CHAPTER 10

Burners and Combustion Systems

Learning Objectives

Upon completion of this chapter, students will be able to:

1. Explain the operation of atmospheric and power burner systems
2. Identify different ignition system types and their operation
3. Understand flame sensing methods and troubleshoot sensor problems
4. Calculate and select proper burner orifice sizes
5. Adjust primary air for optimal combustion
6. Perform combustion analysis and interpret results
7. Calculate combustion air requirements per CSA B149.1
8. Identify and correct common combustion problems
9. Understand burner port loading and flame characteristics
10. Apply pressure and flow relationships to burner operation

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10.1 Atmospheric Burners

Atmospheric burners are the most common type in residential gas appliances, using natural draft and venturi principles.

Basic Operation Principles

Venturi Effect:

The core principle of atmospheric burners:

1. **Gas Flow:** Gas flows through orifice at pressure (typically 3.5" W.C. natural gas, 10" W.C. propane)
2. **Velocity:** High-velocity gas jet creates low-pressure area
3. **Air Entrainment:** Low pressure draws in primary air through air shutter
4. **Mixing:** Gas and primary air mix in venturi throat and mixing tube
5. **Delivery:** Mixed gas-air exits burner ports
6. **Secondary Air:** Additional air drawn from surrounding area during combustion

Components:

Gas Orifice (Spud):

- Precisely sized hole
- Controls gas flow rate
- Threads into manifold or burner
- Sized for gas type and input

Air Shutter:

- Adjustable opening
- Controls primary air entry
- Slide, rotating band, or fixed
- Sets air-fuel ratio

Venturi (Mixing Tube):

- Converging-diverging passage
- Creates low pressure for air entrainment
- Mixes gas and air
- Delivers mixture to burner

Burner Head:

- Port configuration
- Distributes flame
- Various designs (ribbon, inshot, slotted, etc.)
- Material: cast iron, steel, stainless steel

Primary and Secondary Air

Primary Air:

Definition:

- Air mixed with gas BEFORE combustion
- Drawn through air shutter
- Typically 40-60% of total air needed

Control:

- Air shutter adjustment
- Affects flame characteristics
- Critical for proper combustion

Too Little Primary Air:

- Yellow, lazy flame
- Incomplete combustion
- Soot and carbon monoxide production
- Lower efficiency
- Possible flame lifting

Too Much Primary Air:

- Short, sharp blue flame
- Hard, noisy combustion (roaring)
- Flame lifting or blowing off ports
- Flashback possible
- Heat loss through excess air

Correct Primary Air:

- Stable blue flame
- Soft, quiet combustion
- Inner cone distinct
- Slight yellow tips acceptable (minimal)
- No lifting or flashback

Secondary Air:

Definition:

- Air drawn into flame from surrounding area
- Completes combustion
- Approximately 40-60% of total air

Control:

- No direct control mechanism
- Must be available from room/combustion air supply
- Limited by combustion air provisions

Importance:

- Completes combustion
- Prevents CO formation
- Essential for safe operation
- Reason combustion air openings required

Burner Types and Designs

Understanding different burner configurations is essential for proper service and troubleshooting.

Atmospheric (In-Shot) Burners:

Description:

- Most common residential furnace burner
- Gas-air mixture "shoots" horizontally into heat exchanger
- Venturi throat at burner inlet
- Flame projects forward into heat exchanger tubes or clamshell

Construction:

- Cast iron or stamped steel
- Mixing tube with air shutter
- Burner head with port configuration
- Orifice threads into manifold

Operation:

- Gas jet creates venturi effect
- Primary air enters through shutter
- Mixed gas-air travels through mixing tube
- Exits ports and ignites
- Flame projects into heat exchanger

Port Configurations:

- Single row of ports
- Double row (ribbon style)
- Slotted ports
- Various patterns for flame distribution

Advantages:

- Simple and reliable
- Quiet operation
- Easy to service
- Good heat transfer
- Proven design

Applications:

- Residential forced-air furnaces (most common)
- Some commercial furnaces
- Standard efficiency equipment

Service Considerations:

- Air shutter adjustment critical
- Burner alignment important
- Must maintain proper spacing to heat exchanger
- Clean ports if clogged

Upshot (Vertical) Burners:

Description:

- Flame projects vertically upward
- Burner positioned below heat exchanger
- Gas-air mixture shoots upward into heat exchanger
- Common in older furnaces and some boilers

Construction:

- Similar to in-shot but vertical orientation
- Mixing tube vertical or angled
- Burner ports face upward
- Cast iron or steel construction

Operation:

- Venturi mixes gas and air
- Mixture travels up through burner
- Exits upward-facing ports
- Flame rises into heat exchanger above

Heat Exchanger Configuration:

- Clamshell heat exchanger typical
- Sectional cast iron (boilers)
- Heat exchanger surrounds flame

Advantages:

- Natural flame direction (upward)
- Good for gravity systems
- Simple design
- Effective heat transfer

Disadvantages:

- Larger footprint
- Less common in modern equipment
- More difficult to service (access)

Applications:

- Older residential furnaces
- Gravity furnaces (obsolete)
- Cast iron boilers
- Some commercial equipment

Ribbon Burners:

Description:

- Long, narrow burner
- Multiple ports in continuous row(s)
- Creates "ribbon" of flame
- Port arrangement provides wide flame pattern

Construction:

- Stamped steel body
- Hundreds of small drilled or stamped ports
- One or two rows of ports
- Length matches heat exchanger width

Port Configuration:

- Ports: 1/16" to 1/8" diameter typically
- Spacing: 1/4" to 1/2" center-to-center
- Single or double row
- Very uniform distribution

Operation:

- Gas-air mixture enters one end
- Distributes along length of burner
- Burns at many small ports
- Wide, even flame pattern
- Excellent heat distribution

Advantages:

- Very uniform heat distribution
- Efficient combustion
- Good flame stability
- Quiet operation
- Minimal flame impingement risk

Disadvantages:

- Port plugging possible (dust, debris)
- Requires proper manifold pressure
- Cleaning tedious (many small ports)

Applications:

- Modern high-efficiency furnaces
- Premix burners
- Commercial cooking equipment
- Industrial heaters

Service Considerations:

- Check all ports for plugging
- Clean with wire brush or compressed air
- Verify even flame across entire length
- Check for port erosion

Slotted Port Burners:

Description:

- Slots instead of round holes
- Common in water heaters
- Wide flame pattern from each slot
- Simple and economical

Construction:

- Stamped or cast metal
- Rectangular or elongated slots
- Typically 3-8 slots per burner
- Slots: 1/4" to 3/4" long

Operation:

- Gas-air mixture enters from below or side
- Exits through slots
- Each slot produces wide flame
- Flames overlap for coverage

Flame Characteristics:

- Wider, flatter flames than round ports

- Good stability
- Less prone to lifting
- Forgiving of slight adjustment errors

Advantages:

- Less prone to clogging than small ports
- Easy to clean
- Stable flames
- Forgiving design
- Lower cost

Disadvantages:

- Less uniform than many small ports
- Potential for flame impingement if misaligned
- Limited to lower input applications

Applications:

- Residential water heaters (very common)
- Small commercial water heaters
- Pool heaters
- Some space heaters

Service Considerations:

- Easy to clean
- Check for burner alignment
- Verify proper spacing to baffle/flame arrestor
- Look for flame impingement

Drilled Port Burners:

Description:

- Precision-drilled round holes
- Cast iron or heavy steel construction
- Very stable and durable
- Used in boilers and commercial equipment

Construction:

- Cast iron body (typical)
- Precision-drilled ports
- Port size: 1/8" to 1/4" typical

- Spacing designed for specific application
- Heavy, durable construction

Port Patterns:

- Linear rows
- Circular patterns
- Custom patterns for application
- Engineered for specific heat exchanger

Operation:

- Gas-air mixture supplied to burner
- Exits each drilled port
- Individual flame at each port
- Very stable combustion
- Predictable performance

Advantages:

- Very durable (cast iron)
- Long service life
- Precise flame control
- Excellent stability
- Resists warping

Disadvantages:

- Heavy
- Expensive
- Difficult to modify
- Requires proper support

Applications:

- Cast iron boilers (very common)
- Commercial boilers
- Industrial heaters
- High-quality residential boilers
- Long-life applications

Service Considerations:

- Check for cracks (cast iron)
- Clean ports with wire brush
- Verify proper seating/gasketing

- Check for port erosion
- Inspect for flame impingement

Multi-Port (Perforated) Burners:

Description:

- Many small holes (perforations)
- Often 100+ ports per burner
- Produces multiple small flames
- Very uniform heat distribution

Construction:

- Sheet metal with stamped or drilled holes
- Burner may be flat, cylindrical, or shaped
- Port size: 1/32" to 1/16" very small
- High port density

Applications:

- Infrared heaters
- High-efficiency appliances
- Radiant burners
- Commercial cooking (some)
- Specialized industrial applications

Characteristics:

- Many small flames or radiant surface
- Very uniform heating
- Excellent mixing
- Low emissions potential
- Quiet operation

Service:

- Prone to plugging (very small ports)
- Difficult to clean (many ports)
- May require replacement if damaged
- Critical to maintain proper pressure

Radiant Burners:

Description:

- Flame heats ceramic or metal surface
- Surface radiates infrared heat
- No visible flame (sometimes)
- Efficient radiant heating

Construction:

- Perforated burner or porous ceramic
- Gas-air mixture burns at or in surface
- Surface glows orange/red
- Reflector directs heat

Types:

Ceramic Radiant:

- Porous ceramic tile or panel
- Gas burns within ceramic matrix
- Surface glows bright orange
- Infrared radiation

Metal Mesh/Screen:

- Fine metal screen
- Flame stabilizes on screen surface
- Screen glows
- Radiant heat

Operation:

- Gas-air mixture supplied
- Combustion at surface
- Surface heats to 1500-1800°F
- Radiates infrared energy
- No convective heat transfer

Advantages:

- Efficient radiant heating
- Quiet operation
- No visible flame (safer perception)
- Targeted heating
- Good for outdoor/open areas

Disadvantages:

- Fragile (ceramic types)
- Expensive
- Requires precise control
- Can be damaged by impact

Applications:

- Outdoor patio heaters
- Industrial process heating
- Commercial space heating (high bay)
- Infrared comfort heating
- Paint drying, curing

Power Burners (Fan-Assisted):

Description:

- Uses fan to supply combustion air
- Positive or negative pressure
- More complex but higher performance
- Common in modern equipment

Types:

Forced Draft:

- Fan pushes air through burner
- Positive pressure in combustion chamber
- Fan upstream of burner

Induced Draft:

- Fan pulls air through burner
- Negative pressure in combustion chamber
- Fan downstream (after heat exchanger)

Premix:

- Gas and air completely mixed before burner
- Fan mixes and delivers to burner head
- Very efficient
- Lower emissions

Construction:

- Burner head with ports or mesh

- Fan (centrifugal or vane-axial)
- Gas valve with air mixing section
- Electronic controls
- Pressure switches

Advantages:

- Better combustion control
- Higher efficiency
- Can handle longer vents
- More compact
- Less sensitive to building pressure
- Can modulate

Disadvantages:

- More complex
- Higher cost
- Requires electricity
- Fan failure = no heat
- More maintenance

Applications:

- High-efficiency furnaces (90%+ AFUE)
- Condensing boilers
- Modulating equipment
- Commercial equipment
- Sealed combustion appliances

Sealed Combustion Burners:

Description:

- Combustion chamber sealed from room
- All combustion air from outdoors
- Often power burner design
- Direct vent configuration

Construction:

- Sealed combustion chamber
- Concentric vent (air in, flue out)
- Fan-powered typically
- Gaskets seal chamber

Operation:

- Fan draws outdoor air
- Mixes with gas
- Burns in sealed chamber
- Flue gases exhaust outside
- No room air involved

Advantages:

- No combustion air from conditioned space
- No spillage possibility
- Works in tight buildings
- Can install in confined spaces
- Improved efficiency (not heating outdoor air)

Disadvantages:

- More expensive
- Complex installation
- Requires specific venting
- Sensitive to wind effects

Applications:

- Modern high-efficiency equipment
- Tight building installations
- Bedroom closet installations (with restrictions)
- Commercial applications

Conversion Burners:

Description:

- Aftermarket burners
- Convert oil to gas (historical)
- Convert atmosphere to power (rare)
- Retrofit applications

Notes:

- Becoming obsolete
- Usually better to replace entire appliance
- Complex certification issues
- Limited applications today

Specialty Burners:

Bunsen Burner Style:

- Laboratory and process applications
- Adjustable air and gas
- Single flame
- Not common in HVAC

Surface Combustion:

- Industrial applications
- Combustion at or within porous material
- Process heating
- Specialized equipment

Duct Burners:

- Installed in ductwork
- Supplemental heating
- Commercial buildings
- Make-up air heating

Flame Characteristics

Proper Natural Gas Flame:

- Clear blue color
- Distinct inner cone (light blue)
- Outer mantle (darker blue/purple)
- Stable, not lifting or floating
- Soft, quiet combustion
- Minimal yellow tipping at outer edge

Proper Propane Flame:

- Blue flame with slight luminosity
- May show more yellow tipping than natural gas (acceptable if minimal)
- Stable and quiet
- Distinct inner cone

Flame Zones:

Inner Cone (Primary Combustion Zone):

- Light blue

- Hottest part: 1,980°C (3,600°F) for methane
- Primary air combustion
- Distinct boundary

Outer Mantle (Secondary Combustion Zone):

- Darker blue/purple
- Secondary air completes combustion
- Slightly cooler than inner cone
- May show slight yellow at tips

Problem Flames:

Yellow or Orange Flame:

- Insufficient air
- Incomplete combustion
- Soot formation
- CO production
- Requires adjustment

Lifting Flame:

- Flame lifts off ports
- Excessive primary air or gas velocity
- Can cause ignition failure
- Noisy operation
- Reduce primary air or check orifice size

Floating Flame:

- Flame hovers above burner
- Not stable on ports
- Usually too much primary air
- Dangerous - can extinguish

Flashback:

- Flame burns inside burner
- Too much primary air
- Gas velocity too low
- Very dangerous
- Shut down immediately
- Reduce primary air

Impingement:

- Flame contacts surfaces
- Heat exchanger too close
- Misaligned burner
- Causes incomplete combustion
- Yellow flame and CO

10.2 Power Burners

Power burners use fans to force combustion, providing better control and higher efficiency.

Power Burner Operation

Basic Principle:

- Fan forces air into combustion chamber
- Gas injected into air stream
- Premixed before combustion
- More precise air-fuel control

Advantages:

- Better mixing
- More complete combustion
- Higher efficiency
- More compact
- Independent of room conditions
- Can handle longer vent runs

Types:

Forced Draft:

- Fan blows air through burner
- Positive pressure in combustion chamber
- Fan before burner

Induced Draft:

- Fan draws air through burner
- Negative pressure in combustion chamber
- Fan after heat exchanger
- More common in residential

Premix:

- Gas and air fully mixed before combustion
- Very efficient
- Lower emissions
- Complex controls

Modulating Burners

Operation:

- Vary firing rate to match load
- Gas valve and fan modulate together
- Maintain optimal air-fuel ratio
- High efficiency

Advantages:

- Precise temperature control
- Fewer cycles
- Higher seasonal efficiency
- Better comfort

Control:

- Electronic controls monitor demand
- Adjust gas valve position
- Adjust fan speed
- Maintain proper ratio

Applications:

- High-efficiency furnaces
- Modulating boilers
- Premium residential equipment
- Commercial applications

Two-Stage Burners

Operation:

- Two firing rates: high and low
- Typically 65-70% low, 100% high
- Better than single-stage
- Simpler than modulating

Control:

- Thermostat or control board determines stage
- Cold call = high fire
- Moderate call = low fire
- Gas valve switches between outputs

Benefits:

- Reduced cycling
- Better efficiency
- Improved comfort
- Lower cost than modulating

10.3 Burner Orifices

Orifices control gas flow rate and are critical for proper appliance operation.

Orifice Function

Purpose:

- Meter gas flow
- Create specific input rate
- Match appliance requirements
- Convert pressure to flow

How Orifices Work:

- Gas under pressure enters orifice
- Small opening restricts flow
- Flow rate depends on:
    - Orifice size (diameter)
    - Gas pressure
    - Specific gravity of gas

Orifice Sizing

Factors Affecting Size:

Gas Type:

- Natural gas: larger orifices
- Propane: smaller orifices (60% of natural gas size typically)
- Different heating values require different flows

Pressure:

- Natural gas manifold: typically 3.5" W.C.
- Propane manifold: typically 10" W.C.
- Higher pressure = smaller orifice for same flow

Input Required:

- Higher input = larger orifice
- Flow in CFH needed
- Calculate from BTU input

Specific Gravity:

- Heavier gas = slower flow
- Lighter gas = faster flow
- Corrections needed if SG differs from standard

Drill Number Sizing

Drill Number System:

- Standardized drill sizes
- Numbered #1 through #80 (plus wire gauges)
- Higher number = smaller diameter
- Fractional sizes also used

Common Ranges:

- Natural gas: #35 to #50 typical residential
- Propane: #50 to #60 typical residential
- Varies by appliance and input

Example:

- #43 drill = 0.089" diameter
- #54 drill = 0.055" diameter

Measurement:

- Orifice drill size often stamped on orifice
- Can measure with drill bit gauge
- Precision critical (0.001" changes flow significantly)

Orifice Calculation

Basic Formula:

Flow (CFH) = $C \times d^2 \times \sqrt{P / SG}$

Where:

- C = constant (depends on units)
- d = orifice diameter (inches)
- P = pressure (inches W.C.)
- SG = specific gravity

Simplified Approach: Use manufacturer's tables or orifice capacity charts

Example Selection:

Furnace burner:

- Total input: 100,000 BTU/hr
- 5 burners
- Input per burner: 100,000 ÷ 5 = 20,000 BTU/hr
- Natural gas (1,000 BTU/ft^3)
- Flow per burner: 20,000 ÷ 1,000 = 20 CFH
- Manifold pressure: 3.5" W.C.
- From chart: #43 drill provides approximately 20 CFH at 3.5" W.C.

Verify:

- Check manufacturer specifications
- Use provided orifices when available
- Calculate only when needed

Altitude Compensation

At Higher Elevations:

- Less oxygen available
- Must reduce gas flow
- Smaller orifices required
- Or reduce pressure

Typical Adjustment:

- 4% reduction per 1,000 feet above rated elevation
- Accomplished by smaller orifices or lower pressure
- Follow manufacturer de-rating instructions

Example:

- Sea level orifice: #43
- 5,000 ft elevation
- May require #45 or #46 (smaller)
- Or reduce manifold pressure

Orifice Installation

Procedure:

1. Turn off gas supply
2. Release pressure downstream
3. Remove old orifice (wrench on hex)
4. Inspect threads
5. Install new orifice (hand tight then 1/4-1/2 turn)
6. Don't overtighten (brass threads)
7. Pressure test
8. Leak test with soap solution
9. Set manifold pressure
10. Verify input rate

Common Mistakes:

- Wrong orifice size
- Cross-threading
- Overtightening (cracks orifice or manifold)
- Not leak testing
- Forgetting pilot orifice

10.4 Ignition Systems

Modern appliances use various ignition methods to light burners safely and efficiently.

Standing Pilot

Operation:

- Small pilot flame burns continuously
- Ignites main burner when valve opens
- Thermocouple or thermopile proves flame
- Traditional system

Components:

Pilot Burner:

- Small orifice (typically #55-#60 drill)
- Pilot flame directed at thermocouple
- Must remain lit continuously

Thermocouple:

- Generates millivolts when heated
- Provides power to hold pilot safety valve open
- Typically 20-30 millivolts required
- See Chapter 10.5 for details

Pilot Safety Valve:

- Electromagnet holds valve open
- Thermocouple powers magnet
- If pilot out, magnet releases, valve closes
- Prevents gas flow without flame

Advantages:

- Simple and reliable
- No electricity required
- Proven technology
- Easy to relight

Disadvantages:

- Wastes gas (burns continuously)
- Heat loss
- Lower seasonal efficiency
- Not permitted on some high-efficiency equipment

Relighting Procedure:

1. Turn gas control to "OFF", wait 5 minutes
2. Turn to "PILOT"
3. Push and hold pilot button
4. Light pilot with igniter or match
5. Hold button 30-60 seconds
6. Release button - pilot should stay lit
7. Turn to "ON" position
8. Set desired temperature

Intermittent Pilot Ignition (IPI)

Operation:

- Pilot lights electronically only when needed
- Spark ignites pilot
- Pilot ignites main burner
- Pilot extinguishes when main burner off
- Saves gas vs. standing pilot

Components:

Ignition Control Module:

- Electronic controller
- Times ignition sequence
- Monitors flame
- Safety lockout if fails

Spark Generator:

- Creates high-voltage spark (10,000+ volts)
- Ignites pilot
- Similar to car spark plug

Spark Electrode:

- Positioned at pilot
- Gap to ground (typically 1/8")
- Creates arc to ignite pilot

Flame Sensor:

- Flame rod (rectification)
- Or thermocouple
- Proves pilot lit before opening main valve

Sequence:

1. Call for heat
2. Module energizes spark and gas valve (pilot)
3. Pilot ignites (typically 5-7 seconds)
4. Sensor proves pilot lit
5. Main valve opens
6. Main burner ignites from pilot
7. Spark stops
8. When satisfied, main valve closes
9. Pilot extinguishes

Advantages:

- Saves gas vs. standing pilot
- Automatic ignition
- No pilot outage problems
- Safer than standing pilot

Disadvantages:

- Requires electricity
- More complex than standing pilot
- Electronic components can fail
- More expensive

Direct Spark Ignition (DSI)

Operation:

- Spark directly ignites main burner
- No pilot flame
- Most efficient ignition
- Common in modern equipment

Components:

Ignition Control Module:

- Electronic controller
- Provides high-voltage spark
- Monitors flame
- Safety timing and lockout

Spark Electrode(s):

- At main burner
- Creates spark directly to burner ports
- Gap critical (typically 1/8" to 3/16")
- One or multiple electrodes

Flame Sensor:

- Flame rectification rod
- Separate from spark electrode (usually)
- Proves main burner lit
- Immediate sensing

Sequence:

1. Prepurge (induced draft fan runs)
2. Spark begins
3. Gas valve opens (pilot or main)
4. Flame ignites from spark
5. Flame sensor proves ignition
6. Spark stops
7. Normal operation
8. Safety lockout if no flame

Advantages:

- No pilot gas waste
- Fastest ignition
- Highest efficiency
- Fewer components than IPI

Disadvantages:

- Spark electrodes wear
- Gap maintenance required
- More sensitive to improper combustion
- Electronic failure potential

Hot Surface Ignition (HSI)

Operation:

- Silicon nitride or silicon carbide element heats electrically
- Glows bright orange (2,500°F)
- Ignites gas directly when valve opens
- No spark

Components:

Hot Surface Igniter:

- Ceramic element
- Glows bright orange when energized
- Very fragile
- Positioned in gas path

Ignition Control:

- Times warm-up period

- Opens valve when igniter hot
- Monitors flame
- Safety lockout

Flame Sensor:

- Often igniter itself (senses current change)
- Or separate flame rod
- Proves ignition

Sequence:

1. Prepurge (if applicable)
2. Igniter energized (30-90 seconds warm-up)
3. Control confirms igniter hot
4. Gas valve opens
5. Gas ignites instantly from hot igniter
6. Flame sensor confirms
7. Igniter remains energized (most systems) or de-energizes
8. Normal operation

Advantages:

- Very reliable ignition
- No pilot gas waste
- No spark maintenance
- Quiet (no spark noise)
- Long service life (if not damaged)

Disadvantages:

- Fragile (easily broken if touched)
- Warm-up time delay
- Requires replacement when failed
- Cannot be repaired
- Higher current draw than spark

Handling HSI:

- NEVER touch ceramic element with bare hands (oils cause failure)
- Handle by ceramic base only
- Use gloves if must touch
- Very fragile - breaks easily
- Replace if cracked

10.5 Flame Sensing

Flame sensing devices verify ignition and prove flame presence for safety.

Thermocouple Systems

Thermocouple Principle:

- Two dissimilar metals joined
- Heat at junction generates voltage
- Millivolt output (typically 20-30 mV for gas pilot)
- Powers pilot safety valve

Construction:

- Hot junction at tip (in pilot flame)
- Cold junction at base
- Insulated lead wire
- Various lengths

Operation:

1. Pilot flame heats tip
2. Generates 20-35 millivolts typically
3. Powers electromagnetic coil in valve
4. Magnet holds valve open
5. If flame out, voltage drops
6. Magnet releases, valve closes
7. Requires manual reset (relight pilot)

Testing:

- Measure millivolt output with meter
- Hot (in flame): 20-35 mV typically
- Cold (no flame): 0-2 mV
- Replace if output low (under 20 mV)

Problems:

- Weak output (replace)
- Loose connection
- Corroded or dirty tip
- Wrong position in flame
- Pilot flame too small

Thermopile:

- Multiple thermocouples in series
- Higher voltage output (500-750 mV typical)
- Powers gas valve directly (millivolt valve)
- Powers controls
- Common in standing pilot systems

Flame Rectification

Principle:

- Flame conducts electricity in one direction only
- AC current through flame becomes DC
- Control module senses DC current
- Modern standard for proving flame

How It Works:

1. Control applies AC voltage across flame rod and ground
2. Flame ionizes (conducts)
3. Flame acts as diode (conducts better one direction)
4. Resulting current is pulsing DC
5. Control detects DC current
6. DC = flame present
7. No DC = no flame, valve closes

Flame Rod:

- Stainless steel rod
- Positioned in flame
- Small gap to ground (burner)
- Insulated from burner
- Conducts through flame to ground

Signal:

- Microamps (μA) DC current
- Typically 0.5 to 6 μA for good flame
- Above 1 μA generally adequate
- Below 0.5 μA may not prove

Advantages:

- Very reliable
- Fast response (milliseconds)
- No mechanical parts
- Simple and inexpensive

- Standard in modern equipment

Disadvantages:

- Sensitive to grounding problems
- Carbon buildup affects sensing
- Proper positioning critical

Common Problems:

No or Low Flame Signal:

Causes:

- Flame rod positioned wrong (not in flame)
- Carbon buildup on rod
- Insulator cracked (grounding)
- Rod corroded
- Wrong gap to ground
- Poor ground connection at burner
- Weak flame (poor combustion)

Solutions:

- Reposition rod in proper flame zone
- Clean rod with fine steel wool
- Replace if insulator cracked
- Verify good ground path to control
- Check flame characteristics
- Verify proper combustion

Intermittent Flame Loss:

- Loose connections
- Intermittent ground
- Burner not grounded properly
- Control module failure

Testing Flame Rod:

1. Measure microamps with meter
2. Rod to ground with burner firing
3. Should read 1-6 μA typically
4. Below 0.5 μA problematic
5. Verify with manufacturer specifications

Flame Rod Position:

- In outer mantle of flame
- Not in hottest part (inner cone)
- About 1/2" to 1" into flame
- Proper gap to ground (1/8" typical)
- Follow manufacturer positioning

Optical Flame Sensors

Ultraviolet (UV) Sensors:

- Detect UV light from flame
- Fast response
- Commercial/industrial applications
- Not common in residential

Infrared (IR) Sensors:

- Detect IR radiation from flame
- Used in some high-end equipment
- Can distinguish flame from other heat sources

10.6 Combustion Air Requirements

Adequate combustion air is essential for complete, safe combustion.

Theoretical vs. Actual Air Requirements

Theoretical (Stoichiometric) Air:

For complete combustion of methane (natural gas):

- $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$
- Requires 2 molecules O_2 per molecule CH_4
- Air is 21% oxygen, 79% nitrogen
- Need approximately 9.5 ft^3 air per ft^3 natural gas
- This is MINIMUM for complete combustion

Actual Air Required:

Perfect mixing impossible, so excess air needed:

- **Atmospheric burners:** 40-60% excess air typical
- **Power burners:** 15-30% excess air typical
- Total air: theoretical × (1 + excess percentage)

Example:

- Theoretical air: 9.5 ft^3/ft^3 gas
- 50% excess air
- Actual air: $9.5 \times 1.5 = 14.25$ ft^3/ft^3 gas

For 100,000 BTU/hr appliance (natural gas):

- Gas flow: 100 CFH
- Air required: $100 \times 14.25 = 1{,}425$ CFH
- This air must come from somewhere!

CSA B149.1 Combustion Air Provisions

Review from Chapter 9:

Confined Space:

- Less than 50 ft^3 per 1,000 BTU/hr
- Requires combustion air openings

Unconfined Space:

- 50 ft^3 or more per 1,000 BTU/hr
- May have adequate infiltration (old buildings)
- Modern tight buildings may still need openings

Combustion Air Opening Sizing:

Method 1: All Air from Inside

- Two openings (top and bottom)
- Each: 220 in^2 per 100,000 BTU/hr total input
- To adjacent unconfined space or outdoors

Method 2: All Air from Outdoors

- Two openings to outdoors (top and bottom)
- Vertical ducts: 110 in^2 per 100,000 BTU/hr each
- Horizontal ducts: 220 in^2 per 100,000 BTU/hr each

Method 3: Mechanical Ventilation

- Powered ventilation
- 1 CFM per 2,400 BTU/hr minimum
- Special provisions and interlocks

Example Calculation:

System:

- Furnace: 100,000 BTU/hr
- Water heater: 40,000 BTU/hr
- Total: 140,000 BTU/hr

Combustion Air from Outdoors (Vertical):

- Each opening: $140{,}000 \div 100{,}000 \times 110 = 154$ in²
- Convert: $154 \div 144 = 1.07$ ft²
- Approximately 12" × 13" each opening

Make-Up Air Considerations

Building Depressurization:

Modern homes have powerful exhaust equipment:

- Kitchen exhaust fans
- Bathroom fans
- Dryer vents
- Central vacuums
- Fireplaces

Problem:

- Exhaust more air than enters
- Creates negative pressure
- Can overcome draft hood appliances
- Causes spillage
- Pulls CO into living space

Solution:

- Make-up air for powerful exhaust
- Interlock exhaust with make-up air supply
- Or use direct vent/power vent appliances
- Test for depressurization

Pressure Testing:

- Manometer or draft gauge
- Measure with exhaust equipment on
- -3 Pa (-0.01" W.C.) or more negative indicates problem
- Most building codes now address this

10.7 Combustion Analysis

Combustion analysis verifies proper combustion and safety.

Purpose of Combustion Testing

Verify:

- Complete combustion
- Safe CO levels
- Proper air-fuel mixture
- Equipment efficiency
- Vent operation

When Required:

- Initial installation
- Annual service
- After any combustion system repair
- After conversion
- Troubleshooting performance problems
- Code/manufacturer requirements

Combustion Analyzer Operation

Measurements:

Oxygen (O_2):

- Percentage in flue gas
- Indicates excess air
- Normal: 5-9%
- Too low (<5%): insufficient air, danger
- Too high (>10%): excess air, inefficiency

Carbon Dioxide (CO_2):

- Percentage in flue gas
- Indicates combustion completeness

- Natural gas: 8-10% ideal
- Propane: 10-12% ideal
- Lower values = more excess air

Carbon Monoxide (CO):

- Parts per million (ppm)
- Toxic gas measurement
- Air-free (corrected for O_2)
- Must be < 100 ppm air-free (CSA B149.1)
- Goal: < 50 ppm

Stack Temperature:

- Flue gas temperature
- °F or °C
- Indicates heat loss
- Used in efficiency calculation

Draft:

- Pressure in vent
- Negative for natural draft
- Positive for power vent
- Inches of water column

Taking Measurements

Procedure:

1. **Calibrate Analyzer:**
   - Fresh air calibration (bump test)
   - Zero sensors
   - Verify battery charged
2. **Warm Up Appliance:**
   - Run 10-15 minutes minimum
   - Reach steady state
   - Allows proper combustion to establish
3. **Insert Probe:**
   - Into flue per manufacturer instructions
   - 1-2 pipe diameters downstream of appliance
   - Through hole drilled or test port
   - Seal around probe
4. **Allow Stabilization:**
   - Wait 1-2 minutes
   - Readings stabilize

    - Note any fluctuations
5. **Record Readings:**
    - O_2, CO_2, CO (air-free), stack temperature
    - Ambient temperature
    - Draft (if measured)
    - Calculated efficiency
6. **Print or Document:**
    - Most analyzers can print
    - Keep record
    - Compare to previous tests

Interpreting Results

Acceptable Combustion (Natural Gas):

- O_2: 5-9%
- CO_2: 8-10%
- CO (air-free): < 100 ppm (preferably < 50 ppm)
- Stack temp: Varies by appliance type
- Efficiency: Close to rated AFUE

Problem Indicators:

High CO (>100 ppm):

- Insufficient combustion air
- Improper burner adjustment
- Flame impingement
- Heat exchanger problems
- Venting issues
- **Action required - don't leave in service**

Low O_2 (<5%):

- Insufficient air
- Dangerous condition
- High CO likely
- Incomplete combustion risk

High O_2 (>10%):

- Excess air
- Lower efficiency
- Wasted heat
- But safe combustion usually

Low CO_2 (<7%):

- Excess air
- Correlates with high O_2
- Lower efficiency

High Stack Temperature:

- Heat not extracted
- Dirty heat exchanger
- Poor efficiency
- Oversized or short-cycling equipment

Low Stack Temperature:

- Condensing in non-condensing appliance
- Vent sizing problem
- Backdrafting possible

Combustion Adjustments

To Improve Combustion:

High CO:

1. Check combustion air supply
2. Increase primary air (open air shutter)
3. Check for flame impingement
4. Clean burner
5. Verify proper orifice size
6. Check manifold pressure
7. Inspect heat exchanger

High O_2 (Low Efficiency):

1. Reduce primary air (close air shutter slightly)
2. Verify proper orifice size
3. Check manifold pressure
4. Don't reduce too much (watch CO)

General Adjustment:

1. Start with manufacturer settings
2. Adjust primary air for optimal flame
3. Check combustion readings
4. Fine-tune for best results

5. Balance efficiency vs. CO
6. Document final settings

Chapter Summary

Atmospheric burners use the venturi effect to entrain primary air (40-60% of total) with gas before combustion, with secondary air completing combustion at the flame. Proper primary air adjustment is critical: too little causes yellow flames and CO production, too much causes lifting, flashback, or noisy combustion. Correct adjustment produces stable blue flames with distinct inner cones and minimal yellow tipping.

Power burners use fans for forced or induced draft, providing better air-fuel control and higher efficiency. Modulating burners vary firing rate continuously to match load; two-stage burners provide high and low fire rates. Both improve comfort and efficiency compared to single-stage atmospheric burners.

Burner orifices meter gas flow based on size, pressure, and gas specific gravity. Natural gas requires larger orifices than propane (approximately 60% larger for same input). Orifice size is specified by drill number, with higher numbers indicating smaller diameters. Proper sizing is critical for correct input and safe operation.

Modern ignition systems include standing pilot (continuous flame, thermocouple safety), intermittent pilot (electronic spark ignites pilot on demand), direct spark ignition (spark directly ignites main burner), and hot surface ignition (glowing element ignites gas). Each system has specific safety controls and timing sequences per CSA B149.1.

Flame sensing methods include thermocouples (generate millivolts when heated), flame rectification (flame conducts AC current as pulsing DC), and optical sensors. Flame rectification is most common in modern equipment, requiring proper rod positioning in flame and good ground path for reliable operation.

Combustion analysis using electronic analyzers measures O_2, CO_2, CO (air-free), and stack temperature to verify safe and efficient operation. Acceptable natural gas combustion shows 5-9% O_2, 8-10% CO_2, and less than 100 ppm CO air-free (preferably under 50 ppm). High CO readings require immediate correction and indicate insufficient air, improper adjustment, or equipment problems.

Review Questions

Multiple Choice

1. Primary air in an atmospheric burner is typically what percentage of total air required?
    - a) 10-20%
    - b) 40-60%
    - c) 80-90%
    - d) 100%
2. A yellow, sooty flame indicates:
    - a) Perfect combustion
    - b) Too much air
    - c) Insufficient air
    - d) Correct primary air adjustment
3. Natural gas manifold pressure is typically:
    - a) 3.5" W.C.
    - b) 7" W.C.
    - c) 10" W.C.
    - d) 11" W.C.
4. The maximum acceptable CO reading in flue gas per CSA B149.1 is:
    - a) 35 ppm air-free
    - b) 50 ppm air-free
    - c) 100 ppm air-free
    - d) 400 ppm air-free
5. Hot surface igniters should:
    - a) Be touched only with gloves
    - b) Never be touched with bare hands
    - c) Be cleaned with sandpaper
    - d) Be tested by tapping with screwdriver
6. Flame rectification works by:
    - a) Generating voltage from heat
    - b) Measuring temperature
    - c) Detecting DC current through flame
    - d) Optical sensing of UV light
7. For atmospheric burners, theoretical air requirement is approximately:
    - a) 5 ft^3 air per ft^3 gas
    - b) 9.5 ft^3 air per ft^3 gas
    - c) 15 ft^3 air per ft^3 gas
    - d) 24 ft^3 air per ft^3 gas
8. Propane orifices compared to natural gas orifices for the same input are:
    - a) The same size
    - b) Larger
    - c) Smaller
    - d) Depends on pressure only
9. Acceptable O_2 reading in flue gas is typically:
    - a) 0-3%
    - b) 5-9%
    - c) 12-15%
    - d) 18-21%
10. A thermocouple generates approximately how many millivolts?

- a) 5-10 mV
- b) 20-30 mV
- c) 100-200 mV
- d) 500-750 mV

True or False

11. Secondary air is controlled by the air shutter adjustment.
12. Flame lifting indicates too much primary air.
13. Direct spark ignition is more efficient than standing pilot because it eliminates continuous pilot gas consumption.
14. A flame rod must be positioned in the hottest part of the inner cone for best sensing.
15. High CO readings always indicate the appliance must be shut down for safety.

Short Answer

16. Explain the difference between primary air and secondary air in atmospheric burners. (4 marks)
17. List four problems that can cause high CO production in gas burners. (4 marks)
18. Describe the proper characteristics of a correctly adjusted natural gas flame. (4 marks)
19. Why is a hot surface igniter very fragile and how should it be handled? (3 marks)
20. Explain how flame rectification works to prove flame presence. (5 marks)

Long Answer

21. An atmospheric burner produces a yellow, sooty flame with high CO readings (250 ppm air-free). Describe your systematic troubleshooting approach including:
    - What the flame characteristics indicate
    - Possible causes (list at least 5)
    - Step-by-step diagnostic procedure
    - How to correct each possible cause
    - How to verify correction was successful (15 marks)
22. Describe the complete procedure for performing combustion analysis on a natural gas furnace. Include:
    - Equipment preparation and calibration
    - Appliance preparation
    - Probe insertion and positioning
    - Measurements to record
    - Acceptable ranges for each measurement
    - What to do if readings are unacceptable
    - Documentation requirements (15 marks)
23. Compare standing pilot, intermittent pilot ignition (IPI), and hot surface ignition (HSI) systems. Include:
    - How each operates
    - Components in each system
    - Advantages and disadvantages

- Typical applications
- Common problems with each
- Why modern equipment uses electronic ignition instead of standing pilot (15 marks)

Key Terms

Air Shutter: Adjustable opening controlling primary air entry to atmospheric burner.

Atmospheric Burner: Burner using natural draft and venturi effect; no fan.

Burner Port: Opening in burner where gas-air mixture exits and burns.

Combustion Efficiency: Percentage of fuel energy extracted during combustion; measured with analyzer.

Direct Spark Ignition (DSI): Ignition system using spark directly at main burner; no pilot.

Flame Impingement: Flame contacting surfaces, causing incomplete combustion.

Flame Rectification: Flame sensing method using flame's ability to conduct AC as DC current.

Flashback: Flame burning inside burner instead of at ports; dangerous condition.

Hot Surface Ignition (HSI): Ignition using electrically heated ceramic element.

Intermittent Pilot (IPI): Electronically ignited pilot that lights only when needed.

Lifting (Flame): Flame lifting off burner ports; indicates too much air or gas velocity.

Orifice (Spud): Precisely sized opening metering gas flow to burner.

Port Loading: BTU input per inch of burner port; affects flame characteristics.

Power Burner: Burner using fan to force or induce combustion air.

Primary Air: Air mixed with gas before combustion (40-60% of total).

Secondary Air: Air drawn into flame during combustion to complete reaction.

Standing Pilot: Continuously burning pilot flame; traditional ignition method.

Thermocouple: Device generating millivolts from heat; proves pilot flame.

Venturi: Converging-diverging passage creating low pressure for air entrainment.

End of Chapter 10