Burners for Fired Heaters in General Refinery Services

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Burners for Fired Heaters in General Refinery Services

1 Scope

This recommended practice (RP) provides guidelines for the selection and/or evaluation of burners installed in fired heaters in general refinery services. Details of fired heater and related equipment designs are considered only where they interact with the burner selection. This RP does not provide rules for design but indicates areas that need attention. It offers information and descriptions of burner types available to the designer/user for purposes of selecting the appropriate burner for a given application.

The burner types discussed are those currently in industry use. It is not intended to imply that other burner types are not available or recommended. Many of the individual features described in these guidelines will be applicable to most burner types.

In addition to specification of burners, this RP has been updated to include practical guidelines for troubleshooting in service burners as well as including considerations for safe operation.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies. Changes in referenced standards, codes, and specifications shall be mutually agreed to by the owner and the vendor.

API Standard 560, *Fired Heaters for General Refinery Services*

3 Terms and Definitions

For the purposes of this document, the following definitions apply.

3.1
adiabatic flame temperature
Temperature that results from a complete combustion process without any heat transfer or changes in kinetic or potential energy.

3.2
aerosols
A suspension of fine solid or liquid particles in gas (smoke, fog, and mist are aerosols).

3.3
air/fuel ratio
The ratio of the combustion air flow rate to the fuel flow rate. This may either be in mass or volume units and needs to be specified.

3.4
air register
That part of a burner that can admit combustion air through openings around the burner assembly.

3.5
atomization
The breaking of a liquid into tiny droplets to improve fuel–air mixing, thereby improving combustion efficiency. Steam, air, and fuel gas can be used as atomizing media. Steam is the most common in the refining industry. Atomization may also be accomplished by mechanical means.

3.6
autoignition temperature
The lowest temperature required to spontaneously ignite the fuel in air in the absence of an ignition source (e.g. a spark or a flame).

3.7
blowoff
The lifting of a flame when the velocity of the fuel–air mixture exceeds the flame velocity. This may result in the flame being extinguished.

3.8
burner
A device for the introduction of fuel and air into a heater at the desired velocities, turbulence, and air/fuel ratio to establish and maintain ignition and stable combustion.

The type of burner is normally described by the fuel(s) being fired, the method of air supply, and emission requirements. Some fuel examples are gas, oil, and waste gas. Examples of air supply are natural draft and forced draft. Emission requirements are primarily directed towards NO_X limitations. An example of use would be low NO_X, natural draft, gas fired burner. Table 1 provides a comparison between the definitions in API 560 and this RP. This RP differs slightly from API 560 as it relates to burner design and operation rather than heater design and operation.

3.9
burner throat
A restriction in the air flow path formed by the burner block and other burner components. The restriction may be used to initiate turbulence for the mixing of the fuel and air.

3.10
coalesce
To unite into a whole.

3.11
coalescer
A process where aerosols in a stream come in contact with a filter media, combine to form a larger droplet on the downstream surface of the media, and is drained away by gravity.

3.12
CO breakthrough
The point at which the CO level begins to increase rapidly upon reduction of excess air. This breakthrough will vary depending upon the fuel and the type of burner.

3.13
combination burner
A burner capable of burning gas or oil individually or simultaneously (Figure 4).

3.14
combustion
The rapid reaction of fuel and oxygen that liberates heat.

3.15
combustion products
Resultant components of the combustion process such as carbon dioxide, water vapor, and additional components such as sulfur dioxide and ash.

3.16
draft
The flow of combustion air into a heater that is induced by a negative pressure (i.e. vacuum) inside the heater relative to the ambient pressure outside the heater. This pressure differential is created by the density difference inside the heater compared to the density of ambient air outside the heater.

3.17
draft loss
Generally referred to as the air side pressure drop across a burner or the flue gas pressure drop across a portion of the heater system depending which heater component is being referred to.

3.18
excess air
The amount of air above the stoichiometric requirement for complete combustion, expressed as a percentage.

3.19
filter
A porous article or mass (paper, sand, etc.) through which a gas or liquid is passed to separate out matter in suspension.

3.20
firing ports
The orifices in the fuel tip through which the fuel passes.

3.21
firing rate
The heat release from the fuel expressed as units of energy over time (e.g. MW, kcal/hr, or Btu × 10^6/hr).

3.22
flame envelope
The self-sustaining propagation of a localized combustion zone at subsonic velocities [1]. In this zone there are many reactions such as the breakdown of the fuel, the creation of intermediate species, and the oxidation of the fuel. For fuels containing carbon, one measurable intermediate species is carbon monoxide. Under certain conditions, a time averaged concentration of 2000 ppmv dry or greater of carbon monoxide may indicate the presence of a flame.

3.23
flame front
The position where the combustion takes place in a flame.

3.24
flame liftoff
A flame that has lifted from its stabilization point will normally try to reattach to the stabilization point. This movement or pulsing in the flame front causes pressure waves created by the energy of the oscillating flame front to occur.

3.25
flame stabilization point
The region within a burner that acts as a continuous ignition zone for the flame.

3.26
flame stabilizer
A solid or perforated restriction in the combustion air stream that creates a flame stabilizing turbulence or vortex downstream of the restriction.

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[1] Turns, S. R., *An Introduction to Combustion, Concepts and Applications*, Second Edition, McGraw Hill, 2000, p. 254.

3.27
flame temperature

The actual temperature reached during sustained combustion within the burner flame.

3.28
flame velocity

The rate at which a flame propagates through a combustible mixture.

3.29
flashback

The phenomenon that occurs when a flame front instantaneously propagates back into the direction of the fuel–air mixture flow. Flashback occurs in premix burners or pilots when the flame velocity exceeds the velocity of the fuel–air mixture through a burner nozzle.

3.30
forced draft

The difference in pressure produced by mechanical means that delivers air into a burner at a pressure greater than atmospheric.

3.31
fuel

Any matter that releases heat when combusted.

3.32
fuel bound nitrogen

Nitrogen (N) atoms that are chemically bonded within fuel molecules. Examples are ammonia (NH_3), nitrogen monoxide (NO), hydrogen cyanide (HCN), and other complex H–C bonded hydrocarbons. The combustion of these molecules results in the formation of fuel NO_x.

3.33
fuel NO_x

NO formed predominantly due to chemically bonded nitrogen in fuel.

3.34
fuel NO_x mechanism

Fuel-bound nitrogen compounds convert to NO_x through an HCN intermediate inside the combustion zone. A large fraction of the fuel bound nitrogen follows this reaction path, so this mechanism can result in hundreds of ppm of NO_x.

3.35
gas gun

Central tube on a burner that introduces fuel into the combustion zone (see also **riser**).

3.36
heating value, higher
HHV

The total heat obtained from the combustion of a specified fuel at 15.5 °C (60 °F), expressed as unit of heat per mass or volume (e.g. kcal/kg or kcal/m^3 or Btu/lb or Btu/ft^3), which includes the latent heat of vaporization of water; also called gross heating value.

3.37
heating value, lower

The higher heating value minus the latent heat of vaporization of the water formed by combustion of hydrogen in the fuel, expressed as unit of heat per mass or volume (e.g. kcal/kg or kcal/m^3 or Btu/lb or Btu/ft^3); also called net heating value.

3.38
heat release
The heat liberated from the fuel, utilizing the lower heating value of the fuel, expressed as units of energy over time (e.g. MW, kcal/hr, Btu/hr).

3.39
high-intensity burner
A burner in which combustion is completed within a fixed volume resulting in a combustion intensity greater than (0.29 MW) 1×10^6 Btu/hr.ft^3.

3.40
hydrogen/carbon ratio
The mass or volume of hydrogen in a hydrocarbon in the fuel divided by the mass or volume of carbon. The use of mass or volume in determining the ratio should be specified.

3.41
igniter
A device used to light a pilot or main burner.

3.42
ignition ports
Orifices in the burner tip that fire a portion of the fuel into the flame stabilization zone.

3.43
induced draft
The difference in pressure (between inside and outside of the heater) produced by mechanical means resulting in a negative pressure in the heater that causes the flow of combustion air into the heater.

3.44
inspirator
A venturi device used in premix burners or pilots that utilizes the kinetic energy of a jet of gas issuing from an orifice to entrain all or part of the combustion air.

3.45
knockout drum
A device to remove condensable and entrained liquids present in the gas stream.

3.46
light-off
Initial ignition of a fuel.

3.47
low NO_x burner
A burner that is designed to reduce the formation of NO_x below levels generated during normal combustion in conventional burners.

3.48
muffler
A device used to reduce combustion noise propagated back through the burner.

3.49
natural draft
The force serves to draw combustion air into the burner when there are no mechanical means for providing air flow (see also **draft**).

3.50
nitrogen oxides
NO_X
Generic term for a group of gases all of which contain varying amounts of nitrogen and oxygen. NO_X is formed in the combustion process or as a result of the combustion process. Different formation mechanisms contribute to the overall NO_X. See **thermal NO_X**, **fuel NO_X**, and **prompt NO_X**.

3.51
noise
The undesirable sound generated by sources like the combustion process, high-speed gas jets, and equipment such as fans and motors. It is considered a pollutant of which the emissions should be controlled in order to protect plant personnel. Noise is measured either as sound pressure level (SPL) or as sound power level (PWL), expressed in decibels. See also **sound**, **SPL**, and **PWL** definitions.

3.52
pilot
A burner that provides ignition energy to light the main burner.

3.53
plenum
A chamber surrounding the burner(s) used to distribute air to the burner(s) or to reduce combustion noise.

3.54
preheated air
Air heated prior to its use for combustion. The heating is most often done by heat exchange with hot flue gases. Other means of air preheat may be indirect or from another external source (e.g. hot oil or steam air preheaters).

3.55
premix burner
A gas burner in which all or a portion of the combustion air is inspirated into a venturi-shaped mixer by the fuel gas flow. The fuel and air are mixed prior to entering the initial combustion zone (Figure 2).

3.56
primary air
That portion of the total combustion air that first mixes with the fuel.

3.57
prompt NO_X
Formation of NO_X where thermally dissociated nitrogen attaches to a hydrocarbon rather than oxygen radicals to form the intermediate species of HCN found in the fuel NO_X formation mechanism. Prompt NO_X is predominantly found when fuel is concentrated/staged such that interaction with oxygen is limited and there is a greater probability of reaction with the hydrocarbon.

3.58
radiant wall burner
A burner where the flame does not project into the firebox but fans out alongside the wall on which it is installed (Figure 3).

3.59
raw gas burner
A gas burner in which combustion takes place as the fuel is mixed with the combustion air downstream of the fuel tips; nozzle mix burner (Figure 1).

3.60
riser
Piping within the burner that takes the fuel from the distribution manifold to the burner tip.

3.61
secondary air
Portion of the total combustion air that is delivered downstream of the primary combustion zone.

3.62
secondary fuel
The remaining portion of fuel that is injected downstream of the burner block in a staged fuel burner.

3.63
sound
Mechanical vibration of a gas, liquid, or solid medium that generates waves that transfer energy away from the source. The human ear responds logarithmically to the amplitude and the resultant pressure changes of these fluctuations. Therefore, sound levels are measured on logarithmic scale.

3.64
sound power level
PWL
Energy of the transferred sound, PWL = 10 log(P/P_0). The relative changes are expressed in decibels (dB) with the reference value $P_0 = 10^{-12}$ W.

3.65
sound pressure level
SPL
Level of air pressure fluctuations in a fluid, SPL = 20 log(p/p_0). Changes in SPL are expressed in decibels (dB) with the reference value $p_0 = 2 \times 10^{-5}$ N/m^2. If the frequency spectrum is corrected using an "A-weighting" to account for the human ear response, the SPL is reported in dBA or dB(A).

3.66
specific gravity
For a gas, this is the ratio of the density of that gas to the density of dry air at standard temperature and pressure. For a liquid, this is the ratio of the density of that liquid to the density of water air at standard temperature and pressure.

3.67
spider
Gas tip configuration resembling the hub of a wheel and spokes where the spokes contain the gas exit orifices.

3.68
spud
A device with a small gas orifice designed to limit gas flow to a desired rate (see also **tip**).

3.69
stability
The ability of a burner enabling it to remain lit over a wide range of fuel–air mixture ratios and firing rates.

3.70
staged air burner
A low NO_x burner in which a portion of the combustion air is injected downstream of the burner block to mix with the combustion products from the primary combustion zone (Figure 5).

3.71
staged fuel burner
A low NO_x burner in which a portion of the fuel is mixed with all of the combustion air within the burner block while the remainder of the fuel is injected downstream of the burner block to provide delayed combustion (Figure 6).

3.72

stoichiometric air

The chemically correct amount of air required for complete combustion with no unused fuel or air.

3.73

stoichiometric ratio

The ratio of fuel and air required for complete combustion such that the combustion products contain no oxygen.

3.74

strainer

A device to retain solid particles while a gas/liquid passes through the device.

3.75

swirl number

The ratio of angular to axial discharge momentum. It defines the amount of mixing and internal flame recirculation.

3.76

tertiary air

A third portion of the total combustion air that is supplied to the products of combustion in addition to primary and secondary air.

3.77

thermal NO_x

Formation mechanism of NO that relies predominantly on temperature.

3.78

tile

Refractory block surrounding the burner components. The block forms the burner's air flow opening and may help stabilize the flame and provide the desired flame shape; also referred to as muffle block or quarl.

3.79

tip

A device with a small gas orifice designed to limit gas flow to a desired rate. The tip is at the end of the riser or fuel gas gun.

3.80

turndown

The ratio of the maximum to minimum fuel input rates of a burner while maintaining stable combustion.

3.81

windbox

The air plenum that surrounds the burner or burners.

3.82

Wobbe Index

WI

An indicator of the interchangeability of fuel gases, used to compare the combustion energy output with different composition of fuel gases. The WI is equal to the higher heating value (HHV) of the fuel gas in Btu/ft^3 (MJ/m^3) divided by the square root of the specific gravity of the fuel gas.

Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, and Figure 6 are intended to help the reader with the definitions above for different types of burners. The figures are used for illustrative purposes only. Burner features will differ from one supplier to another.

Table 1—Clarification Table Comparing Definitions in API 560 and API 535

API 560		API 535	
Burner Heat Release	**Definition**	**Burner Heat Release**	**Definition**
		Maximum stable heat release	The maximum heat release for the burner at the point of CO breakthrough with the air register at the same setting as “design” heat release or 100 % open.
		Maximum	The heat release for the burner with design excess air and design draft loss with air register 100 % open.
Design	The heat release per burner including a defined capacity margin as a percent of the calculated “normal” heat release.	Design	The specified “design” heat release for the burner with the air register set for the design excess air with design draft loss.
Normal	The heat release per burner required for the design total absorbed duty for the heater divided by the calculated fuel efficiency.	Normal	The specified “normal” heat release for the burner with the air register set for the design excess air with design draft loss.
Minimum	The heat release per burner for the specified turndown of the heater or burner.	Minimum	The specified “minimum” heat release for the burner with the air register set at the same setting as the “normal” heat release or with the air register set for the design excess air.
		Minimum stable heat release	The minimum heat release for the burner at the point of CO breakthrough with the air register at the same setting as “normal” heat release.

4 Mechanical Components for Burners

4.1 General

Burners in common use today each exhibit general features that are described in the following section. While some burner designs may differ in some very detailed respects, most burners will have the components described within this section.

4.2 Pilots and Igniters

4.2.1 General

Pilots shall be provided on each burner unless stated otherwise by the owner. Integral igniters may be used within the pilot as a means of ignition. This may also allow the convenience of pilot flame detection to be incorporated. Burners are often equipped with additional ports that allow the pilot to be ignited by a portable igniter should the main igniter fail or the pilot is not fitted with integral ignition.

While burners have pilots to ignite the main flame, the pilot should not provide stability to the burner through normal operation. The main burner flame is required to be inherently stable through its defined operating range without assistance from the pilot flame.

4.2.2 Pilots

4.2.2.1 Pilots shall be gas fueled. The fuel gas for the pilot should preferably be from a reliable, independent controlled fuel source. However, the same fuel gas as the main burner may be used with additional instrumentation. Instrumentation for the pilot gas supply is detailed in API 556. Clean supplies of pilot gas are preferable with natural gas being the most preferred. Because of the small holes in pilot burners, filtration should be supplied on all fuel

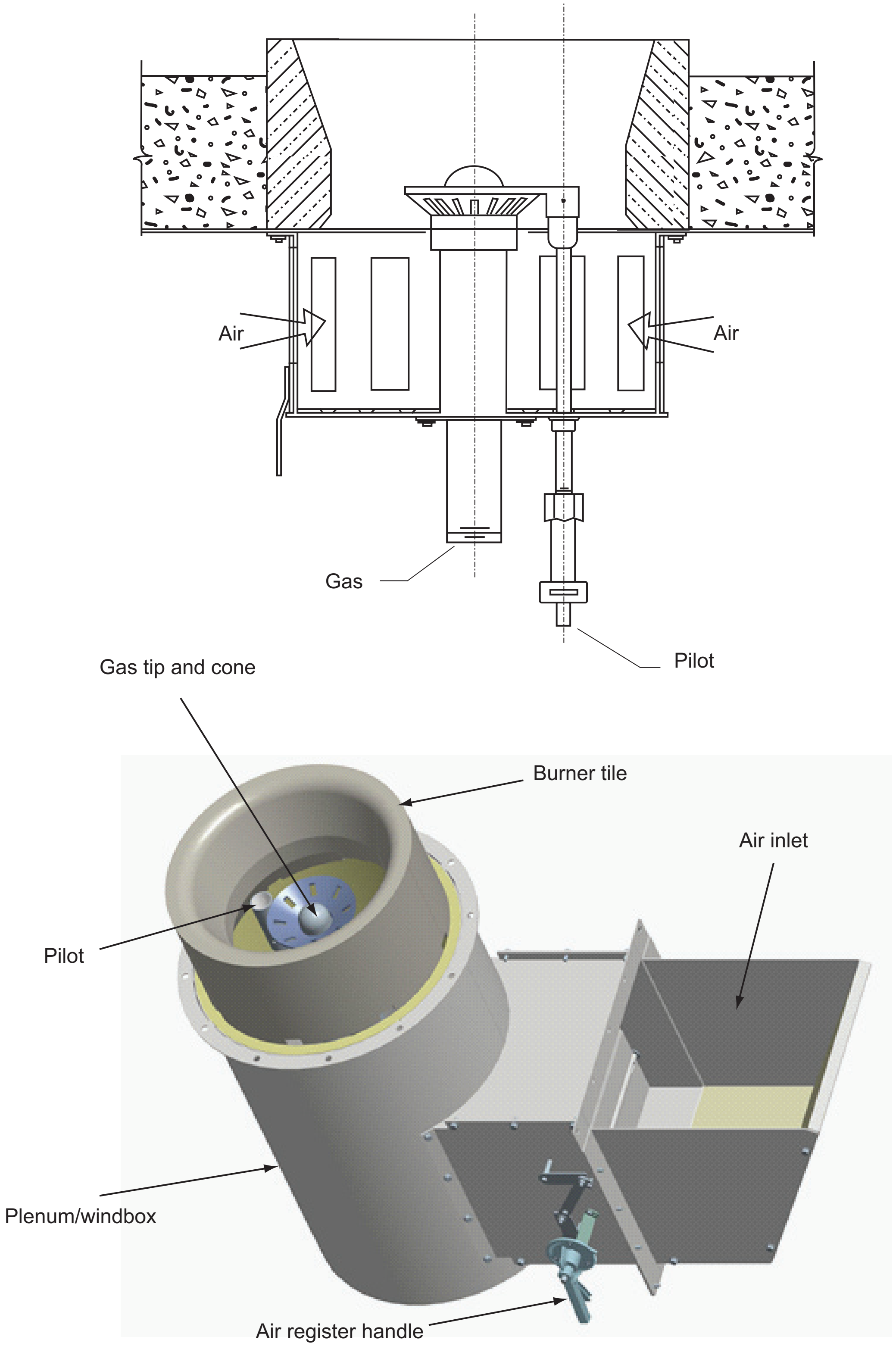


Figure 1—Raw Gas Burner

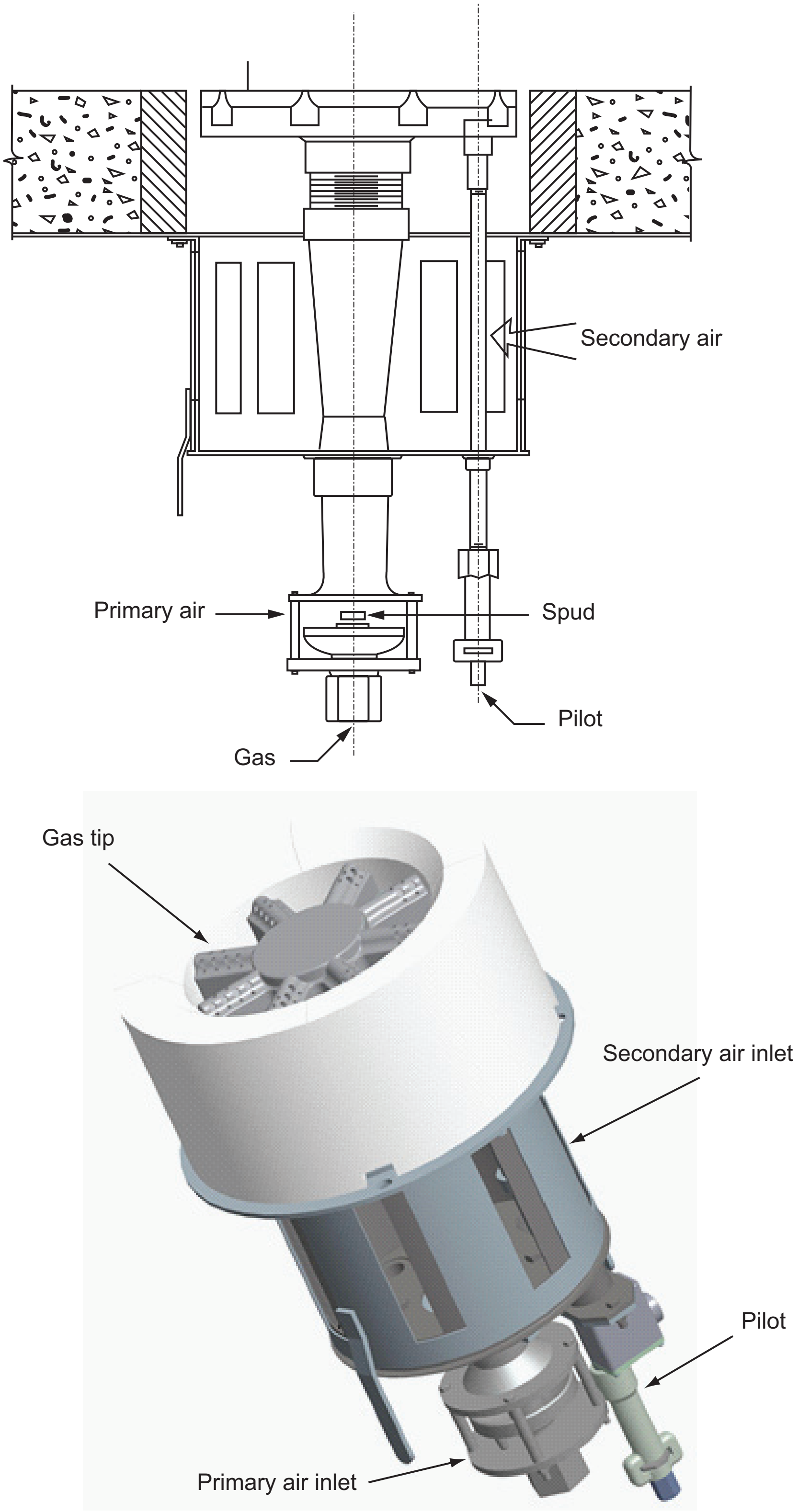


Figure 2—Premix Gas Burner

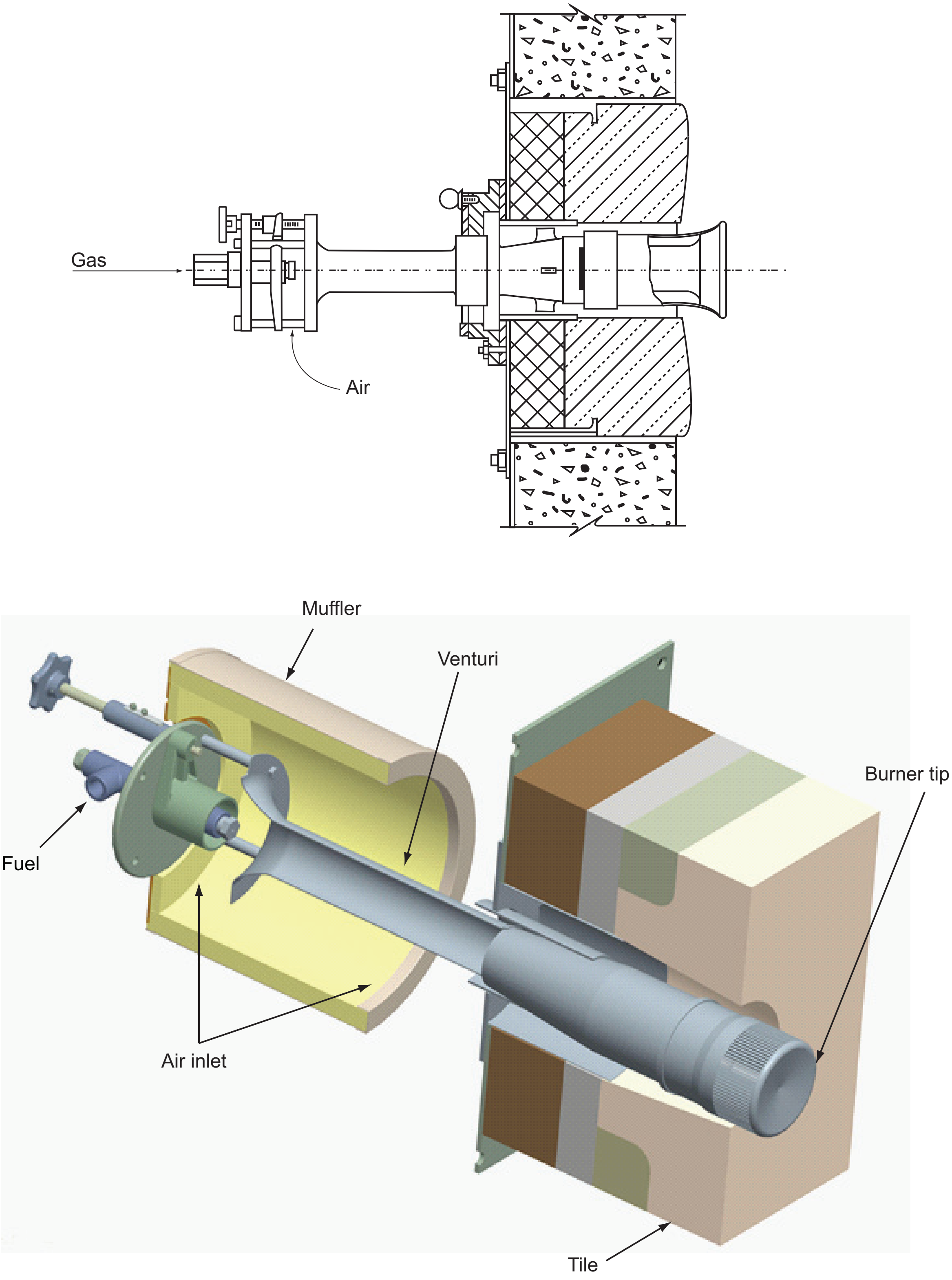


Figure 3—Radiant Wall Burner

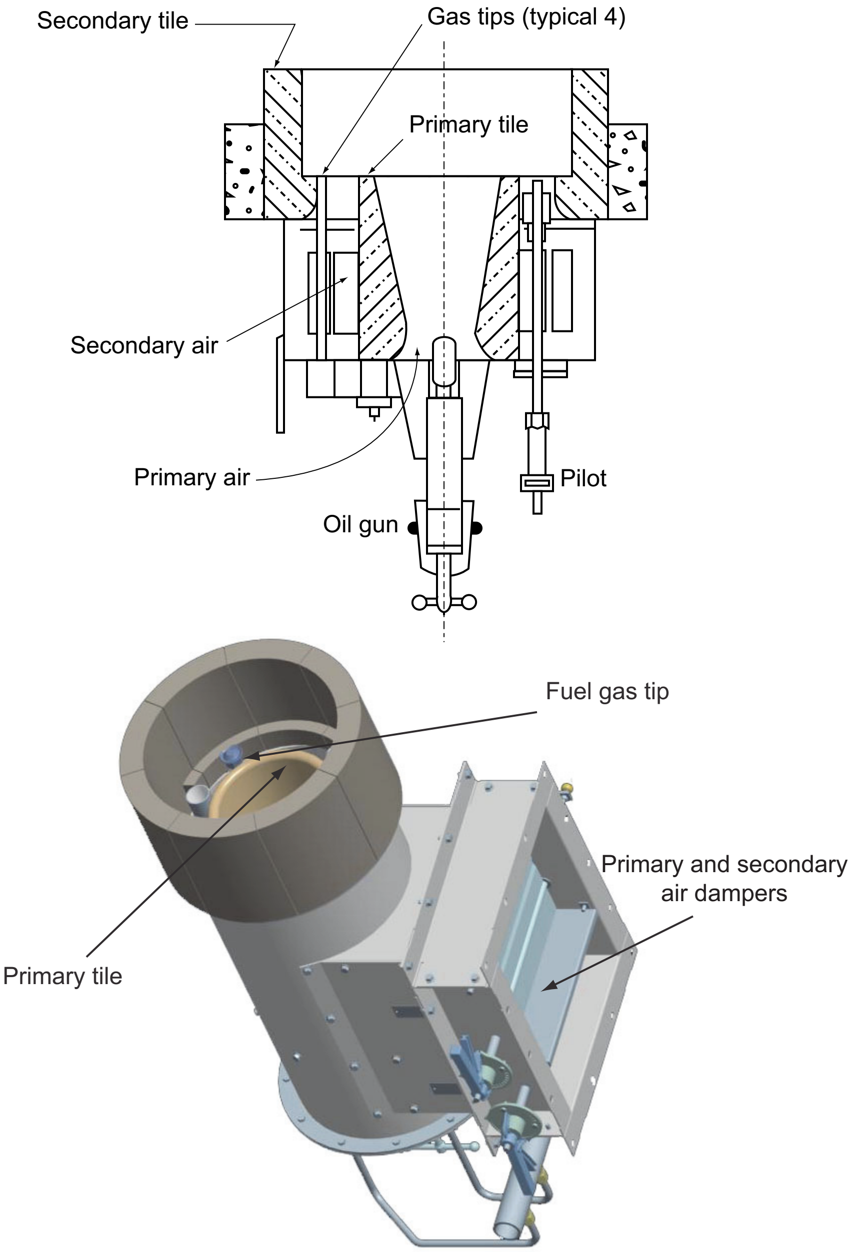


Figure 4—Combination Oil and Gas Burner

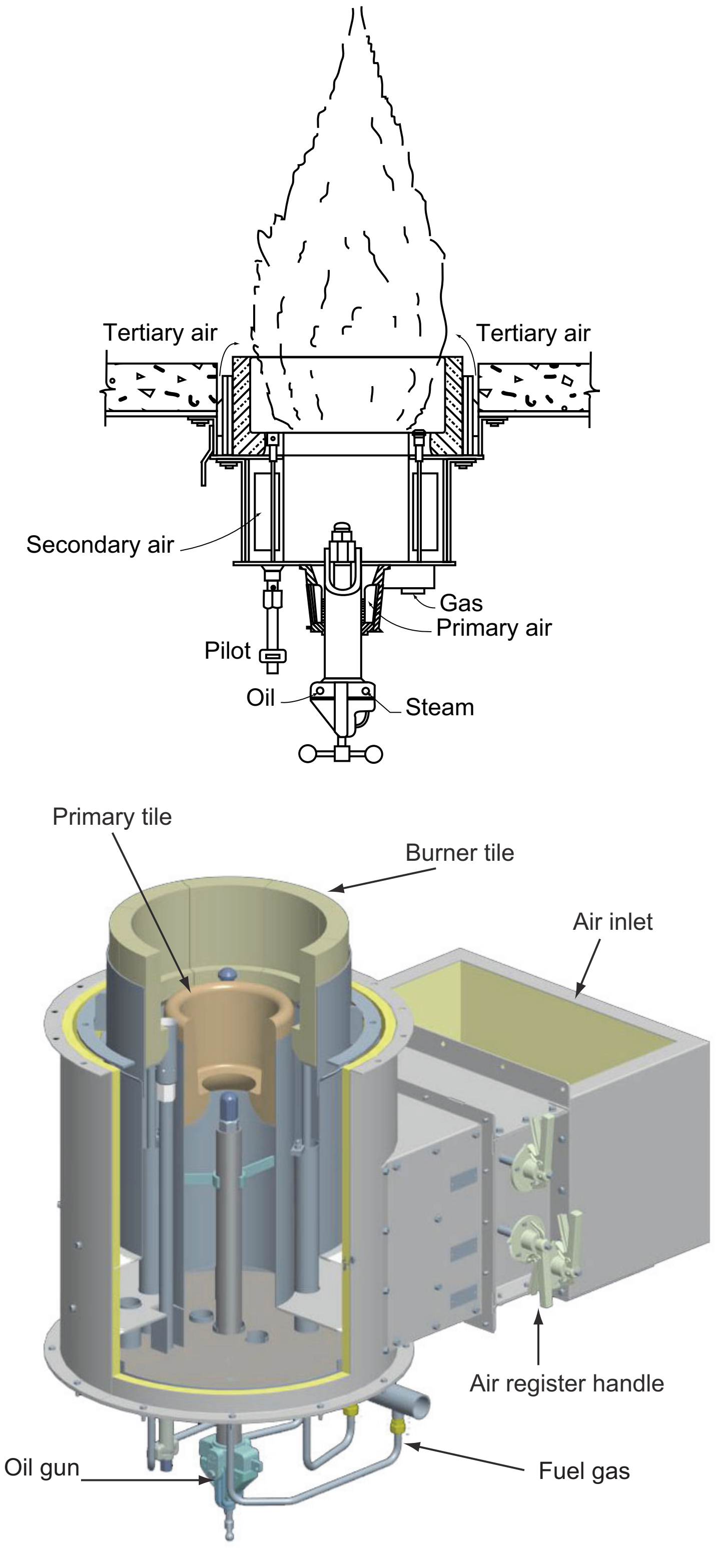


Figure 5—Low NO_x Staged Air Combination Oil and Gas Burner

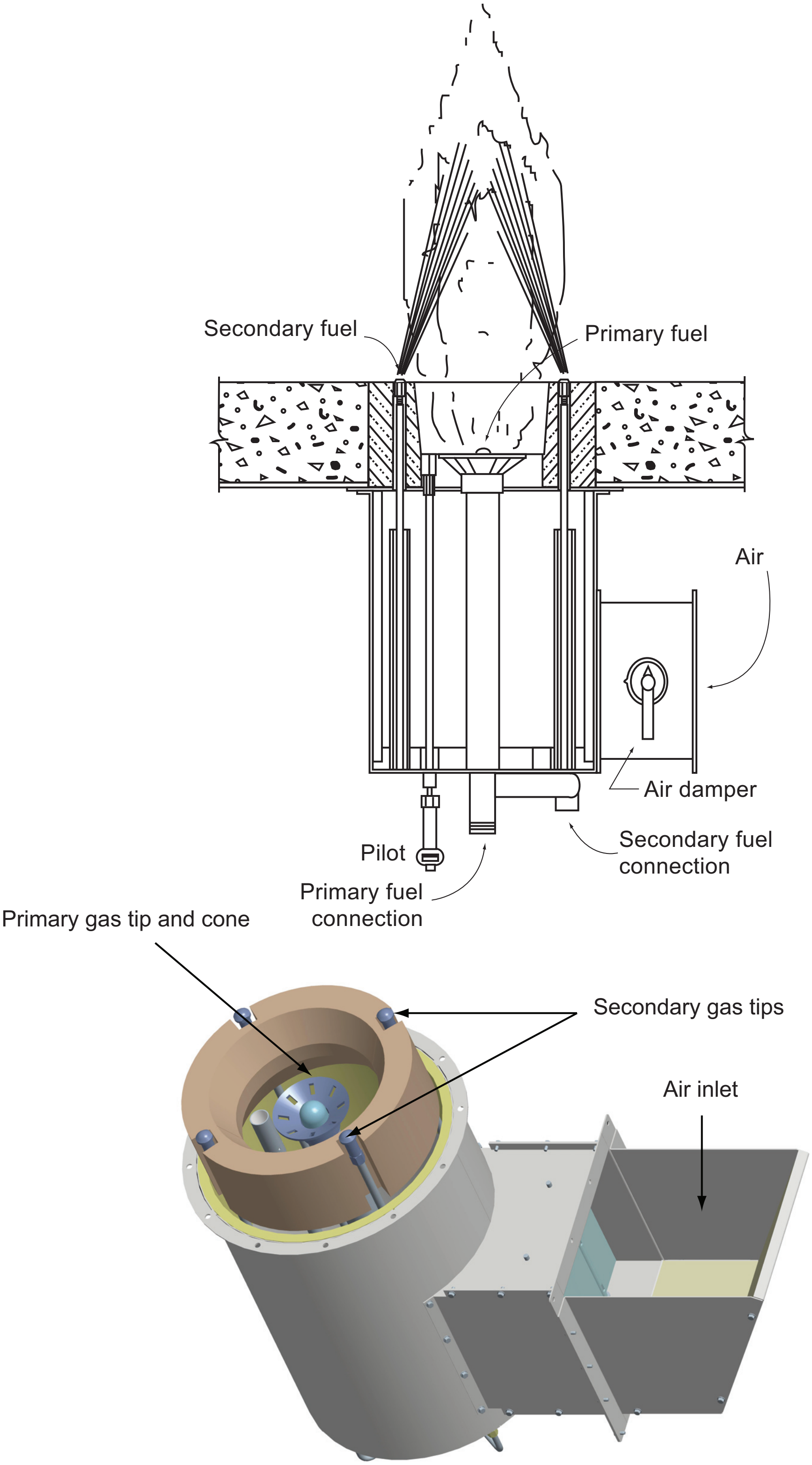


Figure 6—Low NO_x Staged Fuel Gas Burner

sources to ensure that line scale and particulate matter does not plug the small orifice. Some burner suppliers will recommend filters with No. 80 mesh, while some users specify 25 % of the minimum hole size.

4.2.2.2 Pilots shall be positioned to assure ignition of the main burner for all operating conditions of the main burner.

4.2.2.3 The pilot flame shall be clearly visible at all times.

4.2.2.4 Pilots shall be removable for cleaning and maintenance while the burner is in operation.

4.2.2.5 Positive identification of the pilot flame shall be made upon ignition. Proof of pilot flame shall be confirmed visually or electronically (e.g. via flame ionization rods). For multiple burner heaters, pilot flame should be visually confirmed by the operator at each burner prior to lighting the respective burner.

4.2.2.6 Pilots shall have a nominal heat release of 75,000 Btu/hr (22 kW) as per API 560. The minimum heat release shall be approved by the owner when accompanying a burner whose heat release is 15×10^6 Btu/hr (4.4 MW) or greater.

4.2.2.7 The pilot shall be provided with a continuous supply of combustion air under all operating conditions. This includes operation with the main burner in or out of service.

4.2.2.8 The pilot should remain stable over the defined operating range of the main burner. It should remain stable and operational even upon loss of main burner fuel. (This will allow for a safer restart of the main burners and prevents the operators from performing a full restart that has significantly higher associated risks.)

4.2.2.9 The pilot should also be demonstrated to remain stable under adverse heater operating conditions such as high heater draft or high firebox pressure. Pilots should be tested to ensure that the pilots are stable within the expected operating range of the fired heater. Table 17 provides guidance on qualifying pilot stability.

4.2.3 Igniters

Manual ignition of pilot burners may be accomplished with gas or electric portable igniters unless otherwise specified by the owner. Pilot burners may be equipped with electronic or electric ignition.

4.3 Major Burner Components

4.3.1 Plenum/Windbox

Plenums (sometimes referred to as windboxes) are used to distribute combustion air (or other oxygen source) to the burner(s). Plenums are also used to reduce noise produced by the burner. Multiple burners can be installed in a common plenum or each burner can have a separate individual plenum. Some burners have no plenum.

4.3.2 Air Registers

All burners, whether mounted in a plenum or not, should have an air register to control the flow of combustion air to the burner. The air register is normally manually adjusted; however, it may also be adjusted by linking it to an automatic control device linked to a control system designed to maintain the desired oxygen in the flue gas.

Three types of air control devices are commonly found. Early designs consisted of two concentric metal cylinders, each with slots. One cylinder is stationary while the other can be rotated such that all or a portion of the slot on one cylinder can be aligned with those on the other. This allows air to flow through the slots into the burner.

A second air register design is made with slots cut in a single, stationary cylinder. Each slot is fitted with an individual damper blade on a shaft. Each shaft is typically connected to a common air handle.

A third type of air register consists of a single or multiblade damper at the inlet of an individual plenum or burner windbox. This type is most commonly used for new equipment.

Figure 1, Figure 2, Figure 4, and Figure 5 show different types of air registers supplied. The schematics show the older style slotted register, while the three-dimensional pictorial views show a damper or sets of dampers being used to control the air flow to the burner. Table 2 summarizes the characteristics of the three air register types.

Table 2—Air Register Characteristic

	Concentric Cylinders	Slotted Cylinder with Blades	Single or Multiblade Damper
Air controllability	Poor	Fair	Good
Leakage	Poor	Fair	Good
Cost	Good	Fair	Good
Complexity	Fair	Poor	Good
Ease of maintenance	Fair	Poor	Good
Applicability for common plenum	Good	Fair	Fair

The combustion air register should be designed so that it is fully open during operation at the maximum heat release with the design fuel at the maximum specified air flow rate.

When requested by the purchaser, pressure taps should be positioned so that the pressure drop across the air register and burner throat can be accurately measured in a repeatable manner for the purpose of balancing air to individual burners.

Air leakage through a closed air register on an out-of-service burner can reduce combustion efficiency. Fully closed rotating concentric cylinder air registers have leakage rates up to 50 % of the fully open flow rate. Fully closed damper type air registers have leakage rates significantly lower than those of circular registers. Closer tolerances or the use of sealing strips can be specified for use with damper type air registers to decrease leakage rates.

Air register controls shall be easily accessible by the operator. Means of indicating the position of the dampers or registers shall be provided external to the damper and be aligned with the blade inside. Control handles should be supplied with a locking mechanism such as a multiple notch positioner to avoid closure from vibration or inadvertent touching. For registers in plenums or windboxes and other cases where the register/damper is not easily visible, a positive means of securing the position indicator to the register or register shaft should be provided to maintain accurate position indication.

The shafts of damper type air registers may be specified with bushings, packing glands, ball bearing supports, or suitable alternatives. Consideration should be given to the use of corrosion-resistant materials to avoid seizures. Linkage of multiblade damper type registers can be designed for parallel or opposed blade operation. Opposed blade operation, in which adjacent blades rotate in opposite directions, provides more accurate air control at low flow rates than does parallel blade operation. Parallel blade dampers can detrimentally influence air flow if placed close to the burner throat. Multblade dampers give better control than single-blade dampers; however, multiblade dampers are difficult to fit to smaller burners [e.g. less than 2×10^6 Btu/hr (0.6 MW)].

4.3.3 Burner Tile

Burner tiles are typically manufactured from refractory and are designed to control the mixing of air, fuel, and on some burners recirculate flue gas. Burner tiles play an important role in flame shape, flame stability, and ultimately emissions.

The high temperature attained by oil burner tiles, called regen tiles, plays an important role in stabilizing oil flames in some burners.

Burner tiles are exposed to extremely high temperatures and in some cases reducing or oxidizing environments. Installation shall allow them to expand and contract independent of the furnace refractory. Each tile may be made up of several pieces to aid in installation. The number of pieces should be minimized. Burner tiles should be supplied in a ready to fire condition as there is insufficient time or control at start-up to perform this operation.

The combustion air will experience a pressure drop through the burner that is composed of a pressure drop across the air register and a pressure drop across the burner tile. The burner tile should be sized so that the air register will be fully open during operation at maximum heat release with the design fuel and at maximum air flow rate.

4.3.4 Fuel Tips and Risers

Oil guns and gas risers shall be easily removable for cleaning while the heater is in operation. Fuel tips should be threaded for easy replacement unless welded construction is requested by the purchaser. High-temperature antiseize should be used on threaded tips. Fuel tips should be designed with the largest fuel orifices possible to minimize tip plugging. The diameter of fuel tips and risers should be minimized to decrease tip temperature and possible tip plugging associated with coking of liquid condensate in fuel gas. Tip match-marking or other means of positive alignment should be provided if needed. Consider burner numbering or marking to prevent mixing of parts.

4.3.5 Viewing Ports

Sight ports shall be provided to observe the pilot and main flames. A manual lighting port should also be provided for lighting the pilot or main flame. Provision for electronic ignition and flame scanners should also be provided when requested by the purchaser.

4.3.6 Materials of Construction

4.3.6.1 General

The materials used for construction of a burner shall be chosen for the strength, temperature resistance, and corrosion resistance suitable for the anticipated service. Carbon steel is generally used for metal parts unless temperature or corrosion considerations require a more suitable alloy. Table 3, Table 4, Table 5, and Table 6 provide some guidance on burner components to assist users in material selection.

4.3.6.2 Fuel Gas Burner Components (Burner and Pilot)

A metallurgist should be consulted to select appropriate materials to use with corrosive or chloride containing fuels.

In the case of fuels containing high levels of H_2S (>200 ppm), the burner design specification should specify if threaded connections are allowed.

4.3.6.3 Fuel Oil Burner Components

A metallurgist should be consulted to select appropriate materials to use with corrosive or chloride containing fuels.

4.3.6.4 Burner Housing

Table 5 provides the standard materials of construction for the burner housing.

4.3.6.5 Burner Tile

Table 6 provides the standard materials of construction for the burner refractory tile.

Table 3—Fuel Gas Burner Components

Component	Operation	Material
Fuel gas manifold and piping	Normal	Cast iron or carbon steel
	When each of the following is present: >100 ppmv H_2S >300 °F (150 °C) fuel	AISI 316L stainless steel
Fuel gas riser pipe	Normal	Carbon steel
	>700 °F combustion air	AISI 304 stainless steel
	When each of the following is present: >100 ppmv H_2S and either >300 °F (150 °C) fuel >400 °F (205 °C) combustion air	AISI 316L stainless steel
Fuel gas tip	Normal	AISI 310 stainless steel
Premix venturi	Normal	Cast iron or carbon steel
Exterior casing	Normal	Carbon steel
	Preheated combustion air	Insulated carbon steel
Flame stabilizer	Normal	AISI 310 stainless steel
Insulation and noise reduction linings	<700 °F (370 °C) combustion air	Mineral wool
	>700 °F (370 °C) combustion air	Mineral wool covered with an erosion protection liner
Other internal metal components	Normal	Carbon steel
	>700 °F (370 °C) combustion air	ASTM A242 or AISI 304 stainless steel
Flex hose internal lining	Normal	High alloy
Flex hose external braiding	Normal	AISI 304 stainless steel

Table 4—Fuel Oil Burner Components

Component	Operation	Material
Oil gun receiver and body	Normal	Ductile iron
Oil gun tip	Normal	416 stainless steel
	Erosive oils [a]	T-1 or M-2 tool steel
Atomizer	Normal	Brass or 304 stainless steel
	Erosive oils [a]	Nitride hardened nitralloy
Other	Normal	Carbon steel

[a] Erosive oils are defined as fuel oils that contain 3 % or more by weight S or catalyst fines or particulates or other heavy metals.

Table 5—Burning Housing

Component	Operation	Material
Exterior casing	Normal	Carbon steel
	Preheated combustion air	Insulated carbon steel
Flame stabilizer or cone	Normal	300 series stainless steel
Insulation and noise reduction linings	≤750 °F (400 °C) combustion air	Mineral wool [a]
	>750 °F (400 °C) combustion air	Mineral wool covered with erosion protection liner [a]
Other interior metal parts	Normal	Carbon steel
	>750 °F (400 °C) combustion air	A242 or 304 stainless steel

[a] Castable for oil firing on surfaces that can be soaked with oil.

Table 6—Burner Tile

Tile	Material
Normal	>60 % alumina refractory
Oil firing tile: ≤50 ppm (wt.) V + Na	≥60 % alumina refractory
Oil firing tile: >50 ppm (wt.) V + Na	>90 % alumina refractory

4.3.7 Burner Piping

4.3.7.1 General

The operation and control of a fired heater is facilitated by a properly designed fuel delivery system. The basic requirements of such a system are:

- properly sized headers to ensure uniform flow distribution to individual burners while maintaining reasonable velocities;
- provisions for adequate and properly situated drains to permit drainage and cleaning of the manifold system;
- properly sized control valves;
- individual burner and pilot isolation valves;
- pressure tap and valve;
- easily removable gas tips, gas risers, oil guns, and pilots for maintenance purposes.

4.3.7.2 Fuel Gas Piping

The following are guidelines for the design of manifold systems for gas, oil, and combination firing. Specific conditions may dictate some variations.

Fuel gas is usually supplied from a constant pressure mixing drum. The fuel gas system should include a knockout pot or drum with demisting pad for condensate removal. Consider a fuel gas filter/coalescer to minimize burner plugging, particularly with current designs of low NO_x burners as they have small firing ports. The placement and location of the fuel gas filter/coalescer is key to the performance of the liquid removal. The coalescer should be located as close to the heater as possible to minimize the chance of additional condensation after the filter. Consistent temperature and pressure in the system will help to minimize the condensation.

After exiting the mixing drum the main gas supply header branches to each furnace. Each branch acts as a gas distribution header to its heater. The gas distribution header should slope in the direction of gas flow without low spots in the line. A drip leg should be fitted at the lowest point in the line and should be drained on a routine basis. Some users have a knockout drum for each heater and the piping should slope toward this vessel. The distribution header should be heat traced and insulated in climates where ambient temperatures could result in condensate formation downstream of the condensate removal. All fuel gas drains should be piped to a collection system feeding a flare or other safe disposal system.

Flex hoses require special attention to avoid failure due to kinking. The fuel supply piping and burner piping should be positioned so that any flex hose used is within its design radius of curvature. A matched union should be provided to avoid kinking of the flex hose due to rotation during installation. A backing wrench should be used to stabilize the flex hose when tightening nearby joints.

Takeoff piping to each burner should be from the top side of the distribution header to minimize the potential for dirt and scale being carried to the burners. Low point drains should be provided in the piping to the burners for fuel and pilot. Where condensation of liquids is common, a bottom drain should be installed at the end of the fuel header and should be drained on a routine basis. Tracing shall also be provided up to all burner connections. The piping system of headers, branches and take off connections should be designed as symmetrically as possible to yield an equal flow of gas to all burners.

The gas distribution header size is based on the number of burners and the maximum heat release to be supplied from the header. The header velocity normally should not exceed 50 ft/s (15 m/s). The velocity in a takeoff piping to an individual burner should not exceed 75 ft/s (23 m/s).

4.3.7.3 Fuel Oil Piping

Heavy fuel oil is normally supplied from a central storage and preparation area. It is typically delivered through an insulated loop system circulating oil to each oil-fired heater and back to the storage tank. A noncirculating fuel oil system are sometimes provided but suffer when firing heavy oils requiring heating. Dead ended systems result in oil chilling resulting in combustion problems associated with high viscosity.

The loop system should circulate a minimum of 1.5 times the fuel to be consumed. This rate may be increased for cold ambient conditions. The excess oil flow assists in maintaining a uniform temperature and a constant viscosity. It stabilizes the oil supply pressure since load changes will cause individual control valves to affect a smaller fraction of the total flow. Oil velocity in the loop system should not normally exceed 6 ft/s (2m/s).

Takeoff piping to individual burners should come off the top of the loop header. This will minimize the flow of particulates to the burners. The lead to each burner should be as short as possible to minimize oil cooling. Oil headers and take offs should be heated as well as insulated in climates where ambient temperatures can result in significant oil cooling.

Light oils (e.g. diesel/gas oil) normally do not require heating. They may be piped in a manner similar to fuel gas systems. The oil velocity should not exceed 3 ft/s (1 m/s).

4.3.7.4 Atomizing Steam Piping

The atomizing steam system provides dry steam to the burner for fuel oil atomization. The burner design may require either a constant steam pressure or a constant differential pressure above the oil pressure. A differential pressure regulator is used to maintain the steam pressure above the oil pressure when a constant differential is required.

The steam header and branches should be sloped in the direction of flow. They should be trapped at each low point to remove condensate. Steam takeoff piping to individual burners should come off the top of the header branches. This will minimize condensate and particulate carryover to the burners. Velocity in the steam piping normally should not exceed 100 ft/s (30 m/s).

4.3.7.5 Pilot Gas Piping

Piping to each pilot should include a quarter turn manual valve to allow individual pilots to be taken out of service for maintenance. Lockable valves can be purchased if specified by the owner.

Pilots have small orifices that make them susceptible to plugging. Pilot gas headers should be fitted with filters to keep dirt and scale from the pilots. Recommended filter sizes are 25 % of the smallest fuel orifice. Basket type filters are superior to Y-strainers. The filters should be cleanable during operation. Further protection can be achieved by providing stainless steel piping from the filters to the pilots.

5 Environmental Considerations

5.1 General

The principal use of burners is to provide the high level of heat to process streams that cannot be achieved by other means (such as heat integration by exchangers). However, combustion reactions can produce noise and chemical species that may be of concern to humans, animals, and the environment. Different localities may have standards that regulate these pollutants. This publication is not undertaking the duties of employers, manufacturers, or suppliers to warn, properly train, and equip their employees and others exposed concerning health and safety risks, nor is it seeking to undertake their obligations under local, state, or federal laws. The end user shall be aware of their responsibilities and consult with the relevant authorities under their respective legislation.

This section is very often the first consideration that shall be applied to new combustion processes, whether this is a retrofit of burners on existing units or indeed installation of new units. Later sections within this document elaborate on the emissions from burners as well as design aspects applied to all burners to achieve the desired emissions.

5.2 Noise

The design of the burner can affect noise production. Fuels requiring high velocities, such as used in high-intensity burner designs or containing high levels of hydrogen may raise noise levels. Fans, burners, ducts, and stacks may have to be equipped with noise attenuation to mitigate against excessive emission levels. Different localities may have regulations that regulate noise. These may be defined in sound power or more commonly in SPLs. The end user should be aware of the differences and if necessary consult with a noise specialist.

5.3 Flue Gas Emissions

5.3.1 Nitrogen Oxides, NO_x (Usually Reported as NO_2)

5.3.1.1 General

Nitrogen oxides (NO_x) is the generic term for a group of gases, all of which contain varying amounts of nitrogen and oxygen. Many of the nitrogen oxides are colorless and odorless. Nitrogen oxides form when fuel is burned at high temperatures, as in the combustion process of a fired heater. The majority (95 % to 98 %) of the nitrogen oxides formed in fired heaters is in the form of nitric oxide (NO), with the balance other oxides. NO is eventually transformed to nitrogen dioxide (NO_2) after discharging into the atmosphere and as such regulators have defined the legislation in terms of NO_2 emitted. NO_2 is a reddish brown, highly reactive gas. The reader should be aware that brown plumes from stacks are rarely, if ever as a result of NO_2. More commonly, this is a result of aerosols that interact with light at different angles that gives the appearance of a brown plume.

A burner chosen to limit one pollutant may produce higher emissions of another. For example, an oil burner designed to produce a minimum of NO_x may produce high particulate levels. A compromise between these competing emissions will be necessary.

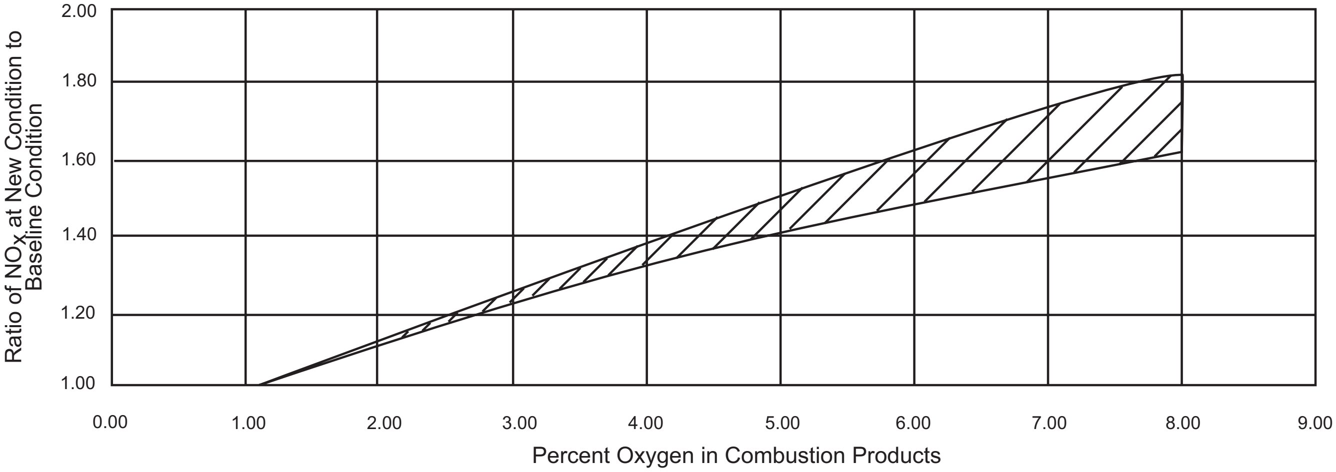
5.3.1.2 NO_x Production Trends

5.3.1.2.1 Effect of Excess Oxygen (Figure 7)

As excess air to a raw gas burner is increased, the NO_x concentration will reach a maximum. Additional increases in excess air will lower the concentration of NO_x.

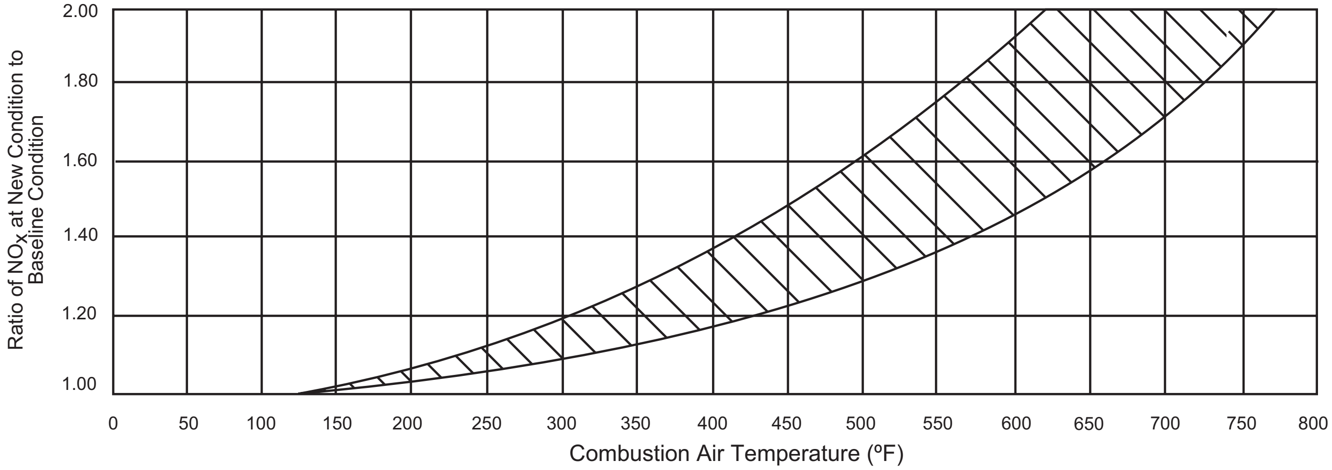
5.3.1.2.2 Effect of Combustion Air Temperature (Figure 8)

NO_x production is favored by high temperatures. Local flame temperatures and NO_x concentrations will increase as the temperature of the combustion air increases. While air preheat can increase efficiency it also increases the firebox temperatures and shall also be considered in design.



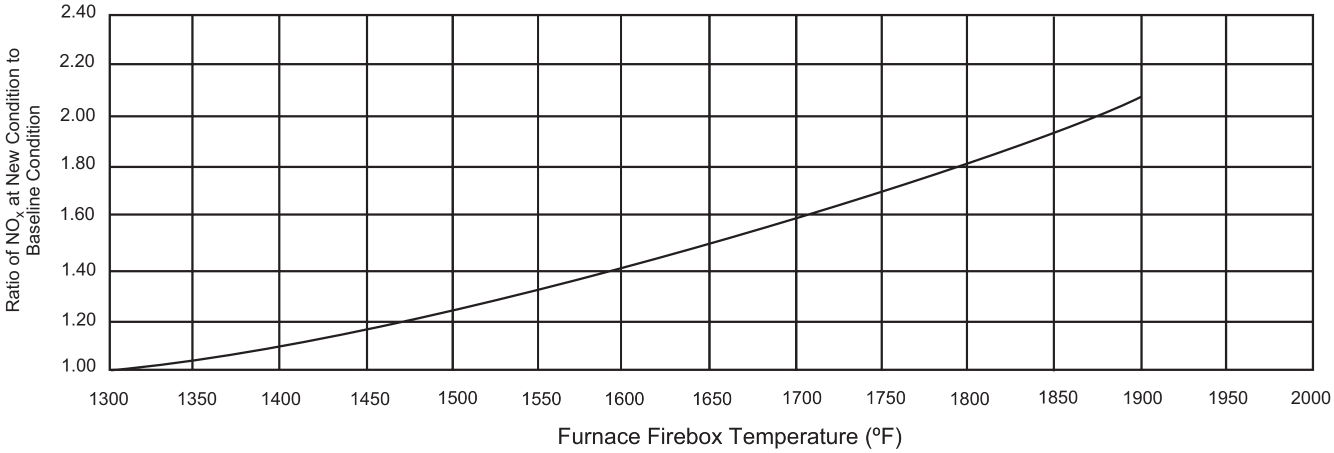
NOTE This figure is representative only and not intended for design or corrections. This figure is a generic curve and not applicable to individual low NO_x burner designs.

Figure 7—Effect of Excess Air on NO_x Emissions



NOTE Figures are used for illustrative purposes and not to be used for verification or corrections. This figure is a generic curve and not applicable to individual low NO_x burner designs.

Figure 8—Effect of Combustion Air Temperature on NO_x Emissions



NOTE Figures are used for illustrative purposes and not to be used for verification or corrections. This figure is a generic curve and not applicable to individual low NO_X burner designs.

Figure 9—Effect of the Firebox Temperature on NO_X Production

5.3.1.2.3 Effect of Firebox Temperature (Figure 9)

NO_X concentrations will increase as the firebox temperature increases. The choice of burners can have an effect on the firebox temperature therefore affecting the NO_X. Burners creating different heat flux variations within a furnace will produce different firebox temperature patterns. The style of burner and the degree of swirl can affect box temperatures and the conversion to nitrogen oxides.

5.3.1.2.4 Effect of Fuel Composition (Figure 10 and Figure 11)

Fuel gases will generally produce lower NO_X levels than fuel oils and will depend greatly on the concentration of nitrogen compounds in the fuel. Any fuel gas containing ammonia and not diatomic nitrogen (N_2) will have elevated NO_X emissions. While fuel bound nitrogen has a dramatic effect on NO_X, diatomic nitrogen (N_2) in the fuel gas does not contribute to NO_X.

Fuels with higher adiabatic flame temperatures will generally produce more thermal NO_X so high hydrogen fuels will frequently produce higher NO_X levels than others. Similarly, the addition of high end (C4+) unsaturates will frequently raise flame temperatures and NO_X concentrations due to prompt NO_X formation.

Figure 10 shows the effect the hydrogen content of the fuel gas has on NO_X production.

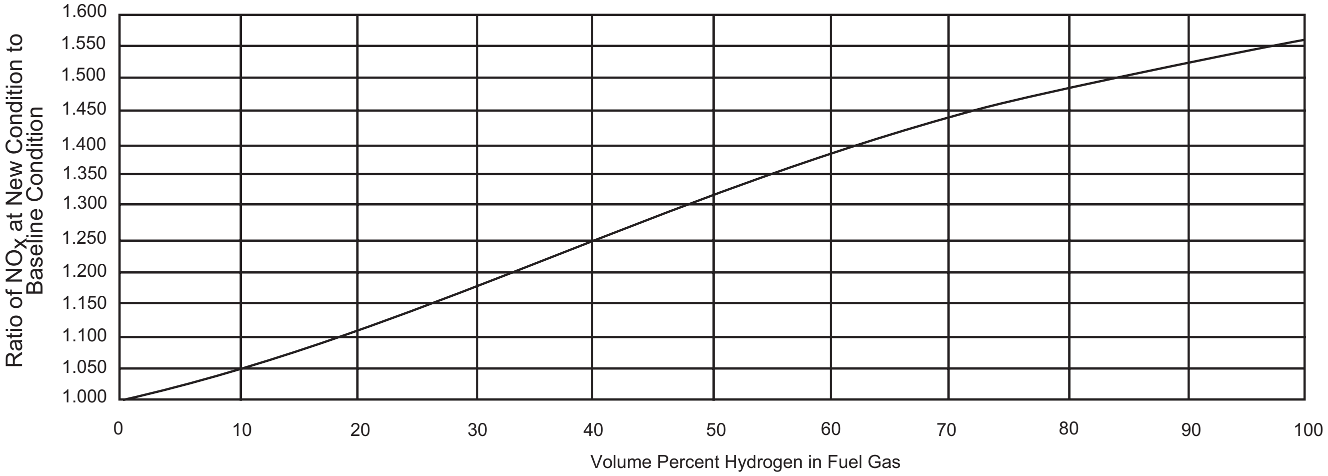
NOTE This graph shows a typical trend and does not apply to all burners as some of the new generation burners mitigate these effects.

Figure 11 shows the effect the fuel oil nitrogen content has on NO_X production.

The adiabatic flame temperature, which is predominantly influenced by fuel composition, air temperature, and excess air, will normally determine the base level of thermal NO_X. The NO_X levels may be reduced from the base case by applying various NO_X reduction techniques and are described in more detail in Section 9 of this RP.

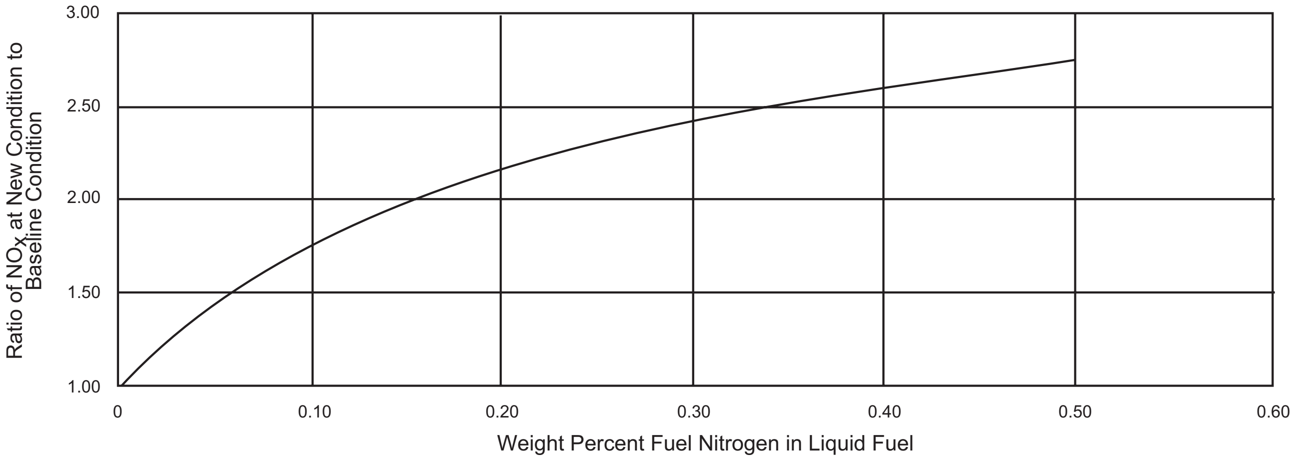
5.3.2 Sulfur Oxides, SOx (Usually Reported as SO_2)

The quantity of SOx emitted is a function of the concentration of sulfur in the fuel and cannot be influenced by the burner design. Sulfur dioxide (SO_2) may make up 94 % to 98 % of the total sulfur oxides produced. The remainder is sulfur trioxide (SO_3). Operation at low excess air levels will reduce the conversion of SO_2 to SO_3.



NOTE Figures are used for illustrative purposes and not to be used for verification or corrections. This figure is a generic curve and not applicable to individual low NO_X burner designs.

Figure 10—Effect of Hydrogen Content of Fuel Gas on NO_x Emission



NOTE Figures are used for illustrative purposes and not to be used for verification or corrections. This figure represents a general trend and is not intended to be a general correction applied to burner data.

Figure 11—Effect of Fuel Nitrogen Content on NO_x Emission

As stated above, the quantity of sulfur or H_2S in the fuel will govern the quantity of SOx produced. Reduction of SOx emissions involves switching to a sweeter fuel, cleanup of fuel, or providing removal facilities downstream of the combustion chamber in the flue gases.

5.3.3 Carbon Monoxide (CO) and Combustibles

CO is a colorless, odorless, poisonous gas formed when carbon in fuels is not burned completely. The carbon monoxide concentration exiting from a burner will increase slowly as the excess air level decreases. The increase will accelerate as excess air levels continue to decline. At a certain point, a further drop in excess air will produce an asymptotic increase in these levels. The concentration curves of CO and combustibles will be similar in response to reducing excess air levels.

The point at which the CO level begins to increase rapidly upon reduction of excess air is referred to as the CO breakthrough. This breakthrough will vary depending upon the fuel and the type of burner.

Emissions of unignited and partially combusted fuel are typical indicators of flame problems. Typically flame instability may be present caused by conditions such as low firebox temperatures and insufficient air for complete combustion.

Heavy oils are more likely to produce greater levels of combustibles (including carbon monoxide) than lighter oils and gas. The heavier components are not as easily atomized and therefore not completely combusted.

Burners that provide a superior degree of mixing allow improved combustion at lower excess air levels. This results in reduced combustibles and CO emissions at equivalent excess air levels.

5.3.4 Particulates

All fuels will contain or produce particulates. Particulates will be formed in greater quantities in fuel oils (especially in heavy fuel oils) than fuel gases. Ash in the fuel will be carried out the stack as particulates. Pyrolysis and polymerization reactions may produce highly viscous or solid particles that remain unburned when firing heavy fuel oils. These contribute to the quantity of the particulates that increase with heavier fuel oils. The asphaltene content and Conradson carbon number of a fuel oil can be an indication of the particulate forming tendencies.

All particulates do not come from the fuel. Some may come from tube or fuel line scale as well as eroded refractory. Particulate matter may be entrained into the burner through the combustion air in some locations. This can be of a particular concern in dusty environments.

Burners with greater swirl and/or higher combustion air pressures (such as forced draft burners) are likely to produce lower particulates since they provide a superior degree of mixing that reduces the formation of particulates.

5.3.5 Volatile Organic Compounds

According to the U.S. EPA (40 *CFR*, Part 51.100), volatile organic compounds are defined as any compound of carbon that can participate in atmospheric photochemical reactions. Among the gases excluded are methane, carbon monoxide, carbon dioxide, carbonic acid, metallic carbides, and ammonium carbonate.

6 Burner Selection

6.1 General

There are many aspects of burner design that need to be considered in conjunction with the design of a fired heater. When designing a fired heater, the proposed mode of operation shall be considered and will dictate the type of burner to be designed. The furnace may be a simple small natural draft heater or a larger, more sophisticated, balanced draft unit with an air preheat system. This section provides the user with the major considerations that shall be accounted for in burner selection and design. In many cases, particularly with the extremely low NO_X numbers required by some local authorities, the burners can only be specified with input from the burner suppliers. The following sections are not meant to replace the dialogue that should take place between the knowledgeable user and the supplier as many times the end result is an iterative process.

Burner information required by the burner supplier should be included in the burner datasheets shown in Annex A of this practice. As the dialogue between the supplier and heater vendor progresses, the datasheet can be updated to ensure the burner is correctly specified.

6.2 Draft

6.2.1 General

Burners are broadly categorized into two types: natural and forced draft. Burners are sized based on consideration of the total air side pressure drop or “draft loss” across the burner. The primary draft loss for a burner is across the burner throat with other components such as air registers and entrance effects accounting for the balance. The burner sizing and the draft loss shall consider corrections for temperature, relative humidity, and atmospheric pressure.

6.2.2 Natural Draft Burners

The combustion air for natural draft burners is induced through the burner either by the negative pressure inside the firebox or by fuel gas pressure educting the air through a venturi. Natural draft burners are the most commonly found burner in general refinery service.

6.2.3 Forced Draft Burners

Forced draft burners operate with combustion air supplied at a positive pressure. The term “forced draft” is so designated because the combustion air or other oxygen source is normally supplied by mechanical means (i.e. a combustion air fan).

Forced draft burners have higher available air supply measured as higher air pressure compared to a natural draft burner. This can allow the use of smaller or few burners for the same equivalent heat release from a natural draft burner.

Because of the positive pressure available, forced draft burners can be increased in heat release capacity relative to natural draft burners, and fewer burners need to be installed for a given heat release.

While the reliability of fans is high (about 98 %), the operational reliability of a forced draft system is always defined by the reliability of the fan and driver. Failure of either may shutdown the heater and unit. The user shall determine whether spare fans and drivers are required, incorporate measures to ensure reliability, or accept reduced load under natural draft conditions in the event of combustion air fan failure. Should burners be specified to have natural draft backup, then these would generally be a modified natural draft burner used in forced draft service. The use of these natural draft burners can also have problems as these burners are a hybrid and the advantages of a forced draft and natural draft design can be lost.

Forced draft burners can also be used when turbine exhaust gas is supplied as a source of oxygen.

6.2.4 Natural Draft Burners in Forced Draft Systems

Natural draft burners are sometimes specified in air preheat systems where natural draft is required for continued operation when the air preheater, fans, or drivers fail. In such cases, air doors in air supply ductwork should open automatically to provide a source of ambient air upon any of the above failures.

Burners have to be sized for the natural draft application. This may necessitate oversized burners for the forced draft air preheat cases or reducing firing rates at natural draft conditions. Burner overdesign factors should be carefully reviewed or the system may be unsatisfactory for forced draft operation. The user should not specify additional margins to the forced draft maximum heat release if the burners are required to provide maximum heat release under natural draft conditions.

Careful layout of the ducting and fresh air doors is recommended when natural draft burners are used for both natural and forced draft applications. Equal air distribution to the burners under natural draft conditions shall be considered when locating the fresh air doors .

The ducting design should supply the air uniformly into the burner plenum. To obtain good air distribution, the air supply ducting should be properly designed with respect to air velocity and distribution. The velocity should be reduced at the air distribution header at the heater. The velocity head in the air distribution header should not exceed 10 % of the burner pressure drop to ensure uniform air distribution to each burner. Avoid abrupt transitions that could cause air misdistribution into the burner plenum. The use of turning vanes in elbows and transitions reduces pressure drop and provides more uniform flow patterns. Computational fluid dynamic (CFD) and cold flow modeling are good tools to ensure proper air distribution.

In considering natural draft backup, the user should be aware that the doors are part of the safety system and should open on demand. Heater shutdown shall occur if sufficient doors do not open and shall be verified open within an acceptable time frame. While on forced draft (considered normal operation) these doors cannot be tested and many have been known not to open on demand. Doors are also designed to fail open and should be positioned in the ductwork with sufficient protection to ensure that the operator is not exposed to hot combustion air during normal operation. Operators should also be prevented for accessing the doors during normal operation as they may trip open at any time. Refer to API 556 for instrument requirements.

6.3 Flame Stability

Above all other considerations a burner shall operate safely and be stable within the burner operating envelope. A stable flame is one where the root of the flame is firmly attached to the designed flame stabilization point, with no signs of the flame root jumping between other possible stability zones. Loose flame tails are not a sign of poor flame stability.

Good fuel and air mixing is one of the most important requirements for stable combustion. It affects the fuel/air proportioning, ignition temperature, and flame speed. The mixing energy is measured at the point of discharge of the burner. It is provided by the potential and kinetic energies of the air, fuel, and in the use of oil firing, the atomizing medium. The mixing of the combustion air with the fuel is critical to flame stability. Too high of a velocity will not allow mixing to take place. The burner designer has many approaches when designing stability that include bluff body stabilizers, swirlers, tile edges/ledges, or perforated plates that create local low-pressure eddies. In addition, stabilization of the flame can be achieved by the design of the refractory burner block. The burner block reradiates the heat back into the mixture to keep the temperature above the autoignition conditions.

Mixing energy can be provided by the fuel discharge velocity and its direction of flow. Natural draft burners have to rely more on fuel energy for mixing than do forced draft burners. They are more likely to have poorer mixing with burner turndown. Natural draft burners normally require higher excess air than forced draft burners, particularly when operating at turndown

Forced draft burners typically use high air-side pressure differential across the burner throat. This creates turbulence within the burner improving the mixing process and enhances flame stability.

A flame will extinguish if the temperature of the fuel/air mixture at the ignition point drops below the autoignition temperature. Flame instability and CO generation can be a problem on low NO_x burners in cold fireboxes (below 1200 °F).

6.4 Design Excess Air

For multiple burner applications, the user should consider limiting the reduction in excess oxygen to prevent some burners from running substoichiometrically due to misdistribution of combustion air and/or leakage through the heaters casing (tramp air). Running below 2 % excess oxygen may warrant additional safeguards, such as separate air control measurement and CO monitoring. In a poorly maintained heater where significant air leakage affects excess oxygen readings, it may not be possible to run as low as 2 % excess oxygen.

The design excess air of the burners may be lower than the specified excess air for the fired heater. This takes into consideration the number of burners, air distribution and air leakage into the fired heater. Fired heaters should be tested for CO/combustibles breakthrough to set the operating excess air at the burner.

Reducing excess air below design level will typically have the effects on emissions as shown in Table 7.

One important exception is premix combustion, where reducing excess air typically increases NO_x emissions.

Table 7— Effects of Reduced Excess Air on Burner Emissions

Pollutant	Effect of Reducing Excess Air
NO_x	Decrease
SO_x	No change to the total SO_x
	Less SO_2 will be converted to SO_3
Carbon monoxide	Increase
Combustibles	Increase
Particulates	Increase

6.5 Combustion Air Preheat

The addition of heat to the combustion air increases the efficiency of the combustion process. As mentioned above, higher air preheat temperatures will increase flame temperatures. This will increase the concentration of NO_x in the flue gas while the mass will reduce. Combustion air preheat systems are described in Appendix E of API 560.

As mentioned above, higher air preheat temperatures will increase flame temperatures. This will increase the concentration of NO_x in the flue gas while the mass emitted may reduce slightly with the efficiency gains. The user shall determine the extent of the air preheat at design conditions and consider this when specifying equipment for low emissions of NO_x.

6.6 Turbine Exhaust Gas

In rare situations, the oxygen for the combustion of fuels in fired heaters can be supplied by flue gas streams such as the exhaust from a gas turbine. Gas turbine exhaust streams contain between 13 to 17 volume percent of oxygen at temperatures between 454 °C (850 °F) and 565 °C (1050 °F) and up to 10 in. H_2O (gauge) pressure. Burners can operate with oxygen contents down to approximately 15 volume percent in turbine exhaust streams. Combustion can become unstable below this level depending upon the temperature and burner type.

6.7 Combustion Air Adjustment

Burners are normally provided with airside control devices to adjust the air rate into the burner. Air registers or dampers are provided for this purpose. Damper controls with positive click positions may be preferred to prevent involuntary movement of the air damper and allow for uniformity of excess air to each burner in a multiburner system. Some operators link the burner to a plenum or a combustion air distribution system for automated air control. While some burners may be fitted with actuators that control air to the individual burners this becomes costly and impractical when the number of exceeds approximately four (4). The individual burner air dampers should still be specified and supplied as these would act as on/off devices when the burner is removed from service for maintenance on an operational heater. These individual burner air dampers should be designed for tight shutoff to allow the burner to be removed from service without affecting the firebox excess air level.

Some burners are provided with a single air side control, others have two or three separate devices to allow the operator to distribute the air to different proportions within the burner. These are typical in air staged burners. These burners tend to have registers fixed to a set ratio on start-up (generally dictated by flame shape and NO_x emissions) and are linked to a distribution system that allows overall adjustment of the combustion air to all of the burners. It would be very impractical to automate all the individual dampers on these burners and even less practical to operate safely.

Dampers, registers, or sometimes air sleeves are provided on forced draft burners. These devices trim the air or provide a directional spin to aid mixing of the air with the fuel. Some forced draft burner vendors use the burner damper to evenly distribute the air throughout the burner.

Total air flow to the forced draft fired heater is normally controlled by adjustment of the inlet guide vane (at the fan inlet) or speed of the forced draft fan using a variable speed drive. Other downstream devices can be used but these are less efficient and require more horse power to be used for a given air flow. When a forced draft fan serves multiple branches of ductwork, control dampers in the individual combustion air ducts should also be provided.

7 Gas Firing

7.1 Raw Gas Firing (Nozzle Mix)

7.1.1 Fuel Gas Pressure

Raw gas burners (Figure 1 and Figure 6) can be designed to operate over a wide range of fuel gas pressures. The gas pressure is normally selected as 15 psig to 25 psig (1 barg to 1.7 barg) for design heat release. This is to ensure reasonable tip drillings to reduce fouling problems during operation. It also provides reasonable pressures for fuel/air mixing at turndown. Combustion can be delayed with the use of lower pressures aiding the burner designer in achieving lower NO_x values. The user should, however, specify the turndown on the fuel gas side as too low a design pressure will compromise the start-up and turndown operations.

Burner capacity curves supplied by the burner manufacturer should be used as a guide for the acceptable gas pressure range. For pressures above the capacity curve, the burner manufacturer should be consulted as liftoff and lack of combustion air may become problems.

Fuel gas pressure is typically read at a point in a supply header just downstream of the pressure regulator, but users should note that burner performance is determined by pressure at the burner tip that can be substantially lower, depending on piping design and line losses. It is often best to measure the fuel gas pressure locally at the burner; connections or permanent gauges for pressure measurements are at the owner’s discretion.

7.1.2 Fuel Composition and Effects

Raw gas burners are most suitable for handling fuel gases with a wide range of gas composition, gravity, and calorific values. Fuel gas compositions can vary from a high hydrogen content to large percentages of high molecular weight hydrocarbons. The gases can contain quantities of other components that may be inert (i.e. CO_2, N_2, water vapor). The full composition range should be considered in the burner design and selection.

Raw gas burners may not be suitable for gases containing droplets of liquid or a high level of unsaturated hydrocarbons. Coke or polymers can form in the burner tip blocking the tip drillings. This can be a significant issue when the tips are exposed to significant radiant heat from the heater floor or are placed in burners with high combustion air temperatures. Tip plugging is a general issue affecting low NO_x burners. For example, the presence of chlorides, amines, etc. can lead to plugging or damaged burner tips disrupting the desired fuel/air mixing leading to a rise in the CO combustibles levels.

A raw gas burner with separate gas nozzles can be supplied if burners are required to operate with a wide range of fuel gas compositions and pressures.

Low heating value fuel gases without hydrogen will require special review by the burner designer. A waste gas stream with a heating value of 300 Btu/ft^3 normally can operate without supplementary firing. Operation at lower heating values as low as 95 Btu/ft^3 are possible if the fuel gas contains hydrogen and or CO (e.g. low Btu or blast furnace gases).

Some process off-gas streams are only available at low pressures [around 8 in. H_2O (gauge)]. They may be fired in raw gas burners with proper tip design or in combination with other fuels in separate burner guns. The end user should advise the burner manufacturer of the composition and flow expected in this stream. Sometimes the off-gases may contain substantial levels of hydrocarbon. As this flow is generally uncontrolled, the main fuel will be turned down to compensate. Too high of a heat release or velocity from the off gases could affect the main burner stability. When the waste gas represents a large portion of the heater heat release, it should be spread over a large number of burners so that it does not exceed 10 % of the individual burner heat release. The waste gas proportion should be determined at the turndown conditions as well as the design conditions as the waste gas may not be turned down in the same ratio as the main fuel gas. Waste gases on burners designed for extremely low NO_x should be reviewed carefully as the waste gas can sometimes dictate the final NO_x emission.

7.1.3 Turndown

Raw gas burners can easily operate with a turndown ratio of 5:1 based upon a single fuel composition. The range of fuel composition and available fuel pressure will affect the acceptable operating range of the burner. Depending on the fuel gas design pressure, turndown could be extended further to 8:1.

The user should note that the lowest available pressure for operation will be dictated by the control system and not necessarily by the burner design. Low-pressure alarms and or shutdown settings will need to be selected such that the burner heat release always remains within the burner operating envelope (see API 556).

7.1.4 Design Excess Air Recommendations

Excess oxygen required for good combustion depends on the burner design, the source of oxygen, the fuel fired, and the fuel conditions. Table 8 provides excess air values (excluding air leakage) that are normally acceptable for good combustion on raw gas burners:

Table 8—Typical Excess Air on Raw Gas Burners

	Single Burner Systems	Multiburner Systems
Natural draft	10 % to 15 %	15 % to 20 %
Forced draft	5 % to 10 %	10 % to 15 %

7.1.5 Draft

Raw gas burners require a minimum pressure drop of 0.20 in. H_2O (5 mm H_2O) at the burner level for adequate air supply for combustion and flame shape. Typical drafts in the range of 0.30 in. H_2O to 0.40 in. H_2O (7.5 mm H_2O to 10 mm H_2O) are more common. The amount of air supplied to a raw gas burner is dependent on the draft available at the burner, which is in turn set by the bridgewall pressure, height, and temperature of the firebox. Turndown of the air at this very low pressure is however extremely limited. Values of 2 or 3:1 are typical.

7.1.6 Flame Characteristics

The flame shape is determined by the burner tile, the drilling of the gas tip, and the aerodynamics of the burner. Round burner tiles are used to produce a conical or cylindrical flame shape. Flame lengths estimates of 1 ft/Btu × 10^6/hr to 2 ft/Btu × 10^6/hr (1 m/MW to 2 m/MW) for natural draft burners are conventionally used for older style burners before the advent of lower NO_x emission burners. Flame lengths have increased with these new low NO_x designs and can be up to 2.5 ft/Btu × 10^6/hr (2.5 m/MW).

Flat flame burners are designed with rectangular burner tiles. These burners are used when firing close to refractory walls and floors, where the tube clearance is limited and where process requirements dictate the desired heating profile.

7.1.7 Burner Heat Release

Natural draft, raw gas burner heat release is normally within the range of 1 × 10^6 Btu/hr to 17 × 10^6 Btu/hr (0.3 MW to 5 MW). At the higher heat releases however mixing between the fuel and air is reduced as the tile is large and the pressure drop (energy for mixing) is low. Most low NO_x burners do not exceed approximately 10 × 10^6 Btu/hr to 12 × 10^6 Btu/hr (2.9 MW to 3.5 MW).

Forced draft burner heat release range is typically between 4 × 10^6 Btu/hr and 70 × 10^6 Btu/hr (1.2 MW and 20.5 MW) for typical fired heater applications. Forced draft burners can be designed for higher rates, but heater design considerations (firebox dimensions, localized heat flux) often limit the size of the burner rather than the burner design itself.

7.2 Premix Firing

7.2.1 Fuel Gas Pressure

The fuel pressure in a premix burner (Figure 2 and Figure 3) is used to inspirate some of the combustion air through a venturi prior to ignition at the tip of the burner. Additional secondary air is supplied through the burner by the draft available at the heater floor.

A typical fuel gas pressure range is 15 psig to 35 psig (1 barg to 2.4 barg) at design heat release. However, higher fuel gas pressures may be required in cases where very low NO_X emissions are required or when a wide range in fuel composition is specified. Fuel gas pressures up to 75 psig (5 barg) are possible.

The minimum fuel pressure is restricted by the composition and range of the fuel specified. Typically, 3 psig (0.2 barg) is the minimum.

The burner capacity curve should be used as a guide for the acceptable gas pressure range. For pressures above the capacity curve, consult with the burner manufacturer, as liftoff may become a problem.

As with raw gas burners, fuel gas pressure is typically read at a point in a supply header, but users should note that burner performance is determined by pressure at the burner tip, which can be substantially lower, depending on piping design and line losses.

7.2.2 Fuel Composition and Effects

The premix burner produces a very stable and compact flame when operating under the appropriate conditions. The velocity of the fuel/air mixture leaving the burner tip shall exceed the flame speed otherwise the flames will flash back and burn inside the venturi. This is applicable to all operating conditions. The turndown is severely limited when using gases with high flame speeds such as hydrogen. Fuels containing a hydrogen content of more than 70 mol% are not generally recommended for premixed burner designs.

A variation in fuel gas composition may change the operating pressure of the fuel for a given heat release. This directly affects the amount of combustion air inspirated.

Premix burners may not be suitable for fuels where the gas composition is constantly changing.

Waste gas can be burned in a premix burner, but may be severely limited by its pressure and composition. An eductor can be used to introduce the fuel to the firebox with low-pressure waste gas. Natural gas or steam can be used as the educting medium.

The maximum heat release may not be achieved when operating with fuel gases much heavier than the design fuel. This is because of the lack of air inspiration due to the low fuel gas pressure. Additional secondary air shall be supplied through the burner to make up the deficiency and draft may not be available.

7.2.3 Turndown

The premix burner is normally limited in turndown to 3:1 for a single fuel gas composition. The burner turndown ratio will be affected and may be limited when operating with a large range of gas compositions. Turndown is normally limited by flashback inside the venturi when considering high hydrogen content fuels.

7.2.4 Design Excess Air Recommendations

Premix burners can operate at lower excess air values than raw gas burners because of the improved air/fuel mixing, 5 % to 10 % excess air may be achieved in a single burner. The primary air rate inspirated into the burner varies from 30 % to 70 % of the total combustion air requirement for typical refinery premix burners. Unique furnace designs may require premix burners with as much as 100 % primary air. The additional combustion air not inspirated is induced into the burner through the secondary air openings, which is dictated by the draft at the furnace floor.

While premix burners can be utilized in forced draft applications, they are typically used for natural draft heaters only. This is due to the burner's unique air inspirating capabilities. Caution should be used when preheated air is considered with premix burners, since high air temperature may cause flashback inside the burner tip and venturi. Table 9 provides typical excess air levels for premix burners.

Table 9—Typical Excess Air on Premix Burners

	Single Burner Systems	Multiburner Systems
Premix burners	5 % to 10 %	10 % to 20 %

7.2.5 Draft

Premix burners can be stable with very low draft (0.05 in. H_2O to 0.10 in. H_2O minimum at the burner level when 100 % premix air is used). The amount of primary air inspirated into the burner is dependent upon the fuel pressure and the design of the eductor.

Large heat release (greater than 4 × 10^6 Btu/hr) burners may not be capable of operating without a higher percentage of secondary air.

7.2.6 Flame Characteristics

The flame volume of a premix burner is smaller and more defined when compared to a raw gas design. The flame shape is determined by the design of the gas tip and, to a certain extent, the shape of the refractory tile. Designs with round tips produce a thin pencil-like flame. Spider tips produce a short compact flame. Fish tail tips produce a fan shaped flame for flat flame applications.

With radiant wall burners (Figure 3), the flame is designed to spread across the burner tile and the furnace wall refractory without any forward projection into the firebox.

7.2.7 Burner Heat Release

The heat release for various burner designs normally varies from 0.5 × 10^6 Btu/hr to 15 × 10^6 Btu/hr (0.15 MW to 4.4 MW).

8 Liquid Fuel Firing

8.1 Types of Fuel Oil

Liquid fuels vary in composition, specific gravity and viscosity from light fuel oils, such as naphtha and light distillate fuel, to heavy residual fuel oils. Other liquid fuels that are waste products of the process plant, such as tar, asphalt, and pyrolysis fuel oil, are also burned in fired heaters. It is necessary to atomize the liquid fuel into a fine mist to allow rapid vaporization and mixing of the combustion air and fuel. Successful combustion of liquid fuels is dependent upon the atomizer design and the fuel/atomizing medium conditions. Specification for grades of liquid fuels can be found in ASTM D396.

Lighter oils are easier to burn than heavier oils. If the user desires conversion from light to heavy oil and vice versa then a different oil gun will probably be required to maintain good flame patterns. Very heavy oils are difficult to atomize, especially in the smaller heat release oil guns due to small passages in the tips.

Flame stability is dependent upon good fuel/air mixing. There should be good atomization to achieve good mixing. The oil tip is positioned in the primary tile or oil stabilization device (swirler or cone) to maximize flame stability for oil firing. The stabilizing device creates a low-pressure zone in the vicinity of the oil tip. This forces the recirculation of an oil mist into the hot combustion zone created by the primary tile. This stabilizes the flame and aids in vaporization of the fuel oil.

The position of the oil tip is critical. If the oil tip is raised too high in the stabilizing device, the recirculation effect is lost and flame stability suffers. If the oil tip is too low in the stabilizing device, impingement of raw oil on the stabilizing device occurs and coking and oil spillage may result.

Unstable conditions will occur when fouled oil guns or atomizers prevent proper mixing. Operation at too great of a turndown will also cause flame instability.

8.2 Atomization

8.2.1 General

To ensure good mixing with the air, the fuel oil droplet should be as small as practicable. Depending on the type of oil fired, there are two commonly used methods employed. Twin fluid atomizers using another atomizing medium or mechanical atomization using high pressure of the oils supplied. The following section describes the use of these in detail.

8.2.2 Steam Atomization

Steam is the most common medium for liquid fuel atomization in refinery practice. Steam should be supplied dry or slightly superheated. Typically atomizers require a pressure of 100 psig to 150 psig (6.5 barg to 10.5 barg). Higher steam pressures [300 psig to 400 psig (20.5 barg to 27.5 barg)] may be required when atomizing heavy or hard to atomize liquid fuels such as residuals and pitch.

Wet steam should be avoided to prevent water droplets forming in the piping or burner gun. The heat to vaporize the water will absorb much of the heat necessary for ignition and complete combustion. Wet steam also causes considerable wear on the atomizer tip, which has a detrimental impact on the atomization and therefore quality of the flame.

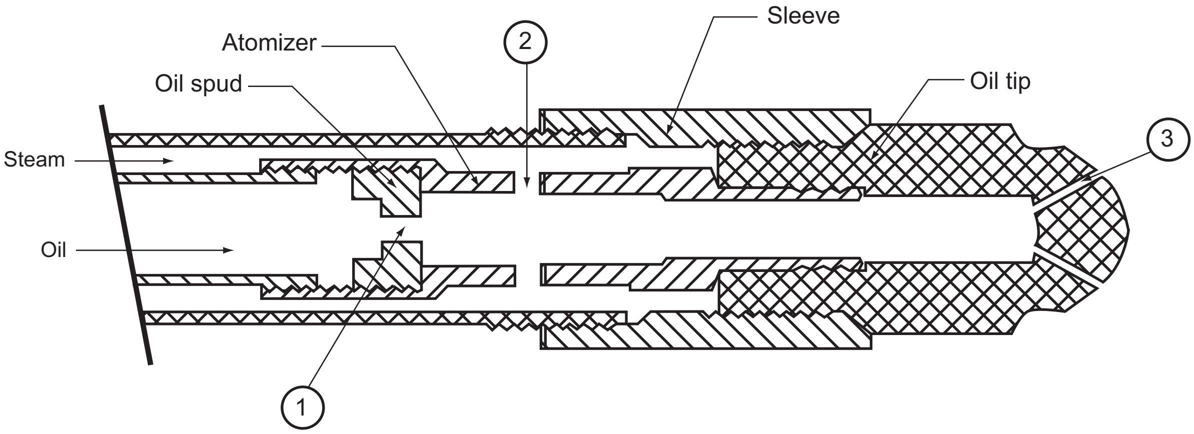
A high degree of steam superheat can partially vaporize the lighter portions of a liquid fuel within the burner gun and atomizer. This can cause oil gun vapor lock. In addition, atomizers are designed with steam on a mass basis. Too much superheat reduces the mass flow and therefore the atomization capabilities.

Steam atomization and steam assist atomization are the most common form of atomizers applied today. The difference between the two types of atomization is the degree of pressure atomization utilized. A steam assist system normally requires higher fuel oil pressures and uses less steam. The following sections briefly describe atomizers that are commonly used today, however, other manufacturers' designs will differ from what is shown here. Each atomizer should be evaluated on its merits.

8.2.3 Steam (Inside Mix) Atomizers

A steam or internal mix atomizer is shown in Figure 12. Key Item 1 is a limiting orifice for fuel oil flow. Steam is injected through the steam ports (Key Item 2) and mixed with partially atomized fuel oil. The steam and oil mixture is discharged through the tip ports (Key Item 3) where additional atomization and flame shaping occurs.

Fuel pressure is typically in the range of 80 psig to 120 psig (5.5 barg to 8.5 barg). Lower fuel oil pressures normally limit the turndown, while higher fuel oil pressures will reduce steam consumption. The atomizing steam pressure is normally maintained at a constant differential pressure of approximately 20 psi to 30 psi (1 barg to 2 barg) above the fuel pressure.



Key

1 limiting orifice for fuel oil flow
2 steam ports
3 tip ports

Figure 12—Inside Mix Atomizer

The nominal steam consumption is approximately 0.15 to 0.30 pounds per pound (kilogram per kilogram) of fuel oil. Higher rates may be required when firing heavy and more viscous fuels. The steam rate is dependent upon the differential utilized and the design fuel oil pressure. High-pressure atomizer designs require less steam, while low-pressure atomizer designs may require substantially more.

Advantages of the steam atomizer include a large fuel orifice that is less susceptible to plugging and a low fuel oil pressure requirement. The main disadvantage is high steam consumption.

8.2.4 Steam Assist (Port Mix or Y Jet) Atomizers

A steam assist or port mix atomizer is shown in Figure 13. The fuel oil is supplied through a series of limiting orifices in the tip (Key Item 1). A set of steam orifices (Key Item 2) is also found in the tip. The fuel oil and steam mix in the discharge port where final atomization takes place.

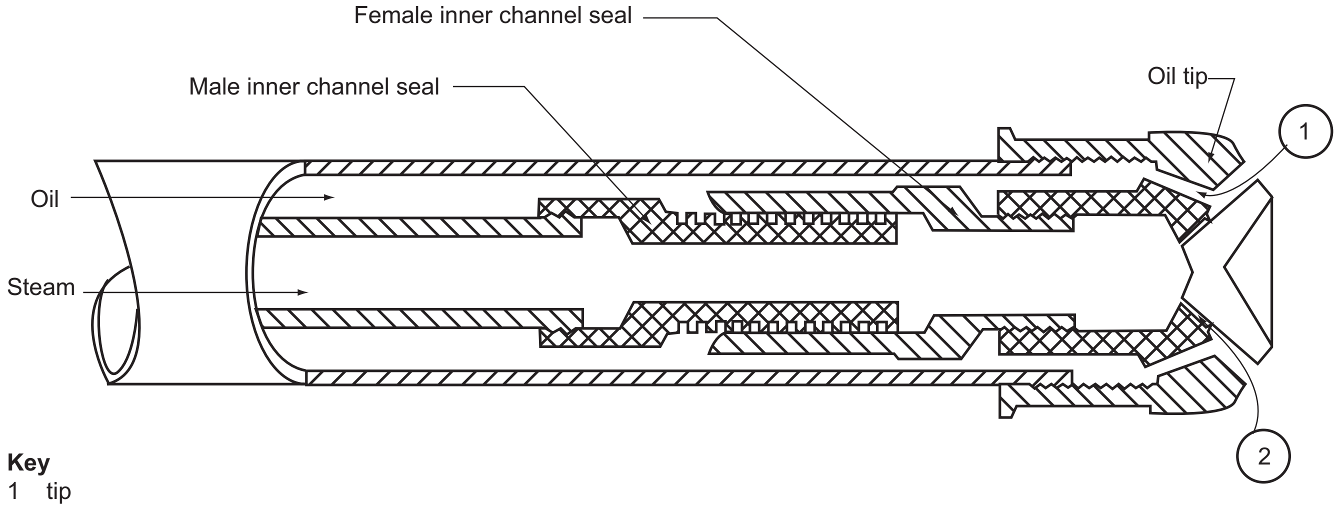
Steam pressure is normally held constant at approximately 100 psig to 150 psig (6.5 barg to 10.5 barg) throughout the operating range.

The steam consumption is approximately 0.10 to 0.20 pounds per pound (kilogram per kilogram) of fuel oil at maximum heat release. The steam rate per pound of fuel will increase at turndown since the steam is at constant pressure. Some constant differential atomizers do exist in this category and are therefore more steam efficient. The cost of steam should be evaluated as part of the overall operating cost of the burner. The steam assist atomizer is mainly selected for larger heat release burners. While the main advantage of this atomizer is low steam consumption the disadvantages include small fuel oil ports and high fuel oil and steam pressure requirements.

8.2.5 Air Atomization

Air atomization is often recommended when light fuel oils are to be fired to prevent vapor lock. Compressed air or sometimes fuel gas may also be used to atomize fuel oil when steam is not available.

Compressed air systems use the same atomizer type as described in the steam atomizer designs. Generally 100 psig to 120 psig (6.5 barg to 8.5 barg) plant air pressure is suitable. Extremely low pressure [1 psig to 2 psig (0.07 barg to 0.14 barg)] air atomization can be provided in some burner designs but is relatively uncommon.



Key
1 tip
2 steam orifices

Figure 13—Port Mix or Steam Assist Atomizer

8.2.6 Mechanical Atomization

The term mechanical atomization is normally associated with pressure jet atomization. Other mechanical designs are available but are not regularly used in refinery fired heaters. The pressure jet atomizer breaks the liquid down into small droplets by using a high pressure drop across the burner tip. The fuel supply pressure has to be sufficiently high to obtain a suitable turndown unless a high-pressure recirculation type of atomizer is used.

The fuel oil pressure at minimum turndown is approximately 80 psig to 100 psig (5.5 barg to 6.5 barg). Therefore, to obtain a turndown of 3 to 1, the fuel pressure for the design heat release would need to be between 700 psig and 900 psig (48 barg to 62 barg). This type of atomization is usually only found with forced draft burners of high heat release. The orifice size is small and is susceptible to fouling with small burners. The high fuel oil pressures used for this type of atomizer requires special safety considerations.

Mechanical atomization is normally used when no other atomizing media is available and is not recommended for natural draft service because the fuel/air mixing is poor.

8.3 Fuel Physical Properties

8.3.1 Naphtha and Light Distillate Fuels

Naphtha is a mixture of liquid hydrocarbons having a true boiling point range as broad as 60 °F to 400 °F (15 °C to 205 °C) and a flash point below ambient temperatures. The ability to vaporize at ambient temperatures, coupled with the low flash point requires specially designed atomizers and safety features.

If liquid naphtha enters the combustion chamber and is not combusted, the unburned liquid will quickly evaporate and produce dense vapors. It becomes a greater potential explosion hazard than fuel oil that, depending on the surrounding temperature, may not vaporize.

Purging before light-off, burner gun removal, and after shutdown is most important for naphtha and light distillate fuels. A purge connection should be provided from the purge line to the fuel line at each burner. Use of this connection allows both the gun and the last section of piping to be purged of fuel oil to prevent accidents. The length of the fuel oil piping should be minimized to reduce the quantity of fuel to be purged. The rate of purging should be controlled to avoid explosions.

Some operating companies require a safety interlock at each burner when firing naphtha and light distillate fuels. This interlock ensures that the fuel flow is shut off before the burner gun may be removed. It requires a purge of the gun before removal. The interlock should ensure that the fuel flow cannot be turned on while the gun is removed, and that the oil cannot be opened prior to opening the steam valve.

Steam atomizers designed for light fuel oils, such as naphtha and light distillates, are provided with separate tubes for the oil and steam. This is to prevent the steam temperature from vaporizing the oil in the gun.

8.3.2 Temperature and Viscosity

Fuel oil temperatures should be sufficient to get the correct viscosity for proper combustion. Recommended viscosity is shown in Table 10.

Table 10—Recommended Viscosity for Typical Fuel Oil Atomizers

Design Viscosity	Maximum Viscosity
120 SSU	200 SSU
20 cSt	45 cSt

Viscous liquid fuels typically used in refinery fired heaters (such as No. 6 oil, vacuum bottoms, pitch, tar, etc.) generally do not atomize well unless heated to reduce viscosity. Experience with the fuel and atomizer type will dictate the amount of heating required and the type of control system necessary. Generally, the lower the viscosity (the higher the fuel temperature), the better the atomization of a fuel will be. However, the fuel temperature for fuel oils with a wide boiling range should not be too high or vaporization in the oil gun will occur. Additionally, the fuel temperature should also be kept below the point where components in the fuel oil could potentially crack so that reactions that could lead to coking or plugging in the oil gun do not take place.

8.3.3 Fuel Composition and Effects

8.3.3.1 General

There are number of contaminants within fuel oils that should be considered by the burner designer when determining the suitability of design and the resultant difficulties that may be encountered by the end user. This section provides some perspective as the effects of the most common contaminants.

8.3.3.2 Water

High water levels in the fuel can result in oil that will not burn properly. The presence of water can affect burner operation and disrupt atomization. The latent heat of the water will absorb much of the heat necessary for ignition and complete combustion. Water can also contribute to erosion of the burner tips thereby leading to poor atomization and degradiation to the flame shape and emissions.

Water can be of benefit if it forms an emulsion with the oil. Special chemicals or mechanical devices are available to produce emulsions. These emulsions, in some cases, can improve combustion and aid efficiency. They may increase erosion of the burner tip and require frequent tip replacement.

The content of water in the fuel should be not more than 1 % by weight unless emulsifiers are employed.

8.3.3.3 Solids

Sediment often leads to atomizer plugging and flameout. Special hardened steels are required to reduce erosion. The fuel oil should be filtered through strainers to prevent burner plugging. The strainer should contain screens whose openings are no larger than 25 % to 50 % of the diameter of the smallest downstream orifice. Severe erosion can result when fine particulates such as catalyst fines are present.

8.3.3.4 Ash

High vanadium and/or sodium levels will cause degradation of the burner refractory and heater tube supports (see API 560). Special high alumina refractory can be used in the burner tiles to reduce degradation within the burner. The need of higher grade refractory is dependent upon the choice of burner and the degree of sodium and vanadium in the fuel. The burner vendor should be consulted as to the choice of burner tile material and expected frequency of replacement.

8.3.3.5 Carbon Content

Excessive soot and particulate emissions often occur with oils that have high asphaltenes, C/H ratio, or Conradson carbon (above 10 wt %). High asphaltene oils are more prone to burner tip coking problems. These problems can be overcome by proper fuel blending and tip design.

8.3.3.6 Unstable Oil Blends

Certain cracked oils may not blend into a stable mixture with certain light cutter stocks. Burner tip and strainer plugging result from unstable oil blends that cause asphaltene precipitation and polymer formation. Fuel oils containing unsaturated hydrocarbons may crack in the oil gun. This can cause fouling of the burner tip. The burner designer can do little to accommodate this feed stock and so the end user should ensure that these fuels are either separated or sufficiently buffered when changing from one to the other to ensure lines remain clear of deposits.

8.3.3.7 Wide Boiling Range Blends

Burner pulsation can result with steam atomizing when low boiling fractions prematurely vaporize. Ignition and stability problems can occur with wide boiling range oil blends. By having separate atomizing steam and oil tubes, vaporizing in the oil gun can be significantly reduced compared to the normal concentric tube employed.

8.3.3.8 High Wax Content

Fuel oils with high wax contents are prone to plugging if proper storage and delivery temperatures are not employed.

8.3.3.9 Nitrogen Content

As mentioned above, fuel bound nitrogen results in higher NO_x emissions.

8.4 Liquid Fuel Turndown

The turndown of liquid fuel burners is dependent upon the fuel pressure available and the atomizer design.

Typical turndown ratios and fuel pressures are provided in Table 11. The size of the burner is a factor in determining the turndown. Small burners have a lower turndown ratio (values are rounded approximations for practical use).

Table 11—Typical Turndown of Liquid Fuel Atomizers

	Turndown Ratio	Design Pressure		Minimum Pressure	
		psig	barg	psig	barg
Internal mix atomizer	3 to 1	120	8.5	30	2
Port mix atomizer	4 to 1	150	10.5	30	2
Mechanical atomizer	2 to 1	600	41.5	100	6.5

8.5 Design Excess Air Recommendations

Typical excess air values for burners firing a single liquid fuel are provided in Table 12. With the correct air to fuel ratios and maintenance, the excess air levels may be lower than outlined in this table.

Table 12—Typical Excess Air for Liquid Fuels

Operation	Fuel	Single Burner Systems %	Multiburner Systems %
Natural draft	Naphtha	10 to 15	15 to 20
	Heavy fuel oil	20 to 25	25 to 30
	Residual fuel oil	25 to 30	30 to 35
Forced draft	Naphtha	10 to 12	10 to 15
	Heavy fuel oil	10 to 15	15 to 25
	Residual fuel oil	15 to 20	20 to 25

The minimum excess air is determined by stability and complete combustion. A rapid increase in unburned particles of fuel is detected in the combustion products when combustion is not complete. Burners should be able to operate with a maximum carbon monoxide content of 50 ppmv for naphtha and 150 ppmv for residual fuels at design firing rate. Specific emission limitations may determine the excess air required to prevent pollution in the atmosphere.

8.6 Flame Characteristics

Oil flames are generally larger in volume than gas flames of the same heat release and produce higher flame luminosity and radiant heat flux. Forced draft burners produce a shorter flame because of the better mixing between the air and fuel. The drilling of the oil tip determines the shape and length of the flame.

The majority of liquid fuel burners are designed with round burner tiles and produce conical flame shapes. Special flat flame burners are available with rectangular tiles and special tip drillings to produce a flat, fishtail flame shape. These are used in close proximity to refractory walls and where clearances to the heating surfaces are limited.

8.7 Burner Heat Release

Natural draft burner heat release is normally in the range of 3×10^6 Btu/hr to 17×10^6 Btu/hr (0.9 MW to 5 MW), while forced draft burner heat release can be in the range of 5×10^6 Btu/hr to 70×10^6 Btu/hr.

8.8 Combination Firing

Some refinery fired heater burners are designed to operate with both liquid and gas fuels. The burner design places the oil gun at the centerline of the burner and gas tips are arranged around the outside perimeter of the oil stabilization device (primary tile, swirler, bluff body, etc.). Combination burners are designed to operate on either oil or gas. A combination burner can normally operate on either fuel at the full heat release of the burner.

Combination burners are commonly designed to operate on both fuels simultaneously; this allows the air to be controlled equally to all the burners. Firing individual fuel on alternate burners will require the air to be controlled globally to the worst performer (i.e. oil flame). It also creates different heat flux profiles with a fired heater as the heat flux from an oil flame is greater than a gas flame. It is important that the design heat release of the burners is not exceeded; otherwise there will be insufficient air for proper combustion. Burner tips may be designed for partial heat release of the burner to improve the turndown performance of each fuel. While gas can often help with oil firing, flames are longer than with each fuel alone. This shall be considered in fired heater design.

9 Low NO_x Burners

9.1 General

As mentioned in 5.3, environmental limits have been imposed for a number of years on NO_x emissions as nitrogen oxides are precursors to acid rain. With the ever increasing drive to reduce NO_x emissions, NO_x concerns have driven burner technology development. This section lays out the development of low NO_x burner technology and is aimed at providing the end user with sufficient knowledge to discuss the various designs with the burner suppliers. As burners are further developed, the techniques used to lower NO_x emissions may go through significant changes. Consequently, the end user should specify the actual NO_x required for the application and the burner supplier should advise what technology would be needed to achieve the requirement. The user is cautioned not to refer to low or ultralow NO_x burners as these are typically meaningless without a NO_x requirement.

9.2 NO_x Formation Chemistry

The production of nitrogen oxides occurs in three ways during the combustion process.

1) *Thermal Conversion (Thermal NO_x)*—The temperature dependent oxidation of molecular nitrogen (N_2) to NO_x. The thermal NO_x reactions are favored by high temperatures. The thermal NO_x production is also time–temperature dependent.

2) *Prompt or Immediate Conversion (Prompt NO_x)*—The production of NO_x from N_2 within the early stages of the combustion process through a hydrocarbon radical mechanism.

3) *Fuel Bound Nitrogen Conversion (Fuel NO_x)*—The conversion of nitrogen compounds within the fuel to NO_x.

Thermal NO_x formation can be significantly reduced by burner technology. Fuel NO_x, however, is a function of fuel composition and much more difficult to moderate. The higher the concentration of chemically bound nitrogen in the fuel, the higher the NO_x emissions. Prompt NO_x typically accounts for only a small quantity of NO_x formation; however, it becomes a considerable portion of the total NO_x when burner design significantly reduces the total NO_x generated.

9.3 Approximate Method to Convert NO_x Measurement in ppmvd to lb/MBtu (HHV)

9.3.1 General

NO_x emission regulations are normally based on a mass per energy fired basis such as lbNO_x/MBtu (HHV). However, many NO_x meters read in volumetric units, such as part per million volume (ppmv). This raw ppmv NO_x value is typically corrected to a 3 % O_2 dry basis hence ppmvd.

This correction is done using Equation (1):

$$\text{NO}_x \text{ corrected to 3 \% } \text{O}_2 \text{ dry basis} = \text{NOx measured raw (ppmvd)} \times \frac{(21-3)}{(21 - \text{measured O}_2\text{ \% dry})} \tag{1}$$

With ppmvd corrected to 3 % O_2 dry basis, it can be converted to lbNO_x/MBtu (HHV) using the conversion factor in Figure 14 and Equation (2):

$$1\text{bNO}_x/\text{Btu}\times 10^6 \text{ (HHV)} = \frac{\text{NO}_x \text{ (corrected to 3 \% } \text{O}_2 \text{ dry basis)}}{\text{conversion factor}} \tag{2}$$

Conversions from and to some other typical units for NO_x emissions are provided below.

9.3.2 Volumetric

To convert mgNO_x/Nm^3 to ppmvd, multiply the mgNO_x/Nm^3 by 0.4874.

To convert gNO_x/Nm^3 to ppmvd, multiply the gNO_x/Nm^3 by 487.4.

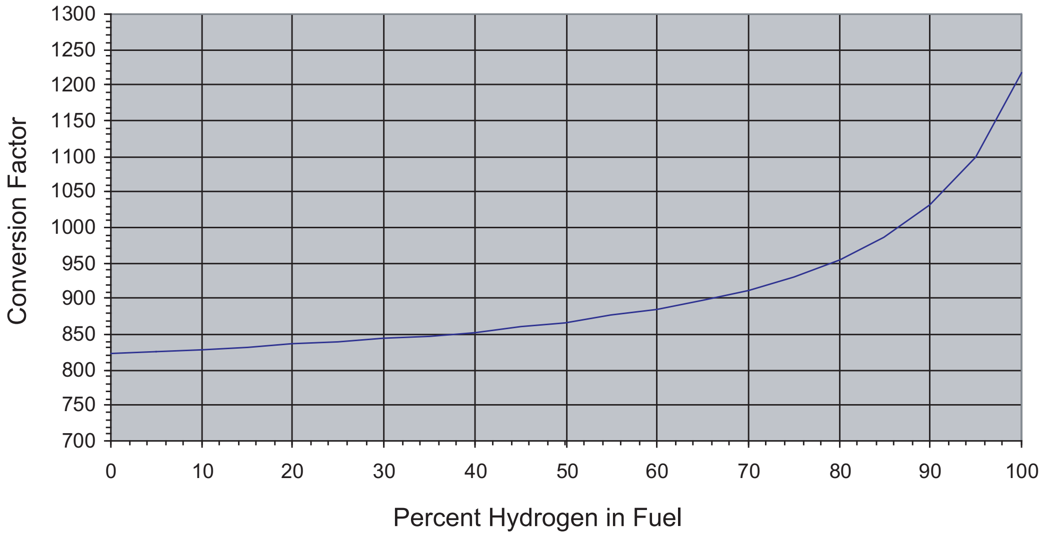


Figure 14—Approximate Conversion Factor from Btu × 10^6/hr to ppmv (3 % O_2, Dry Basis), Based on Typical Refinery Fuel Gas

9.3.3 Mass per Energy

To convert $lbNO_X$/MBtu (HHV) to gNO_X/GJ (HHV), multiply the $lbNO_X$/MBtu (HHV) by 429.9.

To convert $lbNO_X$/MBtu (HHV) to $mgNO_X$/J (HHV), multiply the $lbNO_X$/MBtu (HHV) by 429.9.

9.4 Low NO_X Burner Development

Initial designs for low NO_X burners utilized staged air to achieve NO_X reductions. While this technique is still used for oil firing and some gas designs, additional techniques have been developed that achieve lower NO_X when firing gas only. Most gas firing NO_X reduction techniques involve either staged fuel or flue gas recirculation (internal or external to the burner design) or a combination of both. Low NO_X gas firing designs can utilize a multiplicity of gas injection tips in different zones within a single burner, although some burner suppliers can differ in this respect. Attempting similar designs with multiple oil guns in one burner is impractical when considering the high maintenance attention and small ports of a single oil gun.

NO_X reduction technology for oil fired burners has produced 20 % to 40 % reductions from burners that were used 15 or 20 years ago. Tightening of environmental regulations has reduced the opportunity for application of oil fired burners while development of low NO_X gas firing technology has seen dramatic changes in recent times.

Table 13 and Table 14 below compares typical conventional and staged air low NO_X burner NO_X emissions for ambient air applications. It should be noted that the tables reflect test furnace values. These values are not influenced by burner spacing and interaction issues, or heater condition (e.g. leakage). The range in the table accounts for specific design variations. For example, a burner that utilizes internal flue gas recirculation that is specifically designed for natural gas operation, with the optimum fuel pressure, etc. could generate as low as 10 ppm to 12 ppm of NO_X. But if that same burner is required to have fuel flexibility and operate with high hydrogen or butane fuels, it is not optimized for natural gas operation and may generate 15 ppm to 17 ppm of NO_X. While designs may be grouped together, each burner supplier has their own way of reducing NO_X and one feature adopted by one supplier should not be forced onto a second supplier. In the final application, it is the NO_X emission that is required and not the individual design features.

Table 13—Typical NO_x Emissions for Gas Firing

Technology Utilized	NO_x Range ppmvd	
	Minimum NO_x	Maximum NO_x
Raw gas burner “conventional”	60	>100
Staged fuel/staged air	20	60
Above with internal flue gas recirculation	10	20
Additional features	<5	10

Table 14—Typical NO_x Emissions for Oil Firing

	Conventional Burners ppmvd	Staged Air, Low NO_x Burners ppmvd
Heavy oil (No. 6 fuel oil) with 0.3 wt. % fuel bound nitrogen	300	200 [a] to 250
Light fuel oil (No. 2 fuel oil) with 0.0 wt. % fuel bound nitrogen	120 to 150	95 to 110

[a] Forced draft operation.

Table 13 is based on a burner test rig under test conditions:

— fuel = natural gas with 97 % to 98 % methane and balance nitrogen;

— air = ambient, 15 °C (60 °F), 15 % excess air (3% O_2, volume dry);

— firebox temperature = 815 °C (1500 °F), measured 4.7 m to 6.3 m (15 ft to 20 ft) above burner.

Flame lengths from low NO_x burners are longer because staging mechanisms, both staged air and staged fuel, introduce a delay in fuel/air mixing as compared to conventional burners. This mixing delay produces a lower average flame temperature and reduced levels of NO_x. A longer flame will usually produce a larger flame diameter as well. Staged air, staged fuel, and internal flue gas recirculation burners all produce longer and larger diameter flames than nonstaged burners. Establishing flame length and diameter during testing tends to be subjective. Firebox temperature can play a major role in the assessment of the flame envelope. Extremely hot (bright) furnaces can mask the true “flame” envelope. It is a common practice to utilize a water-cooled probe to take CO samples within the test furnace. Taking these measurements at varying heights and insertion depths can objectively establish the flame envelope.

9.5 Staged Air Burners

9.5.1 General

As mentioned above, air staging is the principal technology used for oil fired applications. They limit the production of thermal NO_x by limiting the temperature in the combustion reaction zone. They reduce the production of fuel NO_x by providing a fuel rich zone in which the fuel bound nitrogen can be converted to molecular nitrogen. The staged air burner is illustrated in Figure 15.

A staged air burner can be designed with primary, secondary, and tertiary air registers or entry ports, although some suppliers will only provide two air entry points. Typical air split range is as follows: primary 15 % to 25 %, secondary 25 % to 35 %, and tertiary 40 % to 55 %.

9.5.2 Primary Combustion Zone (Stage 1)

All fuel is injected in to the primary combustion zone with only a portion of the total air. Much of the fuel does not burn completely since there is insufficient air available. This incomplete combustion results in a lower flame temperature

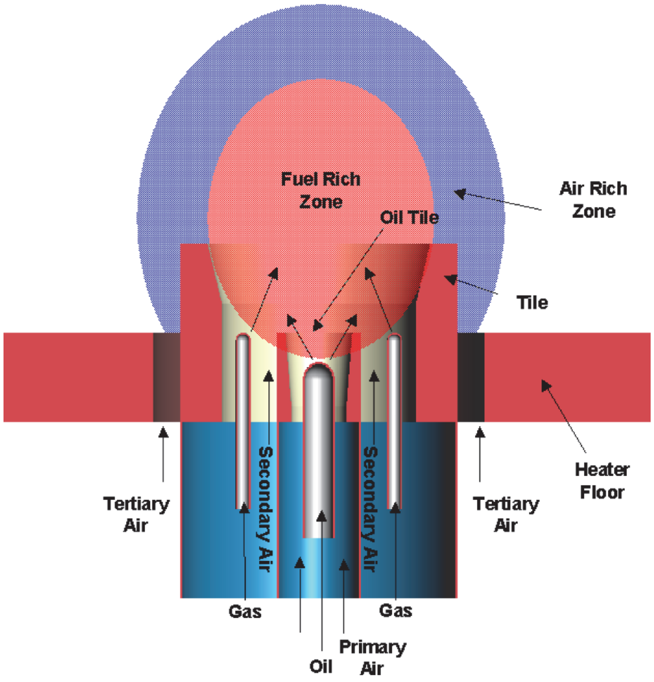


Figure 15—Staged Air Burner (Typical)

than in a burner with no air staging. The flame envelope loses heat as heat radiates to the surroundings. The lower flame temperatures and limited oxygen concentrations contribute to lower thermal NO_x production.

Fuel NO_x is limited because the fuel molecules dissociate under fuel rich (reducing) conditions.

9.5.3 Secondary Combustion Zone (Stage 2)

Combustion is partially completed in the secondary combustion zone (located in most cases outside the burner block).

9.5.4 Tertiary Combustion Zone (Stage 3)

Some suppliers may also stage the air further by dividing the air again into a tertiary combustion air zone. Tertiary air is typically added external to the secondary burner tile. Combustion is completed as the remaining air is injected into the combustion gas stream via the tertiary air zone. Flame temperatures will not approach those in a nonstaged burner. Radiant heat has already been lost to the surroundings during the initial combustion stage.

9.6 Staged Fuel Burners

9.6.1 General

A typical staged fuel burner is illustrated in Figure 16. There are two separate firing zones or stages in the staged fuel burner. A smaller fraction of the fuel is released in the primary combustion zone while a majority of the fuel is released in the secondary stage. A center or multiple risers release the primary fuel within the burner block.

9.6.2 Primary Combustion Zone (Stage 1)

All the combustion air enters the primary combustion zone. Combustion of the primary fuel is completed with an overabundant quantity of air. Typically, 30 % (with a range of 20 % to 40 %) of the total fuel is mixed with 100 % of the total air. By increasing the percentage of primary fuel (i.e. 40 %) flame length will be shortened and NO_x emissions will increase. The additional air quenches the flame producing flame temperatures lower than in no staged or staged air burners leading to lower NO_x.

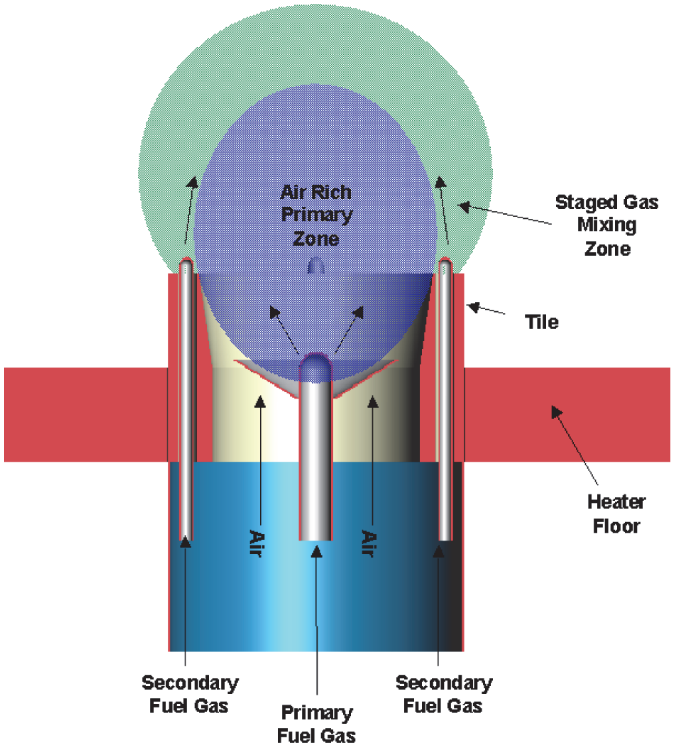


Figure 16—Staged Fuel Burner (Typical)

9.6.3 Secondary Combustion Zone (Stage 2)

Secondary or staged fuel risers inject the remaining fuel into the combustion gas/air stream downstream of the burner block. By increasing the percentage of staged fuel (80 %) flame length will increase, NO_X emissions will be reduced. The excess oxygen from the primary zone provides the oxygen necessary to complete the combustion of the remaining fuel. The peak flame temperatures will not reach the temperatures of nonstaged burners.

Typical flame lengths for staged fuel burners can be up to 50 % longer than conventional burners, making retrofit applications difficult.

9.6.4 Operational Considerations with Staged Fuel Burners

Stable staged fuel burner operation is dependent on a stable primary firing zone. It is the primary firing zone that insures combustion in the staged firing zone, where most of the fuel is released. The more the fuel is staged, the cooler the flame becomes, which can reduce the overall stability of the burner.

9.7 Flue Gas Recirculation

9.7.1 General

Flue gas may be recirculated into the combustion gases where the inert flue gas cools the flame, reduces the partial pressure of oxygen and lowers NO_X emissions. Flue gas recirculation can reduce these emissions further when used with staged combustion burners (either air or fuel).

9.7.2 External Flue Gas Recirculation

In external flue gas recirculation applications, flue gases may be withdrawn from a cold section of the fired heater (usually downstream of the convection section) and ducted to the burners. This may require a motive force to pull flue gases out through an exit duct and back into the burner. External flue gas recirculation designs are rare in general purpose refinery process heaters. The specifics of external flue gas recirculation designs are therefore not discussed in depth in this document.

9.7.3 Internal Flue Gas Recirculation

Burners that employ internal flue gas recirculation use the burner design to manipulate the flow of flue gases from the firebox into the combustion process. Primarily, this is accomplished by utilizing the fuel gas pressure as an educator and the motive force to draw flue gases into the burner. The flue gases then mix with the fuel to lower the flame temperature and as a result NO_x formation. As firing rate increases, so does the quantity of flue gas drawn into the combustion process. A depiction of internal flue gas recirculation is illustrated in Figure 17. Flue gas recirculation rate is fixed by the burner design and is not adjustable by the operator making this system simpler to operate than external flue gas recirculation.

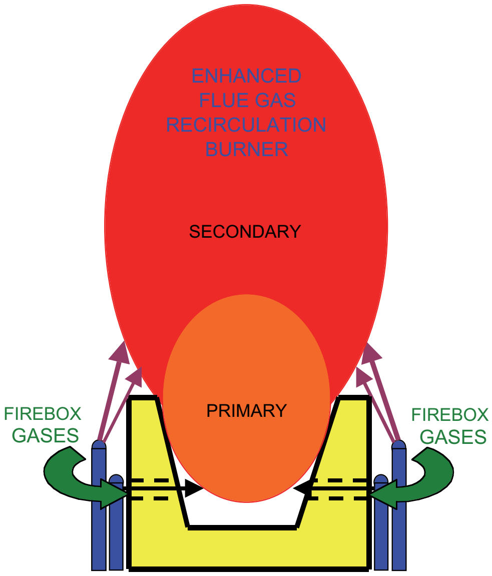


Figure 17—Example of One Type of Internal Flue Gas Recirculation Burner

9.8 Alternate Methods for Reducing Combustion Generated NO_x

9.8.1 Fuel Dilution

In certain applications fuel is diluted using cooler recirculated flue gas. The diluted fuel produces lower adiabatic flame temperatures, which results in lower NO_x.

9.8.2 Steam Injection

Steam injection dilutes the combustion air and reduces peak flame temperatures similar to the use of flue gas recirculation. Steam can be injected upstream of or directly into the flame zone depending on the specific application. Unlike flue gas recirculation there is an operating cost, since the steam is discharged out of the stack and all of the steam energy is lost. Operating costs are higher due to the use of this steam. The installed cost can be lower than external flue gas recirculation systems since no fans or large ducting is used. In certain applications, steam is injected into the fuel gas rather than into the combustion air.

9.8.3 Water Injection

Water injection works the same as steam injection or flue gas recirculation by diluting combustion air and reducing peak flame temperatures. Water has a lower thermal efficiency penalty compared to steam injection with similar installed costs. The primary difference between water and steam injection is that water injection requires evaporation of droplets to absorb heat. Therefore, to reduce peak flame temperatures and NO_X emissions efficiently with the use of water injection requires injection of very small droplets (atomization) or droplet evaporation prior to its introduction into the flame zone.

9.9 Other Design Considerations

9.9.1 General

This section addresses other design considerations as they apply to design of low NO_X burner systems in new heaters.

9.9.2 Limitations of Low NO_X Burner Technology

Many NO_X reduction strategies make flame volumes larger and/or core flame temperatures lower than those of conventional burners. Firebox dimensions should be checked to ensure that they are adequate for the expected flame volume. API 560 can provide guidance in this respect. In addition, consideration should be given to avoiding applications where the core flame temperature is cooled below the autoignition temperature of all possible fuel blends during expected turndown operation. Here the heater designer should work closely with the burner supplier.

9.9.3 Interaction

9.9.3.1 General

NO_X emissions produced by burners in a single burner test furnace may be different than the actual operating conditions. The user should be aware that the final NO_X emissions can only truly be assessed in the final application.

Burner to burner flame interaction could result in higher NO_X, lower quality flame, flame impingement (enlarged flame dimensions), and instability. Burner suppliers typically have minimum distance clearances between adjacent burner tiles. As mentioned previously in this practice, burner design is an iterative process between the end user, heater manufacturer, and burner supplier. Without interaction between all parties, design will not be optimized for the application and more problems will be encountered with the possibility of expensive field changes being made. While many fired heaters can be designed for today's lower NO_X burners, retrofit applications can be the most troublesome. Here it is imperative to involve the burner supplier at the beginning of the process to ensure a good burner fit, particularly if the NO_X numbers are at the lower end of today's technology. Computer modeling has been successfully employed to reduce these issues; see 9.9.7.

9.9.3.2 Burner-to-burner Interaction

Burner technology that uses internal flue gas recirculation for achieving lower NO_X emissions may become less effective when burners are too close together and sufficient area is not provided for the recirculation of flue gas.

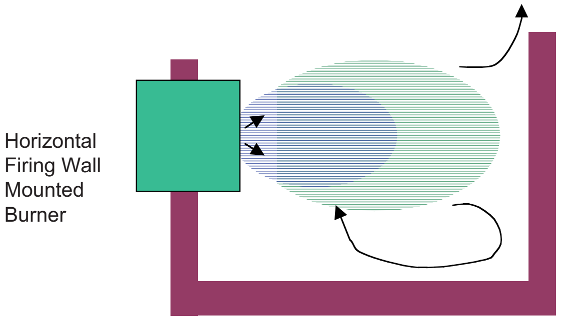
In vertical cylindrical heaters, if the burners are too close together on a single burner circle, burner tips in the inner portion of the burner circle may not get sufficient amounts of recirculated flue gas. Alternative designs, such as installing burners on two different burner circles, reducing the number of burners, or clustering groups of burners, may be explored.

In vertical cylindrical heaters, if burners are too close to each other, the flames may produce a low-pressure zone in the center of the heater causing the flames to merge together and form a spike.

Merged flames are significantly longer than single burner flames and could impinge on the tubes.

9.9.3.3 Burner-to-furnace Interaction

Burner flame direction may change with the presence of a target wall causing higher NO_X as shown in Figure 18. In cabin type heaters horizontal flames shooting towards the target wall may turn back towards the floor raising the temperature of the recirculated flue gas close to the floor and resulting in higher than expected NO_X.



Effect of Target Wall on Flame

Figure 18—Burner-to-furnace Interaction

9.9.4 Burner Operating Envelope Safety Considerations

Burners may become unstable at specific operating conditions (i.e. high turndown). Unstable burner systems may lead to unsafe conditions and cause a flameout. Additional instrumentation can be installed on the fired heater to reduce the associated risk.

Some of the reasons for unstable operation that apply to low NO_X burners specifically are as follows.

— Cool, internally recirculated flue gas may lead to unstable operation, especially at low excess air levels. Floor/vertically-fired heaters having low NO_X burners may become unstable when the floor temperature approaches 540 °C (1000 °F) at any operating condition and excess O_2 level below 6 % to 8 %.

— Multiple fuels and fuels with low flame velocities may create additional reasons for unstable operation. Each anticipated fuel composition should be provided to the burner supplier prior to the burner design. A very wide fuel range may require greater burner sophistication, higher NO_X levels, and greater burner cost. Failure to include certain operating fuels may result in burner instability when these fuels are fired.

— Extreme draft conditions such as high or low draft or a sudden increase or decrease in draft may lead to burner instability.

— High altitude applications pose unique problems due to the reduced partial pressure of oxygen.

Before finalizing the burner design, a review of operating conditions of the heater should be conducted. The operable range of the burner should be confirmed during the burner test. Set points for safety alarms and shutdown logic should be derived based on the burner test results.

9.9.5 Operating Considerations

Low NO_X burners rely on having sufficiently high fuel pressure to transport the flue gas into the flame. If the burners operate at a turned down condition most of the operating time, then the burners need to be designed to have adequate fuel pressure at the turned down condition. If the user operates the fired heater at turndown by shutting down a number of the burners, more care than usual is needed to ensure that operators close the air registers on the burners that are shut down. (It is always recommended that all burners when shut down have their air registers closed if on closed loop O_2 control of air to the fired heater.) If shutting off some of the burners is required to meet certain operating scenarios, then the air registers should be designed to achieve the specified closure (typically closure of 98 % on area.).

If natural gas is used as a fuel for start-up or for future conditions only, then it should be clearly specified to the burner supplier during the burner design. Design of the burner for natural gas as an optional fuel can result in a burner design that yields higher NO_X than if natural gas was not considered. The fuel composition most commonly used in the operating cycle of the heater should be used to guarantee NO_X performance unless local pollution requirements demand otherwise. Extreme fuel compositions should be treated as special cases where NO_X emissions may be greater.

Special start-up and considerations for safe operating procedures may be required for low NO_X burners.

Ultralow NO_X burners can operate with a flame that may, at best, be barely visible, except at night. Operators shall be trained to recognize proper flame characteristics and visible symptoms of poor operation. Bright burner tile or flame holder color is often an indication that the gas tips are operating properly in low NO_X burners.

Operating procedures shall consider that lower NO_X burners may have less turndown capability than older style burners.

9.9.6 Basic Application Requirements

Basic application requirements are as follows.

- *Fuel Cleaning*—Low NO_X burners typically have much smaller openings at the burner tips than in older style burners. A fuel filter or coalescer is recommended to remove particulates, scale, and condensed liquids in the fuels.

- *Combustion Air Control*—Controlling and minimizing the excess air level may be required to achieve the guaranteed NO_X. Automated combustion air control may be useful to reduce oxygen (also aids fired heater efficiency) and NO_X.

9.9.7 Computer Modeling

Where operating data with similar heater/burner/fuel designs is not available, CFD modeling may be used to predict flame shape in multiburner heater applications.

A typical CFD model of the heater firebox is created using the following information:

- physical dimensions of the heater;
- design operating mode of the heater;
- burner design and details such as burner tip size and orientation;
- design fuel composition and heat releases in the operating range;
- location of tubes, tube geometry.

A CFD model is typically used for the following purposes:

- interactions: burner to burner, burner to furnace, burner to tubes;
- indicate that there is no flame impingement on the tubes;
- predict flue gas temperature and velocity profiles in the radiant section;
- ensure that there will not be tube metal temperature increase beyond the limits in the furnace sections;
- heat flux distribution in the furnace;
- air flow distribution in air supply systems.

Success of the CFD model depends on specifying accurate boundary conditions, and the experience of the modeler. It is also important to make a special effort to validate the model from actual experience. In many cases a model of furnace is developed using geometrical symmetry considerations, and actual field data is compared with the CFD model.

9.9.8 Cold Flow Modeling

Cold flow modeling has been used to design heater air plenums and common air ductwork. Cold flow modeling is often used to simulate fluid flow and obtain useful design guidance. For low NO_x multiburner applications, it is important to ensure that combustion air is distributed equally among all the burners.

This modeling technique involves creating a hydraulically similar model of the actual system and visualizing flow of fluid using smoke, colored fluid or neutral density plastic pellets. Results obtained from the model are applied to actual conditions based on experience. Quantitative data is provided by measurements made using a hot wire anemometer, mini pitot tubes for point measurements or venturis tubes for total air flow to burners.

9.10 Fuel Treatment

While many older style burners have orifices $^1/_8$ in. (3 mm) and larger, typical low NO_x burners may have tip drillings as small as 1.5 mm ($^1/_{16}$ in.). These small orifices are prone to plugging and require special protection. Most fuel systems are designed with carbon steel piping. Pipe scale forms from corrosion products and plugs the burner tips. While tip plugging is unacceptable for any burner, it is even more important not to have plugged tips on lower NO_x burners. Plugged tips can result in stability problems and higher emissions. Many users have installed austenitic stainless steel piping downstream of the fuel coalescer/filter to prevent scale plugging problems.

Coalescers and or fuel filters are recommended on all low NO_x burner installations to prevent tip plugging problems. The coalescers are often designed to remove liquid aerosol particles down to 0.3 microns to 0.6 microns. Some users install pipe strainers upstream of the coalescer to prevent particulate fouling of the coalescing elements. Piping insulation and tracing should be used on fuel piping downstream of the coalescer/fuel filter to prevent condensation (fuel gas from reaching dew point). Some users have used a fuel gas heater to superheat the fuel gas in place of pipe tracing.

9.11 Retrofit Considerations

9.11.1 Flame Envelope

In cases where flame length and width are critical parameters due to firebox dimensions and burner layout, CO probing can be considered in addition to visible flame estimates in order to determine the flame envelope. Low NO_x burners typically have longer flames than conventional burners. Longer flames change the heat transfer profile in the firebox. Longer flames can result in flame impingement on the tubes and mechanical supports. Low NO_x burners can be optimized to produce shorter flames at the expense of higher NO_x emissions.

The flame diameter is often defined in terms of ratio of the burner tile outside dimension. Many burners have flame diameters that are 1 to 1 $^1/_2$ times the diameter of the burner tile. Since the tile diameters are often larger for low NO_x burners, the flame diameters at the base of the flame may be slightly larger.

9.11.2 Physical Dimensions of Firebox

Optimized designs have burner spacing that has gaps between the flame envelopes. Since the tile diameters are often larger for low NO_x burners, retrofits can result in closer burner to burner spacing resulting in some flame interaction. Flame interaction can produce longer flames and potentially higher NO_x values. All low NO_x burners should be spaced far enough apart to allow even flue gas recirculation currents to the burners.

The burner centerline to tube centerline dimension is one of the most important dimensions in the firebox. Many tube failures are caused by flame and hot gas impingement. When low NO_x burners are being retrofitted, the larger size of the flame envelope shall be evaluated. Firebox currents can push the flames into the tubes. See API 560 for the required minimum burner to tube clearances.

As with tubes and supports, the larger low NO_x burner diameter may result in the burners being spaced closer to the refractory. Unshielded refractory may require hot face protection.

Many heaters were originally designed for flame lengths that are $^1/_3$ to $^1/_2$ the firebox height. Natural draft low NO_x burners typically have flame heights of 1.5 ft/Btu × 10^6/hr to 2.5 ft/Btu × 10^6/hr (2 m/MW to 2.5 m/MW). Longer flames from low NO_x burners may change the heat transfer profile in the firebox. The longer flames may result in flame or hot gas impingement on the roof and shock tubes. These tubes may require protection to prevent failures. Protection may include metallurgical upgrades, increased tube thickness, or tube shielding. Some older heaters have very short fireboxes and may not be suitable for retrofits with low NO_x burners.

When retrofitting burners, many users will test a prototype burner in a fired heater with similar orientation, combustion conditions, and fuels as the heater to be retrofitted.

Some older heaters where a solid or even checker refractory “Reed Wall” (firebrick walls 12 in. to 18 in. tall between tubes and burners) exists may need to be removed due to its effect on recirculation of flue gas and NO_x.

9.11.3 Fuel Treatment

Fuel treatment is an important consideration in low NO_x burner retrofits. Section 9.10 provides some additional information.

9.11.4 Air Control

Low NO_x burners shall be operated at or near the design excess air level to control NO_x emissions. See Figure 7. Operation below recommended excess air limits could result in higher unburned combustibles, flame instability, and uncontrolled flame patterns. Operation at higher than design excess air will increase NO_x emissions as well as reducing the efficiency of the fired heater.

Most refinery general service heaters operate on natural draft. It is important to control the draft to the design value, typically 2.5 mm H_2O (0.1 in. H_2O) at the top of the radiant section. High draft results in more tramp air ingress and often results in different excess air levels between the O_2 measurement point and at the burners. This condition results in higher NO_x levels in the heater. Automated draft control may be installed on retrofits for better control of excess air and draft.

Designing this way allows the burner supplier to control the air flow into the burner and not rely on the design of air distribution systems. Because excess air control is so important on these burners, some users have installed individual actuators on each burner damper for better control for vertical cylindrical heater. When the burner count exceeds four burners, this method can be costly and an air distribution system with automated air control may be more appropriate. For heaters (e.g. horizontal tube cabin heaters), the burner dampers have been attached to a jack shaft for air control. A common plenum should be analyzed using CFD or cold flow modeling to ensure uniform air distribution to and around each burner, particularly for forced draft applications. Internal baffles may be required to obtain even air distribution.

New heaters are designed with seal welded construction to prevent tramp air ingress. Many older heaters have bolted panel design. High-temperature silicon and foil tape have been used on these heaters to reduce tramp air. Observation openings should be designed to minimize excess air ingress. Observation openings should be closed when not in use. Use of high-temperature glass should be considered on observation ports to minimize air leakage. Other possible openings, such as tube penetrations through the floor or guide penetrations, should also be fitted with tight seals to prevent air ingress.

When burners are not attached to common distribution systems, they are supplied with mufflers to control noise emissions. The mufflers are often an effective device to eliminate excess air fluctuations due to wind. Windscreens are often installed to eliminate wind effects when burner mufflers are not used. A 15 mph (25 km) wind can cause a

±2.8 mm H_2O (0.11 in. H_2O) draft variation at the burner, resulting in a ±15 % change in excess air level for a burner designed at 10 mm H_2O (0.4 in. H_2O) draft.

Forced draft systems may be considered for low NO_X burner retrofits. The forced draft system provides better excess air control, eliminates wind effects, and the increased burner pressure drop often results in a smaller flame envelope.

9.11.5 Structural Considerations

Most low NO_X burners designed and supplied today are larger and heavier than the burners being replaced. Casing cutouts may need to be altered. In some cases it is more economical to replace large panels encompassing multiple burners. The structural capacity and stiffness should also be evaluated. The user/installer needs to ensure that the heater floor steel is level to ensure proper installation and alignment of new burners. Bowed sections should be repaired or replaced to level them.

The floor refractory thickness should be checked against the general arrangement drawings to supply accurate information to burner vendor. The floor refractory thickness should be checked to ensure the heater floor steel is designed for the expected temperature.

Physical constraints below the firebox floor should be checked. There should be sufficient space underneath the burner bottom plate for burner and tip removal. Installing flanges in the horizontal piping supplied to burners helps facilitate burner removal.

9.11.6 Process Related Parameters

Low NO_X burners often have longer flames that result in a change to the heat flux profile. This can be beneficial when attempting to even a heat flux profile from some older style burners and is especially important on cracking heaters such as cokers and visbreakers. The longer flames may increase the bridgewall temperature and change the duty split between the radiant section and convection section. Retrofitting low NO_X burners in short fireboxes can result in high roof and shock tube metal temperatures. It is important to review existing plant data in conjunction with the original design data. Heater tube fouling may result in higher bridgewall temperatures. Fouled convection sections may result in higher firing rates. Proposed burner changes should be evaluated with this in mind.

Low NO_X burners may have less turndown capability than conventional burners. High CO levels can occur when firebox temperatures are below 705 °C (1300 °F). Flame instability and flameout can occur when firebox temperatures are below 648 °C (1200 °F) and at low oxygen levels or floor temperature is less than 540 °C (1000 °F).

The proper design basis for the burner retrofit is extremely important. Supplying original datasheets may not be appropriate as the process requirements may have changed significantly since the furnace was designed. Important design basis be agreed and should include as a minimum the following:

- emission requirements,
- process duty requirements,
- heater general arrangement drawings,
- turndown requirements,
- fuel composition and ranges,
- fuel pressure,
- start-up considerations,

— API Fired Heater Datasheet,

— existing burner datasheet with markups.

9.11.7 Instrumentation

When retrofitting with low NO_X burners, instrumentation and controls may have increased importance in providing safe, reliable, and successful NO_X reduction results. API 556 provides a more complete discussion on this topic.

As already mentioned, control of oxygen to design values results in the best NO_X performance. Accuracy of firebox O_2 measurement is important. Draft measurement and control is also emphasized to reduce tramp air ingress. Damper actuation is often automated to improve sustainability of low excess air operation. Some older style dampers may also have been deliberately designed with significant open area. These dampers may need to be replaced to achieve desired draft levels, particularly if the heater is to be operated at turndown. CO or combustibles measurement is often provided as a warning of reducing combustion air too much.

9.11.8 Installation Checks

Correct burner installation is very important. It is recommended that the installation be performed by experienced people or be supervised by knowledgeable personnel.

Tip size, orientation, and height should be checked against the vendor's drawings. The burner tile shall be installed in accordance with the vendor's specifications and tolerances. The diameter should be checked in different locations to ensure concentricity of burner tips, tiles and any other internals. Improper installation results in improper burner operation.

As with all burners, the air control damper or air registers should be checked. Register or damper opening should match the position indicator. This should be checked before and after the air ducting is installed.

10 Burner Operation

10.1 General

The safety of fired heaters is determined by the operators and the automated functions installed. API 556 provides guidance on the instrumentation applied to fired heaters. API 556 also provides the minimum consideration for burner light-off for both natural and forced draft heaters.

10.2 Excess Air Controls

10.2.1 Optimum Excess Air Levels

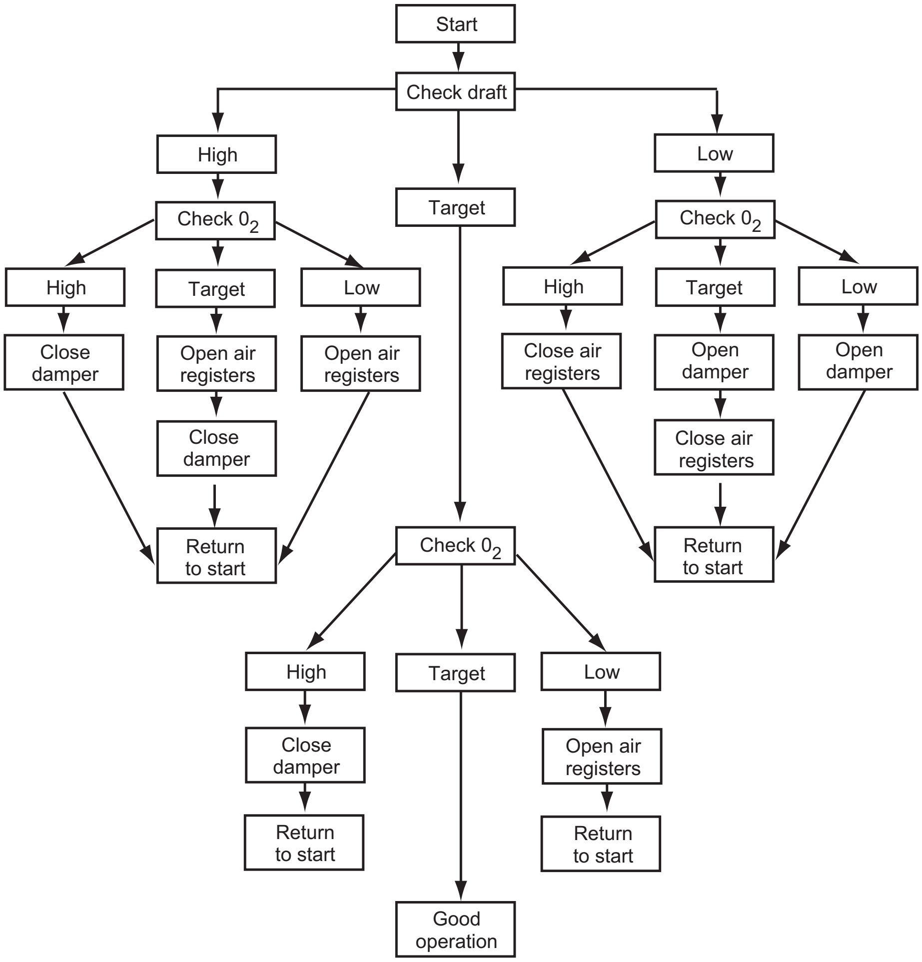
The highest energy efficiency is achieved when the combustion takes place using the exact stoichiometric requirement of air. However, a certain level of excess oxygen is required to prevent the emission of unburned hydrocarbons and to account for fluctuations in operating conditions such as fuel composition, ambient conditions and firing rate.

There is an optimum level of excess oxygen in the flue gas for each type of heater, burner, and fuel used. Typical excess air and oxygen levels are shown in Table 15. The sophistication of the burners or the presence of only one burner may allow reduced levels. The user may find their own optimum excess air level by conducting CO breakthrough tests. Figure 19 may be used to adjust excess air to a minimum. By alternatively setting draft at the bridgewall and measuring both O_2 and CO optimum excess air can be set.

A completely sealed heater containing a few burners and automatic oxygen and draft controls may allow a reduction in these O_2 levels. An existing heater with significant casing leakage may not achieve the oxygen levels in Table 15 without significant CO emissions.

Table 15—Optimum Excess Air Levels

Burner Type	Combustion Air Supplied with Forced Draft Fan	Fuel	Excess Air %	O_2 Content, % (dry basis)
Natural draft	No	Gas	15	3
Natural draft	No	Oil	20	4
Natural draft	Yes	Gas	10	2
Natural draft	Yes	Oil	15	3
Forced draft	Yes	Gas	10	2
Forced draft	Yes	Oil	15	3



High draft = Draft at radiant section exit is higher (greater negative pressure) than the target level.
Low draft = Draft at radiant section exit is lower (smaller negative pressure) than the target level.
Low or high O_2 = Flue gas oxygen content at the radiant section exit is lower or higher than the target.

The action to be taken under low oxygen, as indicated in the figure above, assumes the combustibles or carbon monoxide remains within acceptable levels.

Figure 19—Natural Draft Heater Adjustment Flow Chart

As well as determining the CO break point, operational settings should consider:

a) the cyclical firing nature of the process at both heater design rates and turndown,

b) the speed of response of the O_2 analyser and control system to affect change, and

c) the speed at which compositional changes of the fuel gas may be encountered.

10.2.2 Disadvantages of High Excess Air

Higher excess air than design will increase NO_x emissions for most types of burners.

High excess air will reduce heater efficiency for the following reasons.

- More fuel is required to the heat the additional air entering the burners.
- Additional air lowers the flame temperature resulting in a lower radiant thermal efficiency.
- Increased flue gas flow rate lowers draft. This may result in a positive pressure in the heater forcing a reduction in capacity.

10.2.3 Advantages of Increased Excess Air

Increased excess air allows for bigger fluctuations in process operations and ambient conditions such as wind velocity and direction.

Increased excess air can lower CO formation, although too much air may chill the flame increasing CO emissions.

Increased excess air can improve the flame quality and length in for fuel gases containing heavy hydrocarbons as well as oil fired burners. Again too much excess air on oil fired heaters may lead to “stripping” where there is insufficient heat recirculated back to the flame to complete burn all the fuel. Oil droplets may be emitted from the fired heater.

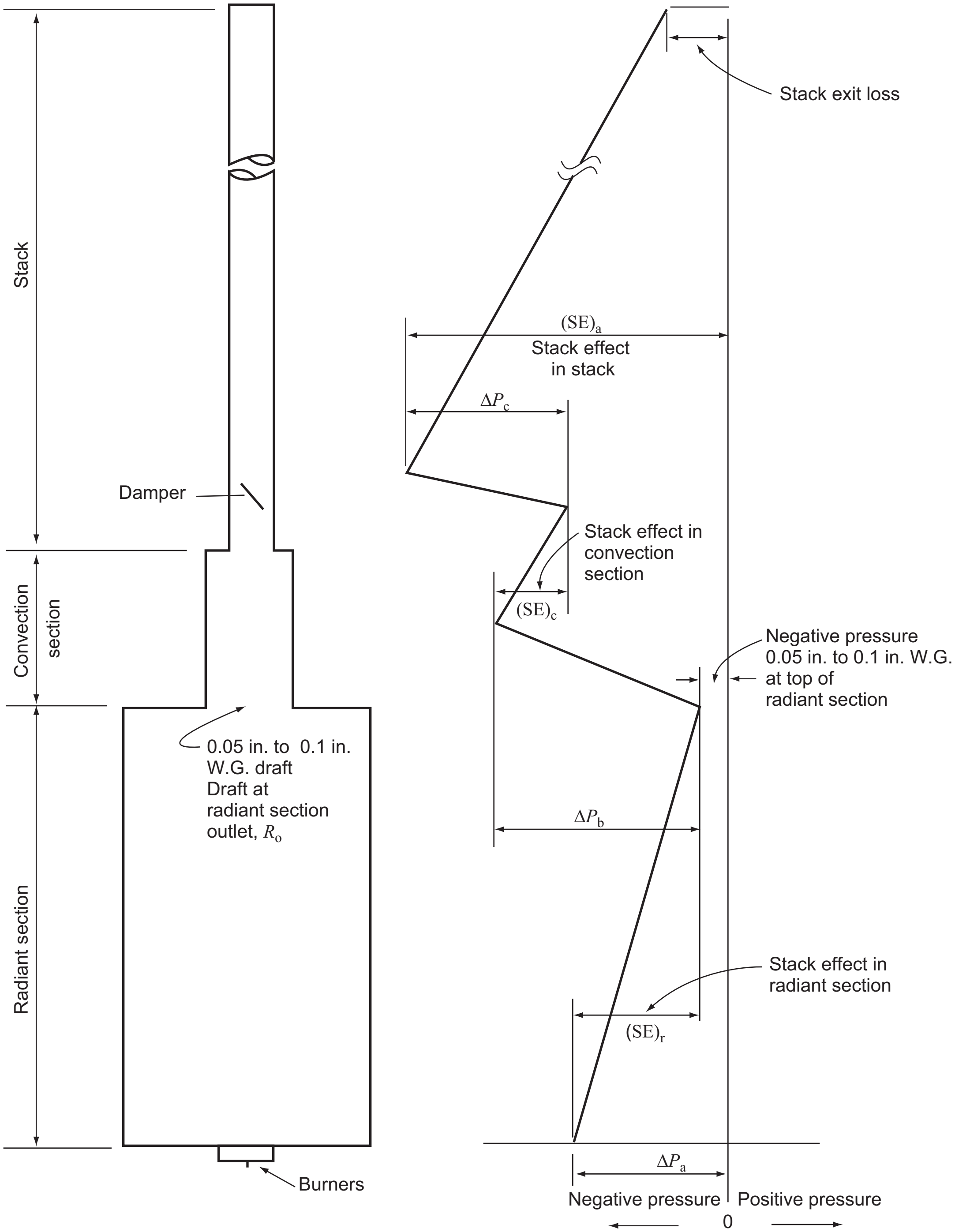
Increased excess air will increase the convection section duty at the expense of the radiant duty. Radiant section tube metal temperatures may fall while the convection section tube metal temperatures will increase. Increasing the convection duty may be of value if a greater duty is desired from a waste heat coil (steam, reboiler, hot oil, etc.).

10.2.4 Excess Air Adjustment

Excess air and draft are interrelated. Adjusting the excess air changes the flow of flue gases through the heater, affecting the draft. Adjusting the draft affects the flow of air through the burners. It is necessary to readjust the air control registers this changes the flow of flue gases through the heater, consequently affecting the draft. Correcting the draft by means of the stack damper or induced draft fan suction damper (or variable speed drive) affects the flow of air through the burners as the pressure at the burner changes. It will be necessary to readjust the air control registers/dampers and stack damper or induced fan setting when the draft and excess air are properly set.

As mentioned earlier in this practice, a negative pressure shall be maintained throughout a heater. A positive pressure inside the heater will cause flue gas leakage and damage to the furnace casing and structure. It can also be a safety hazard to operating personnel. Figure 20 shows a typical draft profile within a fired heater. A draft reading of 1.5 mm H_2O to 2.5 mm H_2O (0.05 in. H_2O to 0.10 in. H_2O) at the radiant section arch is desired.

The user should always ensure there is sufficient excess air available to combust all the fuel. Combustion air should be increased prior to an increase in heater duty or fuel flow. Efficient operation is achieved when an optimum excess air level for combustion without producing a positive pressure at the heater arch. Using the stack damper without draft constraint applications on draft and O_2 is not advisable. A combination of the two adjustments is necessary to obtain the optimum draft and excess air.



$(SE)_r + R_o = P_a$

$(SE)_a + (SE)_c = P_b + P_c + \text{Stack exit loss} + R_o$

P_a = Pressure drop across burners (draft available at burner level).

P_b = Flue gas pressure drop across convection section.

P_c = Losses due to damper, stack friction, stack entrance.

Figure 20—Typical Draft Profile in a Natural Draft Heater

Figure 19 is a draft adjustment chart. For a given heater, with constant duty and fuel composition, closing the stack damper will, in general, have the following effects.

1) Reduced oxygen to the burners and in the flue gases.

2) Decreased draft at the radiant arch.

3) Increased flue gas temperature leaving radiant section.

4) Decreased stack temperature.

5) Increased radiant heat flux density (an all-radiant process coil will have an unchanged radiant heat flux density).

6) Decreased convection heat flux density.

7) Increased heater efficiency.

Closing burner registers has the same effect on performance as closing the stack damper except the draft at the radiant arch will increase due to the reduction in pressure drop through the system with the flue gas flow.

11 Maintenance

11.1 Shipping

All burner and pilot tips should be wrapped to keep them clean during shipment. Any exposed flanges or threaded connections should be adequately protected. Burner tiles are generally shipped separately and should be adequately protected to avoid damage.

11.2 Burner Parts Inspection

Mistake in manufacturing, supply of wrong parts, or damage in transit can lead to burners not performing correctly. Following receipt and initial installation, the following inspections should take place.

1) Burner parts should be inspected to confirm they conform to the vendor drawings and datasheets.

2) The orifice sizes of the burner tips should be checked to ensure the proper gas tip is being used. The back side of a drill bit may be used for this purpose.

3) Burner tip orientation should be in accordance with the burner drawing. Burner gas tips are often supplied with notch cuts or arrow indicators to aid in proper tip alignment.

4) Gas risers should be inspected to confirm that they match to the burner drawing.

5) All orifices should be free of deposits.

6) Air openings should be inspected to confirm that they conform to the burner drawing.

7) Any noise dampening materials should be verified intact and not broken or damaged during shipment.

8) All bolted, threaded, or compression fitting connections should be checked for tightness.

11.3 Installation and Initial Setup

Burners should be installed in accordance with burner supplier’s procedures. The burner should be installed properly to obtain good flame quality at low excess air levels. Improper setup results in poor fuel–air mixing and flame stability problems. The burner tile acts as an air orifice controlling the flow of air to each burner. Poor installation can result in lopsided flames due to zones of high and low velocities. The following tolerances are permissible in the absence of manufacturer's tolerances.

1) Burner tile diameter: ±6 mm (±$^1/_4$ in.).
2) Burner tile concentricity (out of roundness): ±6 mm (±$^1/_4$ in.).
3) Tip port angles: ±4°.
4) Bolting dimensions: ±3 mm (±$^1/_8$ in.).
5) Gas tip locations—horizontal, ±6 mm (±$^1/_4$ in.); vertical, 9.5 mm (±$^3/_8$ in.).

11.4 Post-installation Checkout

After installation there are a number of additional inspection tasks, including:

1) air registers and dampers should be checked for freedom of movement;
2) primary air control devices, if separate from above, should be tested for full movement;
3) check the burner installation for plumb and check tile for level;
4) insure the expansion joint material around the burner has been installed properly.

11.5 Maintenance Program

11.5.1 General

A burner maintenance program should be developed for reliable burner operation. The following items should be included in routine surveillance rounds and maintenance programs.

11.5.2 Visual Inspection

Operating burners should be checked visually at least once per shift. Any unusual situation, such as flame impingement on tubes and supports, improper flame dimensions, oil dripping, uneven heat distribution, smoky combustion, etc. should be noted and corrected as soon as possible.

11.5.3 Check Burners with Original Design

The following items should be checked with the original design to ensure compatibility with the present operating conditions:

1) fuel pressure.
2) fuel characteristics (heating value, composition, viscosity, sulfur content, etc.);
3) gas tip and oil guns (orifice size, drilling angle, and tip and gun position);
4) turndown.

Cleaning or replacement of burner tip or gun, or complete burner should be considered if the original burner cannot be operated satisfactorily.

11.5.4 Burner Cleaning

Each user should establish their own cleaning schedule based upon their experience.

Gas tips and risers are typically cleaned when the gas pressure drop across the burner has increased approximately 30 % above the design pressure for a given fuel and heat release. They are cleaned when irregular flame patterns develop from a burner tip.

Oil guns normally require more frequent cleaning than gas tips. Oil guns should be cleaned at least once a week when burning No. 6 oil and more frequently when firing heavier oils. When firing a heavy vacuum residue it is recommended to inspect the oil gun daily. Always have a spare oil gun ready for replacement as this will aid fuel balancing when removing oil guns. Spare guns can be cleaned at leisure.

11.5.5 Burner Tile

The burner tile should be inspected. Cracks and spalled sections should be repaired to a smooth surface commensurate with the original design. Repairs should be accomplished with a plastic refractory comparable to the existing material and with at least the same temperature rating. Burner tiles requiring extensive repair should be replaced.

11.5.6 Air Regulating Devices

Air dampers and registers should be operable at all times.

11.5.7 Remove Unused Burners

As many burners as practicable should be in operation to achieve good heat distribution. Unnecessary burners should be removed and the burner openings sealed to prevent air leakage. Remaining burners should be arranged to provide good heat distribution.

Oil guns not in operation should be removed. Burner oil tiles may be left in place.

Unnecessary burners should be removed and the register doors closed to prevent air leakage. The remaining firing pattern should provide good heat distribution.

11.5.8 Burner Replacement or Modification

Burners should be replaced or modified if they have deteriorated where substantial maintenance is required. They should be replaced if satisfactory combustion with optimum excess air operation cannot be maintained.

Burners should be replaced or modified if the existing burners are unsuitable for the new operating requirements. These requirements may be environmental, fuel change, heat release, process, etc.

A burner manufacturer, or a qualified professional, should be consulted when burner replacement or modification is required.

11.5.9 Spare Parts

The number of spare parts depends on burner design, fuel, plant location, and operation and maintenance experiences. It is recommended that 10 % of all tips, oil guns, and burner tiles should be the minimum purchased spares. When spare parts are used, ensure that these parts are the correct components and are properly installed on the correct burners.

12 Testing

12.1 General

This procedure covers the requirements for testing a single burner in a test furnace. Single burner tests do not necessarily reflect operation in a multiple burner operation. Testing in multiple burner arrangements is often possible and may be considered in critical applications.

Burner testing is intended to determine the following at test furnace firebox temperatures: burner operating envelope, pilot operating envelope, burner control band, pilot control band, and the burner ignition operating envelope. Tests for environmental performance are not necessarily conclusive as the test furnaces are not representative of the final application. Many burner suppliers have sufficient test data to compare with field data to develop a “test rig factor” for site comparisons. Where unusual situations arise environmental performance can only be determined after installation.

Tests are recommended for each specified operating mode (e.g. natural or forced draft, preheated air, fuel type, etc.).

12.2 Test Requirements

12.2.1 General

The purchaser shall provide information concerning proposed burner installation, site conditions, and intended operation. This information is provided through a datasheet such as those contained in API 560. The following information should be considered the minimum requirements:

1) heat release and intended operating range;

2) fuel specifications;

3) firebox configuration and burner clearances;

4) bridgewall temperature for the defined operating cases;

5) combustion air conditions and available draft;

6) environmental performance requirements;

7) maximum and minimum flame dimensions, as applicable.

The test furnace and burner orientation should be as similar as possible to the actual installation. The test facilities should be capable of reproducing similar firebox temperature and draft at the burner consistent with heater design.

A description of test facilities, measurement devices, proposed test procedures, and fuels to be used shall be provided for the purchaser to review and approve prior to testing.

Calibration of all flue gas analytical instruments shall be conducted at the beginning of each test day or more if specified. Calibration information on other instrumentation such as fuel measurement devices shall be available for purchaser to review. Flue gas analyzers shall be calibrated with span gas cylinders that have a composition characteristic of the burner guarantee values.

Complete burner retesting may be required if physical modifications are made to the burner or burner test system. The extent of the retesting will be determined by mutual agreement between the purchaser and vendor.

12.2.2 Recommended Test Sequence

Following is the recommended sequence for testing. The extent of the testing shall be specified by the purchaser.

1) Damper/register leakage tests (if specified).
2) Pilot ignition and stability tests.
3) Single fuel burner tests.
4) Combination fuel burner tests (if specified).

12.2.3 Burner Design

The number, size, and orientation of fuel orifices and number and location of fuel tips should be recorded for each test. Dimensions used in the successful tests should be included in the burner performance test report. In consideration of the proprietary nature of a particular design, some orientation information may only be made available for inspection purposes at the time of the test. As a minimum however, the number and size of the fuel orifices and the number and location of the fuel tips should be reported.

12.3 Test Fuels

12.3.1 General

The fuels used for burner and pilot testing should be mutually agreed to between burner vendor and purchaser prior to testing. In cases where multiple fuel gas compositions are specified, testing may be done with a range (max. to min.) of fuel compositions encompassing the spectrum of the specified fuels.

12.3.2 Blended Gas Fuels

To simulate the combustion characteristics of the fuel expected in the actual service, blending of various gas fuel streams is most often required. Blending of a gas fuel requires accurate measurement of each gas stream as part of the overall calculation of the simulated fuel. Rotometer type flow elements or orifice runs are acceptable means of measurement. Fuel should be blended considering the heating value, specific gravity, Wobbe number, flame speed, and stoichiometric air requirement for the actual service fuel gas as specified or as mutually agreed to with the purchaser. Hydrogen and inert content of the gas should be in the same volumetric proportion as in the specified actual service, if those proportions significantly impact burner performance.

12.3.3 Liquid Fuel Conditions

It is generally impractical and cost prohibitive to simulate the exact composition of the site fuel oil. Instead, the tests are normally performed using commercially available fuel oils such as diesel, No.6 oil and naphtha. Relevant correction factors should be applied to correct for the differences between test and site fuel, such as fuel bound nitrogen content. Many burner suppliers have the facility to accommodate unusual fuels that may be supplied by the end user.

Liquid fuel viscosity shall be maintained by temperature control. When an atomizing media is required, both atomizing media temperature and pressure shall be measured at each test point. The mass ratio of atomizing media shall be recorded at the maximum condition.

Atomizing media should be representative of the anticipated operation (i.e. steam, high-pressure gas, etc.). When steam is required, the steam shall be within the burner manufacturer's recommended temperature and pressure range.

12.3.4 Fuel Orifice Capacity Curves

The burner manufacturer shall provide capacity curves (fuel pressure vs. heat release) for each specified fuel covering the burner operating envelope. For staged fuel burners supplied with the intent to use only the primary stage, capacity curves for the primary fuel stage shall be provided in addition to the entire burner.

12.4 Air Supply

12.4.1 General

During burner testing, the measured draft loss for the burner needs to be corrected for temperature, relative humidity, and atmospheric pressure if the test facility conditions are different than the operating site. The design combustion air temperature can readily be provided during a burner test; however, differences in atmospheric pressure cannot. The method of correction should be resolved in advance of the burner test.

12.4.2 Preheated Air

Preheated air can be provided by either direct or indirect heating. Indirect air heating is necessary to determine burner emissions. However, if test center equipment limits the achievable temperature, NO_X corrections should be made to the raw data to account for the deviation. When direct heating is used, correction of oxygen content should be considered. In general, the combustion air preheat temperature should be as close as possible to design conditions. However, if test center equipment limits the achievable temperature, NO_X corrections should be made to the raw data to account for the deviation.

12.4.3 Oxygen-reduced Air

A practical example of oxygen-reduced air is turbine exhaust gas. Turbine exhaust gas may be simulated by cooling post-combustion gases from a test furnace, duct burner or a direct fired air heater. The temperature, oxygen concentration, NO_X, and carbon monoxide of the oxygen-reduced stream should be measured prior to entering the burner.

12.4.4 Flue Gas Recirculation

Flue gas can be recirculated from the test furnace or it can be simulated. A direct fired burner with a heat exchanger placed downstream for temperature control can be used for simulating the flue gas.

12.4.5 Air Capacity Curves

The burner manufacturer should provide air capacity curves for all burners for use in defining the burner operating envelope. The air capacity curves (draft loss vs. heat release at design excess air) should include air at standard temperature as well as design temperature for applications with air preheat. The curves should include operating points consistent with the fuel capacity curves. The air capacity curves should be adjusted accordingly for changes in atmospheric pressure relative to the test facility.

Whenever staged air burners are used, information relative to the split between primary and staged air should be provided.

12.5 Pilot and Igniters

12.5.1 General

The pilot and or igniter system shall be the same as that proposed for the actual burner installation. As the pilot should not provide stability to the burner when the burner is operated inside the burner operating envelope, the end user may elect to have the pilot off during tests to establish the true operating range of the burner.

Pilot fuel, when possible, should be the same as specified for actual operation. Main burner fuel may be substituted for the pilot fuel only on approval by the purchaser.

12.5.2 Pilots

Prior to main burner testing, the pilot shall be proven stable at the design draft and operating conditions under each of the following conditions.

1) Damper/register position adjusted from closed to 100 % open in a "cold" firebox.

2) Damper/register quickly opened and closed.

3) Fuel pressure adjusted over the defined operating range.

The main burner test may also include additional pilot stability tests including a partial or full fuel trip. Some pilot suppliers have small furnaces for testing the pilots only. Further tests that would be impractical when testing in a large test rig (e.g. positive pressure testing) is more practical in these units.

12.5.3 Igniters

The igniter shall be proven to reliably ignite the pilot, or main flame if so intended, under the burner recommended light-off conditions. The pilot igniter should also be proven with the damper or register adjusted from closed to 100 % open in a "cold" firebox.

12.6 Main Burner Test

12.6.1 General

The main burner shall be tested for each fuel and operating condition specified. The purchaser shall specify the number of test points and required measurements for each point.

Since the test furnace operating conditions cannot completely reproduce those in the operating facility, it is recommended that those points intended to establish the burner operating envelope for the heater be verified during commissioning and early stages of operation of the fired process heater.

12.6.2 Test Points

Following is a description of the minimum recommended test points, which should to be mutually agreed between the burner manufacturer and purchaser prior to testing. All test points are performed with design draft at the floor of the test furnace.

1) Normal heat release at design excess air.

2) Minimum specified heat release with the air register set in the same position as Point 1.

3) Minimum stable heat release at CO limit (250 ppmvd) or flame instability with air register set in the same position as Point 1.

4) Minimum heat release with air register adjusted for design excess air (Note 1).

5) Design heat release. Air register set for design excess air (Note 2).

6) Maximum stable heat release at CO limit (250 ppmvd) or flame instability (Note 3).

7) Maximum heat release with air register 100 % open.

NOTE 1 Test Point 4 is intended to establish the turndown capability of the burner while operating with design excess air. This point may require a heat release greater than the minimum specified value. The information obtained from this test point can be useful in further defining the safe operating envelope for the burner in particular when low NO_X burner technology is applied.

NOTE 2 Test Points 5 and 7 are the same if air register is designed for 100 % opening and design excess air. Test Point 7 may be omitted.

NOTE 3 The maximum stable heat release Test Point 6 is normally taken with the air register at the same setting as that for the design heat release of the burner at design excess air (Test Point 5). Alternately, if specified by the purchaser, the test point may be at the air register setting of Test Points 1 or 7. This test point may be considered as the upper safe heat release for the burner and is intended to demonstrate stable combustion of the burner up to and including the point of CO breakthrough.

12.6.3 Combustion Stability

Burner operation is considered unacceptable if combustion instability is exhibited at any specified operating condition. Combustion instability exists if any of the following conditions are detected.

1) Pulsation or vibration of burner flame, burner, or furnace.

2) Uncontrollable fluctuations in the flame shape.

3) Significant combustibles in the flue gas (i.e. over 250 ppmvd CO).

4) Flashback into the venturi on premix burners.

5) Loss of flame from one or more tips or from the flame stabilization point.

12.6.4 Recommended Test Procedure—Main Fuel (Burner) Ignition

The time required for a furnace/burner system to reach stable operating conditions will depend on the sequence of the test.

The following test procedure sequence is recommended to minimize the time to collect test data:

1) Follow the established work practices for the test facility to prepare equipment and personnel for the safe handling of fuels and introduction of flame in the test furnace.

2) Establish pilot and perform pilot test if applicable.

3) Demonstrate satisfactory light-off and cold-firing stability of the burner. Record burner gas pressure at light-off. [Typically burners will light-off at a very low pressure (1 psi to 2 psi); however, some users have minimum stops and higher light-off pressures. These peculiarities should be discussed and agreed prior to testing.)

4) Verify the burner can be light-off at the specified light-off air register position and fuel gas pressure. For example, set draft or fan to maximum burner design and determine damper setting for reliable ignition of the burner.

5) Increase the heat release, open the burner register and stack damper as required to establish conditions for design heat release, Test Point 5. Record required data.

6) Increase the heat release with the air register set for Test Point 5 until CO limit (250 ppmvd) to establish the maximum stable heat release. Record required data.

7) Adjust the air register to the full-open position. If the excess air exceeds design with design draft, increase the heat release to meet design excess air and establish the maximum heat release, Test Point 7. Record required data.

8) Establish conditions for the normal operating point (Test Point 1). The oxygen content of the test furnace flue gas should be no greater than that quoted for normal operation. Record required data including noise data if specified.

9) Confirm burner and pilot stability in a high draft condition by quickly ramping back the heat release without adjusting excess air to the minimum specified heat release as established for Test Point 2.

10) Vary the fuel rate without changing other burner settings to establish the minimum specified heat release and the minimum stable heat release, Test Points 2 and 3, respectively. Record required data for each test point.

11) Adjust the air register setting and adjust fuel rate as necessary to establish the minimum heat release with design excess air, Test Point 4. Record required data.

12) Fully isolate fuel to the burner and confirm stable operation of the pilot.

13) Repeat test points as required for each fuel composition

Some burners may need to have their air registers adjusted to light-off at normal or design air rates and maximum draft. An additional test may be performed that evaluates where the air register or damper setting should be for light-off (e.g. set draft or fan to maximum burner design and determine damper setting for reliable ignition of the burner).

Special test procedures should be developed and agreed to by the purchaser and burner and heater manufacturers for more complicated burner systems or more specialized operating conditions. An example test procedure for burners and pilots can be seen in Table 16 and Table 17, respectively.

Table 16—Minimum Recommended Test Procedure to Verify Burner Operating Envelope and Emissions for Burners

Test Point	**Burner Heat Release** Btu × 10^6/hr	**Percent Excess O_2** vol., dry	**Furnace Draft** in. H_2O	**Description/Objective of Test Point**
1	—			Pilot stability; vary furnace draft from maximum to minimum possible draft.
2	—			Pilot stability; vary pilot fuel pressure from 5 psig to 15 psig (0.34 barg to 1 barg).
3	TBD	TBD	Design	Cold furnace light-off; determine minimum fuel pressure to achieve.
4	Maximum	Design	Design	Maximum heat release.
5	TBD	TBD	Design	CO breakthrough; increase fuel until CO > 250 ppm.
6	Normal	Design	Design	Normal heat release; design excess air.
7	Minimum	TBD	Design	Minimum heat release; burner damper; set per normal heat release.
8	TBD	TBD	Design	Absolute minimum heat release; burner damper set per normal heat release; 250 ppm CO or flame instability.

The pilot qualification procedure shown in Table 17 can be used to demonstrate the pilot flame stability and reliability.

12.6.5 Combination Firing

When gas and oil combination burner test firing is specified, test the burner using the procedures in 12.6.4 for each gas and oil fuel separately. The burner shall then be tested with combined fuel firing in the following gas/oil heat release ratios, 25/75, 50/50, and 75/25 or as specified by purchaser at the design, normal and minimum heat release rate (Test Points 1, 2 and 5, respectively)

12.6.6 Visible Flame Characteristics

12.6.6.1 Quality

Acceptable flames are free of smoke, haze, sparklers or fireflies. Carbon or oil deposited on the burner, burner throat, or on furnace walls are unacceptable.

Table 17—Pilot Testing Procedure (Optional)

Test Point	**Burner Heat Release** Btu × 10^6/hr	**Percent Excess O_2** vol., dry	**Furnace Draft** in. H_2O	Description/Objective of Test Point
1				Determine the required fuel gas pressure for a given fuel gas composition, while the main burner is in and out of service. As a minimum, pilots should be capable of stable operation at 50 % of pilot design liberation for each pilot fuel under consideration.
2				Prove pilot flame stability at 130 % of maximum design main burner combustion airflow and at design combustion air temperature range with the main burner in and out of service.
3				Demonstrate pilot capability to light-off the main burner at 130 % of maximum design combustion airflow. For natural draft burners, light-off can be demonstrated at a minimum burner air throat velocity of 50 ft/s (15.3 m/s).
4				Pilot should remain stable with the main burner register(s) and/or damper(s) fully closed.
5				Pilots used with burners in forced draft service should remain stable in fireboxes against a minimum positive back pressure of 1.5 in. (38 mm) of water at normal pilot gas pressure.
6				Pilots used with burners in natural draft service should remain stable against a minimum positive back pressure of 0.5 in. (12.5 mm) of water at normal pilot gas pressure.
7				Pilot shall remain stable while the main burner fuel gas valve is closed and opened once per second, several consecutive times.
8				Verify pilot performance under maximum draft conditions where test facilities permit.
9				Verify pilot performance with rapid fluctuations in main burner air rate, achieved by opening and closing the main burner damper or register.
10				The pilot should provide a positive response from the flame rod provided with it. Verify the performance of the flame rod over the test envelope.
11				Verify the ability to light the pilot over the range of test conditions. Include integral (where installed) and portable ignition devices.

Flame characteristics of extremely low NO_x burners are often difficult to visually define. See below for determination of flame dimension parameters in particular for this style of burners.

12.6.6.2 Shape

Flame shape should be uniform, centered on the burner axis and with length and width within specified requirements. Flame is the visually observable element of the combustion process. Flame dimensions should be recorded by visual observation and referenced off known test heater dimensions. The purchaser should specify desired dimensions as well as if there are minimum requirements. For example, both upper and lower limits for flame dimensions should be specified. If CO probing is required as a secondary method of verifying flame dimensions, the CO level should be determined ahead of time. It is generally considered that 99.99 % of the combustion reactions are complete at a CO isosurface of 2000 ppmvd. Also, the CO recorded should be averaged over a time period as CO fluctuates greatly as the measurement is being made in a turbulent environment.

The flame size (diameter or cross section and length), shape and intensity (color, luminosity and transparency) should be recorded for each test point. The test furnace dimensions (length, width and height) should be recorded.

12.6.7 Noise

Noise level guarantees provided by the burner manufacturer are typically at a location 1 m (3 ft) directly in front of the burner air intake at the same elevation as the centerline of the burner intake for natural draft burners. Noise level measurements for a single burner should be recorded at the design heat release for the burner. When several burners are installed in the operating facility, the noise level at 1 m (3 ft) from the burner may be higher than for a single burner due to the noise contribution from surrounding burners. The heater/burner manufacturer's guarantee shall account for the contribution of multiple burners in multiple burner applications.

Noise should generally not be recorded during burner tests where the application of the heater is forced draft operation. The noise has no line of sight for measurement and background noise is typically higher than the guaranteed value due to the nature of test facility equipment and temporary nature of the setup.

12.7 Test Instrumentation

12.7.1 General

Flow, temperature and pressure elements, gas analyzers, and other instrumentation are required to conduct a burner test. A typical burner test setup with required instrumentation is shown in Figure 21.

12.7.2 Flue Gas Analyzers

Continuous emission analyzers should be used as continuous recording of data is recommended. Analyzers shall be zeroed and calibrated over the intended range of operation before, after, and as required during testing. Certified analyzer calibration gases spanning the intended range of operation should be available for calibration.

Heated sample lines may be required to ensure accurate measurement of the flue gas components.

12.8 Measurements

12.8.1 General

The following parameters are necessary to assess the performance of the burner during testing to ensure it meets the design requirements.

12.8.2 Fuel Gas

Fuel gas parameters for data collection include as a minimum:

1) temperature,

2) flow,

3) pressure.

12.8.3 Liquid Fuel

Fuel oil parameters for data collection include as a minimum:

1) temperature,

2) flow,

3) pressure.

12.8.4 Atomizing Media

Atomizing medium parameters for data collection include as a minimum:

1) temperature,

2) flow,

3) pressure.

12.8.5 Combustion Air (Air, Turbine Exhaust Gas, or Air/Flue Gas Mixture)

Combustion air/oxidant parameters for data collection include as a minimum:

1) temperature,
2) atmospheric pressure and humidity,
3) oxygen concentration (CO and NO_x also for turbine exhaust or direct heated air),
4) pressure (forced draft systems),
5) draft loss across the burner/burner tile,
6) air register position,
7) air register leakage if specified.

12.8.6 Furnace

Test furnace parameters for data collection include as a minimum:

1) draft at the floor and arch,
2) temperature exiting radiant section,
3) floor temperature.

12.8.7 Flue Gas

Flue gas parameters for data collection include as a minimum:

1) O_2 (%),
2) NO_x (ppmvd),
3) CO (ppmvd).

12.8.8 Other

The owner may specify any additional test parameters desired, such as noise.

13 Troubleshooting

13.1 Burner Plugging

13.1.1 General

Burner plugging can lead to flame and burner instability. Flame impingement can occur. Flames can blow out when high burner pressures and/or plugged burner ports disrupt the normal flame patterns. Increased fuel velocities may cause blowout of the flames. Obstructions within the burner block can develop, disrupting burner fuel and air flow patterns.

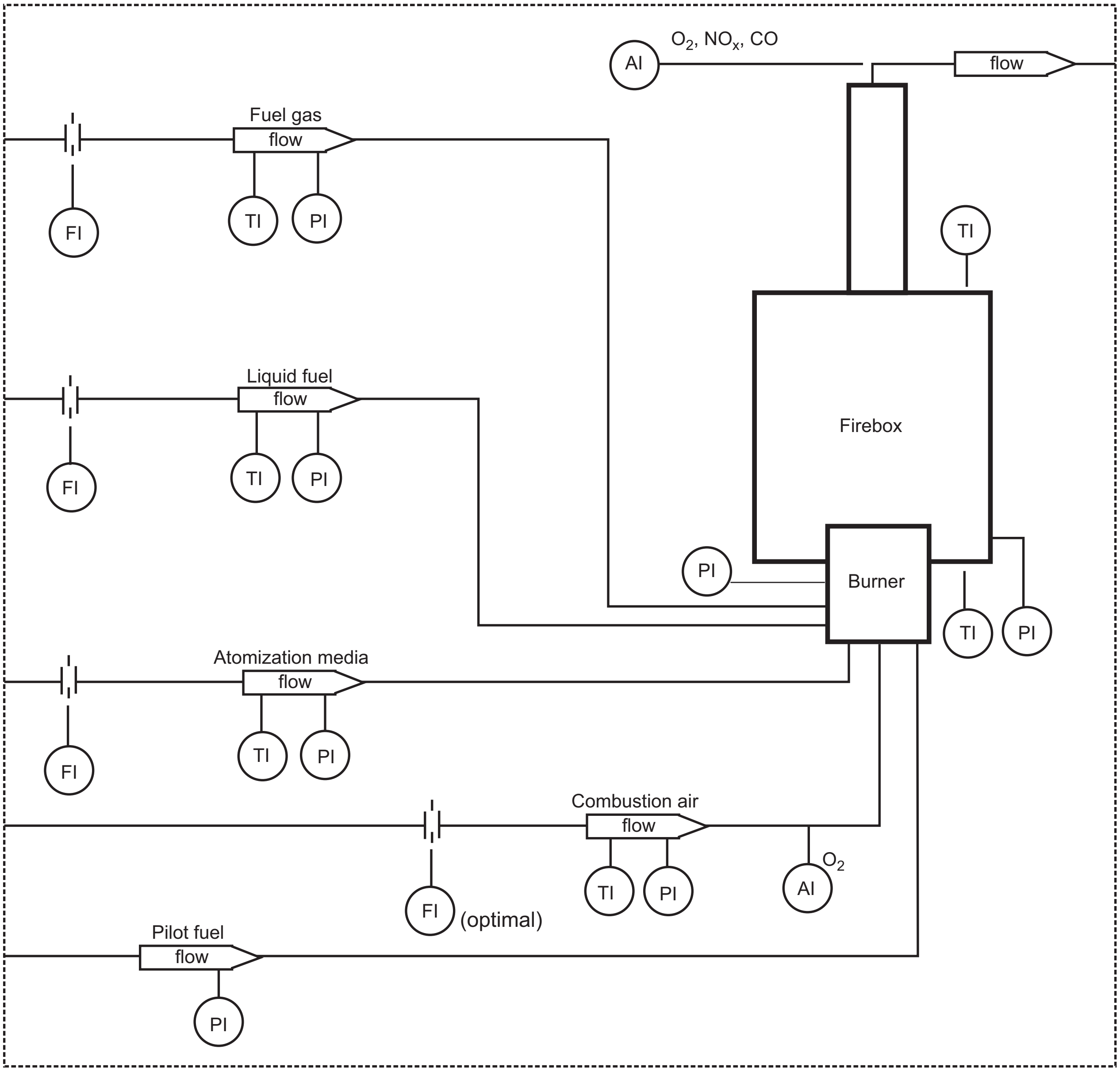


Figure 21—Typical Burner Test Setup

Burner plugging problems can often be solved if the source of the plugging can be determined. The following can cause plugging:

1) scale in the fuel gas lines,
2) liquid/aerosol carryover into the burners,
3) unsaturates, primarily propylene, in the fuel gas,
4) amine carryover into the fuel gas system,
5) chlorides,
6) high tip/riser temperatures.

The first two items may be the most likely of the six possibilities listed above. An analysis of the obstructions may give an indication of the cause of the plugging. The cause of the problem can sometimes be readily determined. Deposits present in a burner riser may be analyzed. The potential for burner plugging can be reduced if the burners are designed to operate at lower fuel gas pressure and the size of the burner tip fuel gas ports is increased, although there may be tradeoffs with other aspects of burner performance, such as available turndown or emissions. With lower NO_X burners designed today there is a tendency to have a larger number of small holes that need to be kept clean and clear making it necessary to include filtration or coalescing devices in the fuel gas line.

13.1.2 Scale

It is recommended that strainers or filters be used in all fuel lines. All fuel gas lines, gas manifolds, burner risers, and tips downstream of the filter or coalescer should be blown free of scale, cleaned, flushed, and dried. Scale in the fuel gas lines can also be removed with steam or plant air. Cleaning the lines at the heater alone may not be sufficient. Fuel gas lines should be inspected and cleaned, if necessary, at every turnaround.

13.1.3 Liquid/Aerosol Carryover

Burner plugging is often caused by liquid/aerosol carryover in the fuel gas lines. The flashing of this liquid causes coke formation in the tips/risers. The presence of dark solid shapes attached to the burner tips or tiles can denote the presence of significant liquid within the fuel gas. These may form as plates, cones, or other shapes within the burner tile.

The following frequently cause liquid carryover.

1) Heavy hydrocarbons in fuel systems [butane (C4) and higher].

2) An undersized fuel gas drum knockout drum, high velocities in the drum and or damaged or missing coalescing mesh pad at the fuel gas outlet of the drum.

3) Insufficient steam or heat tracing in fuel delivery lines downstream of the knockout drum, whereby heavier components in the fuel gas condense before reaching the burners.

4) Cooling of a fuel gas saturated with heavier hydrocarbons due to exposed fuel lines or pressure drops across a control valve.

Coalescers are used downstream of the fuel gas drum to aid in the removal of any further liquid/aerosol entrainment. These should ideally be located as close to the heater as possible and should be downstream of the fuel gas control valve for maximum protection.

13.1.4 Unsaturates

The presence of greater than 10 % unsaturates, most notably propylene and butadiene, can plug burner tips/risers. When burner design has not considered these components, it may be possible to reduce the plugging by reducing the number and increasing the size of the burner firing orifices. This may not be applicable in all burners or in all heaters.

13.1.5 Amines

The presence of amines in the fuel system can cause plugging of burner tips and risers. Carryover from the amine treating system should be eliminated. A well-designed water-wash system can remove entrained amines from the fuel gas if the amine unit is the source. Coalescers can be used downstream of fuel gas knockout drums as another way of removing amines.

Carbon steel manifolds and risers can corrode as a result of amine carryover. This can be corrected by using stainless steel components.

13.1.6 Chlorides and Ammonia

Chlorides may be present when guard beds become saturated and cease removal. Chlorides and ammonia can lead to burner tip/riser plugging. Ammonia in the gas will produce ammonium salts and sulfur in the gas will produce iron sulfides. Both of these can be removed by a coalescer, if located properly. Unreacted ammonia and sulfur will pass through the filter or coalescer and can react downstream to cause the same problems.

13.2 Troubleshooting Gas Fired Low NO_X Burners

Burners designed to emit low NO_X levels, will have operational considerations that differ from standard gas or oil burners due to the differences in burner design. Low NO_X burners often require more fuel gas tips than other burners. The average size of the fuel gas tip holes in low NO_X burners is typically smaller than those in standard burners. The smaller orifice sizes are more conducive to plugging. Many low NO_X burners have burner tips containing both firing and ignition ports. The firing ports can be the same size or much larger than the ignition ports. The ignition ports being relatively small can plug more readily than the firing ports.

The flame produced from the primary tips ignite the secondary fuel gas. Failure of the primary fuel to ignite may prevent ignition of the secondary fuel.

Routine visual inspection of the burner flames is required to monitor fuel gas tip plugging.

- Safe operation of a low NO_X burner relies on a stable primary combustion zone, which should appear bright and hot. Conversely, a dark primary combustion zone may indicate plugged primary tips.
- Intermittent lifting off of the staged flame is an indication of instability. This may be the result of an unstable primary combustion zone.
- Burner tips (primary or staged) that glow brightly may indicate that the tips are plugged, because the cooling effect of fuel gas flowing through the tip is absent.
- Staged burner tips may have firing ports that are angled in a way that the fuel gas splashes on the burner tile. This often results in a dark area on the tile where the (relatively cool) fuel gas splashes on the tile. The absence of this dark area may indicate a plugged staged tip.

Because of the complicated nature of low NO_X burners, care shall be taken to ensure that all components are kept in good mechanical condition. Any troubleshooting efforts should first confirm that the tip orientation and positions are correct; the flame holder is undamaged and positioned correctly; the tile is undamaged; the tips are not plugged; and the tip orifices have not been eroded. Table 20 outlines some of the potential operating problems and solutions related specifically to low NO_X burners.

13.3 Burner Operation Troubleshooting Table

Some of the problems normally experienced in burner operation and possible causes and solutions are given below in Table 18, Table 19, and Table 20.

(These tables are solely suggestions and are not meant to replace the burner operating and maintenance manuals. The vendor should be consulted whenever components are to be replaced or modified.)

14 Considerations for Safe Operation

14.1 General

The intention of this section is to emphasize certain conditions that can provide a significant safety hazard to the operator directly or indirectly. This section supplements Section 13, which in itself recognizes certain problems that may pose safety hazards.

Table 18—Gas Burners

Trouble	Causes	Solutions
Failure to light.	Pilot positioned incorrectly, not operating or operating incorrectly.	Assure pilot, its constituents, and flame are positioned properly.
	Fuel gas contains nitrogen left over after pressure testing/line clearing.	Flush nitrogen from fuel gas lines with fuel gas.
	Fuel pressure too low.	Increase fuel pressure.
	Too much or too little draft.	Ensure draft is optimum; if too high reduce, too low increase using either stack damper or induced draft fan.
	Too much combustion air.	Close air register to approximately 50 % open when initially firing. Reduce this further if burner still fails to ignite.
Burners go out. NOTE Actions are taken only after heater has been brought to a safe condition where adjustments can be made.	Gas/air mixture too lean (i.e. too much air).	Reduce total air. Reduce primary air (premix only).
	Too much draft.	Reduce stack damper opening.
	Gas/air mixture too rich (i.e. too much fuel).	If a flooding/bogging situation is occurring, cut fuel rate according to equipment procedures.
	Fuel pressure is too high.	Reduce fuel pressure, maintaining stable flame. Add burners to reduce the fuel gas pressure.
	Fuel pressure is too low.	Increase fuel pressure, maintaining stable flame. Reduce the number of operating burners, if necessary.
Flame flashback (premix only).	Low gas pressure.	Increase fuel pressure, if applicable. Shut off burners to raise the fuel gas pressure to the operating burners, if necessary. It may be necessary to reduce burner orifices' size.
	High hydrogen concentration in the fuel gas.	Adjust primary air. A new burner or tip drilling may be required.
	Premix mixture too rich.	Open primary (premix) air door.
Insufficient heat release.	Low gas flow. Check for low gas pressure.	Increase gas flow/fuel gas pressure.
	Burner tip orifices too small.	Check with burner manufacturer and burner curves. Larger orifices may be required but it shall be confirmed that sufficient air will be available through the air registers for the increased fuel rate before making a change. Replacement burners may be required.
	Tip/riser plugging.	Perform maintenance/cleaning. Determine source of plugging.
	Gas composition not per spec.	Correct the composition or consult burner manufacturer for possible replacement tips.
Pulsating fire or "breathing" (flame alternately ignites and goes out, sometimes with almost explosive force).	Lack of oxygen/draft—flooding/bogging situation.	Immediately take corrective action to safely move out of flooding/bogging. Establish complete combustion at lower firing rates. Do not introduce air into a flooded heater. Check damper position. Check draft and excess oxygen. Adjust stack damper and/or burner register as needed. When heater has equilibrated, increase air before increasing fuel.
	Operation outside of design envelope.	Adjust firing.
	Incorrect fuel composition.	Check/adjust fuel composition.
	Flame operation in natural frequency of furnace (acoustic coupling).	Consult burner manufacturer.

Table 18—Gas Burners (Continued)

Trouble	Causes	Solutions
Flame instability. Flame lift-off.	Excessive air flow.	Adjust air register/draft.
	High fuel pressure.	Check/adjust fuel pressure. Clean tips.
	Over-firing (above design).	Operate within design envelope. Consult burner manufacturer to investigate changing tips.
	Incorrect fuel composition.	Check/correct fuel composition.
	Plugged orifices.	Clean burner orifices.
	Lack of oxygen/draft—flooding/bogging situation.	Immediately take corrective action to safely move out of flooding/bogging. Establish complete combustion at lower firing rates. Do not introduce air into a flooded heater. Check damper position. Check draft and excess oxygen. Adjust stack damper and/or burner register as needed. When heater has equilibrated, increase air before increasing fuel.
Flame shape/appearance. Excessively long or large diameter. Lazy/smoky flame. Heat flux shift.	Lack of air/too much fuel.	Adjust air registers. Reduce fuel.
	Incorrect fuel composition.	Check for presence of heavy hydrocarbons in the fuel composition.
	Excessive fuel pressure.	Adjust firing to within defined operating envelope.
Erratic flames (not a stiff flame).	Lack of combustion air.	Reduce firing then adjust air register and/or stack damper.
	Incorrect position of burner tip.	Install tips per burner manufacturer's drawings.
	Furnace currents.	Perform CFD modeling to determine furnace currents effects and potential burner changes.
Gas flame too long.	Excessive firing.	Reduce firing rates.
	Too little primary air (premix only).	Increase primary air; decrease secondary air.
	Worn/damaged burner tip.	Replace tip.
	Tip drilling angle incorrect.	Consult burner manufacturer.
Gas flame too short.	Too much primary air (premix only).	Increase secondary air, decrease primary air.
	Tip drilling angle incorrect.	Consult burner manufacturer.
Tilting/leaning flames.	Poor burner air distribution.	Examine burner for restrictions. Determine if air register is causing the problem (e.g. a single-blade air register may be preferentially sending most of the air to one side of the burner).
	Poorly oriented burner tip.	Check orientation of burner tips and adjust, if necessary
	Flue gas recirculation patterns in heater.	Provide a short wall of bricks (Reed Wall), either in a solid or checkerboard pattern to obstruct the flow of flue gas against the burner. NOTE Standard burners may require a solid wall while certain styles of low NO_x burners may require a checkerboard pattern. Consult burner manufacturer before implementation. May require more sophisticated analysis with CFD.
Flame impingement. High tube skin temperature. Coke formation on tubes. Localized coking. Heat flux shift.	Tip plugging.	Burner maintenance.
	Poorly oriented tip(s). Abnormal operation.	Perform burner maintenance. Adjust heater/ burner operation.
	Refer to causes for long flame above.	Refer to actions for long flames above.
Burner tip plugging.	See Section 11.	

Table 18—Gas Burners (Continued)

Trouble	Causes	Solutions
Coke formation. Deposits on tubes, refractory, burner tile, and tips.	Poor mixing of fuel and air.	Check alignment against design.
	Heavy ends/liquid/aerosols/amines in fuel gas.	Check fuel temperatures/composition/knockout drum level.
	Low fuel operating pressure.	Raise fuel gas pressure by removing burners from service.
	Low fuel temperature.	Install system to heat fuel.
High carbon monoxide or combustibles in flue gas. (Incomplete combustion.)	Inadequate air.	Reduce firing. Adjust air registers. Check O_2/ combustibles meter calibration. Seal heater leakage to remove source of oxygen and misleading oxygen reading.
	Individual burner flameout.	Determine cause of flameout and reestablish flame, if safe.
	Over-firing.	Reduce firing. Consult with burner manufacturer.
	Insufficient air to one or more burner.	Determine which burner is lean on air and increase its combustion air.
	Burner component (such as burner tip or riser) oriented improperly or damaged.	Determine which burner is causing the high combustibles. Inspect/repair affected components.
	Obstruction (e.g. fallen refractory) within burner block.	Determine which burner is causing the high combustibles. Inspect burner for obstruction and remove, if present.
	Flame holder damaged.	Determine which burner is causing the high combustibles. Inspect flame holder. Repair/ replace, if necessary.
Afterburning. High convection flue gas/ tube temp. High stack temperature.	Incomplete combustion in radiant section. Air leakage in convection section	Refer to incomplete combustion (see above). Reduce fuel. Adjust air register, if needed. Seal air leakage.

14.2 Flooding

Flooding (substoichiometric operation) is a term used to indicate operation with insufficient combustion air, resulting in unburned fuel or combustibles in the firebox and/or flue gas. As the furnace is typically on automatic coil outlet temperature control, the lack of combustion within the firebox allows the outlet temperature to reduce and the control system calls for more fuel exacerbating the situation. If unabated, this cycle can eventually lead to burner flameout. Unburnt hydrocarbons can also result in afterburning.

Flooding on a natural draft heater is generally accompanied by erratic firebox pressures or “panting” at the furnace air inlets. With too much fuel and too little air, combustion is erratic, pressure in the firebox is reduced allowing more air to enter, and as combustion occurs, pressure increases restricting the entry of air. It is the small differential pressures across the natural draft burners that make this situation prevail. It is less prevalent with forced draft systems where cross limiting air fuel ratio control can prevent this situation. Pressure drop across the burners in an forced draft system dampens the effect of the increases/decreases in combustion induced pressure changes.

Other causes of flooding may include:

— fuel compositions beyond the recommended limits of the burner;

— low draft leading to insufficient air entering the burners.

API 556 discusses methods of addressing unburned combustibles within the fired heater protective system.

Table 19—Additional Considerations for Oil Burners

Trouble	Causes	Solutions
Burners dripping. Coke deposits on burner blocks. Coking of burner tip when firing fuel oil only. Dark color/smoking.	Insufficient combustion air.	Adjust air register and/or stack damper.
	Improper atomization due to water in steam.	Correct steam conditions.
	High oil viscosity.	Check fuel oil type and temperature at the burner. Increase fuel temperature to lower viscosity to proper level.
	Improper blending of oil constituents.	Check composition of fuel for heavier fractions or incompatible fuels.
	Clogging of burner tip.	Clean or replace burner tip. Confirm burner tip is in proper location.
	Insufficient atomizing steam.	Increase atomizing steam.
	Improper location of burner tip.	Adjust tip location.
	Worn burner parts.	Replace worn parts.
Failure to maintain ignition.	Too much atomizing steam.	Reduce atomizing steam until ignition is stabilized. During start up, have atomizing steam on low side until ignition is well established.
	Too much primary air at firing rates.	Reduce primary air to minimum or eliminate it entirely.
	Too much moisture in atomizing steam.	Assure appropriate insulation is on steam lines. Confirm steam traps are functioning. Adjust quality and temperature of atomizing steam to appropriate levels.
	Too low an oil pressure.	Raise oil pressure.
	Burner tile in combination, oil, and gas burner too cool.	Fire burner initially on gas to heat up burner block, and then add the oil. Remove gas when the burner is lit and well established.
Coking of oil tip when firing oil in combination with gas.	High rate of gas with a low rate of oil resulting in high heat radiation to the fuel oil tip.	Increase atomization steam to produce sufficient cooling effect to avoid coking. Reduce gas fire rate. Dedicate individual burners to either fuel.
	Incorrect oil gun position.	Adjust tip location.
	Lack of steam purge on gun.	Purge oil gun prior to shut off.
Erratic flames (not a stiff flame).	Lack of combustion air.	Reduce firing then adjust air register and/or stack damper.
	Plugged burner gun.	Clean burner gun.
	Worn burner gun.	Replace burner gun.
	High rate of gas firing while firing a low rate of oil.	Reduce gas rate. Dedicate burners to either fuel.
Excess smoke at stack (evidence of incomplete combustion).	Insufficient atomizing steam.	Increase atomizing steam.
	High oil viscosity.	Increase oil temperature, check oil properties.
	Low excess air.	Increase excess air.
	Moisture in atomizing steam.	Requires knockout drum or increase in super heat. Alter steam at steam source.
	Insufficient combustion air.	Adjust air register or stack damper.
Fire flies or sparks.	Water in atomizing steam.	Requires knockout drum or increase in super heat. Alter steam at steam source.
	High oil viscosity.	Increase oil temperature. Check oil properties.

Table 20—Additional Considerations for Low NO_X Burners

Trouble	Causes	Solutions
All burner tips fail to light.	Burner, fuel gas pressure too low.	Increase burner fuel gas pressure.
	Burner tips plugged.	Remove burner from service and clean burner tips.
	Poor air distribution around burner.	Check burner for obstructions. Determine if the air register is causing the air distribution problem.
Flame shape/appearance. Excessively long or large diameter. Lazy/smoky flame. Heat flux shift.	Burner spacing too close.	Consult manufacturer.
High NOx emissions.	High fuel bound nitrogen in fuel (i.e. ammonia).	Verify fuel composition.
	High excess air.	Reduce excess air.
	Incorrect fuel composition.	Check fuel.
	Excessive air preheat temperature.	Reduce air preheat if possible.
	High furnace temperature.	Investigate reasons for high furnace temperature such as heat transfer surface fouling.
	Tramp air.	Seal heater to reduce/remove tramp air.
	Inaccurate NO_X measurement.	Calibrate and validate instruments.
Flame pulsation. Excessive heater vibration and excessive noise.	Poor mixing of fuel and air.	Check alignment against design.
	Ignition ports on staged fuel risers are plugged.	Check staged gas tips for plugging.
	Primary burner tips not aligned properly for cross lighting of staged tips.	Check alignment of primary burner tips against burner manufacturer's drawing.
	Ports on primary gas tip used for cross lighting of staged tips are plugged.	Check primary burner tips for plugging and clean as required. Install/check filters.

14.3 Afterburning

Afterburning is a condition where combustion occurs in an area downstream of the radiant section of the heater. Afterburning occurs when the burner fails to properly mix the fuel with the combustion air or there is insufficient combustion air necessary to complete combustion. Unburned fuel, leaving a combustion zone, does not combust until it comes in contact with tramp air or air from another burner, cell, or another heater sharing the same combined flue gas duct or stack. The fuel can come from burners lean on air or burners that are plugging, leaking fuel (e.g. crack in a riser), or have misaligned tips.

In some cases, opening an observation door adjacent to unburned fuel can cause this fuel to ignite. A pressure surge can be created in the vicinity of the door. This forces the hot combustion product out through the opening and can cause injury to the individual opening the observation door. Heater components, in the vicinity where afterburning is occurring, will experience elevated temperatures and may suffer damage.

14.4 Insufficient Draft

Insufficient draft at burners operating under natural draft can create air deficient situation where unburned fuel leaves the burner area. A problem can arise should an individual open an observation opening where a positive pressure (representative of inadequate draft) resides. The hot, unignited fuel gas could blow out of the heater and ignite as it hits the ambient air. The operator could be burned. This is more likely to happen at the top of the radiant section where the heater internal pressure is closest to atmosphere. Operators should not expect that a draft at the bottom of the heater indicates it is safe to open elevated observation doors.

14.5 Fuel Leak in Burner Riser

A fuel leak in a burner riser can lead to combustion problems and damage to surroundings. This can occur if the burner is not positioned properly or the adjacent refractory is not properly lapped up against the burner or has deep and long cracks. The fuel from the crack can ignite overheating the refractory or the casing. This can weaken the casing around the burner causing the casing or the burner to sag and potentially fail.

14.6 Liquid in Fuel Gas Line to Burners

Failure to remove liquid from the fuel gas can cause a slug of liquid to blow out of a burner, potentially extinguishing the the burner(s) or increasing the amount of heat released beyond the design of the equipment and subsequently allowing unburned fuel to enter the firebox. A slug of liquid entering a burner can also ignite and spill out of a bottom-fired burner causing danger to personnel and possibly overheating equipment outside of the fired heater.

14.7 Debris in Fuel Gas Lines

Debris such as corrosion products can not only plug burner tips and risers but can also plug burner block valves and deposit within the fuel gas manifold. The latter can cause a misdistribution of fuel to the burners. Either plugging burner block valves or sediment laying down in the fuel gas manifold can change the air to fuel ratio among the multiple burners in a heater potentially leading to afterburning or flooding.

14.8 Oil Atomization Issues

Improper atomization of a fuel oil can lead to oil dripping back through a burner causing burner fires, potentially burning personnel or igniting outside the heater if the problem is excessive. Improper atomization can cause oil to contact heater tubes where the oil can ignite and elevate tube metal temperatures to unacceptable levels. Similarly, should the oil contact the refractory, the refractory could overheat and deteriorate, especially if ceramic fiber insulation is used on the heater walls.

On oil fired burners, it is recommended to have an oil drain at the low point of the burner. Typically, this is on the burner air plenum. Routine cleaning and maintenance of the oil gun helps maintain proper atomization and helps minimize the potential for oil drips.

Annex A
(informative)

Burner Datasheets

PURCHASER / OWNER :	**ITEM NO. :**
SERVICE :	**LOCATION:**

1	**GENERAL DATA**			**REV**
2	TYPE OF HEATER			
3	* ALTITUDE ABOVE SEA LEVEL, ft.			
4	* AIR SUPPLY:			
5	AMBIENT / PREHEATED AIR / GAS TURBINE EXHAUST			
6	TEMPERATURE, °F. (MIN. / MAX. / DESIGN)			
7	RELATIVE HUMIDITY, %.			
8	DRAFT TYPE: FORCED / NATURAL / INDUCED			
9	DRAFT AVAILABLE: ACROSS BURNER, in. H_2O.			
10	ACROSS BURNER, in. H_2O.			
11	* REQUIRED TURNDOWN			
12	BURNER WALL SETTING THICKNESS, in.			
13	HEATER CASING THICKNESS, in.			
14	FIREBOX HEIGHT, ft.			
15	TUBE CIRCLE DIAMETER, ft.			
16	**BURNER DATA**			
17	MANUFACTURER			
18	TYPE OF BURNER			
19	MODEL / SIZE			
20	DIRECTION OF FIRING			
21	LOCATION (ROOF / FLOOR / SIDEWALL)			
22	NUMBER REQUIRED			
23	MINIMUM DISTANCE BURNER CENTERLINE, ft.:			
24	TO TUBE CENTERLINE (HORIZONTAL / VERTICAL)			
25	TO ADJACENT BURNER CENTERLINE (HORIZONTAL / VERTICAL)			
26	TO UNSHIELDED REFRACTORY (HORIZONTAL / VERTICAL)			
27	BURNER CIRCLE DIAMETER, ft.			
28	* PILOTS:			
29	NUMBER REQUIRED			
30	TYPE			
31	IGNITION METHOD			
32	FUEL			
33	FUEL PRESSURE, Psig.			
34	CAPACITY, MM Btu/hr.			
35	**OPERATING DATA**			
36	* FUEL			
37	HEAT RELEASE PER BURNER, MM Btu/hr. (LHV)			
38	DESIGN			
39	NORMAL			
40	MINIMUM			
41	* EXCESS AIR @ DESIGN HEAT RELEASE, %.			
42	AIR TEMPERATURE, °F.			
43	DRAFT (AIR PRESSURE) LOSS, in. H_2O.			
44	DESIGN			
45	NORMAL			
46	MINIMUM			
47	FUEL PRESSURE REQUIRED @ BURNER, Psig.			
48	FLAME LENGTH @ DESIGN HEAT RELEASE, ft.			
49	FLAME SHAPE (ROUND, FLAT, ETC.)			
50	ATOMIZING MEDIUM / OIL RATIO, lb/lb.			
51	NOTES:			
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BURNER DATASHEET **API STANDARD 535**	**USC UNITS**			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			1 OF 3	

GAS FUEL CHARACTERISTICS

1	* FUEL TYPE					REV
2	* HEATING VALUE (LHV)	(Btu/scf) (Btu/lb)				
3	* SPECIFIC GRAVIRTY (AIR = 1.0)					
4	* MOLECULAR WEIGHT					
5	* FUEL TEMPERATURE @ BURNER, °F.					
6	* FUEL PRESSURE; AVAILABLE @ BURNER, Psig.					
7	* FUEL GAS COMPOSITION,	MOLE % .				
8		CH4				
9		C2H6				
10		C3H8				
11		C4H10				
12		C5H12				
13		H2				
14		N2				
15						
16		TOTAL				
17	**LIQUID FUEL CHARACTERISTICS**					
18	* FUEL TYPE					
19	* HEATING VALUE (LHV) , Btu/lb.					
20	* SPECIFIC GRAVITY / DEGREE API					
21	* H / C RATIO (BY WEIGHT)					
22	* VISCOSITY, @	°F. (SSU)				
23	@	°F. (SSU)				
24	* VANADIUM, ppm.					
25	* SODIUM, ppm.					
26	* POTASSIUM, ppm.					
27	* NICKEL, ppm.					
28	* FIXED NITROGEN, ppm.					
29	* SULFUR, % wt.					
30	* ASH, % wt.					
31	* LIQUIDS:	ASTM INITIAL BOILING POINT, °F.				
32		ASTM END POINT, °F.				
33	* FUEL TEMPERATURE @ BURNER, °F.					
34	* FUEL PRESSURE AVAILABLE / REQUIRED @ BURNER, Psig.					
35	* ATOMIZING MEDIUM:	AIR / STEAM / MECHANICAL				
36		TEMPERATURE, °F.				
37		PRESSURE, Psig.				
38	**MISCELLANEOUS**					
39	BURNER PLENUM:	COMMON / INTEGRAL				
40		MATERIAL				
41		PLATE THICKNESS, in.				
42		INTERNAL INSULATION				
43	INLET AIR CONTROL:	DAMPER OR REGISTERS				
44		MODE OF OPERATION				
45		LEAKAGE, %.				
46	BURNER TILE:	COMPOSITION				
47		MINIMUM SERVICE TEMPERATURE, °F.				
48	NOISE SPECIFICATION					
49	ATTENUATION METHOD					
50	PAINTING REQUIREMENTS					
51	IGNITION PORT:	SIZE / NO.				
52	SIGHT PORT:	SIZE / NO.				
53	* FLAME DETECTION:	TYPE				
54		NUMBER / LOCATION				
55		CONNECTION SIZE				
56	SAFETY INTERLOCK SYSTEM FOR ATOMIZING MEDIUM & OIL					
57	* PERFORMANCE TEST REQUIRED (YES or NO)					
58	NOTES:					
59						
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BURNER DATASHEET **API STANDARD 535**	**USC UNITS**			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			2 OF 3	

EMISSION REQUIREMENTS

1	FIREBOX TEMPERATURE, °F.			REV
2	NOx	* ppmv(d) or lb / MM Btu (LVH)		
3	CO	* ppmv(d) or lb / MM Btu (LVH)		
4	UHC	* ppmv(d) or lb / MM Btu (LVH)		
5	PARTICULATES	* ppmv(d) or lb / MM Btu (LVH)		
6	SOx	* ppmv(d) or lb / MM Btu (LVH)		
7				
8	* CORRECTED TO 3% O_2 (DRY BASIS @ DESIGN HEAT RELEASE)			
9	NOTES:			
10	**1. VENDOR TO GUARANTEE BURNER FLAME LENGTH.**			
11	**2. VENDOR TO GUARANTEE EXCESS AIR, HEAT RELEASE, AND DRAFT LOSS ACROSS BURNER.**			
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BURNER DATASHEET **API STANDARD 535**	**USC UNITS**			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
			3 OF 3	

PURCHASER / OWNER :		**ITEM NO. :**
SERVICE :		**LOCATION:**

1	**GENERAL DATA**			**REV**
2	TYPE OF HEATER			
3	* ALTITUDE ABOVE SEA LEVEL, m.			
4	* AIR SUPPLY:			
5	AMBIENT / PREHEATED AIR / GAS TURBINE EXHAUST			
6	TEMPERATURE, °C. (MIN. / MAX. / DESIGN)			
7	RELATIVE HUMIDITY, %.			
8	DRAFT TYPE: FORCED / NATURAL / INDUCED			
9	DRAFT AVAILABLE: ACROSS BURNER, Pa.			
10	ACROSS PLENUM, Pa.			
11	* REQUIRED TURNDOWN			
12	BURNER WALL SETTING THICKNESS, mm.			
13	HEATER CASING THICKNESS, mm.			
14	FIREBOX HEIGHT, m.			
15	TUBE CIRCLE DIAMETER, m.			
16	**BURNER DATA**			
17	MANUFACTURER			
18	TYPE OF BURNER			
19	MODEL / SIZE			
20	DIRECTION OF FIRING			
21	LOCATION (ROOF / FLOOR / SIDEWALL)			
22	NUMBER REQUIRED			
23	MINIMUM DISTANCE BURNER CENTERLINE, m.:			
24	TO TUBE CENTERLINE (HORIZONTAL / VERTICAL)			
25	TO ADJACENT BURNER CENTERLINE (HORIZONTAL / VERTICAL)			
26	TO UNSHIELDED REFRACTORY (HORIZONTAL / VERTICAL)			
27	BURNER CIRCLE DIAMETER, m.			
28	* PILOTS:			
29	NUMBER REQUIRED			
30	TYPE			
31	IGNITION METHOD			
32	FUEL			
33	FUEL PRESSURE, kPa.g.			
34	CAPACITY, MW.			
35	**OPERATING DATA**			
36	* FUEL			
37	HEAT RELEASE PER BURNER, MW. (LHV)			
38	DESIGN			
39	NORMAL			
40	MINIMUM			
41	* EXCESS AIR @ DESIGN HEAT RELEASE, %.			
42	AIR TEMPERATURE, °C.			
43	DRAFT (AIR PRESSURE) LOSS, Pa.			
44	DESIGN			
45	NORMAL			
46	MINIMUM			
47	FUEL PRESSURE REQUIRED @ BURNER, kPa.g.			
48	FLAME LENGTH @ DESIGN HEAT RELEASE, m.			
49	FLAME SHAPE (ROUND, FLAT, ETC.)			
50	ATOMIZING MEDIUM / OIL RATIO, kg/kg.			
51	NOTES:			
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BURNER DATASHEET **API STANDARD 535**	**SI UNITS**			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
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GAS FUEL CHARACTERISTICS

1	* FUEL TYPE				REV
2	* HEATING VALUE (LHV) (kJ/Nm^3) (kJ/kg)				
3	* SPECIFIC GRAVIRTY (AIR = 1.0)				
4	* MOLECULAR WEIGHT				
5	* FUEL TEMPERATURE @ BURNER, °C.				
6	* FUEL PRESSURE; AVAILABLE @ BURNER, kPa.g.				
7	* FUEL GAS COMPOSITION, MOLE % .				
8	CH4				
9	C2H6				
10	C3H8				
11	C4H10				
12	C5H12				
13	H2				
14	N2				
15					
16	TOTAL				

17	**LIQUID FUEL CHARACTERISTICS**			
18	* FUEL TYPE			
19	* HEATING VALUE (LHV) , kJ/kg.			
20	* SPECIFIC GRAVITY / DEGREE API			
21	* H / C RATIO (BY WEIGHT)			
22	* VISCOSITY, @ °C. (SSU)			
23	@ °C. (SSU)			
24	* VANADIUM, ppm.			
25	* SODIUM, ppm.			
26	* POTASSIUM, ppm.			
27	* NICKEL, ppm.			
28	* FIXED NITROGEN, ppm.			
29	* SULFUR, % wt.			
30	* ASH, % wt.			
31	* LIQUIDS: ASTM INITIAL BOILING POINT, °C.			
32	ASTM END POINT, °C.			
33	* FUEL TEMPERATURE @ BURNER, °C.			
34	* FUEL PRESSURE AVAILABLE / REQUIRED @ BURNER, kPa.g.			
35	* ATOMIZING MEDIUM: AIR / STEAM / MECHANICAL			
36	TEMPERATURE, °C.			
37	PRESSURE, kPa.g.			

38	**MISCELLANEOUS**			
39	BURNER PLENUM:	COMMON / INTEGRAL		
40		MATERIAL		
41		PLATE THICKNESS, mm.		
42		INTERNAL INSULATION		
43	INLET AIR CONTROL:	DAMPER OR REGISTERS		
44		MODE OF OPERATION		
45		LEAKAGE, %.		
46	BURNER TILE:	COMPOSITION		
47		MINIMUM SERVICE TEMPERATURE, °C.		
48	NOISE SPECIFICATION			
49	ATTENUATION METHOD			
50	PAINTING REQUIREMENTS			
51	IGNITION PORT:	SIZE / NO.		
52	SIGHT PORT:	SIZE / NO.		
53	* FLAME DETECTION:	TYPE		
54		NUMBER / LOCATION		
55		CONNECTION SIZE		
56	SAFETY INTERLOCK SYSTEM FOR ATOMIZING MEDIUM & OIL			
57	* PERFORMANCE TEST REQUIRED (YES or NO)			
58	NOTES:			
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BURNER DATASHEET **API STANDARD 535**	**SI UNITS**			
	PROJECT NUMBER	DOCUMENT NUMBER	SHEET	REV
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EMISSION REQUIREMENTS

1	FIREBOX TEMPERATURE, ^{o}C.		**REV**
2	NOx * ppmv(d) or mg / Nm^3		
3	CO * ppmv(d) or mg / Nm^3		
4	UHC * ppmv(d) or kg / kJ (LHV)		
5	PARTICULATES * ppmv(d) or kg / kJ (LHV)		
6	SOx * ppmv(d) or mg / Nm^3		
7			
8	* CORRECTED TO 3% O$_2$ (DRY BASIS @ DESIGN HEAT RELEASE)		
9	NOTES:		
10	**1. VENDOR TO GUARANTEE BURNER FLAME LENGTH.**		
11	**2. VENDOR TO GUARANTEE EXCESS AIR, HEAT RELEASE, AND DRAFT LOSS ACROSS BURNER.**		
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Bibliography

[1] API Recommended Practice 556, *Instrumentation, Control and Protective Systems for Gas Fired Heaters*

[2] ASTM D396 [2], *Specification for Fuel Oils*

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[2] ASTM International, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, www.astm.org.

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