost invisible** flame means **too much excess air.**
Problems this causes:

- Wasted heat going up the stack.
- Increased NOx emissions.
- Potential flame instability (flame lifting off).

Fix: Reduce excess air slightly while monitoring CO and flame stability.

Yellow or Orange Flames: Not Always Bad, But Often a Warning
What a Yellow/Orange Flame Tells You:

- You're **running rich** (too much fuel, not enough air).
- CO or soot formation **is likely happening**.
- You may have **improper fuel atomization** (for oil burners).

If you see **orange streaks or tips**, you might just have:

- **Dust in the air** burning off (not a major issue).
- **Sodium from contaminated fuel** (needs checking).
- **Carbon deposits burning off from equipment**.

When is a yellow flame okay?

- In **some low-NOx burners**, a slightly yellow core is normal.
- In **older oil burners**, some yellowing is common due to atomization limitations.

When to worry: If the entire flame is **solid yellow** and **CO levels are high**, you've got a **rich combustion** problem.

Red Flames: You've Got Carbon Buildup
A **red or dark orange** flame usually means:
Excess fuel is depositing carbon.
Fuel impurities (heavy oils, tar, or unburnt hydrocarbons) are present.
Red flames mean trouble if:

- You see **carbon buildup on the burner or furnace walls**.
- Your efficiency is dropping.
- You're getting **random burner trips or unstable operation**.

Fixes:
Increase excess air slightly (but not too much).
Check for **fuel atomization issues (for oil burners).**
If burning solid fuels, check **coal/biomass moisture content**.

Green Flames: You've Got a Problem
A green flame usually means you have contaminants in your fuel.
Common Causes of Green Flames:

- **Copper contamination** (can come from piping corrosion).
- **Organics burning off** (paints, chemicals, waste fuels).
- **Halogenated hydrocarbons** (burning plastic—bad idea).

Why you should care:

- Some green flame causes (like plastics or heavy metals) produce **toxic emissions.**
- If it's a **fuel contamination issue**, you need to track down the source **immediately**.

Fix:
Check your fuel supply and combustion air for contamination.
Inspect burner components for **corrosion or metal deposits**.

Purple or Violet Flames: Fuel Impurities or Alkali Metals
What causes a purple or violet flame?

- **Potassium, sodium, or lithium** in the fuel.
- **Burning alcohols or other high-energy fuels.**
- **Trace metals in the fuel supply.**

Should you worry?

- If you're **burning waste fuels**, YES—track the impurities.
- If you're **burning standard fuels**, it might just be sodium/potassium traces.
- If it's **intermittent**, monitor for changes in combustion quality.

White or Gray Flames: You've Got Hydrocarbon Carryover
A white or Gray flame usually means:

- **Unburnt hydrocarbons are passing through the flame.**
- **Something is overheating (like the refractory).**
- **There's a lot of ash or particulates in the fuel.**

Big warning signs:

- If white flames **appear suddenly**, check **flue gas for unburnt hydrocarbons.**
- If you're burning oil, check for **poor atomization or water contamination**.
- If refractory damage is suspected, inspect for **hot spots or cracking.**

Fix:
Verify proper fuel mixing and atomization.
Inspect flame pattern—ensure its stable and not overheating equipment.
Check for refractory damage and inspect flue gas composition.

How to Use Flame Colour for Tuning
When adjusting a burner, **watch the flame colour change** as you tweak fuel and air.
More air = bluer flame, but at a cost.
Less air = yellower flame, but watch for CO.
Green or purple? Stop and investigate your fuel.
Best practice: Tune using **flame colour + flue gas analysis together**—don't rely on just one.

Final Thoughts: Listen to Your Flame
✓ A stable, bright blue flame = good combustion.
✓ A solid yellow or orange flame = something's wrong.
✓ Green, purple, or white? Time to investigate.
Your flame is **the best real-time diagnostic tool you have.** If it changes suddenly, it's trying to tell you something.
The question is: **Are you paying attention?**

Chapter 7: When Too Much Air is Worse Than Not Enough
Why "just add more air" is terrible advice (and why over-airing creates more CO, not less).

The Myth of "More Air is Always Better"
If I had a dollar for every time someone said, *"Just add more air to fix it,"* I'd have enough money to buy a gas turbine and test it myself.
Yes, air is necessary for combustion. But too much air? **That's just as bad as too little.**
Too little air = CO formation, soot, and inefficient combustion.
Too much air = heat loss, flame instability, and sometimes… more CO.
Wait, more air can create CO?
Yes. **Because physics is cruel.**

What Happens When You Add Too Much Air?
Adding too much air does the following:

1. **Lowers Flame Temperature**
   - More air means **more nitrogen** (which doesn't burn) absorbing heat.
   - Lower temperatures slow down the combustion reaction.
   - This can cause **incomplete combustion**, leading to… CO formation.
2. **Creates Over-Air Momentum (Fuel Gets Stripped Away)**
   - High-velocity air jets **blow fuel out of the reaction zone too quickly**.
   - Fuel molecules don't fully combust before leaving the burner.
   - **Result? CO instead of CO_2.**
3. **Increases Heat Loss Up the Stack**
   - More air = more mass flow of hot gases going up the chimney.
   - Instead of transferring heat to the process, **you waste it by heating the atmosphere.**
4. **Increases NOx Formation**
   - High excess air **creates more oxygen molecules available for NOx reactions.**
   - High oxygen + high flame temp = **high NOx emissions.**
   - Now you've got **two problems: wasted fuel and regulatory issues.**

Excess Air: How Much is Too Much?
Every burner has a **sweet spot** for excess air. **Too little, and you get CO. Too much, and you lose efficiency.**

Fuel Type	Ideal O_2 (%)	Excess Air (%)	What Happens if You Go Too High?
Natural Gas	2-4%	5-15%	Heat loss, NOx increase, CO from stripping
Fuel Oil	3-5%	10-20%	Poor atomization, flame quenching
Coal/Biomass	5-8%	20-30%	Increased fly ash, incomplete combustion

Rule of Thumb: Stay within 5-15% excess air for most systems. More than 20%? You're wasting heat.

Why Over-Air Flames Can Still Make CO
Most operators think **CO only happens when there's not enough air.**
But **high excess air can create CO by disrupting mixing and cooling the flame too fast.**
How?

1. **Flame Quenching from Excess Air**
   - If the air is **too high**, the flame cools before combustion is fully complete.
   - CO doesn't have time to convert to CO_2.
   - Your flue gas analyser still sees O_2, so people assume it's fine—but CO is silently forming.
2. **Air Jets Stripping Fuel Before It Burns**
   - High-velocity air **pulls fuel away from the flame zone.**
   - Fuel molecules **don't get enough time to combust.**
   - **Result? Partial combustion → CO instead of CO_2.**

Key Lesson: You can have **a blue flame and still be making CO if your excess air is too high.**

How to Tell If You Have Too Much Air
Symptoms of Over-Airing:

- Flue gas **O_2 is above 6%** (unless it's a special low-NOx burner).
- CO fluctuates **even when the burner is stable**.
- The flame looks **weak, transparent, or lifted.**
- The process is **running cooler than expected.**
- Stack temperature is **too high** (wasted heat).

Big Warning Sign: If your O_2 is high and you **still** have CO, you're over-airing.

Fixing an Over-Aired Burner (Without Causing CO Spikes)
If you suspect you're over-airing, here's how to **bring it back to optimal levels safely.**

1□Slowly Reduce Excess Air (But Watch CO!)

- Drop excess air in **small steps** (1-2% at a time).

- If CO **suddenly jumps**, you've gone too far—back it off slightly.

2️⃣ Adjust Swirl and Air Registers to Improve Mixing

- More swirl = **better mixing** = lower excess air needed.
- Poorly directed air jets **strip fuel too soon**—reposition if necessary.

3️⃣ Monitor Stack Temperature and Efficiency

- If stack temp **drops** as you reduce air, you're recovering lost heat.
- If it suddenly **jumps**, you might be forming soot or carbon deposits—check flame condition.

4️⃣ Optimize for Load Changes

- Some burners **need more air at high loads** but **less air at turndown.**
- Use control logic to **adjust excess air dynamically** instead of setting a fixed value.

The Perfect Air-to-Fuel Balance is a Moving Target

What works at **one load might not work at another.**
What works in **winter might not work in summer.**
What works for **one fuel might not work for another.**
Instead of chasing a single "perfect" air number, aim for:

✓ **Stable flame shape and anchoring.**

✓ **Low, steady CO levels.**

✓ **Minimal NOx without excessive excess air.**

✓ **Efficient heat transfer (not wasting energy up the stack).**

The best combustion setup **is the one that works best for your specific burner and process.**

Final Thoughts: Stop Over-Airing Your Flames

✓ More air is **not always better.**

✓ Too much air **steals heat and creates inefficiency.**

✓ Over-airing **can create CO instead of preventing it.**

✓ **Flame quenching and air jet stripping are real problems.**

Next time someone says, *"Just add more air to fix it,"* ask them:
"Are you sure about that?"

Chapter 8: NOx, SOx, and Other Gases That Make Regulators Nervous

Why NOx is more than just a number, how it forms, and how to keep it under control without wrecking efficiency.

Why NOx and SOx Matter (Beyond Just Regulations)

Nobody likes emissions regulations, but NOx and SOx aren't just numbers on a compliance report—they're direct indicators of **how well (or badly) your combustion process is running.**

✓ **Too much NOx?** You're running too hot or too lean.

✓ **Too much SOx?** Your fuel quality is bad, or you're not managing sulphur properly.

✓ **Both are too high?** You might need to rethink your burner design.

NOx: The Flame Temperature Killer

What is NOx?

NOx (oxides of nitrogen) is a mix of **NO (nitric oxide) and NO_2 (nitrogen dioxide).**
It forms when nitrogen in the air reacts with oxygen at high temperatures.
More heat = more NOx.

How NOx Forms in Combustion

There are **three major ways NOx is created in flames:**

1. Thermal NOx (The Big One)

- Forms at **high flame temperatures** (>1500°C / 2700°F).
- The hotter and longer the flame, the **more NOx you get**.
- Main culprit in **gas-fired burners and high-temperature furnaces**.

2. Prompt NOx (The Sneaky One)

- Happens **even at lower temperatures** when nitrogen reacts with hydrocarbon radicals.
- More common in **fuel-rich flames with bad mixing**.
- Forms **quickly**, before the flame stabilizes.

3. Fuel NOx (The One You Can't Avoid with Certain Fuels)

- Comes from **nitrogen compounds inside the fuel itself**.
- More common in **coal, biomass, and heavy fuel oils**.
- Not much you can do **unless you change fuels or use post-combustion treatment**.

How to Reduce NOx Without Destroying Efficiency

✓ Lower Peak Flame Temperature

- Use **flue gas recirculation (FGR)** to bring cooler gases back into the burner.
- Reduce **excess air** (but not too much—CO will spike).
- Use **staged combustion** to spread heat out over a larger flame zone.

✓ Improve Mixing Without Increasing Oxygen

- Better **burner design** (low-NOx burners optimize air distribution).
- **Swirl adjustments** can help distribute heat better.
- **Avoid over-airing**, which increases NOx by raising flame temp.

✓ Use Alternative Fuels Where Possible

- Hydrogen and ammonia can reduce NOx, but bring their own challenges.
- If you're stuck with high-N fuel, **staged combustion and post-treatment (SCR, SNCR) may be needed.**

Warning: If you only focus on lowering NOx without watching CO, **you might end up with incomplete combustion problems.**

SOx: The "Bad Fuel" Problem

Sulphur oxides (SO_2 and SO_3) form when **sulphur in fuel reacts with oxygen.**

✓ Natural gas? **Almost no sulphur = almost no SOx.**

✓ Fuel oil? **Lots of sulphur unless you desulfurize it.**

✓ Coal? **SOx is inevitable unless you treat it.**

Why You Should Care About SOx

- Causes **acid rain** (environmental issue).
- Reacts with moisture to form **sulfuric acid**, which eats metal for breakfast.
- **Damages refractory linings** and heat exchangers in high concentrations.

How to Control SOx Emissions

✓ Use Low-Sulphur Fuels

- Ultra-low sulphur diesel (ULSD) reduces SOx dramatically.
- Natural gas avoids the problem entirely.

✓ Desulfurize Fuel Before Burning

- Scrubbing fuel before combustion reduces sulphur load.
- Most refineries already do this for gas and light oils.

✓ Post-Combustion Treatment (Flue Gas Desulfurization - FGD)

- **Limestone scrubbing ($CaCO_3 + SO_2 = CaSO_4$).**
- **Wet or dry scrubbing processes to remove SOx from flue gas.**

If you can't change your fuel, you have to capture SOx after combustion.

Balancing NOx, SOx, and CO (The Tuning Triangle)

Here's the problem:

- Lower NOx **by lowering flame temp** → You might create CO.
- Reduce SOx **by changing fuels** → You might increase NOx (if new fuel burns hotter).
- Improve CO **by reducing excess air** → You might spike NOx.

✓ The goal is **balancing all three without wrecking efficiency.**

The Real-World Approach to NOx & SOx Control

✓ **If NOx is too high:**

- Reduce **peak flame temperature** (use FGR or staged combustion).
- Avoid **excess air** (more O_2 = more NOx).
- Improve **mixing** to avoid hot spots.

✓ **If SOx is too high:**

- Switch to **low-sulphur fuel** if possible.
- Use **flue gas desulfurization (FGD)** if fuel change isn't an option.

✓ **If CO is creeping up while fixing NOx:**

- Fine-tune **excess air carefully**—don't overdo it.
- Ensure **mixing is good**—bad mixing creates localized CO pockets.
- Consider **oxygen trim control** to keep air-fuel balance steady.

Important: NOx, SOx, and CO are all symptoms of **combustion quality.**

✓ If you have high emissions, **you don't just need a scrubber—you need better tuning.**

Final Thoughts: Why This Matters Beyond Compliance

✓ **Regulators care about NOx and SOx.**

✓ **Your efficiency depends on getting these right.**

✓ **Bad combustion = wasted fuel, poor heat transfer, and high emissions.**

The best emissions control strategy? Get combustion right in the first place.

Chapter 9: Flue Gas – The Smoke Signals of Your System

What your stack gas is really telling you, and how to diagnose combustion problems using flue gas analysis.

Why Flue Gas Matters

Your flue gas is the **final report card** on how well your burner is running.

- **CO creeping up?** You've got incomplete combustion.
- **O_2 too high?** You're over-airing and wasting fuel.
- **NOx spiking?** Your flame is too hot or has poor mixing.
- **Unburnt hydrocarbons in the stack?** You're wasting fuel and likely failing emissions limits.

If you know how to read your flue gas, you can diagnose and fix most combustion problems—before they turn into costly shutdowns.

What's in Flue Gas (And Why You Should Care)?

Flue gas isn't just smoke—it's a **snapshot of your combustion process.**

Gas	What It Tells You	Too High Means…
O_2 (Oxygen)	Air-to-fuel ratio health	Too much air → heat loss & high NOx
CO_2 (Carbon Dioxide)	Combustion efficiency	Low CO_2 = excess air or incomplete combustion
CO (Carbon Monoxide)	Incomplete combustion indicator	Fuel-rich conditions or flame quenching
NOx (Nitrogen Oxides)	Flame temp & mixing quality	Too much heat or bad staging
SOx (Sulphur Oxides)	Sulphur in fuel	Fuel contamination or bad desulfurization
Unburnt Hydrocarbons (CxHy)	Poor fuel burnout	Fuel carryover → efficiency loss

Rule of Thumb:

- **Low O_2, High CO?** You're running too rich.
- **High O_2, High NOx?** You're over-airing and overheating the flame.
- **High CO, High Unburnt Hydrocarbons?** Your combustion is a mess—fix it.

How to Interpret Your Flue Gas Analyzer Readings

1. Oxygen (O_2) – The Balancing Act

✓ Low O_2 = **More efficient combustion, but higher risk of CO formation.**

✓ High O_2 = **Less risk of CO, but more heat loss and NOx formation.**

Target O_2 Levels for Efficiency:

- **Natural Gas Burners:** 2-4%
- **Oil Burners:** 3-5%
- **Coal & Biomass:** 5-8%

If O_2 is too low:

- CO may spike → **risk of incomplete combustion.**
- Flame may **struggle to stabilize**, leading to burner trips.

If O_2 is too high:

- You're **wasting energy heating excess air**.
- You might be **stripping fuel away from the flame** → CO formation.
- NOx may spike due to **high flame temp with excess O_2.**

✓ **Fix?** Adjust air-to-fuel ratio **gradually** while watching CO and flame behaviours.

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2. Carbon Dioxide (CO_2) – Efficiency Check

✓ Higher CO_2 usually means **better efficiency.**

✓ Lower CO_2 means **you're over-airing or burning inefficiently.**

Ideal CO_2 Levels in Flue Gas:

- **Natural Gas:** 8-10%
- **Oil Burners:** 10-12%
- **Coal/Biomass:** 12-15%

If CO_2 is too low:

- You're **letting too much air into the system** → wasting fuel.

✓ **Fix?** Reduce excess air slightly while monitoring CO levels.

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3. Carbon Monoxide (CO) – The Red Flag

✓ CO = **You're losing energy in unburnt fuel.**

✓ CO spikes mean **incomplete combustion is happening somewhere.**

Acceptable CO Levels:

- **Low Fire (<10% load):** <50 ppm
- **Normal Operation:** <10-20 ppm
- **High Fire (>80% load):** <50 ppm (higher acceptable in some cases)

If CO is too high:

- **Not enough air (rich combustion).**
- **Too much air stripping fuel away (lean CO formation).**
- **Poor flame mixing or quenching.**

✓ **Fix?** Adjust air-fuel balance and improve flame stability.

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4. NOx – The "Too Much Heat" Warning Sign

✓ NOx comes from **excess oxygen and high flame temperature.**

Ideal NOx Levels:

- **Standard Burners:** <100 ppm
- **Low-NOx Burners:** <30 ppm
- **Ultra-Low NOx Systems:** <9 ppm

If NOx is too high:

- Your flame is too hot → **lower excess air slightly.**
- You need **flue gas recirculation (FGR) or staged combustion.**

✓ **Fix?** Reduce peak flame temp **without killing combustion stability.**

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5. SOx – The Fuel Contamination Indicator

✓ SOx is **directly linked to fuel quality**.

Acceptable SOx Levels:

- **Natural Gas:** ~0 ppm (almost no sulphur).

- **Low-Sulphur Oil:** <50 ppm
- **Coal/Biomass:** Varies, depends on sulphur content.

If SOx is too high:

- Your fuel contains **too much sulphur** → switch to low-sulphur options.
- Your **scrubbing/desulfurization process isn't working.**

✓ **Fix?** Switch fuels or improve SOx scrubbing methods.

Using Flue Gas to Diagnose Combustion Issues
Flue Gas Symptoms & What They Mean

Symptom	Possible Issue	Fix
High O_2, Low CO_2	Too much excess air	Reduce excess air gradually
Low O_2, High CO	Running too rich	Increase air slightly
High CO, Even at High O_2	Poor mixing or flame quenching	Improve swirl, check flame shape
High NOx	Too hot flame, too much O_2	Reduce peak temp, lower excess air
SOx Increasing	Fuel contamination	Check fuel quality or scrubbing process
Fluctuating CO	Unstable combustion	Tune air/fuel control, check burners

Rule of Thumb:
If **CO_2 is low, you're wasting fuel.**
If **CO is high, you're not burning fuel completely.**
If **O_2 is too high, you're losing efficiency.**
If **NOx is too high, your flame is too hot.**

Final Thoughts: Your Stack Gas is Talking—Are You Listening?

✓ Flue gas isn't just compliance data—it's a **real-time diagnostic tool.**

✓ If you know how to **read it**, you can **catch problems before they cost you money.**

✓ **Don't just look at O_2—watch CO, NOx, and CO_2 together.**

A well-tuned combustion system = low CO, optimized O_2, minimal NOx, and high efficiency.

Chapter 10: Tuning a Burner is Like Tuning a Guitar (But louder)

Fine-tuning your burner for stability, efficiency, and responsiveness—without making it sound like a jet engine.

Why Tuning is an Art (Not Just Science)
If combustion tuning were purely a science, you'd just punch in the perfect air-to-fuel ratio and be done. But real life doesn't work that way.

✓ **Fuel composition changes.**

✓ **Load fluctuates.**

✓ **Airflow varies with duct pressure, humidity, and temperature.**

✓ **Burners don't always behave the way you expect.**

A well-tuned burner doesn't just hit the "right" O_2 number—it **adapts to process conditions, stays stable, and delivers heat exactly where it's needed.**

Tuning a burner is like tuning a guitar: If it's off even slightly, it sounds (and runs) like crap.

What a Well-Tuned Burner Looks Like
A properly tuned burner should:
Light quickly and cleanly.
Maintain a stable, well-anchored flame.
Burn efficiently, with minimal CO and NOx.
Respond smoothly to load changes.
Not sound like a jet engine preparing for take-off.
If your burner is unstable, noisy, or producing inconsistent emissions, you need to tune it.

The Three Pillars of Burner Tuning
1. Air-Fuel Ratio – The Foundation of a Good Tune

Too much air?

- **Heat loss, high NOx, weak flame.**
- **Fuel gets stripped away before burning completely → CO spikes.**

Too little air?

- **Incomplete combustion, CO formation, soot buildup.**
- **Potential flame instability and burner trips.**

✓ **The sweet spot?** Enough air to fully combust fuel without excessive excess air.

✓ **Tune air/fuel gradually. Lower excess air until CO starts to rise, then back off slightly.**

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2. Flame Shape & Stability – If It Looks Wrong, It Is Wrong

Flame shape tells you **how well combustion is happening inside the burner.**

What to look for:

✓ Well-anchored flame, no lift-off.

✓ No flame impingement on walls or tubes.

✓ No pulsing or unstable flame movement.

Warning Signs:

Flame lifting off? Air velocity is too high—reduce excess air.

Flame hitting process tubes? Lower fuel pressure or increase swirl.

Flame pulsing? Poor mixing or unstable air/fuel supply.

✓ **Solution:** Adjust burner swirlers, diffusers, or fuel injector angles to stabilize the flame.

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3. Load Response – A Well-Tuned Burner Should Adapt

Your burner needs to respond smoothly as load changes. If it **hunts, pulses, or spikes emissions** when firing rate changes, something is wrong.

Signs of Poor Load Response:

- CO spikes when load changes.
- Flame lifts or pulses at high fire.
- Burner struggles to stay stable at low fire.

✓ **Solution:** Tune air/fuel response curves so both adjust **at the same rate** during load shifts.

Step-by-Step Burner Tuning Process

Step 1: Establish a Baseline

- Check **current flue gas readings** (O_2, CO, NOx).
- Inspect **flame shape, anchoring, and stability.**

Step 2: Adjust Air-Fuel Ratio

- **Reduce excess air slowly.** Watch for CO spikes—**if CO rises suddenly, you've gone too far.**
- **Balance efficiency and flame stability.**

Step 3: Optimize Swirl & Air Distribution

- Increase swirl if flame is **too long and lazy.**
- Reduce swirl if flame is **too short and aggressive.**

Step 4: Test Load Transitions

- Increase and decrease firing rate while monitoring:
  ✓ CO stability
  ✓ Flame anchoring
  ✓ NOx trends

How to Tune for Low NOx Without Wrecking Combustion

✓ Use **staged combustion** (gradual mixing of air and fuel).

✓ Lower peak flame temp **without over-airing.**

✓ Use **flue gas recirculation (FGR)** if needed.

What NOT to do:

Don't just increase excess air—it **raises NOx and reduces efficiency.**

Don't let the flame cool too much—**CO will spike.**

Key Lesson: The best NOx reduction strategy is **good combustion in the first place.**

Common Burner Tuning Mistakes (And How to Avoid Them)

Mistake #1: Only Looking at O_2

O_2 alone doesn't tell the whole story. **Watch CO, NOx, and flame behaviours too.**

Mistake #2: Reducing Air Too Much

If you go too lean, CO will spike, and flames may become unstable.

Mistake #3: Not Testing at Different Loads

Burners behave differently at high vs. low fire—**tune across the full range.**

Mistake #4: Ignoring Noise and Pulsation

A pulsing flame = an inefficient flame. Tune for stability, not just emissions.

Final Thoughts: The Perfect Tune is a Moving Target

✓ **Tuning isn't a one-time thing. Conditions change, and your burner needs adjustment.**

✓ **Don't chase numbers—chase stability and efficiency.**

✓ **A well-tuned burner doesn't just burn fuel—it burns it cleanly, efficiently, and reliably.**

Get the air-fuel ratio right, stabilize the flame, and make sure it responds to load properly. That's how you tune a burner like a pro.

Chapter 11: Kilns, Furnaces, and Other Things That Eat Heat for Breakfast

Why combustion in a kiln is different from a boiler, and how to tune for the unique challenges of high-temperature processes.

Why Kilns and Furnaces Are Different from Boilers

Most people think **combustion is the same everywhere**—but **a kiln doesn't behave like a boiler, and a furnace doesn't behave like a burner in a refinery.**

Boilers focus on **heat transfer through water or steam.**

Kilns and furnaces focus on **direct heat transfer to solids.**

The key difference? **Boilers extract heat from hot gases into water**, while **kilns and furnaces rely on radiation and convection to heat materials.**

The Three Big Challenges in Kiln and Furnace Combustion

1️⃣High-Temperature Environments

- Kilns and furnaces operate at **extreme temperatures (1000-1700°C+ / 1800-3100°F+).**
- This affects **flame shape, refractory wear, and NOx formation.**

2️⃣Flame and Heat Distribution

- Unlike a boiler, where **steam absorbs heat**, kilns require **even heat distribution** to prevent hot spots.
- Poor flame placement = **inconsistent product quality.**

3️⃣Process Interaction

- In a kiln, the flame directly **interacts with raw materials**—affecting reactions (like $CaCO_3$ decomposition in lime kilns).
- The combustion process **affects material chemistry and efficiency.**

Kilns and furnaces don't just need a flame—they need the right flame in the right place.

Kiln & Furnace Burner Tuning: Key Considerations

1. Flame Shape Matters More Than Just Temperature

- A **long, lazy flame** can overheat one section and leave another cold.
- A **short, aggressive flame** can cause localized overheating and refractory damage.

✓ **For a kiln, you want a flame that spreads heat evenly** across the bed or chamber.

✓ **For a furnace, you want controlled heat zones** that match process requirements.

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2. Temperature Control and NOx Management

- High-temperature combustion = **high NOx production.**
- Kilns **require controlled combustion staging** to prevent excess NOx while maintaining heat.

✓ **Use staged combustion**—introduce fuel in different zones to control peak flame temperature.

✓ **Use exhaust gas recirculation (EGR)** where possible to cool the flame slightly.

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3. Fuel Considerations for Kilns & Furnaces

Gas-fired kilns/furnaces → Cleaner combustion, precise control, but potential NOx issues.
Oil-fired kilns/furnaces → Good energy density, but needs **proper atomization** to prevent soot.
Solid-fuel kilns (coal, biomass, etc.) → More complex combustion dynamics, need for staged air introduction.

Kilns burning solid fuels must manage:

- **Particle size & distribution** (affects combustion quality).
- **Ash buildup & clinker formation** (can reduce efficiency).
- **Airflow control for consistent heat release.**

✓ **Each fuel requires a different tuning approach to maintain optimal combustion.**

Tuning a Kiln Burner: Step-by-Step

Step 1: Check Baseline Conditions

✓ **Measure flue gas composition (O_2, CO, NOx, SOx).**

✓ **Inspect flame pattern inside the kiln.**

✓ **Check kiln pressure to ensure proper draft control.**

Step 2: Adjust Air-Fuel Ratio for Stability

✓ **Reduce excess air while monitoring CO and flame stability.**

✓ **Ensure good fuel/air mixing to avoid localized rich or lean zones.**

If CO spikes or flame destabilizes, you've gone too far—back off slightly.

Step 3: Optimize Flame Shape & Placement

✓ **Adjust burner momentum** (fuel velocity) to control flame length.

✓ **Use swirlers or diffusers** to shape the flame as needed.

✓ **Ensure the flame is heating the product evenly—not just the refractory.**

Warning: If the flame impinges on the refractory, it will cause **hot spots and potential damage.**

Step 4: Monitor and Adjust Based on Process Feedback

✓ Check **temperature uniformity** across the kiln.

✓ Monitor **flue gas and product quality**—CO spikes indicate incomplete combustion.

✓ Adjust **load-based control strategies** to handle fluctuations in process demand.

✓ **The best tuning isn't just about emissions—it's about consistent process heat delivery.**

Kiln & Furnace Troubleshooting Cheat Sheet

Problem	Likely Cause	Fix
Flame is too long	Low momentum, too much swirl	Increase burner pressure or reduce swirl
Flame is too short	High momentum, too little swirl	Reduce burner pressure or increase swirl
Flame impingement on walls	Poor burner angle or excessive length	Adjust burner angle, fine-tune swirl
CO spikes at high load	Poor air-fuel mixing, excess fuel	Improve mixing, reduce excess fuel slightly
NOx increasing rapidly	Too high peak flame temp	Use staged combustion, reduce peak temp
Process temperature unstable	Poor burner control, load swings	Improve air-fuel response tuning

✓ **A kiln burner isn't just about combustion—it's about process control.**

Why Kiln Pressure and Draft Control Matter
Unlike a boiler, which is typically **positive pressure**, many kilns operate at **negative pressure.**

✓ **If kiln pressure is too low (excess draft):**
- **Flame can pull away from the burner**, causing instability.
- **Cold air leaks in**, reducing process efficiency.

✓ **If kiln pressure is too high (low draft):**
- **Flame may push against the material**, causing overheating.
- **Flue gas won't flow properly**, leading to inefficient heat transfer.

Solution: Use **precise damper and draft fan control** to maintain consistent pressure.
If kiln pressure fluctuates, combustion efficiency will suffer.

Final Thoughts: The Art of Kiln & Furnace Tuning

✓ Kilns and furnaces **aren't just about a blue flame—they're about stable, even heat delivery.**

✓ Air-fuel ratio tuning **must be done with process goals in mind.**

✓ NOx and CO must be **balanced with flame temperature and distribution.**

✓ Kiln pressure control **is just as important as burner tuning.**

The best kiln tuning delivers stable combustion AND consistent product quality.

Chapter 12: Oil Burners – Atomization, Steam, and Premature Ignition Nightmares
How oil burners work, why atomization is critical, and what happens when things go wrong.

Why Oil Burners Are Trickier Than Gas Burners
If you've only worked with gas burners, **congratulations—you've had it easy.**
Oil burners are a different beast. Unlike gas, which is already a vapor, **oil has to be atomized before it can burn properly.**

✓ If atomization is bad, **combustion is bad.**

✓ If oil isn't preheated properly, **it won't flow or atomize correctly.**

✓ If atomization is too fine or too coarse, **flame shape and efficiency suffer.**

The key to oil burner tuning? Atomization. Get that wrong, and everything else is wrong.

How Atomization Works (And Why It's Critical)
To burn oil efficiently, you need to **break it into tiny droplets.**
- **Smaller droplets = more surface area = better combustion.**
- **Bigger droplets = slower combustion, risk of soot and CO formation.**

Warning: If oil isn't properly atomized, you're not burning fuel—you're just heating up a liquid mess.
How Oil Is Atomized

1️⃣ **Pressure Atomization**
- High-pressure oil is forced through a nozzle, breaking it into fine droplets.
- Common in **industrial burners with mechanical atomizers.**
- **Simple, reliable, but needs high pump pressure.**

2️⃣ **Steam or Air Atomization**
- Steam or compressed air mixes with oil, breaking it into tiny droplets.
- Used in **larger burners, refineries, and power plants.**
- **More control over droplet size, but requires a steam/air supply.**

3️⃣ **Rotary Cup Atomization**
- Oil is thrown off a spinning cup, breaking it into fine mist.
- Used in **marine and large industrial burners.**
- **Good for burning heavy fuels, but more moving parts.**

Which one is best? Depends on your fuel type and burner setup.

Why Oil Preheating Matters
Unlike gas, oil **doesn't flow easily at room temperature.**
- **Light oils (diesel, kerosene) flow easily but still benefit from slight preheating.**
- **Heavy oils (residual fuel, bunker fuel) need significant preheating to reduce viscosity.**

✓ **If oil is too cold:** It won't atomize properly → larger droplets → poor combustion → soot.
✓ **If oil is too hot:** It may flash before the burner → premature ignition risk.
Preheat oil to the correct temperature for optimal viscosity.

Oil Type	Ideal Preheat Temp (°C)	Why?
Diesel / Kerosene	40-60°C	Improves flow, minor viscosity reduction
Light Fuel Oil (LFO)	80-120°C	Ensures proper atomization
Heavy Fuel Oil (HFO)	130-160°C	Reduces viscosity for proper atomization
Bunker / Residual Oil	160-180°C	Needed for proper spray formation

Too cold? Poor atomization, large droplets, CO formation.
Too hot? Risk of flash vaporization, leading to pump cavitation or burner flameouts.

How Oil Burner Combustion Goes Wrong

1. Poor Atomization = Soot and CO Formation

- If oil droplets are too big, they burn **too slowly** or **not at all.**
- This leads to **smoke, soot buildup, and high CO emissions.**

Fix: Improve atomization by adjusting fuel pressure or increasing steam/air assist.

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2. Premature Ignition (Steam Atomization Nightmare)

- In steam atomization, **if the oil is too hot or the burner is too cold, the oil can ignite prematurely inside the burner.**
- This is **dangerous** and can lead to **explosive ignition, burner trips, or even system damage.**

Signs of premature ignition:

- **Flame before the burner is fully lit.**
- **Loud "pop" or bang on ignition.**
- **Burner trips due to unstable flame.**

Fix: Ensure proper oil temperature and verify burner purge sequence.

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3. Oil Carryover (Fuel Dripping from the Nozzle)

- If the burner shuts down but oil keeps dripping, it can pool inside the furnace.
- On the next ignition, **that oil can ignite violently.**

Fix: Install an **oil shutoff valve** to prevent drips and check nozzle pressure at shutdown.

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4. Flame Impingement (Oil Flames That Hit Tubes or Refractory)

- Oil flames tend to be **longer and more radiant than gas flames.**
- If they hit furnace tubes or refractory, they cause **carbon buildup and localized overheating.**

Fix: Adjust swirlers or burner angle to control flame shape.

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5. Load Response Problems (Flame Struggles to Adjust to Changes)

- Oil burners take **longer to respond** to load changes than gas burners.
- If load changes suddenly, **the burner might over fuel or underfired temporarily.**

Fix: Use a **fuel-air ratio controller** to adjust oil flow smoothly.

Oil Burner Tuning Cheat Sheet

Problem	Likely Cause	Fix
Flame too long, hitting tubes	Oil pressure too low, poor atomization	Increase pressure or improve atomization
Flame too short, unstable	Oil pressure too high, poor swirl	Reduce pressure slightly, adjust burner swirl
Black smoke / soot	Poor atomization, low air	Improve atomization, increase air slightly
High CO levels	Incomplete combustion, excess fuel	Tune air-fuel ratio, improve fuel mixing

Problem	Likely Cause	Fix
Delayed ignition / flameouts	Premature vaporization, poor ignition sequence	Check oil temp, verify ignition system
Steam explosion on ignition	Too hot oil, moisture in fuel lines	Reduce oil temp, check fuel quality

✓ **The key to oil burner success is proper atomization and preheating.**

Final Thoughts: Mastering Oil Burner Combustion

✓ Atomization is **everything**—bad atomization = bad combustion.

✓ Oil **must be preheated correctly** to flow and atomize properly.

✓ Steam atomization is **great, but risky** if not controlled properly.

✓ A properly tuned oil burner **delivers stable, efficient heat without soot or CO issues.**

If your oil burner is misbehaving, start by checking atomization and preheat settings.

Chapter 13: Weird Fuel? Weird Flame. How Fuel Type Affects Combustion

What happens when you burn something other than gas or oil—and how to handle combustion challenges with alternative fuels.

Why Fuel Choice Matters More Than You Think

Most combustion engineers spend their time dealing with **natural gas and fuel oil**—but what happens when your fuel isn't standard?

✓ **Coal?** Expect slagging, fly ash, and tricky air distribution.

✓ **Biomass?** It burns, but not always predictably.

✓ **Methanol or hydrogen?** Get ready for near-invisible flames.

Every fuel has different combustion properties, and if you don't adjust for them, your burner will be a nightmare to control.

How Fuel Type Changes Combustion

Key Fuel Properties That Affect Burning:

Fuel Property	Why It Matters	How It Affects Tuning
Heating Value (BTU or MJ/kg)	How much energy is released per unit of fuel	Affects flame length, air-to-fuel ratio
Flame Speed	How fast the flame propagates	Affects burner stability
Stoichiometric Air Requirement	How much air is needed to fully combust the fuel	Affects O_2 tuning and excess air strategy
Volatile vs. Fixed Carbon	How easily fuel ignites and burns	Determines ignition conditions
Ash and Impurities	What's left after combustion	Affects slagging, deposits, and heat exchanger fouling

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Combustion Characteristics of Different Fuels

1. Natural Gas (CH_4, Methane-Based Fuels)

✓ **Easy to burn, clean combustion, predictable flame.**

✓ **High flame speed = stable ignition.**

✓ **Low ash, no sulphur concerns.**

Challenges:

- **High NOx potential due to flame temperature.**
- **Requires precise air-fuel ratio control.**

✓ **Tuning Tip:**

Use **low-NOx burners** or flue gas recirculation (FGR) to reduce NOx.

---

2. Propane & Butane (LPG Fuels)

✓ Higher **BTU value per cubic meter** than natural gas.

✓ More compact storage but **requires different burner orifices.**

✓ Produces **less CO than natural gas if properly tuned.**

Challenges:

- **Air-to-fuel ratio must be adjusted** (propane needs less air than methane).
- **Can cause soot formation if burned too rich.**

✓ **Tuning Tip:**

Adjust **burner nozzles and air registers** to handle the different flame characteristics.

---

3. Hydrogen (H_2) – The Future, But with a Catch

✓ **Super-fast flame speed** = high stability but increased risk of flashback.

✓ **Zero carbon emissions—NO CO_2, no soot.**

✓ **Very wide flammability range** (4-75% in air!).

Challenges:

- **Invisible flame**—hard to detect combustion visually.
- **High NOx due to extreme flame temperatures.**
- **Leaks are dangerous—small molecules escape easily.**

✓ **Tuning Tip:**

Use **high-velocity burners with staged combustion** to control NOx.

---

4. Methanol & Ethanol (Alcohol Fuels)

✓ **Burns cleanly, very low CO emissions.**

✓ **Fast evaporation and ignition.**

✓ **Less soot and no sulphur issues.**

Challenges:

- **Low heating value** → Requires **higher fuel flow rates.**
- **Very light flame → Hard to detect with traditional flame scanners.**

✓ **Tuning Tip:**

Use **optical flame detectors or UV sensors** for flame monitoring.

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5. Coal – The Old-School Workhorse

✓ **High energy content per ton.**

✓ **Widely available and cheap (if regulations allow it).**

✓ **Works well in large-scale combustion applications.**

Challenges:

- **Solid fuel = inconsistent combustion.**
- **High ash content = slagging & fouling issues.**
- **SOx emissions unless scrubbed.**

✓ **Tuning Tip:**

Use **staged combustion and air preheating** to improve efficiency and lower emissions.

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6. Biomass & Waste Fuels (Wood, Peat, Bagasse, Municipal Waste)

✓ **Renewable, lower net CO_2 emissions.**

✓ **Can be co-fired with coal or gas.**

✓ **Ash contains nutrients (useful for agriculture).**

Challenges:

- **High moisture content = reduced efficiency.**
- **Inconsistent fuel quality = unpredictable combustion.**
- **High alkali content = fouling on heat exchanger surfaces.**

✓ **Tuning Tip:**

Dry biomass before burning or use **gasification to stabilize combustion.**

How to Tune for Alternative Fuels

✓ **1. Adjust Air-Fuel Ratio Based on Stoichiometry**

- Different fuels **require different air amounts**.
- **Example:** Coal needs ~9 kg of air per kg of fuel, while hydrogen needs only ~34% of that per MJ of energy.

✓ **2. Modify Flame Detection as Needed**

- **Hydrogen & alcohol flames are nearly invisible.**
- Use **UV or infrared flame scanners** for proper monitoring.

✓ **3. Monitor & Control NOx and CO Formation**

- High-temp fuels (hydrogen, methane) = **more NOx.**
- Incomplete combustion fuels (coal, biomass) = **more CO risk.**

✓ **4. Adapt Burner Hardware to Fuel Type**

- **Gas fuels = premix burners with precise control.**
- **Liquid fuels = atomization system must match fuel viscosity.**
- **Solid fuels = careful control of fuel feed rate and air distribution.**

Alternative Fuel Troubleshooting Cheat Sheet

Fuel Type	**Common Problem**	**Fix**
Hydrogen	Flashback, NOx spikes	Use high-velocity burners, stage combustion
Methanol/Ethanol	Hard to detect flame	Install UV flame scanners
Coal/Biomass	Inconsistent combustion	Pre-dry fuel, improve air distribution
Propane/Butane	Soot formation	Adjust burner nozzles, check excess air

✓ **Different fuels = different tuning strategies. Get it wrong, and efficiency and emissions suffer.**

Final Thoughts: The Right Fuel Needs the Right Setup

✓ **Combustion is not one-size-fits-all.**

✓ Every fuel has **unique characteristics that require tuning.**

✓ **Don’t assume a burner tuned for one fuel will work perfectly with another.**

If you switch fuels, you have to retune EVERYTHING: air-fuel ratios, flame monitoring, burner pressure, and emissions control.

Chapter 14: Combustion Myths That Refuse to Die

Debunking the worst advice ever given about combustion tuning.

Why Combustion Myths Exist (And Why They Won’t Go Away)

Combustion is a mix of **science, experience, and trial and error**—which means people have developed all sorts of "rules" over the years.
Some are true.
Some were true once but no longer apply.
And some are just **completely wrong.**
Bad combustion advice leads to poor efficiency, high emissions, and burner problems.
Let’s set the record straight.

The Top 10 Combustion Myths (And Why They’re Wrong)

Myth #1: "If You See a Blue Flame, Combustion is Perfect."

Wrong. A blue flame just means **you have enough air to fully combust the fuel—but it doesn’t mean efficiency is optimized.**

✓ You can have **a blue flame and still be wasting fuel** if excess air is too high.

✓ A blue flame **doesn’t mean no CO—it just means the flame is hot enough to burn most carbon.**

What You Should Do:

Check flue gas composition (O_2, CO, NOx, CO_2). A blue flame **alone** doesn’t confirm complete combustion.

Myth #2: "More Air Always Means Better Combustion."

Wrong. Too much air cools the flame and reduces efficiency.

✓ High excess air **strips fuel from the flame before it fully burns, causing CO.**

✓ Too much air **increases stack temperature, meaning heat is wasted instead of going into the process.**

What You Should Do:

Set **the lowest possible excess air level** while keeping CO near zero and flame stable.

Myth #3: "CO Only Forms When There's Too Much Fuel."

Wrong. CO can also form when there's **too much air.**

✓ If the **air jets strip fuel away too fast**, incomplete combustion happens, and CO sneaks through.

✓ Poor flame stability can **cause CO spikes, even at "correct" air-fuel ratios.**

What You Should Do:

✓ **Balance air and fuel properly.**

✓ Avoid over-airing that **quenches the flame too soon.**

Myth #4: "Tuning to 3% O_2 is Always Correct."

Wrong. The right O_2 level depends on **fuel type, burner design, and process conditions.**

✓ 3% O_2 may work for **gas burners, but oil and coal burners** need different O_2 levels.

✓ If a burner **can operate at 2.5% O_2 safely, why leave money on the table?**

What You Should Do:

Tune for the lowest stable O_2 level while keeping CO near zero and maintaining stable combustion.

Myth #5: "NOx is Just a Regulatory Problem, not a Performance Issue."

Wrong. High NOx means **high flame temperatures, which can hurt burner performance and cause overheating.**

✓ High NOx flames can **damage refractories, increase heat stress, and reduce equipment life.**

✓ NOx **also indicates poor staging or too much excess air.**

What You Should Do:

✓ Use **staged combustion** and **flue gas recirculation (FGR)** to control NOx.

✓ Avoid excessive **flame temperatures that waste energy.**

Myth #6: "You Can Tune a Burner Just by Watching the Flame."

Wrong. Flame colour and shape **tell you a lot, but they don't show CO, O_2, or NOx levels.**

✓ A flame that looks **perfect may still be wasting fuel.**

✓ You need **flue gas analysis** to confirm efficiency and emissions.

What You Should Do:

✓ **Use a flue gas analyser** AND watch the flame—it's a **combination** of visual and measured data.

Myth #7: "Boiler Combustion and Kiln/Furnace Combustion Are the Same."

Wrong. Boilers heat **water/steam**, while kilns and furnaces **heat materials directly.**

✓ Boilers need **tight excess air control** to maximize heat transfer to water.

✓ Kilns/furnaces need **flame shaping** to ensure even material heating.

What You Should Do:

✓ **Tune based on the process**, not just the burner—boilers and kilns require different air-fuel strategies.

Myth #8: "Oil Burners Work the Same as Gas Burners."

Wrong. Oil burners need **atomization**—gas burners don't.

✓ Poor atomization = **soot, high CO, and inefficient combustion.**

✓ Oil requires **preheating and correct droplet size for proper burning.**

What You Should Do:

✓ Check **oil preheat temperature** and **atomization quality** before adjusting air-fuel ratio.

Myth #9: "Set It and Forget It—Once a Burner is Tuned, It Stays That Way."

Wrong. Burners drift over time due to:

✓ Fuel variations

✓ Air system changes
✓ Equipment wear
✓ Seasonal temperature/humidity shifts
What You Should Do:
✓ Perform **regular combustion checks and re-tuning.**
✓ Adjust for **seasonal air density changes (cold air is denser = more oxygen).**

Myth #10: "Bigger Flames Mean Better Heat Transfer."
Wrong. Bigger flames **often mean wasted energy.**
✓ Long flames **can impinge on tubes and refractories, causing damage.**
✓ **Controlled, compact flames** ensure better heat transfer.
What You Should Do:
✓ Adjust **flame shape, not just length**, for efficient heat transfer.
✓ **Use swirlers and diffusers** to shape the flame properly.

Final Thoughts: Tune Smart, Not by Myths
✓ **Not all blue flames are efficient.**
✓ **Not all CO problems are from too much fuel.**
✓ **Excess air can be just as bad as too little air.**
✓ **Every fuel and burner require unique tuning—there's no universal "magic number."**
The best combustion tuning follows facts, not outdated myths

Chapter 15: The Fine Art of Troubleshooting (or: Why Your Burner Won't Cooperate)

How to systematically diagnose and fix combustion problems like a pro.

Why Troubleshooting is a Skill (Not Just Guesswork)
If you've been around combustion long enough, you've dealt with a burner that **absolutely refuses to behave.**
✓ It **lights… then trips out.**
✓ It **runs fine… until you change the load.**
✓ It **burns fuel… but efficiency is terrible.**
✓ It **randomly pulses, roars, or lifts off.**
And, of course, when you finally get it working, someone changes a setting and screws it up again.
Troubleshooting a burner isn't about luck—it's about systematically finding the problem and fixing it right.

The Golden Rule of Troubleshooting: Start Simple
The worst thing you can do. **Start randomly adjusting everything at once.**

- **Check the basics first.**
- **Make one change at a time.**
- **Observe the result before touching anything else.**

✓ **"Is there fuel?"** (You'd be surprised how often someone forgets to open a valve.)
✓ **"Is there air?"** (Blocked filters, broken dampers, or fan trips are more common than you think.)
✓ **"Did anything change?"** (New fuel batch? New burner setting? Maintenance did "something"?)
90% of combustion problems come from something simple that got overlooked.

The Burner Troubleshooting Cheat Sheet

Problem	Likely Cause	Fix
Burner won't light	No fuel, no spark, or purge cycle issue	Check igniter, purge settings, and fuel valves

Problem	Likely Cause	Fix
Burner lights but trips on flame failure	Weak flame, bad scanner, unstable combustion	Adjust air-fuel ratio, verify flame sensor
Flame lifts off burner	Too much air velocity, poor anchoring	Reduce excess air, adjust swirl, increase fuel pressure
Flame impingement (hitting tubes/walls)	Poor burner alignment, flame too long	Adjust burner angle, fine-tune swirl, check fuel pressure
Flame pulsing or unstable	Poor mixing, fluctuating air/fuel	Stabilize air supply, check control loops
High CO levels	Incomplete combustion, excess fuel	Tune air-fuel ratio, improve fuel mixing
High NOx levels	Too high flame temp, excess air	Reduce peak temp, use staged combustion
Delayed ignition or flameouts	Premature vaporization, poor ignition sequence	Check oil temp, verify ignition system
Burner cycles too often	Load mismatch, improper PID tuning	Adjust control loop, check load demand

✔ **The key to troubleshooting? Look at symptoms, not just numbers.**

Troubleshooting by Symptoms (What Your Burner is Telling You)
Problem: Burner Lights, Then Immediately Trips on Flame Failure
Possible Causes:

✔ Weak flame signal (bad scanner alignment, dirty lens).

✔ Poor flame stability (bad air-fuel ratio, wrong swirl setting).

✔ Ignition issue (pilot weak, oil not atomizing properly).

Fix:

✔ Clean and realign flame scanner.

✔ Adjust excess air—too much air makes flames invisible to sensors.

✔ Verify ignition timing and sequence.

Problem: High CO, Even Though O_2 is Normal
Possible Causes:

✔ Poor mixing—fuel and air aren't blending well.

✔ Over-air stripping—excess air moving fuel away too fast.

✔ Low flame temp—flame quenching before full combustion.

Fix:

✔ Improve air distribution or swirl pattern.

✔ Reduce excess air slightly to keep fuel in the flame zone.

✔ Check for cold spots or water leaks affecting temperature.

Problem: Burner Runs Fine at Low Load, But Trips at High Fire
Possible Causes:

✔ Air damper response too slow, causing momentary fuel-rich spikes.

✔ Fuel pressure dropping at high load—starving burner.

✔ Flame stability lost at high momentum.

Fix:

✔ Tune air damper control for smoother response.

✔ Verify fuel pressure at high load—adjust regulators if needed.

✔ Adjust burner swirl to stabilize flame at high fire.

Problem: NOx is Too High, Even at Normal Air Settings
Possible Causes:
✓ Flame temperature too high—peak temp needs to be reduced.
✓ Excessive air—more O_2 means more NOx formation.
✓ Poor flame staging—burning all fuel at once.
Fix:
✓ Use **staged combustion** (introduce fuel in steps to cool peak flame temp).
✓ Reduce excess air slightly (without causing CO issues).
✓ Consider **flue gas recirculation (FGR)** to reduce peak flame temps.

Problem: Burner Sounds Like a Jet Engine (Too Loud or Pulsing)
Possible Causes:
✓ Poor mixing—air and fuel not blending smoothly.
✓ Excessive air velocity—causing turbulence inside the burner.
✓ Resonance—burner throat is interacting with combustion chamber.
Fix:
✓ Adjust air registers to distribute airflow better.
✓ Reduce air velocity slightly to prevent flame instability.
✓ Check burner throat design—sometimes a small adjustment fixes noise issues.
If your burner sounds like it's about to take off, something's wrong.

The Right Way to Approach Troubleshooting
1 **Look at the Symptoms First**
- What's actually happening?
- What changed recently?
- Any abnormal noise, smoke, or flame movement?

2 **Start with the Basics**
- **Fuel, air, ignition.** If one of these is missing or out of balance, nothing works.
- Are all **valves, dampers, and sensors** functioning?

3 **Make One Change at a Time**
- **Adjust slowly** changing multiple things at once just makes troubleshooting harder.
- **Watch the result, then adjust again if needed.**

4 **Use Flue Gas Readings as a Guide**
- **O_2 too high?** You're wasting fuel.
- **CO present?** Incomplete combustion somewhere.
- **NOx too high?** Too much flame heat or excess air.

Final Thoughts: Smart Troubleshooting Saves Time and Money
✓ A burner never "just stops working"—there's always a reason.
✓ Most problems come from simple issues (bad air-fuel ratio, sensor issues, or maintenance changes).
✓ Take a systematic approach, don't just "try things" randomly.
Good troubleshooting is about observation, logic, and patience—not luck.

Chapter 16: The Last Burn – Final Thoughts on the Art of Combustion
A reflection on combustion tuning, what we've learned, and why making flames behave is an art as much as a science.

Why Combustion is More Than Just Air, Fuel, and Fire
If you've made it this far, you now know something that many engineers, operators, and even combustion experts sometimes overlook:
Combustion is not just a science—it's an art.

✓ You can have the **right O_2 numbers** and still have a terrible flame.

✓ You can have a **flame that looks perfect** but still be making CO.

✓ You can have **a perfectly tuned burner** today and a totally different beast tomorrow because of fuel changes, air conditions, or load fluctuations.
That's why the **best combustion engineers aren't just number crunchers**—they're also problem solvers, flame watchers, and process whisperers.

What We've Learned (And What You Should Never Forget)

1 **The Perfect Flame is a Lie – But Optimal Combustion is Real**
- No burner runs at **one single ideal setting** forever.
- The goal is to **continuously optimize based on process conditions.**

2 **Flame Shape Matters More Than You Think**
- A burner can hit all the "right" emissions numbers but still have **a bad flame shape that wastes energy or damages equipment.**
- **Always check the flame—not just the analyser.**

3 **CO Can Happen Even with Excess Air**
- Too much air can **strip fuel from the flame before full combustion happens.**
- **A CO spike doesn't always mean "too rich" combustion—it could mean over-airing.**

4 **Tuning is Not a One-Time Thing**
- **Air density changes with seasons.**
- **Fuel quality changes between batches.**
- **Load demand changes daily.**
- **A burner tuned in winter may not run the same in summer.**

5 **Different Fuels, Different Rules**
- **Gas, oil, coal, hydrogen, and biomass all burn differently.**
- If you switch fuels, **you must retune everything**—airflow, ignition, burner settings, and emissions controls.

6 **NOx Control is About Managing Flame Temperature**
- High NOx usually means **too much flame heat, too much excess air, or poor fuel staging.**
- Use **flue gas recirculation (FGR), staged combustion, or lower excess air** to control NOx **without losing efficiency.**

7 **Atomization is Everything for Oil Burners**
- **If oil isn't atomized properly, it won't burn efficiently.**
- **Preheat oil, use the right pressure, and check nozzle condition regularly.**

8 **You Can't Tune a Burner with Just One Measurement**
- O_2 alone **doesn't tell the full story.**
- CO, NOx, flame shape, and heat transfer **all play a role in proper combustion.**

9 **Burners Are Like Musical Instruments—They Need to Be Tuned to Work Well**
- Every burner **has a personality**—some are easy, some fight you every step of the way.
- **The best combustion engineers listen to the flame, not just the data.**

1 **When in Doubt, Look at the Flame**
- If a burner is acting up, **the flame will usually tell you what's wrong.**
- Pulsing? Too much air or poor mixing.
- Lifting? Air velocity too high.
- Long, lazy flame? Fuel pressure too low or poor atomization.

The Future of Combustion: What's Next?

Hydrogen combustion? It's coming fast—but **needs tuning strategies to prevent flashback and NOx issues.**

AI in burner control? Smart combustion systems are starting to **autotune themselves—but they still need humans who understand the fundamentals.**

Ultra-low NOx burners? New designs continue to **reduce emissions—but require fine-tuned operation to avoid CO spikes.**

✓ No matter how much technology advances, good combustion tuning will always require people who understand flames.

Final Thoughts: What Makes a Great Combustion Engineer?

✓ They don't just adjust O_2—they watch the flame and tune for real-world performance.

✓ They troubleshoot logically, not randomly.

✓ They know that every burner is different and treat tuning as an ongoing process.

✓ They respect the power of combustion—because getting it wrong can mean wasted fuel, poor efficiency, or even dangerous situations.

Master combustion, and you don't just save fuel—you make flames behave.

And that? **That's an art worth mastering.**

Thank You for Reading – Now Go Tune Some Burners!

C S Prescott