Burners for Fired Heaters in General Refinery Services

Manufacturing, Distribution and Marketing Department

API PUBLICATION 535
FIRST EDITION, JULY 1995

American
Petroleum
Institute

SPECIAL NOTES

1. API PUBLICATIONS NECESSARILY ADDRESS PROBLEMS OF A GENERAL NATURE. WITH RESPECT TO PARTICULAR CIRCUMSTANCES, LOCAL, STATE, AND FEDERAL LAWS AND REGULATIONS SHOULD BE REVIEWED.

2. API IS NOT UNDERTAKING TO MEET THE DUTIES OF EMPLOYERS, MANUFACTURERS, OR SUPPLIERS TO WARN AND PROPERLY TRAIN AND EQUIP THEIR EMPLOYEES, AND OTHERS EXPOSED, CONCERNING HEALTH AND SAFETY RISKS AND PRECAUTIONS, NOR UNDERTAKING THEIR OBLIGATIONS UNDER LOCAL, STATE, OR FEDERAL LAWS.

3. INFORMATION CONCERNING SAFETY AND HEALTH RISKS AND PROPER PRECAUTIONS WITH RESPECT TO PARTICULAR MATERIALS AND CONDITIONS SHOULD BE OBTAINED FROM THE EMPLOYER, THE MANUFACTURER OR SUPPLIER OF THAT MATERIAL, OR THE MATERIAL SAFETY DATA SHEET.

4. NOTHING CONTAINED IN ANY API PUBLICATION IS TO BE CONSTRUED AS GRANTING ANY RIGHT, BY IMPLICATION OR OTHERWISE, FOR THE MANUFACTURE, SALE, OR USE OF ANY METHOD, APPARATUS, OR PRODUCT COVERED BY LETTERS PATENT. NEITHER SHOULD ANYTHING CONTAINED IN THE PUBLICATION BE CONSTRUED AS INSURING ANYONE AGAINST LIABILITY FOR INFRINGEMENT OF LETTERS PATENT.

5. GENERALLY, API STANDARDS ARE REVIEWED AND REVISED, REAFFIRMED, OR WITHDRAWN AT LEAST EVERY FIVE YEARS. SOMETIMES A ONE-TIME EXTENSION OF UP TO TWO YEARS WILL BE ADDED TO THIS REVIEW CYCLE. THIS PUBLICATION WILL NO LONGER BE IN EFFECT FIVE YEARS AFTER ITS PUBLICATION DATE AS AN OPERATIVE API STANDARD OR, WHERE AN EXTENSION HAS BEEN GRANTED, UPON REPUBLICATION. STATUS OF THE PUBLICATION CAN BE ASCERTAINED FROM THE API AUTHORING DEPARTMENT [TELEPHONE (202) 682-8000]. A CATALOG OF API PUBLICATIONS AND MATERIALS IS PUBLISHED ANNUALLY AND UPDATED QUARTERLY BY API, 1220 L STREET, N.W., WASHINGTON, D.C. 20005.

FOREWORD

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any federal, state, or municipal regulation with which this publication may conflict.

Suggested revisions are invited and should be submitted to the director of the Manufacturing, Distribution and Marketing Department, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C., 20005.

CONTENTS

Page

Tables

Burners for Fired Heaters in General Refinery Services

SECTION 1—GENERAL

1.1 Scope

This publication 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 publication does not provide rules for design, but indicates areas that need attention. This publication offers information on and descriptions of burner types available to the designer or user for purposes of selecting the appropriate burner for a given application.

The burner types discussed are those currently in industry use. There is no intention 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.

1.2 Referenced Publications

The editions of the following standards, codes, and specifications that are in effect at the time of publication of this publication shall, to the extent specified herein, form a part of this publication. Changes in referenced standards, codes, and specifications shall be agreed to by the owner and the vendor.

AMCA[1]

500 *Test Methods for Louvers, Dampers, and Shutters*

API

RP 533 *Air Preheat Systems for Fired Process Heaters*

Std 560 *Fired Heaters for General Refinery Services*

1.3 Definition of Terms

Some of the terms used in this standard are defined in 1.3.1 through 1.3.48.

1.3.1 *Air/fuel ratio* is the ratio of the combustion air flow rate to the fuel flow rate when both are measured under the same conditions. Air/fuel ratio is the reciprocal of fuel/air ratio.

1.3.2 The *air register* is that part of a burner that can admit combustion air through openings around the burner assembly.

1.3.3 *Atomization* is the breaking of a liquid into tiny droplets to improve fuel-air mixing and to improve combustion. Steam, air, and fuel gas are normal atomizing media. Atomization may also be accomplished by mechanical means.

1.3.4 The *auto-ignition temperature* is the lowest temperature required to initiate self-sustained combustion in the absence of a spark or flame.

1.3.5 *Blowoff* is the lifting of a flame due to the velocity of the fuel-air mixture exceeding the flame's velocity. This condition usually results in the flame's being extinguished.

1.3.6 A *bluff body stabilizer* is a solid or perforated restriction in a combustion air stream that creates a flame-stabilizing vortex downstream of the restriction.

1.3.7 A *burner* is 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 proper ignition and stable combustion.

1.3.8 The *burner block* is the refractory block surrounding the burner components. The block forms the burner's air flow opening and helps stabilize the flame. Synonyms are *burner tile*, *muffle block*, and *quarl*.

1.3.9 *Burner throat* is a restriction in the air flow path formed by the burner block and other burner components. The restriction initiates turbulence for the mixing of the fuel and air.

1.3.10 A *combination burner* is a burner capable of burning gas and oil individually or simultaneously.

1.3.11 *Combustion* is the rapid combination of fuel and oxygen that liberates heat.

1.3.12 *Combustion products* are the matter resulting from combustion, such as flue gases and ash.

1.3.13 *Draft* is the difference in pressure that causes the flow of combustion air into the heater. The pressure differential is caused by the difference in the densities of the combustion products in the heater and stack and the air external to the heater.

1.3.14 *Draft loss* is generally referred to as the air side pressure drop across a burner.

1.3.15 *Excess air* is the amount of air above the stoichiometric requirement for complete combustion, expressed as a percentage.

1.3.16 *Firing rate* is the rate at which fuel is supplied to a burner or heater. It is usually expressed in heat units such as British thermal units per hour (Btu/hr).

[1]Air Movement and Control Association, Inc., 30 West University Drive, Arlington Heights, Illinois 60004-1893.

1.3.17 *Flame temperature* is the temperature reached during sustained combustion within the burner flame. The adiabatic flame temperature is the theoretical flame temperature calculated at adiabatic conditions and corrected for dissociation.

1.3.18 *Flame velocity* is the rate at which a flame propagates through a combustible mixture.

1.3.19 *Flashback* is the phenomenon that occurs when a flame front propagates in the direction opposite to the fuel-air mixture flow. Flashback occurs when the flame velocity exceeds the velocity of the fuel-air mixture through a burner nozzle.

1.3.20 *Forced draft* is the difference in pressure produced by mechanical means that delivers air into a burner at a pressure greater than atmospheric.

1.3.21 *Fuel* is any matter that releases heat when combusted.

1.3.22 *Heat release* is the total heat liberated from the fuel, using the lower heating value of the fuel, expressed in Btu/hr.

1.3.23 *Heating value, higher* is the total heat obtained from the combustion of a specified fuel at 60°F, expressed as Btu per pound or per cubic foot; *gross heating value*.

1.3.24 *Heating value, lower* is the higher heating value minus the latent heat of vaporization of the water formed by combustion of hydrogen in the fuel, expressed in Btu per pound or per cubic foot; *net heating value*.

1.3.25 A *high-intensity burner* is a burner in which combustion is completed within a fixed volume resulting in a combustion intensity greater than 1,000,000 Btu/hr/cu.ft.

1.3.26 The *hydrogen/carbon ratio* is the weight of hydrogen in a hydrocarbon fuel divided by the weight of carbon.

1.3.27 An *igniter* is a device used to light a pilot burner.

1.3.28 *Induced draft* is the difference in pressure produced by mechanical means resulting in a negative pressure in the heater that serves to induce the flow of combustion air.

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

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

1.3.31 A *natural draft* is a difference in pressure resulting from the tendency of hot furnace gases to rise, thus creating a partial vacuum in the heater. This serves to draw combustion air into the burner.

1.3.32 The *pilot burner* is a small burner that provides ignition of the main burner.

1.3.33 The *plenum* is a chamber surrounding the burner(s) that is used to distribute air to the burner(s) or to reduce combustion noise; *windbox*.

1.3.34 *Preheated air* is air heated prior to its use for combustion. The heating is most often done by heat exchange with hot flue gases.

1.3.35 A *premix burner* is 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.

1.3.36 *Primary air* is that portion of the total combustion air that first mixes with the fuel.

1.3.37 A *radiant wall burner* is a premix burner where the flame does not project into the firebox but fans out alongside the wall on which it is installed.

1.3.38 A *raw gas burner* is a gas burner in which combustion takes place as the fuel is mixed with the combustion air downstream of the fuel discharge orifices; *nozzle mix burner*.

1.3.39 *Secondary air* is that portion of the total combustion air that is supplied to the products of combustion and unburned fuel downstream of the area in which primary air and fuel are mixed.

1.3.40 *Secondary fuel* is the remaining portion of fuel that is injected downstream of the burner block in a staged fuel burner.

1.3.41 A *spud* is a small drilled hole for limiting gas flow to a desired rate; *gas orifice*.

1.3.42 *Stability* is that quality of a burner enabling it to remain lit over a wide range of fuel-air mixture ratios and input rates.

1.3.43 A *staged-air burner* is 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 and unburned fuel from the primary combustion zone.

1.3.44 A *staged-fuel burner* is 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 a second portion of the fuel is injected downstream of the burner block to provide delayed combustion.

1.3.45 The *stoichiometric ratio* is the ratio of fuel and air required for complete combustion so that the combustion products contain no oxygen.

1.3.46 The *swirl number* is the ratio of angular to axial discharge momentum. The swirl number defines the amount of mixing and internal flame recirculation.

1.3.47 *Tertiary air* is that portion of the total combustion air that is supplied to the products of combustion downstream of the secondary zone.

1.3.48 *Turndown* is the ratio of the maximum to minimum fuel input rates of a burner while maintaining stable combustion.

1.4 Nomenclature

The type of burner is normally described by the fuel(s) being fired, the method of air supply, and emission requirements. Some fuels 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.

Figure 1 illustrates a raw gas burner. Figure 2 shows a premix gas burner, and Figure 3 shows a radiant wall burner. Figure 4 illustrates a combination oil and gas burner. Figures 5 and 6 show a low-NO_x, staged-air, combination oil and gas burner and a staged-fuel, gas burner, respectively. Figure 7 illustrates a high-intensity, combination oil and gas burner.

(Text continued on page 10.)

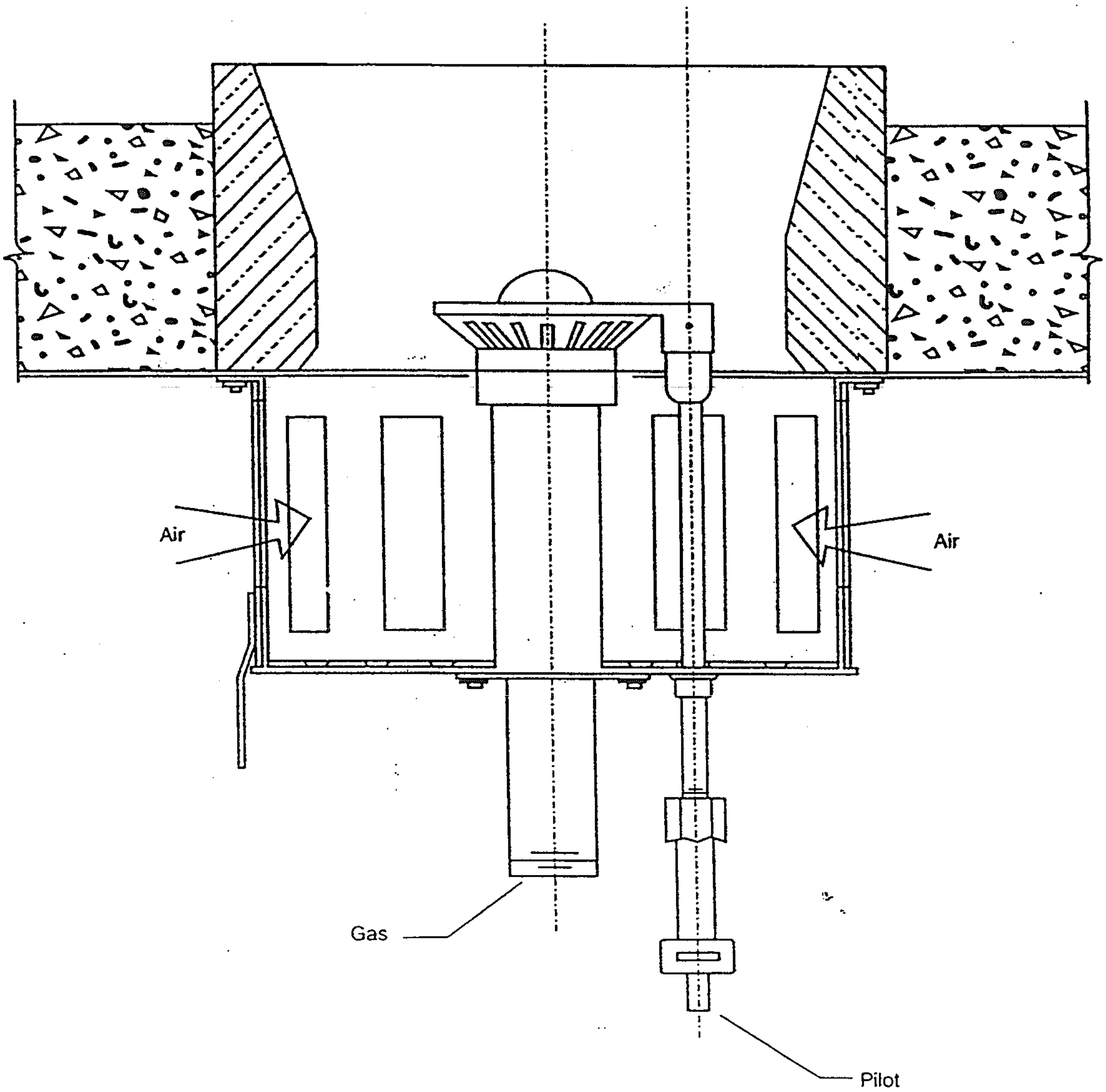


Figure 1—Typical Raw Gas Burner

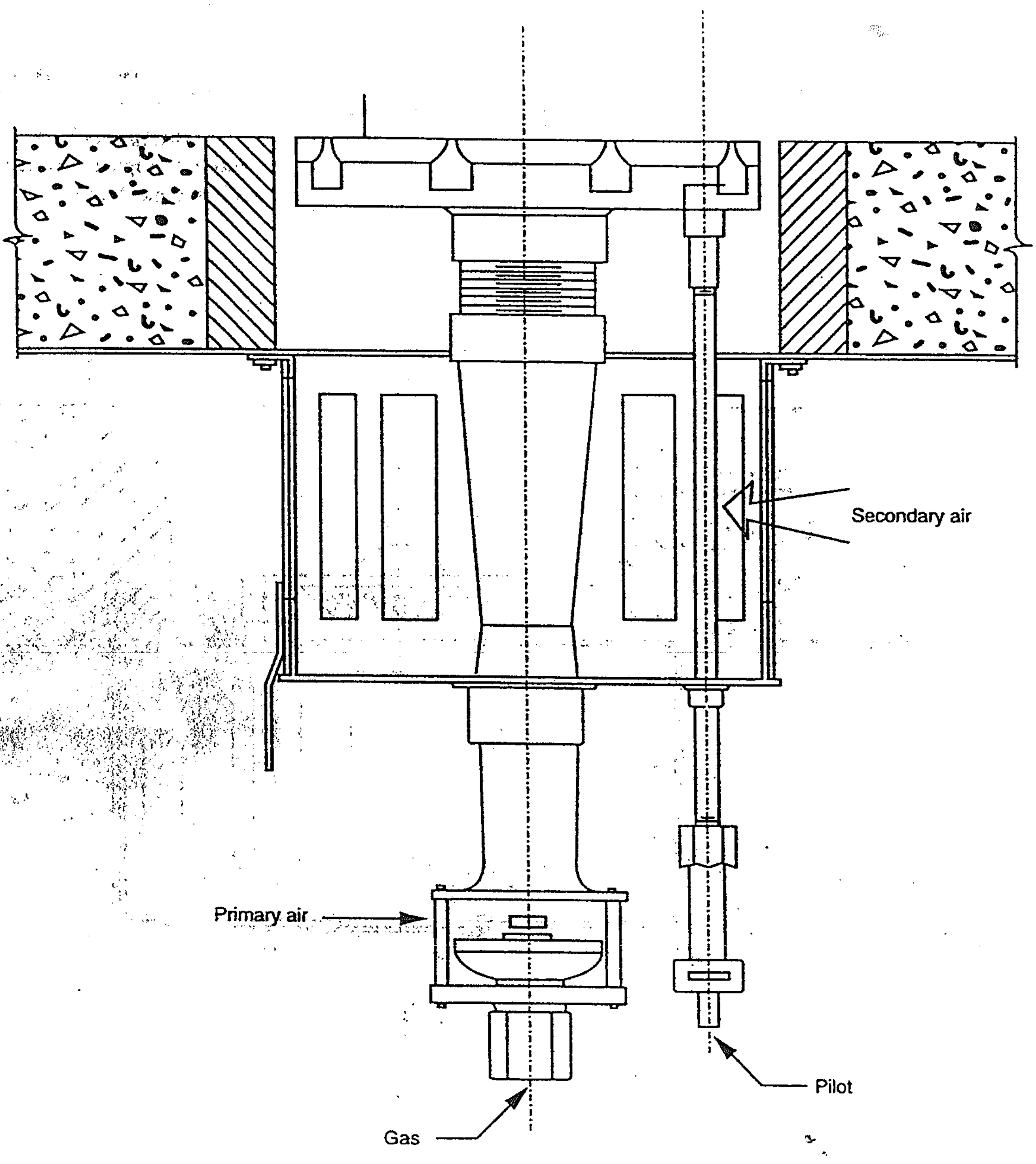


Figure 2—Typical Premix Gas Burner

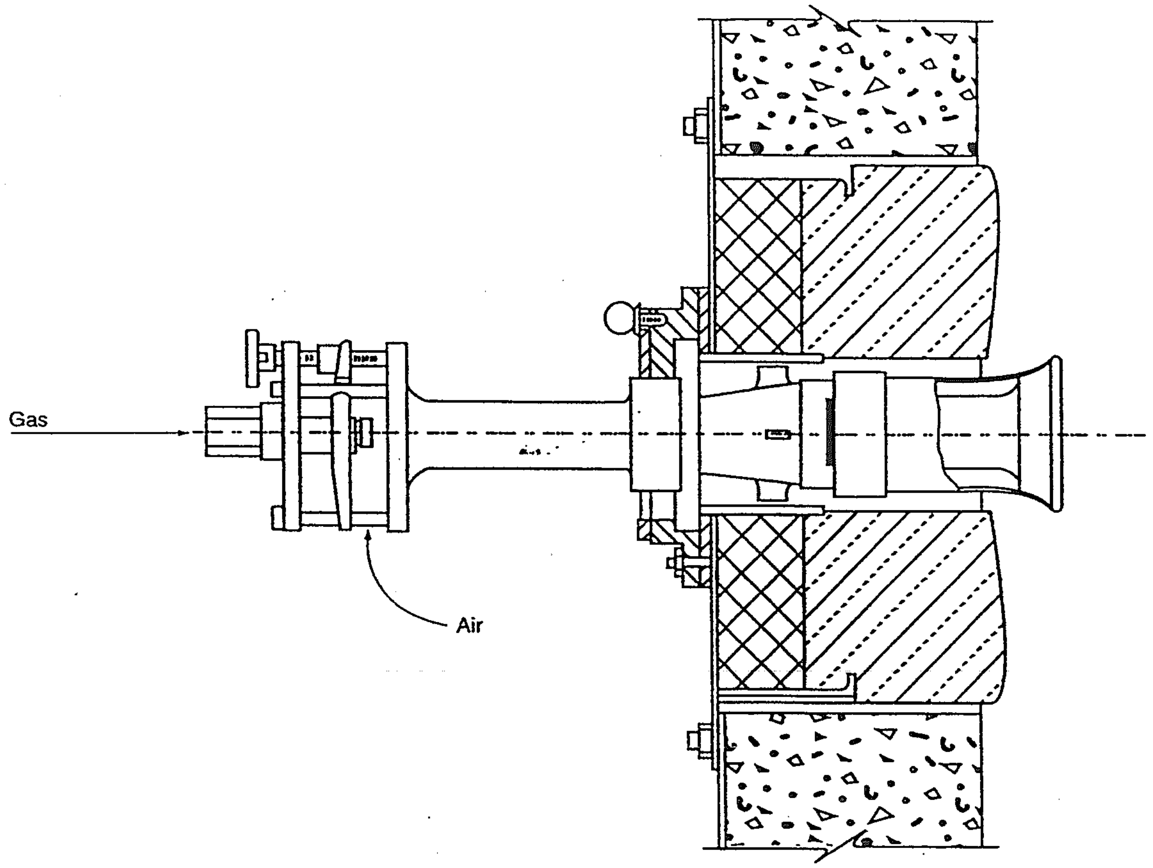


Figure 3—Typical Radiant Wall Burner

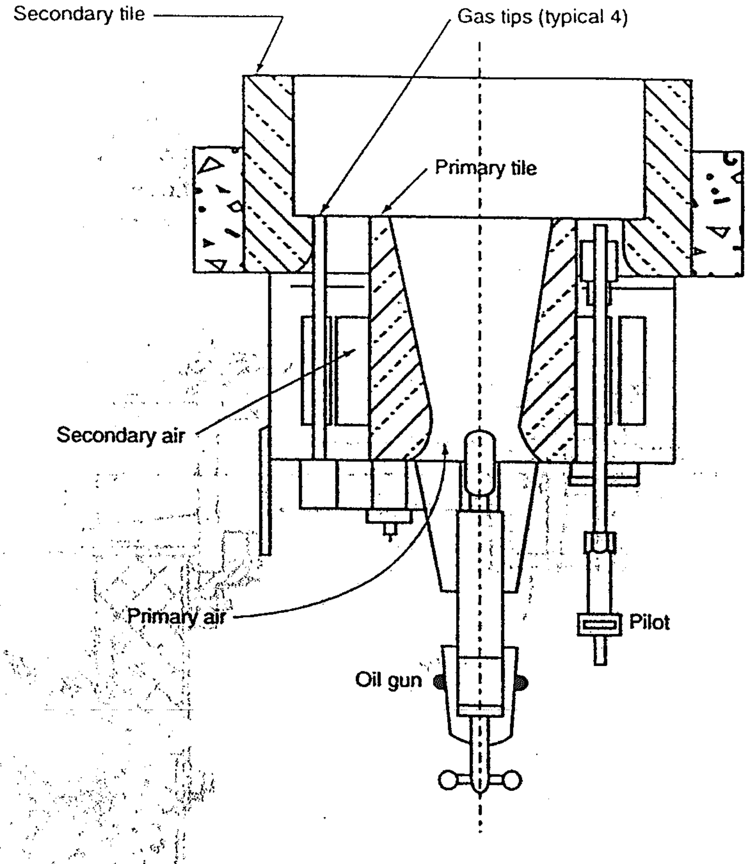


Figure 4—Typical Combination Oil and Gas Burner

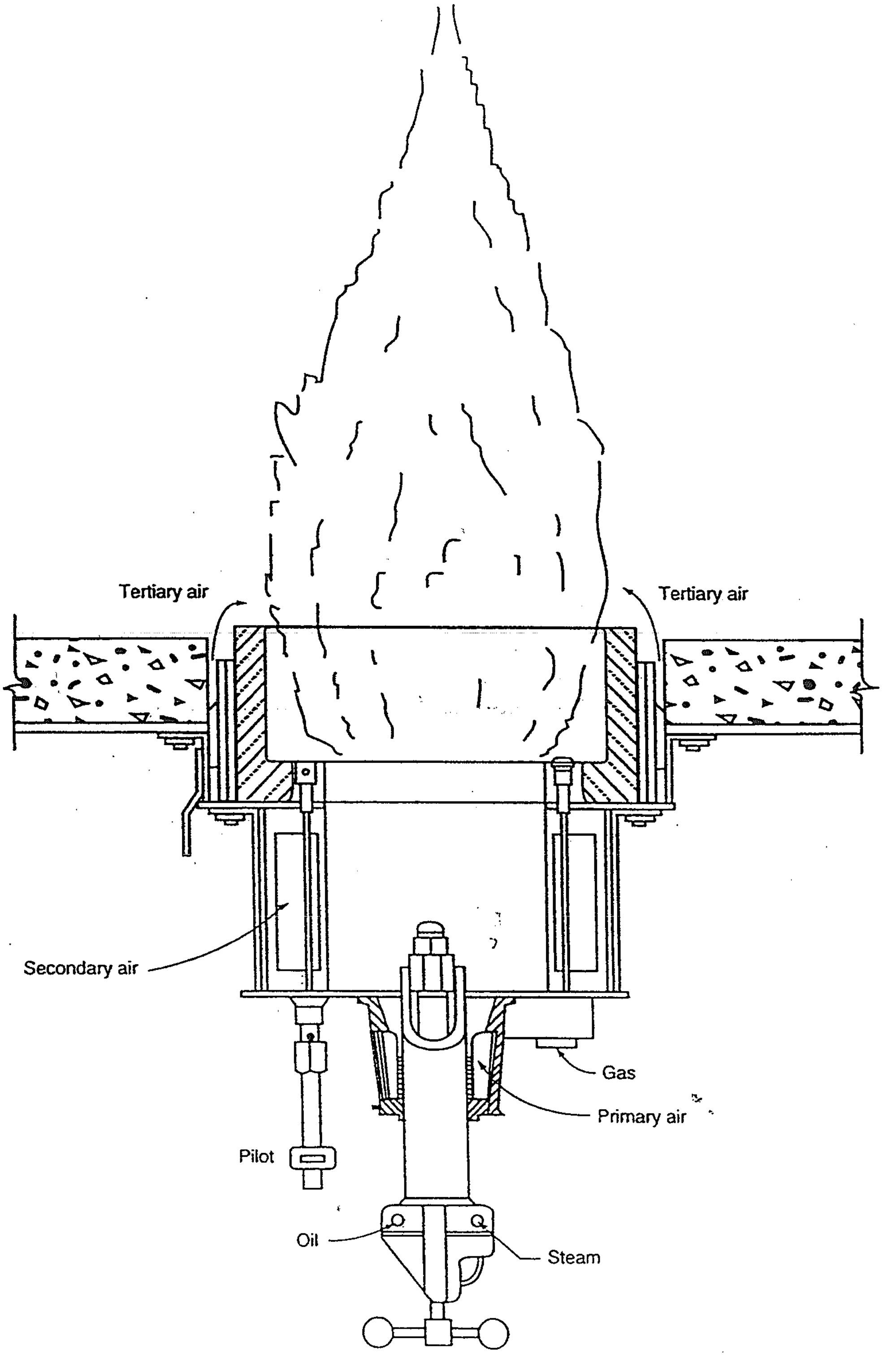


Figure 5—Typical Staged-Air, Combination Oil and Gas Burner

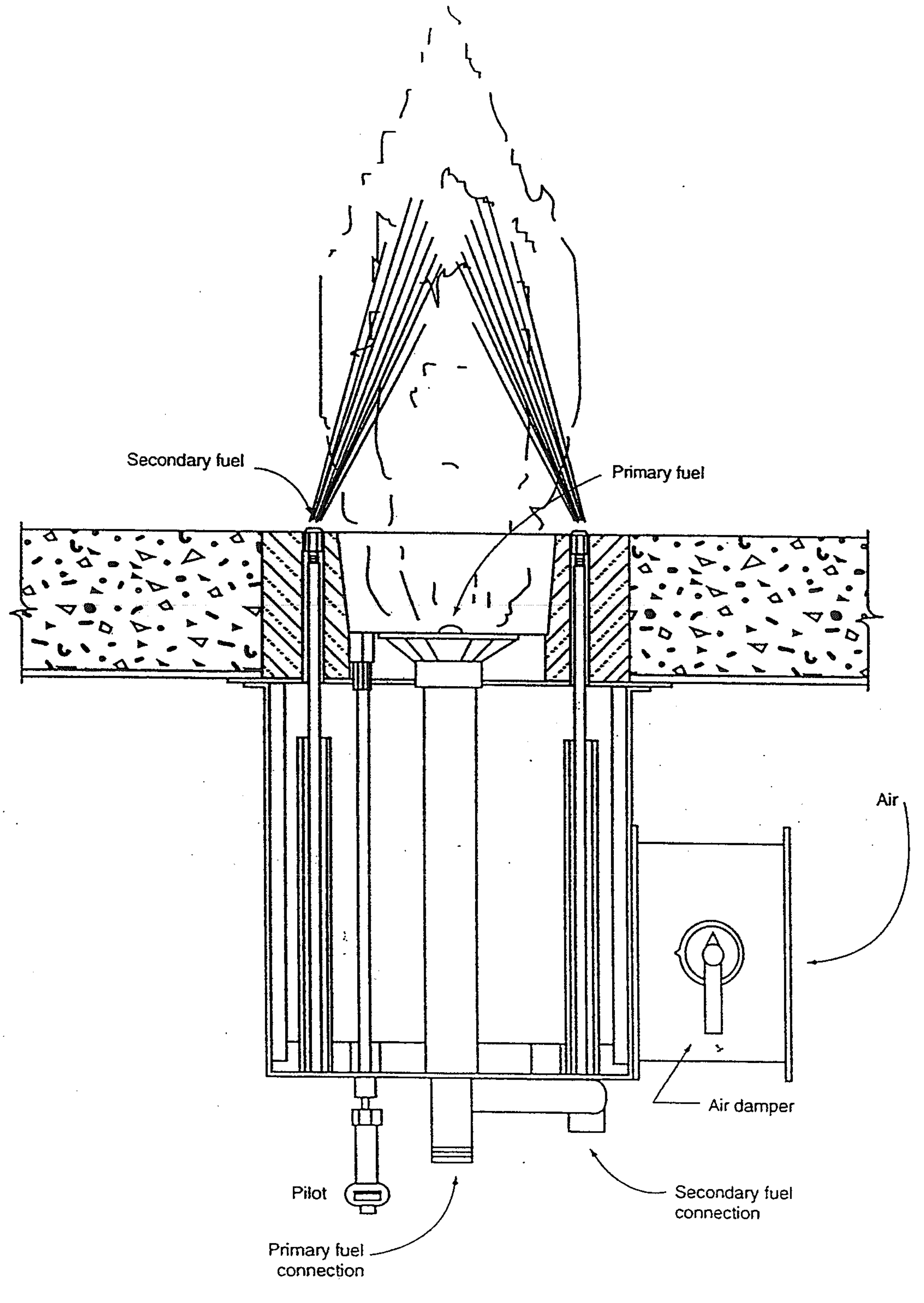


Figure 6—Typical Staged-Fuel Gas Burner

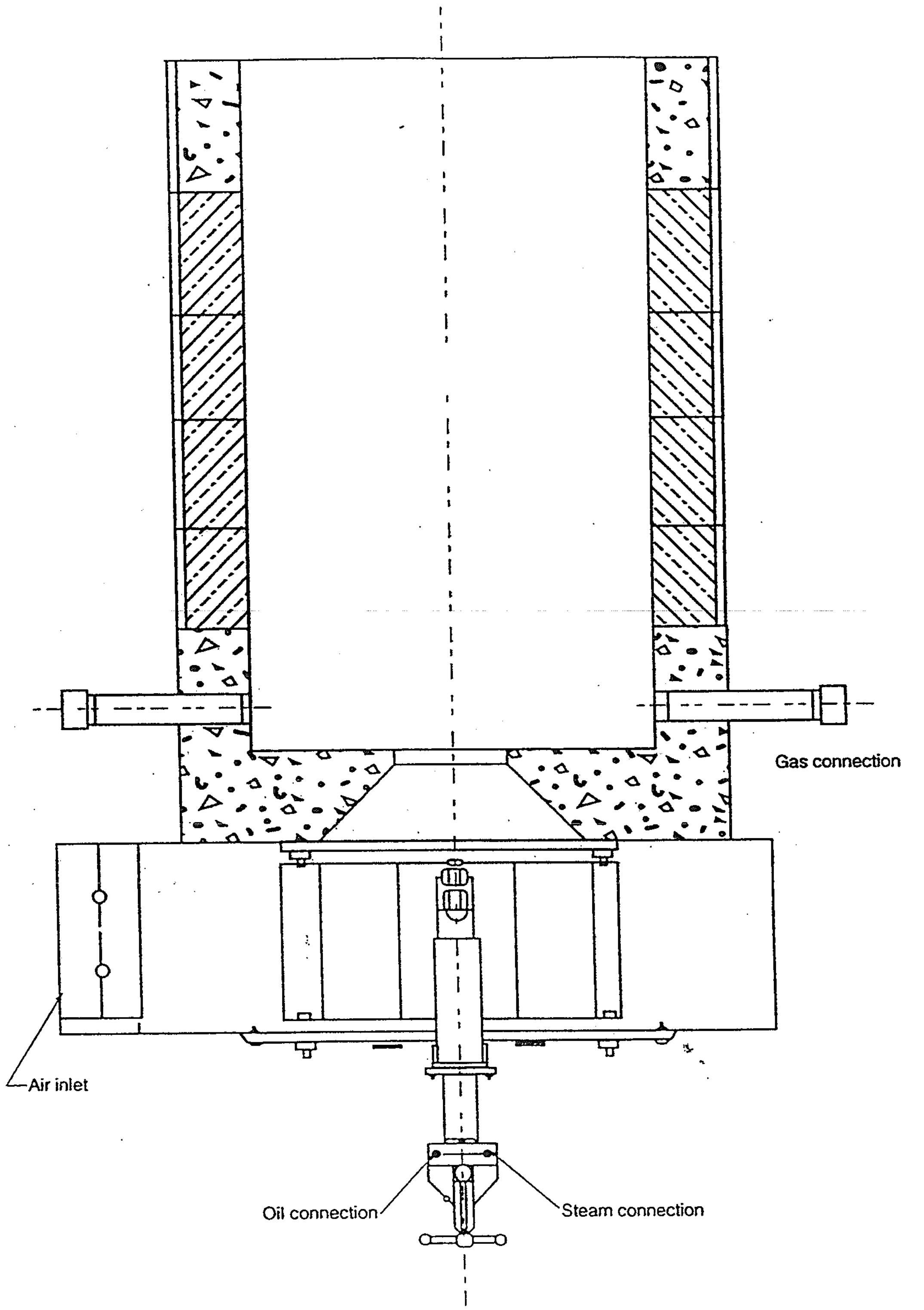


Figure 7—Typical High-Intensity, Combination Oil and Gas Burner

SECTION 2—ENVIRONMENTAL CONSIDERATIONS

2.1 General

CAUTION: Combustion reactions can produce noise and chemical compounds that may be of concern regarding humans, animals, and the environment. Different localities may have regulations that regulate these pollutants. The user must be aware of them. Different localities may have regulations that regulate noise. This publication is not undertaking the duties of employers, manufacturers, or suppliers to warn and properly train and equip their employees, and others exposed, concerning health and safety risks and precautions, nor undertaking their obligations under local, state, or federal laws.

2.2 Noise

The design of the burner can affect noise production. Fuels requiring high velocities, such as high-intensity designs or with high-hydrogen fuels, may raise noise levels. Forced draft burner systems—including fan, ducts, and burners as well as natural draft burners—may have to be insulated with noise-attenuating materials. Different localities may have regulations that regulate noise.

2.3 Flue Gas Emissions

2.3.1 NITROGEN OXIDES (NO_x, USUALLY REPORTED AS NO_2)

The majority of the nitrogen oxides formed by burners is in the form of nitric oxide (NO). NO is eventually transformed to nitrogen dioxide (NO_2) after discharging into the atmosphere.

NO_x Production Trends

Effect of excess oxygen: NO_x concentrations will increase as the excess oxygen increases in raw gas burners and will decrease in premix burners. This is true for typical refinery heater excess oxygen (1–5 percent O_2, wet basis) rates. As excess air is increased further to a raw gas burner, the NO_x concentration will reach a maximum. Beyond this point, the NO_x concentration begins to decline with a further increase in excess oxygen. This maximum may occur at excess air rates in the vicinity of 60–70 percent (7–8 percent O_2, wet basis).

Figure 8 demonstrates the effect excess oxygen has on NO_x production in raw gas burners.

Effect of combustion air temperature: 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.

Figure 9 demonstrates the effect the combustion air temperature has on NO_x production.

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

Figure 10 demonstrates the effect the firebox temperature has on NO_x production.

Effect of humidity: Some research (though not duplicated by others) has noted a tendency of NO_x concentrations to decline as moisture in the combustion air increases. This change is theorized to occur by the following mechanisms: (a) the inert water in the air reduces the flame temperature, and (b) the presence of water causes the water to disassociate with fuel constituents and improve the combustion process.

Effect of hydrogen in the fuel gas: NO_x concentrations tend to increase as the hydrogen content of a fuel gas i. increased. Increasing the hydrogen content will raise the flame temperature. The increase in flame temperature will produce more NO_x.

Figure 11 demonstrates the effect the hydrogen content of the fuel gas has on NO_x production.

Effect of nitrogen in the fuel oil: Nitrogen in fuel oil is converted to what is called *fuel NO_x*. The greater the quantity of nitrogen in the fuel oil, the greater the total NO_x produced.

Figure 12 demonstrates the effect the fuel oil nitrogen content has on NO_x production.

2.3.2 SULFUR OXIDES (SO_x, USUALLY REPORTED AS SO_2)

The production of sulfur oxides is a function of sulfur, H_2S, and other sulfur compounds in the fuel. Sulfur dioxide (SO_2) may make up 94–98 percent of the total sulfur oxides produced. The remainder is SO_3. Operation at low excess air rates will reduce the conversion of SO_2 to SO_3.

2.3.3 CARBON MONOXIDE (CO) AND COMBUSTIBLES

The carbon monoxide and combustibles exiting a burner will increase slowly as the excess air rate decreases. The increase will accelerate as excess air levels continue to decline. A further drop in excess air will produce an asymptotic increase in these levels.

The point at which the CO level begins to turn into an asymptote is referred to as the CO breakpoint. The CO breakpoint will vary depending upon the fuel and the burner.

Typical carbon monoxide control points range between 150 and 200 parts per million (ppm). This range usually results in the best overall heater efficiency. Certain localities may require lower emission limits.

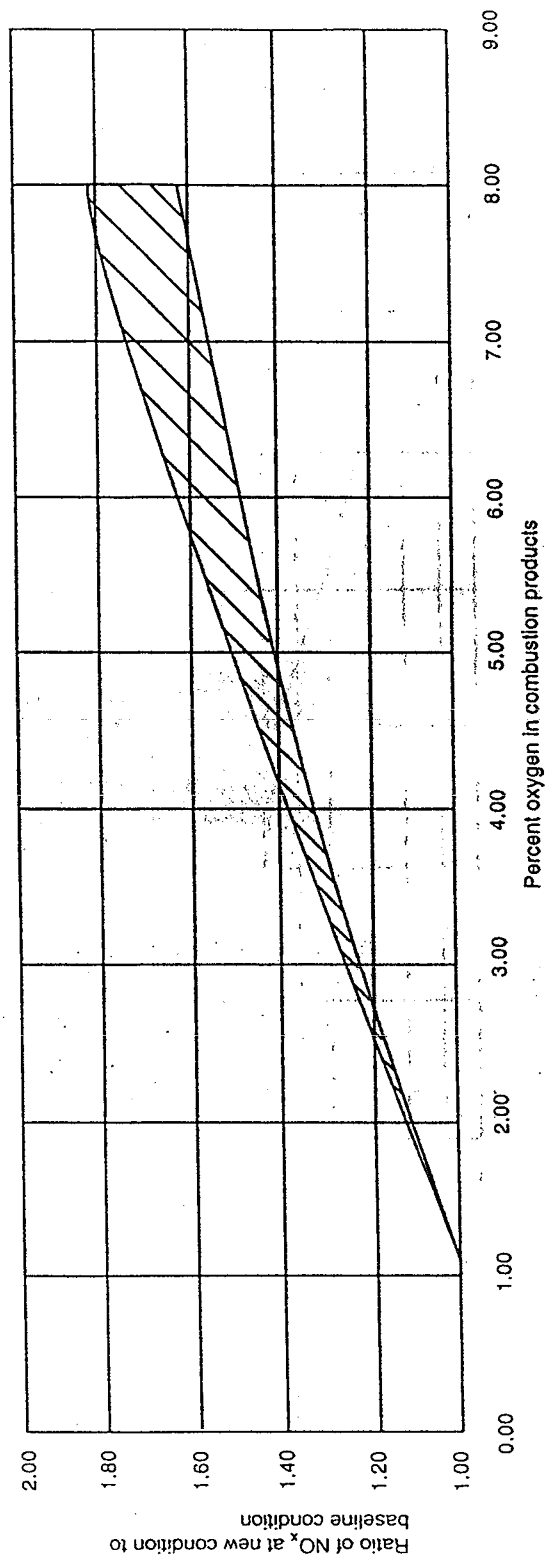


Figure 8—Effect of Excess Oxygen on NO_x in Raw Gas Burners

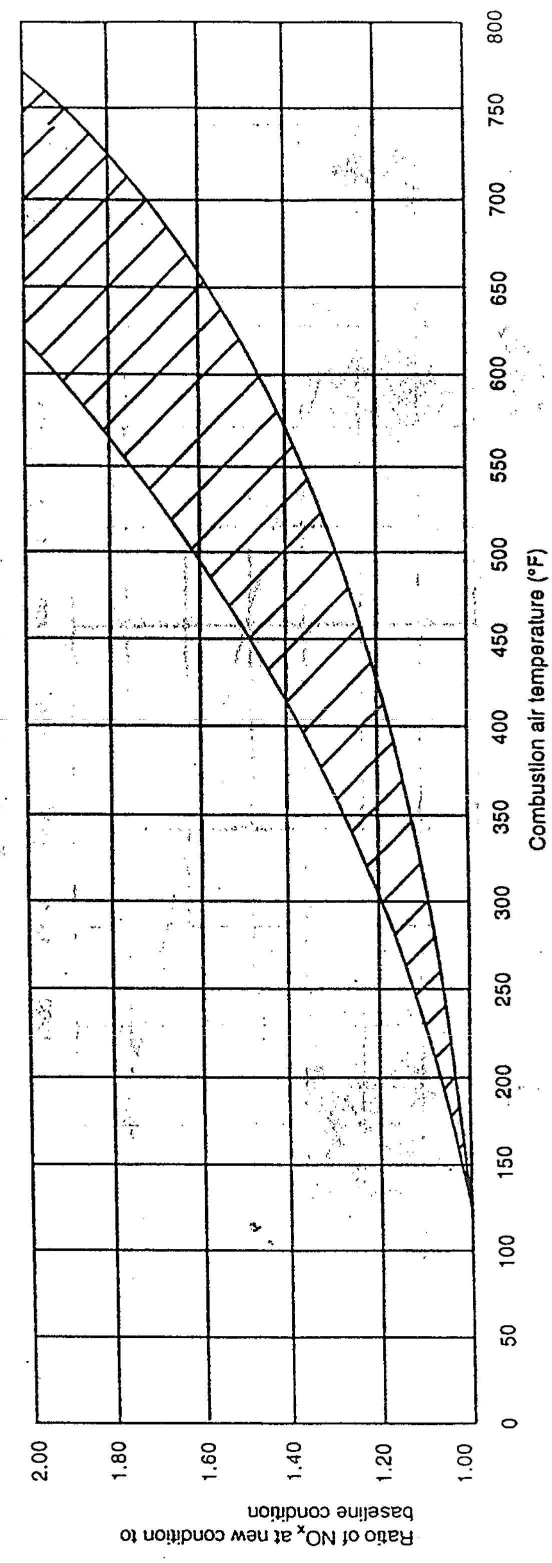


Figure 9—Effect of Combustion Air Temperature on NO_x

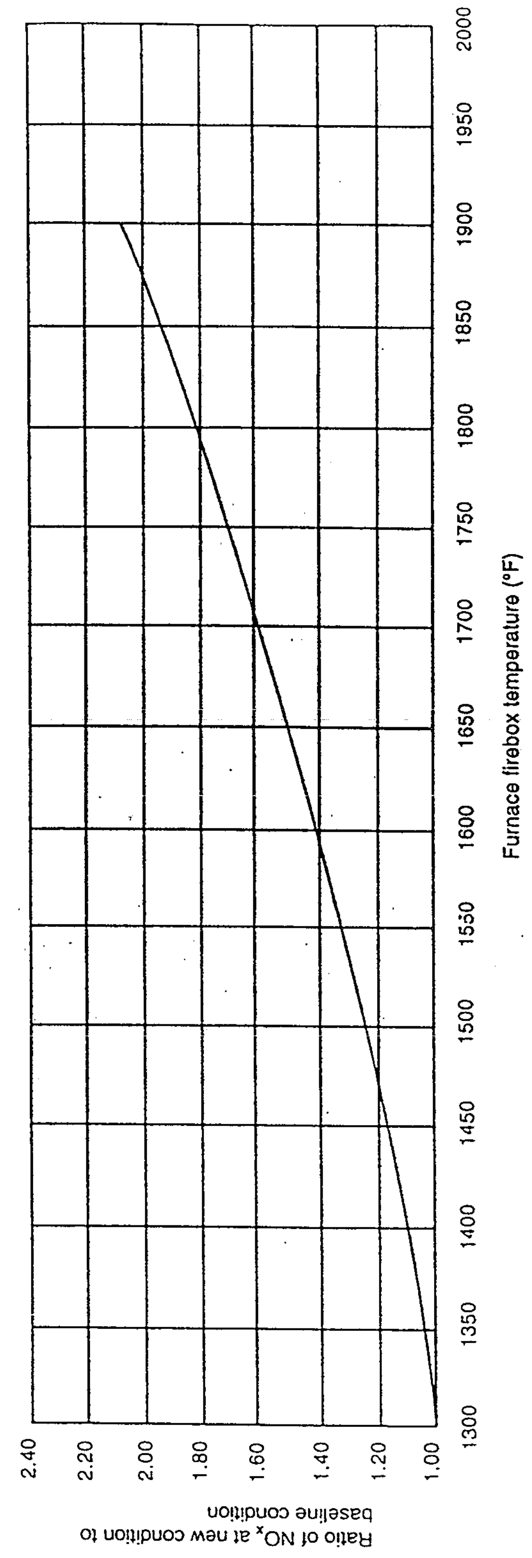


Figure 10—Effect of Firebox Temperature on NO_x

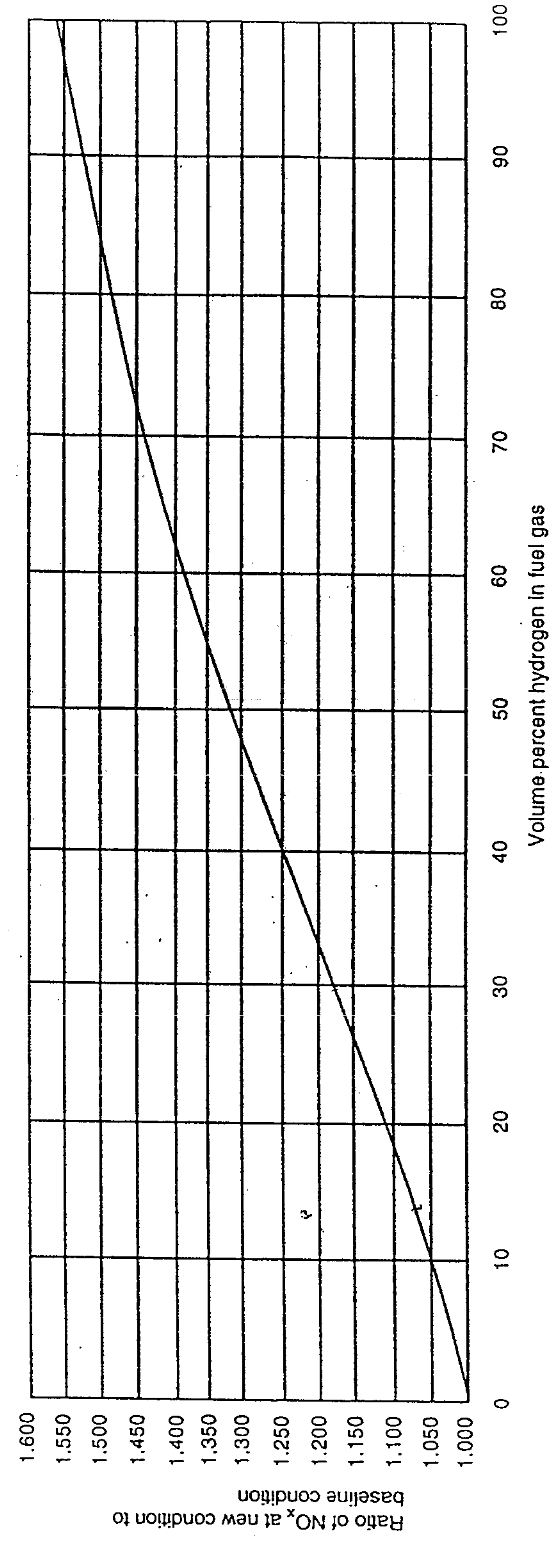


Figure 11—Effect of Fuel Gas Hydrogen on NO_x

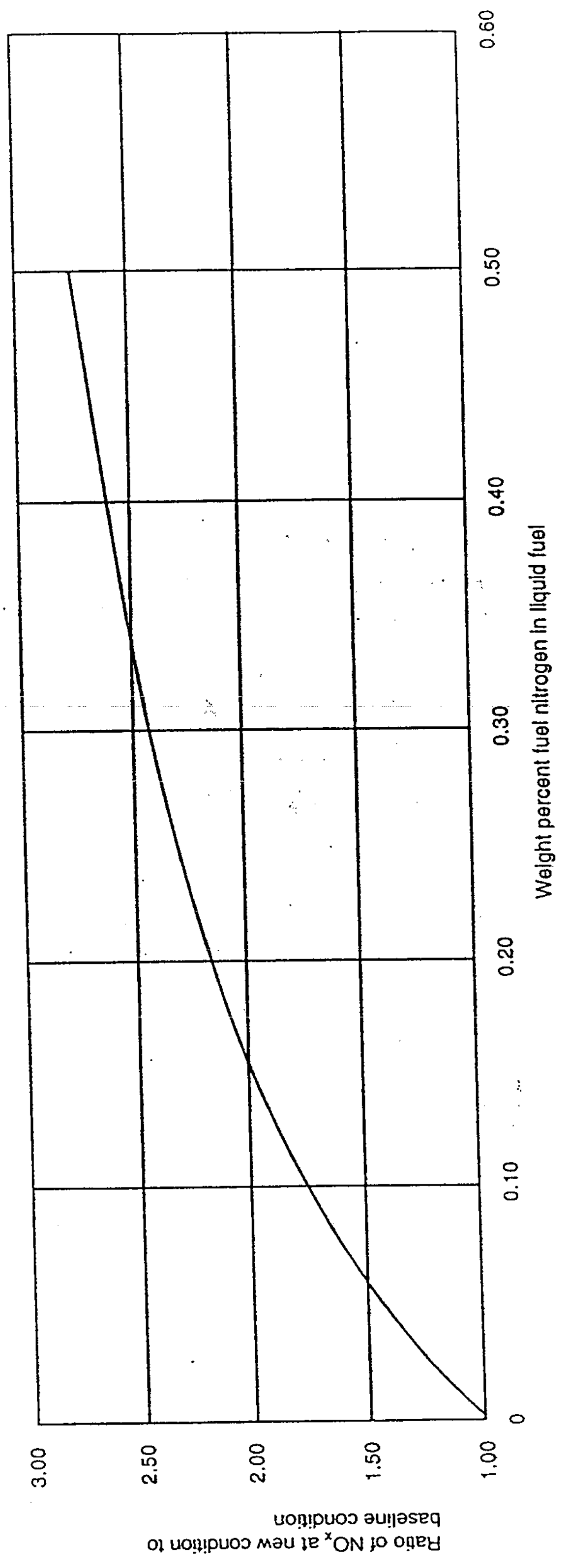


Figure 12—Effect of Bound Nitrogen in the Liquid Fuel on NO_x

2.3.4 PARTICULATES

All fuels will contain or produce particulates. Particulates will be formed in greater quantities in fuel oils (especially in heavy fuel oils) than in 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 reactions contribute to the quantity of the particulates. 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 within the combustion air in some locations.

2.4 Fuel Selection/Composition

The choice of fuel will play a role in the quantity of each pollutant leaving the heater.

2.4.1 NO_x

Fuel gases will generally produce lower NO_x levels than fuel oils.

Fuels with higher adiabatic flame temperatures will generally produce more NO_x. High-hydrogen fuels (producing high flame temperatures) will frequently produce more NO_x levels than others. Similarly, the addition of high-end (C4+) unsaturates will frequently raise flame temperatures and NO_x concentrations.

2.4.2 SULFUR OXIDES (SO_x, USUALLY REPORTED AS SO_2)

The quantity of sulfur or H_2S in the fuel will govern the quantity of SO_x produced. Reduction of SO_x emissions involves switching to a sweeter fuel or providing removal facilities downstream.

2.4.3 CARBON MONOXIDE (CO) AND COMBUSTIBLES

The combustion of hydrogen and paraffin-rich fuel gases will produce a minimum of combustibles including CO. The presence of unsaturated hydrocarbons can lead to pyrolysis and polymerization reactions resulting in a greater possibility that combustibles and CO will be produced. Unsaturated hydrocarbons, chlorides, amines, and the like can plug or damage burner tips disrupting the desired fuel/air mixing. This can raise the combustibles levels.

Heavy oils are more likely to produce greater levels of combustibles (including carbon monoxide) than lighter oils. Heavier components are not as easily atomized and ignited. Polymerization and pyrolysis reactions are more likely to occur.

2.4.4 PARTICULATES

Heavy fuel oils are more likely to produce greater levels of particulates than light oils. The Conradson carbon number and ash content can give the user a good comparative basis of the particulate-forming ability of two fuels.

2.5 Excess Air

Reducing excess air will typically have the effects on the emissions from any one style of burner shown in Table 1.

Table 1—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

2.6 Burner Selection

The owner should be aware that a burner chosen to limit one pollutant may produce higher emissions of another. A burner designed to produce a minimum of particulates may produce high NO_x levels.

2.6.1 NITROGEN OXIDES (NO_x)

The fuel composition will normally determine the NO_x level leaving a standard burner. The NO_x levels may be reduced 30 percent if staged air rather than standard burners are employed. The NO_x levels may be reduced 60 percent or more if staged-fuel burners (currently applicable to fuel gas firing only) rather than standard burners are employed. NO_x levels leaving staged-fuel burners may be reduced further with the addition of flue gas recirculation, whether internal or external to the firebox.

For additional information, see Section 6.

2.6.2 SO_x

Equivalent heat releases will result in equivalent SO_x emissions among different burners. SO_x emissions are a function of the fuel composition alone (see 2.3.2). Burners capable of operating at lower excess air rates will produce less SO_3. Burners with greater swirl and/or higher combustion air pressures (such as forced-draft burners) are more likely to operate at lower excess air rates than are standard, natural draft burners. Burners with greater swirl and/or higher combustion air pressures provide a superior degree of mixing to allow lower excess air rates. This provides a lower partial pressure of oxygen, reducing the formation of SO_3.

2.6.3 CARBON MONOXIDE (CO) AND COMBUSTIBLES

Burners with greater swirl and/or higher combustion air pressures (such as forced draft burners) will have lower CO breakpoints. These burners provide a superior degree of mixing to allow improved combustion at lower excess air rates. Combustibles and CO contents will be reduced at equivalent excess air rates.

2.6.4 PARTICULATES

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

Greater atomization of fuel oil into finer particles will reduce particulate emissions.

High-intensity burners can considerably reduce particulates formed in the combustion products. The high degree of swirl, coupled with the high-temperature reaction zone, induces superior combustion of the particulates. Such burners may increase NO_x levels substantially.

SECTION 3—COMBUSTION AIR

3.1 Draft

Burners are broadly categorized into two types: natural draft burners and forced-draft burners.

3.1.1 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 that educes the air through a venturi.

Natural draft burners are the simplest and least expensive burners available. They are also the most commonly found burners in refinery service.

3.1.2 FORCED-DRAFT BURNERS

Forced-draft burners are supplied with combustion air at a positive pressure. The term *forced draft* is used because the combustion air or other oxygen source is normally supplied by mechanical means (that is, a combustion air fan).

Forced-draft burners normally operate at an air side delivery pressure in excess of 2 inches H_2O (g). They utilize the air pressure to provide a superior degree of mixing between fuel and air.

Forced-draft burners are often used with air preheat systems. These burners are also used when turbine exhaust gas is supplied as a source of oxygen.

The operating disadvantage of a forced-draft system is the unreliability of the fan and driver. Failure of either may shut down the heater and unit. The user must either determine whether spare fans and drivers are required or accept a reduced load under natural draft conditions in the event of combustion air fan failure.

3.1.3 NATURAL DRAFT BURNERS IN FORCED-DRAFT SYSTEMS

Natural draft burners are sometimes specified in air preheat systems. Natural draft may be required when the air preheater, fans, or drivers fail. Air doors 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 process may necessitate oversized burners for the forced-draft, air-preheat cases. Burner overdesign factors should be carefully reviewed; otherwise, the system may be unsatisfactory for forced-draft operation.

The user should not specify additional margins to the burner heat release if there is a requirement that the burners should provide sufficient liberation for full duty under natural draft.

Careful layout of the ducting and fresh air doors is recommended when natural draft burners are used for both natural and forced-draft applications.

3.2 Design Excess Air

3.2.1 Excess oxygen required for good combustion depends on the burner design, the source of oxygen, the fuel fired, and the fuel conditions. Typical excess air levels for fired-heater design are given in Sections 4 and 5 for the respective fuels fired.

3.2.2 The design excess air of the burners may be lower than the specified excess air for the fired heater. The required excess air for the fired heater is governed by the number of burners, air distribution, and air leakage into the fired heater.

3.3 Combustion Air Preheat

3.3.1 The addition of heat to the combustion air increases the efficiency of the combustion process. Combustion air preheat systems are described in API Recommended Practice 533.

3.3.2 The flame temperature will increase with the addition of air preheat. This process will increase the percentage of NO_x in the flue gas. This effect has to be considered when specifying equipment for low-NO_x emissions.

3.4 Turbine Exhaust Gas

3.4.1 The oxygen for the combustion of fuels in fired heaters can be supplied by oxygen-containing gas streams such as the exhaust from a gas turbine.

3.4.2 Gas turbines operate at high excess air. The turbine exhaust stream contains between 13 and 17 mole percent of oxygen at temperatures between 850°F and 1050°F and up to 10 inches H_2O (g) pressure.

3.4.3 Burners can operate with oxygen contents down to approximately 15 volume percent in combustion-supporting streams. Combustion can become unstable below this level, depending upon the temperature and burner type. Burner vendors should be consulted about the feasibility of using combustion-supporting streams containing less than 15 mole percent of oxygen.

3.5 Combustion Air Adjustment

3.5.1 Burners are normally provided with air side control devices to adjust the air rate into the burner. Air registers or dampers are provided for this purpose.

3.5.2 Some burners are provided with a single air flow adjustment. Others have two or three separate devices to allow the operator to distribute the air in different proportions within the burner.

3.5.3 Dampers or registers are provided on forced-draft burners. Dampers or registers trim the air or provide a directional spin to aid mixing of the fuel and air. Some forced-draft burner vendors use the burner damper to evenly distribute the air throughout the burner. This damper is not intended to be moved except to isolate the burner when it is taken out of service. Total air flow to the fired heater is normally controlled at the forced-draft fan or by control louvers in the combustion air ducts.

3.6 Flame Stability

3.6.1 Good fuel and air mixing is one of the most important requirements for stable combustion. Mixing affects the fuel/air proportioning, ignition temperature, and speed of burning.

3.6.2 The mixing energy is measured at the point of discharge of the burner. Mixing energy is provided by the potential and kinetic energies of the fuel, the atomizing medium, and the combustion air.

3.6.3 The mixing of the combustion air with the fuel is critical to flame stability. Too high a velocity will not allow mixing to take place. The use of bluff body stabilizers to create local low-pressure eddies can improve the mixing between the fuel and air.

3.6.4 Forced-draft burners use a high air-side pressure differential across the burner throat. This creates turbulence within the burner, improving the mixing process.

3.6.5 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. Natural draft burners are more likely to have poorer mixing with burner turndown. Natural draft burners normally require larger excess air rates than forced-draft burners, particularly when operating at turndown.

3.6.6 The flame will go out if the temperature of the fuel/air mixture drops below the auto-ignition temperature. Primary combustion air has to be limited to prevent cooling the flame too much.

3.6.7 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 auto-ignition conditions.

3.6.8 Burners should be selected to use the maximum draft loss available across the burner tile for the highest specified liberation. This will improve the air/fuel mixing and the turndown.

SECTION 4—GAS FIRING

4.1 Raw Gas Firing (Nozzle Mix)

4.1.1 FUEL GAS PRESSURE

Raw gas burners can be designed to operate over a wide range of fuel gas pressures. The gas pressure is normally selected as 15–20 psig for design liberation. This ensures reasonable orifice diameters to reduce fouling problems during operation. It provides reasonable pressures for fuel/air mixing at turndown.

Some process off gas streams are available only at low pressures [around 8 inches H_2O (g)]. These streams may be fired in raw gas burners with proper tip design. These streams may be fired in combination with other fuels in separate burner guns.

4.1.2 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 high-hydrogen contents to large percentages of hydrocarbons with high-molecular weights. The gases can contain quantities of other compounds, such as inerts (namely CO_2, N_2, water vapor) and unsaturated hydrocarbons, all of which have to be considered in the burner design and selection.

Raw gas burners are used when the fuel gas hydrogen content is over 70 mole percent, when the fuel composition is constantly fluctuating or when the fuel gas contains a significant fraction of inerts (greater than 15 mole percent).

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 small orifices.

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

Waste gas or gases containing a high percentage of inerts may require supplementary firing with another gaseous or liquid fuel to stabilize the flame.

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/scf normally can operate without supplementary firing. Operation at lower heating values are possible if the fuel gas contains hydrogen.

When the waste gas represents a large portion of the heater liberation, the waste gas should be spread over a large number of burners so that it does not exceed 10 percent of the individual burner liberation. This is particularly important when the flow of the waste gas is uncontrolled.

4.1.3 TURNDOWN

Raw gas burners can operate with a turndown ratio of 5 to 1 based upon a single fuel composition.

The range of fuel composition, gravity, calorific value, and available fuel pressure will affect the acceptable operating range of the burner.

The low fuel gas pressure alarm and shutdown settings have to be selected within the stable operating range of the burner.

4.1.4 EXCESS AIR

The excess air values in Table 2 (excluding air leakage) are normally acceptable for good combustion on raw gas burners.

4.1.5 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 of 1–2 ft/MM Btu/hr for standard natural draft burners are typical for fuel gas firing.

The gas tip drilling angle of a centered gas nozzle in a round burner tile affects the length of the flame; a 70-degree firing port, total included angle produces a relatively long narrow flame while a 100-degree total included angle gives a relatively short, wide flame pattern.

Table 2—Excess Air Values for Raw Gas Burners

	Single Burner Systems	Multi-Burner Systems
Natural draft	10–15 percent	15–20 percent
Forced draft	5–10 percent	10–15 percent

Flat flame burners are designed with rectangular burner tiles and produce a fish-tail-shaped flame. These burners are used when firing close to refractory walls or where the tube clearance is limited.

4.1.6 BURNER LIBERATION

Natural-draft, raw gas burner liberation is normally within the range of 1.0–15 MM Btu/hr.

Forced-draft burner liberation range is normally 4–20 MM Btu/hr for fired heater applications.

High-intensity burners have heat liberations from 15 to 70 MM Btu/hr.

4.2 Premix Firing

4.2.1 FUEL GAS PRESSURE

The fuel pressure in a premix burner is used to inspirate combustion air through a venturi prior to ignition at the tip of the burner.

The fuel gas pressure range is 15–35 psig at design liberation.

The minimum fuel pressure is restricted by the composition and range of the fuel specified. The minimum is typically 3.0 psig.

4.2.2 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 must exceed the flame speed; otherwise, the flames will burn back inside the venturi (flashback). 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 mole percent 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 liberation. This variation 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 via a premix burner, but may be severely limited by the gas 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 educing medium.

4.2.3 TURNDOWN

The premix burner is normally limited in turndown to 3 to 1 for a single fuel gas composition.

The burner turndown ratio may be limited when operating with a range of gas compositions.

Turndown is normally limited by flashback inside the venturi when considering high-hydrogen-content fuels.

The maximum liberation 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 must be supplied to make up the deficiency.

4.2.4 EXCESS AIR

Premix burners can operate at lower excess air values than raw gas burners because of the improved air/fuel mixing. In a single burner, from 5- to 10-percent excess air may be achieved (see Table 3).

The primary air rate inspirated into the burner varies from 30–70 percent of the total combustion-air requirement for typical refinery premix burners. Unique furnace designs may require premix burners with as much as 100 percent primary air.

4.2.5 DRAFT

Premix burners can be stable with very low draft (minimum 0.05–0.10 inches H_2O at the burner level when 100 percent 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 MM Btu/hr) burners may not be capable of operating without a higher percentage of secondary air.

4.2.6 FLAME CHARACTERISTICS

The flame characteristics are as follows:

a. The flame volume of a premix burner is smaller and more defined when compared to a raw gas design.
b. The flame shape is determined by the design of the gas tip and, to a certain extent, by the shape of the refractory tile.
c. Designs with round tips produce a thin pencil-like flame.
d. Spider tips produce a short, compact flame.
e. Fish tail tips produce a fan-shaped flame for flat flame applications.
f. With radiant wall burners, the flame is designed to spread across the burner tile and the furnace wall refractory without any forward projection into the firebox.

4.2.7 BURNER LIBERATION

The heat release for various burner designs normally varies from 0.5 to 15 MM Btu/hr.

Table 3—Excess Air Values for Premix Burners

Operation	Burner Type	Percent Excess Air: Single Burner Systems	Percent Excess Air: Multi-Burner Systems
Natural draft and Forced draft	Premix	5–10	10–20

SECTION 5—LIQUID FUEL FIRING

5.1 Types of Fuel Oil

Liquid fuels vary in composition, specific gravity, and viscosity. Light fuel oils, such as naphtha and light distillates, differ considerably from 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 proper mixing of the combustion air and fuel. Successful combustion of liquid fuels is dependent upon the atomizer design and the fuel/atomizing medium conditions.

Lighter oils are easier to burn than heavier oils. Very heavy oils are difficult to atomize (see 5.2), especially in small heat release oil guns because of small passages. Conversion from light to heavy oil and vice versa may require a different oil gun to obtain good flame patterns.

CAUTION: a. Naphtha is a mixture of liquid hydrocarbons having a true boiling point (TPB) range as broad as 60–400°F 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.

b. Naphtha is a highly flammable liquid and vaporizes at relatively low temperatures. Naphtha use requires more stringent safety precautions to protect against fire and furnace explosions.

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

d. Purging with steam before light-off, before burner gun removal and after shutdown is most important for naphtha and light distillate fuels. A purge steam connection should be provided from the steam 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.

e. 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.

f. It is mandatory that a safety interlock be provided 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 steam purge of the gun before removal. The interlock should ensure that the fuel flow cannot be turned on while the gun is removed.

5.2 Atomization

5.2.1 General

Atomizer types commonly used in industry are as follows:

a. *Atomizing median type*: Separate atomizing mediums may be employed such as steam or air. Almost any gas or vapor can be used to atomize liquid fuel if it is available in sufficient quantity and pressure.

b. *Mechanical atomization type*: The term *mechanical atomization* is normally associated with pressure jet atomization.

5.2.2 STEAM ATOMIZATION

5.2.2.1 Steam is the most common medium for liquid fuel atomization in refinery practice.

5.2.2.2 Steam must be supplied dry or slightly superheated. Typically atomizers require a pressure of 100–150 psig. Higher steam pressures (300–400 psig) may be required when atomizing heavy liquid fuels such as residuals and pitch.

5.2.2.2.1 Wet steam must be avoided to prevent wate droplets forming in the pipework or burner gun. The heat to vaporize the water will absorb much of the heat necessary for ignition and complete combustion.

5.2.2.2.2 A high degree of steam superheat can partially vaporize the liquid fuel within the burner gun. This can cause oil gun vapor lock.

5.2.2.3 Steam atomization and steam assist atomization are most common. 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.

5.2.2.3.1 Steam (inside mix) atomizers are as follows:

a. A steam or internal mix atomizer is shown in Figure 13. Circled Item 1 is a limiting orifice for fuel oil flow. Steam is injected through the steam ports (Item 2) and mixed with partially atomized fuel oil. The steam and oil mixture is discharged through the tip ports (Item 3) where additional atomization and flame-shaping occurs.

b. Fuel pressure is typically in the range of 80–120 psig. Lower fuel oil pressures normally limit the turndown; whereas, higher fuel oil pressures will reduce steam consumption. The atomizing steam pressure is normally maintained at a constant differential pressure of approximately 20–30 psi above the fuel pressure.

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

d. 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.

5.2.2.3.2 Steam assist (port mix or Y jet) atomizers are as follows:

a. A steam assist or port mix atomizer is shown in Figure 14. The fuel oil is supplied through a series of limiting orifices in the tip (circled Item 1). A set of steam orifices (circled Item 2) is also found in the tip. The fuel oil and steam mix in the discharge port where final atomization takes place.
b. Steam pressure is normally held constant at approximately 100–150 psig throughout the operating range.
c. The steam consumption is approximately 0.10–0.20 pounds per pound of fuel oil at maximum liberation. The steam rate per pound of fuel will increase at turndown since the steam is at constant pressure.
d. The steam assist atomizer is mainly selected for larger heat release burners. The main advantage of this atomizer is low steam consumption while the disadvantages include small fuel oil ports and high fuel oil and steam pressure requirements.

5.2.2.4 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.

5.2.3 AIR ATOMIZATION

Air atomization is often recommended when light fuel oils are to be fired.

Compressed air can 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 100–120 psig plant air pressure is suitable.

Low pressure (1–2 psig) air atomization can be provided in some burner designs.

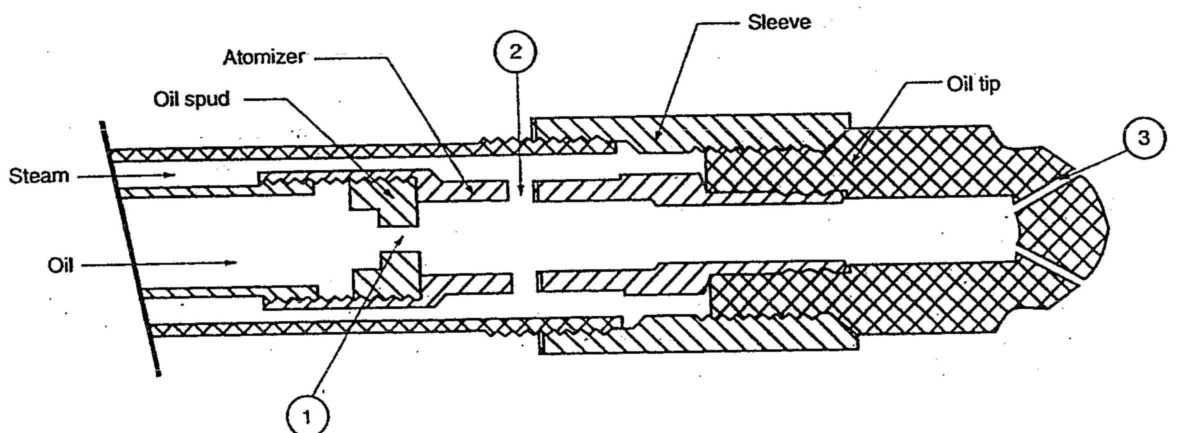


Figure 13—Typical Inside Mix Steam Atomizer

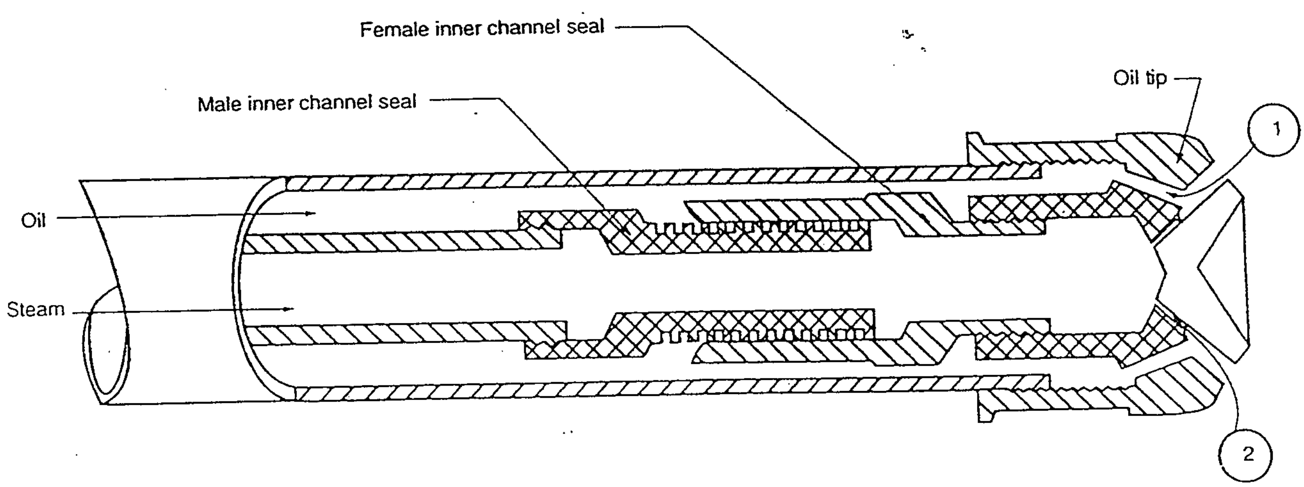


Figure 14—Port Mix or Steam Assist Atomizer

5.2.4 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 80–100 psig. To obtain a turndown of 3 to 1, the fuel pressure for the design liberation would be 700–900 psig.

This type of atomization is usually found only with burners of high heat release. The orifice size is small and is susceptible to fouling in small burners.

The high fuel oil pressures used for this type of atomizer require special safety considerations.

Mechanical atomization is normally used when no other atomizing medium is available.

5.3 Fuel Physical Properties

5.3.1 TEMPERATURE AND VISCOSITY

Fuel oil temperatures must be sufficient to get the correct viscosity for proper combustion. Table 4 provides viscosities required.

Viscous liquid fuels (such as #6 oil, vacuum bottoms, pitch, tar, and the like) 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. The fuel temperature for fuel oils with a wide boiling range must not be too high, or vaporization in the oil gun will occur.

5.3.2 FUEL COMPOSITION AND EFFECTS

5.3.2.1 Water

High water levels in the fuel can result in an 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.

Table 4—Typical Fuel Oil Viscosity Requirements at the Burners

Design Viscosity	Maximum Viscosity
120 SSU	200 SSU
25 Cs	45 Cs

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

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

5.3.2.2 Solids

Sediment often leads to atomizer plugging and flameout. Special hardened steels are required to reduce erosion (see 8.6.2). The fuel oil should be filtered through a duplex strainer to prevent burner plugging. The strainer shall contain screens whose openings are no larger than half the size of the smallest downstream orifice. Severe erosion can also result when fine particulates such as catalyst fines are present. Filters are recommended for pilot gas lines because of the pilot's small orifice diameters.

5.3.2.3 Ash

High vanadium and/or sodium levels will cause degradation of the burner refractory. Special high alumina refractory can be used in the burner tiles to reduce degradation. The need for 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 the expected frequency of replacement. Subsection 8.6.4 describes burner block materials.

5.3.2.4 Carbon Content

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

5.3.2.5 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.

5.3.2.6 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.

5.3.2.7 High-Wax Content

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

5.3.2.8 Nitrogen Content

Fuel bound nitrogen results in higher NO_x emissions.

5.3.3 FLAME STABILITY

Flame stability is dependent upon good fuel/air mixing. There must be good atomization to achieve good mixing.

The oil tip is positioned in the primary tile to maximize flame stability for oil firing. The primary tile or block creates a low-pressure zone in the vicinity of the oil tip. The low-pressure zone 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 primary tile, the recirculation effect is lost, and flame stability suffers. If the oil tip is too low in the primary tile, impingement of raw oil on the tile 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 cause flame instability.

5.4 Turndown

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

5.4.2 Typical turndown ratios and fuel pressures are as shown in Table 5.

5.4.3 The size of the burner is a factor in determining the turndown. Small burners have a lower turndown ratio.

5.5 Excess Air

5.5.1 Typical excess air values for burners firing a single liquid fuel are as shown in Table 6.

5.5.2 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.

Table 5—Typical Turndown Ratios and Fuel Pressure for Liquid Fuel Firing

Atomizer Type	Turndown Ratio	Design Pressure (psig)	Minimum Pressure (psig)
Internal mix	3 to 1	120	30
Port mix	4 to 1	150	30
Mechanical	2 to 1	600	100

Table 6—Typical Excess Air Values for Liquid Fuel Firing

Operation	Fuel	Excess Air (percent)	
		Single Burner Systems	Multi-Burner Systems
Natural draft	Naphtha	10–15	15–20
	Heavy fuel oil	20–25	25–30
	Residual fuel oil	25–30	30–35
Forced draft	Naphtha	10–12	10–15
	Heavy fuel oil	10–15	15–25
	Residual fuel oil	15–20	20–25

5.5.3 Burners should be able to operate with a maximum carbon monoxide content of 50 (v)ppm for naphtha and 150 (v)ppm for residual fuels.

5.5.4 Specific emission limitations may determine the excess air required.

5.6 Flame Characteristics

5.6.1 The majority of liquid fuel burners are designed with round burner tiles and produce a conical flame shape.

5.6.2 Special flat flame burners are available with rectangular tiles and special tip drillings to produce a flat, fish tail flame shape. These burners are used in close proximity to refractory walls and where clearances to the heating surfaces are limited.

5.6.3 The drilling of the oil tip determines the shape and length of the flame. The normal included angle of a burner tip is 40–70 degrees. With a 50-degree included angle, the flame length will be approximately 2 feet per MM Btu/hr for natural draft burners. Reducing the angle to 40 degrees produces a longer, narrower flame. Increasing the angle to 70 degrees produces a shorter, bushier flame.

5.6.4 Forced draft burners produce a shorter flame because of the better mixing between the air and fuel.

5.7 Burner Liberation

5.7.1 Burner liberation is normally dictated by the maximum flame dimensions for the firebox and proper distribution of heat within the heater.

5.7.2 Natural draft burner liberation is normally in the range of 3–14 MM Btu/hr.

5.7.3 Forced draft burner liberation is normally in the range of 5–40 MM Btu/hr.

5.7.4 High intensity burner liberation is normally in the range of 5–70 MM Btu/hr.

5.8 Combination Firing

5.8.1 Some refinery fired heater burners are designed tc operate with both liquid and gas fuels.

5.8.2 The oil gun is located on the centerline of the burner, and the gas tips are arranged around the outside of the primary tile.

5.8.3 Combination burners are normally designed to operate on either oil or gas. A burner can operate on either fuel at the full heat release of the burner.

5.8.4 Combination burners sometimes are designed to operate on both fuels simultaneously. It is important that the design heat release of the burners is not exceeded; otherwise, there will be insufficient air for proper combustion.

5.8.5 Burners that are designed to fire both fuels simultaneously should have the burner tips of both fuels designed for a partial heat release of the burner to improve the burner turndown.

5.8.6 Firing in combination with both liquid and gas fuels will increase the length and volume of the flame and can cause coking of the oil and gas tips.

SECTION 6—LOW-NO_X BURNERS

6.1 General

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

a. 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.
b. 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.
c. 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 is a function of fuel composition. The higher the chemically bound nitrogen in the fuel, the higher the NO_x emissions. The fuel NO_x can be reduced 30–50 percent in staged-air burners.

The thermal NO_x production is limited by reducing the flame temperature. Since the reaction to NO_x is favored by high temperatures, reducing the flame temperature will reduce the NO_x formed. The thermal NO_x production is time-temperature dependent.

Prompt NO_x typically accounts for only a small quantity of NO_x formation. Prompt NO_x becomes a significant portion of the total NO_x when low-NO_x burners are used.

6.2 Staged-Air Burners

6.2.1 GENERAL

Staged-air burners are classified as low-NO_x burners. Staged-air burners 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.

Staged-air burners complete combustion in two separate combustion zones. Air is injected into each zone. The flame temperatures in either zone does not approach that in a standard burner. Combustion occurs in two distinct stages. The burner is thus called a staged-air burner. Figure 5 is a typical staged-air burner.

6.2.2 PRIMARY COMBUSTION ZONE (STAGE ONE)

All fuel is injected into the primary combustion zone with only a portion of the total air. Much of the fuel does not ignite since there is insufficient air available. This incomplete combustion results in a lower flame temperature than in a standard burner. 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. Some of the nitrogen atoms formed from the fuel nitrogen can combine to form molecular nitrogen (N_2) rather than oxidize to NO_x.

6.2.3 SECONDARY COMBUSTION ZONE (STAGE TWO)

Combustion is completed in the secondary combustion zone (located in most cases outside the burner block). Combustion is completed as the remaining air is injected into the combustion gas stream. Flame temperatures will not approach those in a standard burner. Heat has already been lost to the surroundings during the initial combustion stage.

6.3 Staged-Fuel Burners

6.3.1 GENERAL

Staged-fuel burners are classified as low-NO_x burners. They limit the production of NO_x by limiting the temperature in the combustion reaction zone.

Staged-fuel burners complete combustion in two separate combustion zones. Fuel is injected into each zone. The flame temperature in either stage does not approach that in a standard burner. Combustion is completed in two stages. The burner is thus called a staged-fuel burner. Figure 6 is a typical staged-fuel burner.

6.3.2 PRIMARY COMBUSTION ZONE (STAGE ONE)

All of the combustion air enters the primary combustion zone. Only a portion of the fuel enters the primary zone.

Combustion of the primary fuel is completed with an overabundant quantity of air. The surplus air reduces the flame temperature. The flame envelope loses heat as heat radiates to the surroundings.

6.3.3 SECONDARY COMBUSTION ZONE (STAGE TWO)

The remaining fuel is injected downstream into the secondary combustion zone where the surplus air from the primary zone provides the oxygen necessary to complete the combustion of the remaining fuel. The flame envelope will not reach temperatures met in standard burners. Some heat had already been transferred to the surroundings in the initial stage.

6.4 Flue Gas Recirculation

6.4.1 GENERAL

Flue gas may be recirculated into the combustion gases. The inert flue gas cools the flame, reduces the partial pressure of oxygen, and lowers nitrogen oxide emissions. Flue gas recirculation can reduce these emissions further when used with staged-combustion burners.

6.4.2 EXTERNAL FLUE GAS RECIRCULATION

Flue gases may be withdrawn from a furnace (usually downstream of the convection section) and ducted to the burners. This may require an induced-draft fan to pull flue gases out an exit duct and back into the burner.

6.4.3 INTERNAL FLUE GAS RECIRCULATION

The burner itself may inspirate flue gases from the firebox into the burner. This can be accomplished by utilizing the combustion air or fuel gas streams to produce a low-pressure area. This can drive firebox gases into the burner through openings in the burner block.

6.4.4 CONSIDERATIONS

Flue gas recirculation rates into combustion air can affect flame stability. The burner vendor should be consulted as to the recommended flue gas recirculation rates.

Burners with internal flue gas recirculation must be careful to avoid similar problems found with premix burners (for example, flashback).

6.5 Other Burners

To reduce nitrogen oxide pollution, industry is currently modifying and developing burners other than those cited. The previous sections are not intended to preclude other varieties of burners, but to describe the types of burners that predominate in the petroleum industry. Others presently available or available in the future may be suitable.

SECTION 7—PILOTS AND IGNITORS

7.1 General

Pilot burners, commonly known as pilots, ignite and with continuous (as opposed to intermittent) pilots, unremittingly reignite and sustain combustion of a main burner over its full operating range. Pilot burners provide a source of ignition and assist in stabilizing the main burner flame throughout all operating conditions. Pilot burners are safety devices used to prevent unsafe mixtures from igniting in areas other than the desired combustion zone. Pilot burners shall be provided on each burner unless stated otherwise by the owner.

Ignitors provide a safe method of lighting pilots.

7.2 Pilot Burners

7.2.1 Pilot burners shall be gas fueled.

7.2.2 Pilot burners shall be positioned to assure ignition of the main burner for all operating conditions.

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

7.2.4 Pilot burners shall be removable for cleaning and maintenance when the heater is in operation.

7.2.5 Positive identification of the pilot flame shall be made upon ignition.

7.2.6 Continuous pilot burners shall meet the following conditions:

a. The pilot shall have a minimum heat release of 75,000 Btu/hr. The minimum heat release must be approved by the owner when accompanying a high-intensity burner or a burner whose heat release is 15 MM Btu/hr or greater.

b. The pilot burner 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.

c. The pilot burner shall remain stable over the full firing range of the main burner. The pilot burner shall remain stable upon loss of main burner fuel, under conditions of minimum-to-maximum draft and all combustion air rates and operating temperatures.

7.3 Ignitors

Manual ignition of pilot burners shall be accomplished with gas or electric portable ignitors unless otherwise specified by the owner.

SECTION 8—MECHANICAL

8.1 Plenum

Plenums are used to distribute combustion air 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.

8.2 Dampers and Registers

A burner mounted in an individual plenum shall have an air control damper. The damper regulates the flow of combustion air to the burner. This damper is normally manually adjusted. It can be adjusted by an automatic control device.

Multiple burners mounted in one common plenum are provided with air registers to trim combustion air to individual burners. These air registers are generally manually controlled.

Two types of registers are commonly found. The more common air register consists 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. Another 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 connected to a common air register control.

Dampers and burner registers shall be sized such that the air rate can be controlled over a range of at least 40–100 percent of burner capacity. Means of indicating the position of the dampers or registers shall be provided. Controls must be easily accessible.

8.3 Burner Block

A burner refractory block or quarl is provided to aid in shaping the flame. Burner blocks are exposed to high temperatures. Installation must allow them to expand and contract independently of the furnace refractory. A field cure and dryout shall be performed at the time of the initial burner start-up. Free water must be removed to minimize the possibility of spalling. Each block may be made up of several pieces to aid in installation. The number of pieces should be minimized.

8.4 Fuel Injectors

Oil and gas tips shall be easily removable for cleaning while the heater is in operation.

8.5 Sight Ports and Lighting Ports

Sight ports shall be provided to observe the pilot and main flames. A lighting port shall also be provided for lighting the pilot or main flame.

8.6 Materials of Construction

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.

8.6.1 FUEL GAS COMPONENTS (BURNER AND PILOT)

The operation and materials of the fuel gas burner and pilot are noted in Table 7.

A metallurgist should be consulted to select appropriate materials with corrosive gases.

8.6.2 FUEL OIL COMPONENTS

The operation and materials of fuel oil components are noted in Table 8.

A metallurgist should be consulted to select appropriate materials with corrosive liquids.

8.6.3 BURNER HOUSING

The materials of burner-housing components are noted in Table 9.

Table 7—Fuel Gas Burner and Pilot Components Materials

Component	Operation	Material
Fuel gas manifold and piping	Normal	Cast iron or carbon steel
	>100 ppm H_2S and >300°F; >400°F combustion air	321L stainless steel
Fuel gas riser pipe	Normal	Carbon steel
	>700°F combustion air	304 stainless steel
	>100 ppm H_2S and >300°F; >400°F combustion air	321L stainless steel
Fuel gas tip	Normal	Cast iron or 300 series stainless steel
	>100 ppm H_2S and >300°F; >400°F combustion air	321L stainless steel
Premix venturi	Normal	Cast iron or carbon steel

Table 8—Fuel Oil Burner Component Materials

Component	Operation	Material
Oil gun receiver and body	Normal	Ductile iron
Oil gun tip	Normal Erosive oils	416 stainless steel T-1 tool steel
Atomizer	Normal >3%(wt.) sulfur	Brass 303 stainless steel
Atomizer body only Other	Erosive oils Normal	Nitride hardened nitraloy Carbon Steel

Table 9—Materials of Burner Housing Components

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	≤700°F combustion air	Mineral wool
	>700°F combustion air	Mineral wool covered with metal liner
Other interior metal parts	Normal	Carbon steel
	>700°F combustion air	a high-strength low-alloy structural steel (ASTM Specification A 242/A 242M) or 304 stainless steel

8.6.4 BURNER BLOCK

Table 10 provides the minimum material requirements for burner blocks (burner tiles).

8.7 Burner Piping

8.7.1 FUEL DELIVERY SYSTEM

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 as follows:

a. Properly sized headers to effect uniform flow distribution to individual burners while maintaining reasonable velocities.
b. Provisions for adequate and properly situated drains to permit drainage and cleaning of the manifold system.
c. Properly sized control valves.
d. Individual burner isolation valves.

Table 10—Burner Block Material

Burner Type	Material
High intensity combustor	>40% alumina refractory >85% alumina castable refractory/firebrick
Oil firing	
≤ 50 ppm (wt.) V + Na	≥60% alumina refractory
>50 ppm (wt.) V + Na	>90% alumina refractory

8.7.2 GUIDELINES FOR THE DESIGN OF MANIFOLD SYSTEMS

8.7.2.1 General

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

8.7.2.2 Fuel Gas Piping

Fuel gas is usually supplied from a constant pressure mixing drum. The fuel gas system should include a knockout pot or drum for condensate removal.

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. The distribution header should be heat traced and insulated in climates where ambient temperatures could result in heavy condensate formation. All fuel gas drains should be piped to a collection system feeding a flare or other safe disposal system.

Takeoff leads to each burner should be off the top side of the distribution header to minimize the potential for liquid carryover to the burners. The piping system of headers, branches, and lead 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/sec. The velocity in a takeoff lead to an individual burner should not exceed 75 ft/sec.

The fuel flow control valve should be installed near the furnace in the distribution header between the main gas supply header and the first branch. Piping to each burner should include a block valve. This will allow the fuel to each burner to be taken out of service.

8.7.2.3 Fuel Oil Piping

Heavy fuel oil is normally supplied from a central storage and preparation area. It is delivered through an insulated loop system circulating oil to each oil-fired furnace and back to the storage tank. A non-circulating fuel oil system is unac ceptable when firing heavy oils requiring heating. Dead-ended systems result in oil chilling with consequent combustion problems.

The loop system should circulate a minimum of 1.5 times the fuel to be consumed; three volumes are delivered, two consumed, and one returned. 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/sec.

Takeoff leads 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 leads should be heated as well as insulated in climates where ambient temperatures can result in significant oil cooling.

Light oils 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/sec.

8.7.2.4 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 leads 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/sec.

8.7.2.5 Pilot Gas Piping

Fuel gas for pilot burners should be independent of the main fuel gas system.

Pilot burners have small orifices that make them susceptible to plugging. Pilot gas headers should be fitted with filters to keep dirt and scale from the pilot burners. Further protection can be achieved by providing stainless steel piping from the filters to the pilot burners.

SECTION 9—OPERATION

9.1 Light-Off Procedures

9.1.1 SCOPE

The following procedures are provided as a minimum only. User's light-off procedures will take precedence.

9.1.2 PREPARATION FOR LIGHT-OFF

Preparation for light-off is as follows:

a. Maintain flow through the tubes to protect the tubes from overheating.

b. Determine that all fuel and burner instrumentation is in operating condition. Set all instrumentation in a manual mode with safety trips bypassed.

c. Verify that all gas tips and oil burner guns are clean and unobstructed.

d. Verify that the push-button, electric ignitor system or portable ignitor is ready.

e. Block in and blind all fuel headers. All burner valves should be closed.

f. Drain condensate from all fuel gas (including pilot) and atomizing steam lines. Remove any water and solid particles.

g. Verify that fuels are at their correct operating temperatures and pressures. Confirm that adequate fuel is available.

h. Determine that the atomizing media are at the appropriate conditions. Confirm that the desired differential between fuel and atomizing media is available. Atomizing steam shall be dry, saturated, or slightly superheated.

i. Open the vent valve on double block-and-bleed arrangements in fuel gas lines (if provided).

j. Determine that the stack damper is operating properly. Open the stack damper wide.

k. Steam- or air-purge the firebox for a minimum of 15 minutes. The volume of purge medium should be at least three times the firebox volume. If forced draft air is used as the purge medium, check the combustibles content of the firebox exit gases with a combustibles analyzer.

9.1.3 LIGHT-OFF GUIDELINES

Light-off guidelines are as follows:

a. The burner manufacturer's light-off procedures should be followed.

b. Remove blinds in pilot gas lines immediately prior to lighting pilots. Remove blinds for main fuel gas lines after all pilots are lit and prior to lighting main gas burners.

c. If pilots are provided, begin lighting the pilot burners. Each pilot shall be ignited with a portable gas or electric ignitor.

d. Ignite the pilot burner. Re-purge the heater if the first pilot fails to ignite or extinguishes. Adjust the pilot orifice as necessary.

e. Adjust main burner air registers and dampers to a fully closed, then fully open position. Re-purge the heater if, while the first pilot is being tested, the fire pilot fails to remain lit. If subsequently other pilots have been lit, block in the fuel to

the extinguished pilot and open the air fully to that burner. Ignite another pilot distant from the one extinguished. Do not attempt to re-light an extinguished pilot for five minutes once it is blocked in.
f. If pilots are provided, all pilots should be lit before igniting any main burner.
g. Light the main gas burner from the pilot. Light the main gas burner from a portable gas or electric ignitor if a pilot is not provided. Provide good heat distribution when lighting subsequent burners.
h. Remove blind or blinds in the fuel oil system. Start fuel oil circulation and establish fuel oil pressure at the burner block valve after all pilots are lit.
i. Achieve good flow distribution to all burners with all fuels and atomizing steam.
j. Light the oil burner from the pilot. Light the oil burner from a portable gas or electric ignitor if a pilot is not provided. Lighting of subsequent burners shall provide good heat distribution.

9.1.4 SPECIAL SAFETY REMINDERS

CAUTION: The following safety precautions should be observed:

a. Do not use the adjacent burner or hot brickwork as ignition for a pilot or for main burners. Always use the appropriate ignitor or a properly operating pilot to light the burners.
b. The shutdown safety interlocks should be in service.
c. Re-initiate the start-up from the appropriate step if immediate ignition does not occur.
d. Shut off fuel valves and repurge the furnace after failure of furnace burners. Fuel line blinds should be reinstalled if there will be a delay prior to relighting.
e. Do not remove an ignitor unless it is certain that the burner or pilot will remain lit.
f. Do not close the stack damper completely. During the initial light-off, it may be necessary to close the burner register completely on that specific burner to maintain the ignitor in service.
g. Always use a face and eye shield or wear colored safety glasses when observing the furnace flame pattern.

9.2 Excess Air Control

9.2.1 OPTIMUM EXCESS AIR LEVELS

There is an optimum level of excess oxygen in the flue gas for each type of heater, burner, and fuel used. Typical excess air levels are indicated in 4.1.4, 4.2.4, and 5.5.1.

A completely sealed heater containing a few burners and automatic oxygen and draft controls may allow a reduction in the typical excess air rates. An existing heater with significant casing leakage may require an increase in the given excess air rates.

9.2.2 DISADVANTAGES OF INCREASED EXCESS AIR

9.2.2.1 High excess air will reduce heater efficiency for the following reasons:

a. More fuel is required to heat the additional air entering the burners.
b. Additional air lowers the flame temperature, resulting in a lower radiant thermal efficiency.

9.2.2.2 Increased excess air will increase the flue gas flow rate and will raise the flue gas pressure differential. This may result in a positive pressure in the heater, forcing a reduction in capacity.

9.2.3 ADVANTAGES OF INCREASED EXCESS AIR

9.2.3.1 Reduction in Radiant Section Tube Wall Temperatures

Increased excess air will increase the convection section duty while reducing that in the radiant. This will reduce the radiant section tube wall temperatures.

9.2.3.2 Increased Convection Section Duty

Increased excess air will raise the convection section duty. This may be of value if a greater duty is desired from a waste heat coil (steam, reboiler, hot oil, and so forth).

9.3 Draft Control

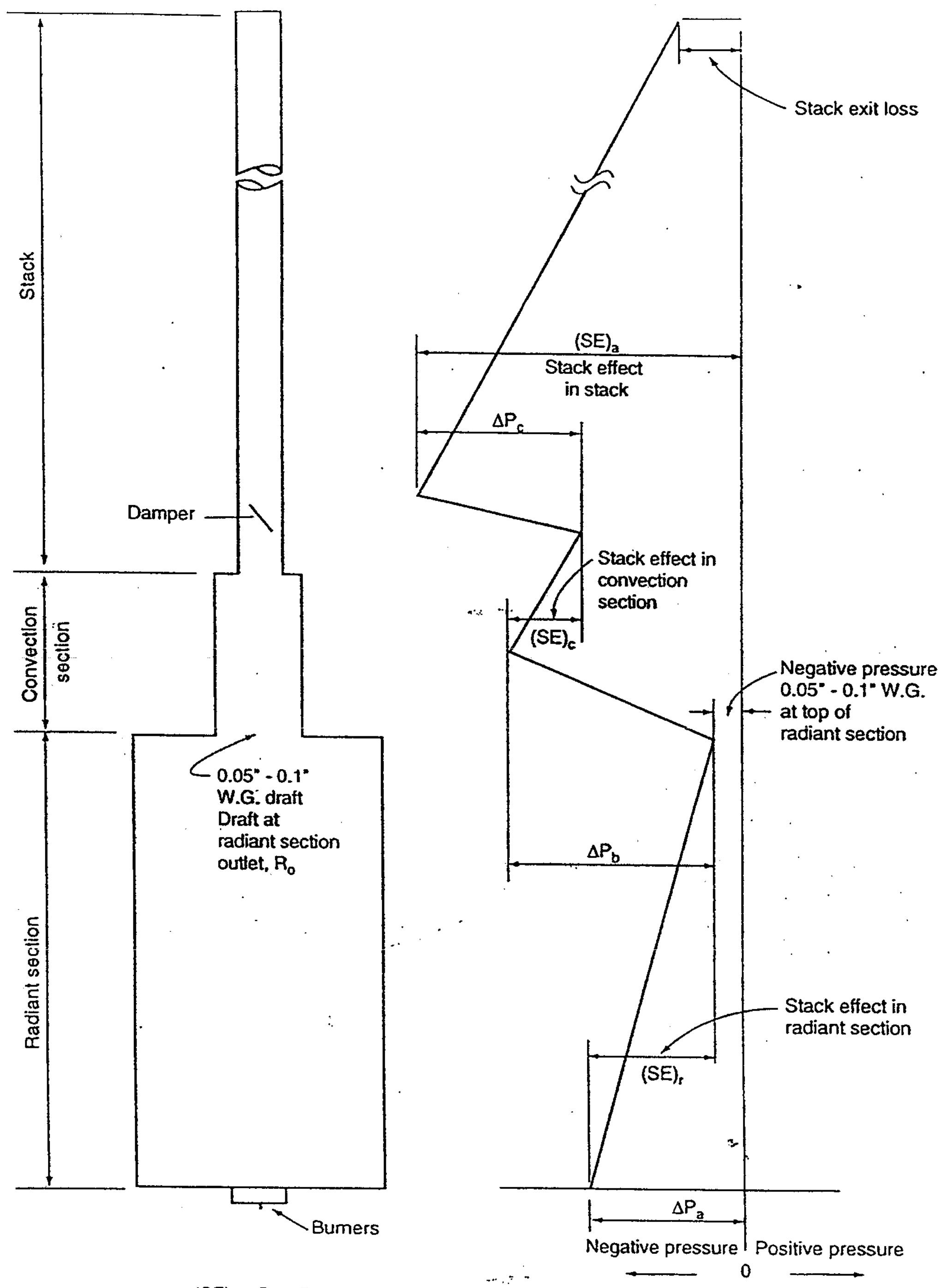
9.3.1 GENERAL

CAUTION: Refinery process heaters operate with a negative pressure (draft) in the firebox. Forced draft or balanced draft systems should maintain a negative pressure throughout the furnace. Rarely are refinery process heaters designed to operate under a positive pressure. Draft is the first item that should be closely watched when adjusting the heater in order to achieve safe and economical operation.

9.3.2 TYPICAL DRAFT PROFILE

CAUTION: A negative pressure must be maintained throughout a heater. A positive pressure inside the heater will cause flue gas leakage and damage to the furnace casing and structure. A positive pressure inside the heater can provide a safety hazard to operating personnel. Figure 15 shows a typical draft profile.

A draft reading of 0.05–0.10 inches H_2O at the radiant arch location is desired. Too much draft will increase air leakage. In that case, efficiency will be reduced and operation could be limited.



$(SE)_r + R_o = P_a$

$(SE)_a + (SE)_c = P_b + P_c +$ Stack exit loss $+ R_o$

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

ΔP_b = Flue gas pressure drop across convection section.

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

Figure 15—Typical Draft Profile in a Natural Draft Heater

9.3.3 EXCESS AIR ADJUSTMENT

Excess air and draft are interrelated. Adjust excess air by means of the air dampers or registers. This adjustment will affect the draft as the flue gas rate changes. Correct the draft by means of the stack damper or induced draft fan suction damper. This correction will affect the flow of air through the burners as the pressure at the burners changes. Readjustment of the air registers and damper may be necessary until the draft and excess air are properly set.

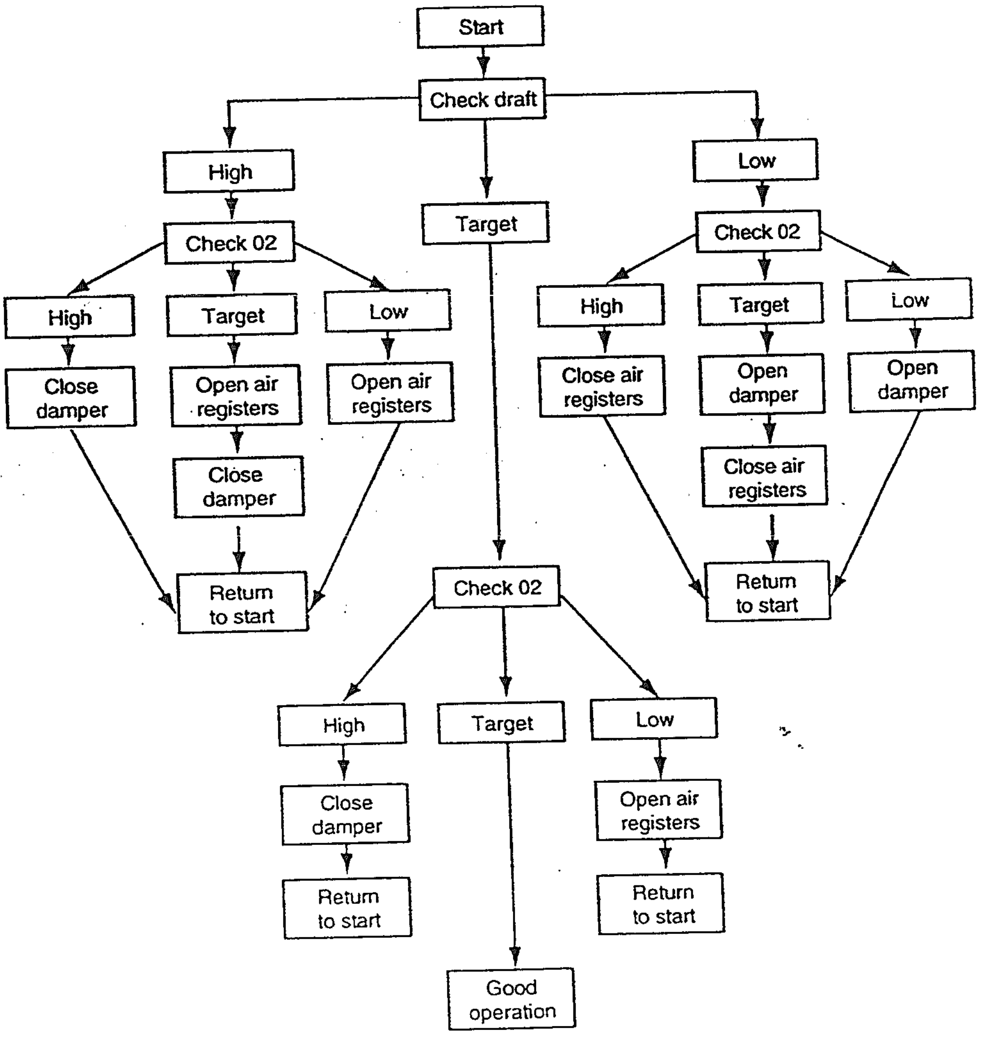
The objective is to achieve an optimum excess air level for combustion without producing a positive pressure at the heater arch. Achieve the desired excess air rate while maintaining a slightly negative pressure at the heater arch.

Do not use the stack damper or burner air register alone for draft and excess air control. A combination of the two adjustments is necessary to obtain the proper draft and excess air. Table 11 is a guide to adjusting stack damper and burner registers. Also see Figure 16, a draft adjustment chart.

For a given heater with constant duty and fuel composi-

Table 11—Adjustment of Stack Damper and Burner Registers

Heater Conditions	Adjustments
High O_2 and high draft	Close stack damper
Low O_2 and low draft	Open stack damper
High O_2 and low draft	Close burner registers
Low O_2 and high draft	Open burner registers



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 O2 = Flue gas oxygen content at the radiant section exit is lower or higher than the target.

Figure 16—Natural Draft Heater Adjustment Flow Chart

tion, closing the stack damper will have the following effects:

a. Reduced oxygen in the flue gases.
b. Decreased draft at the radiant arch.
c. Increased flue gas temperature leaving the radiant section. (For an all-radiant heater, the radiant flux density is constant. When the excess air level is reduced, the bridgewall temperature will be reduced.)
d. Decreased stack temperature.
e. Increased radiant heat flux density.
f. Decreased convection heat flux density.
g. 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.

9.4 Burner Operation Trouble-Shooting

Some of the troubles normally experienced in burner operation and their possible causes and solutions are given in Tables 12 and 13.

The burner manufacturer should be consulted whenever burner components are replaced or modified.

Table 12—Trouble-Shooting for Gas Burners

Trouble	Causes	Solutions
Burners go out	Gas-air mixture too lean (namely, too much air)	Reduce total air. Reduce primary air
	Too much draft	Close stack damper or air register
Flame flashback	Low gas pressure	Shut off burners to raise the fuel gas pressure to the operating burners; it may be necessary to reduce burner orifices' size
	High hydrogen concentration in fuel gas	Reduce primary air; tape the primary air shut if flashback continues; a new burner or tip drilling may be required
Insufficient heat release	Low gas flow, check for low gas pressure	Increase gas flow
	Burner tip orifices too small	Increase burner tip orifice size; determine that sufficient air will be available through the air registers for the increased fuel rate
	Desired heat release exceeds design capacity	Larger burner tips or new burners may be required
Pulsating fire or "breathing" (flame alternately ignites and goes out, sometimes with almost explosive force)	Lack of oxygen/draft	Reduce firing rate immediately; establish complete combustion at lower rate; open stack damper and/or air registers to increase air and draft; reduce fuel before increasing air!
Erratic flame	Lack of combustion air	Adjust air register and/or stack damper
	Incorrect position of burner tip	Locate tips per manufacturer's drawings
	Damaged burner block	Repair block to manufacturer's tolerances
Gas flame too long	Excessive firing	Reduce firing rates
	Too little primary air	Increase primary air; decrease secondary air
	Worn burner tip	Replace tip
	Tip drilling angle too narrow	Change to wide drilling angle tip
Gas flame too short	Too much primary air	Increase secondary air; decrease primary air
	Tip drilling angle too wide	Change to narrow drilling angle tip

Table 13—Trouble-Shooting for Oil Burners

Trouble	Causes	Solutions
Burners dripping Coke deposits on burner blocks Coking of burner tip when firing fuel oil only	Improper atomization due to:	
	High-oil viscosity	Check fuel oil type Increase fuel temperature to lower viscosity to proper level
	Improper blending of oil constituents	Check composition of fuel for heavier fractions
	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	Place tip in location as per burner drawing. If this fails, readjust burner tip +/- 0.5 inches (13 mm) until dripping ceases
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
	Too much moisture in atomizing steam	Assure appropriate insulation is on steam lines Confirm steam traps are functioning Adjust quality of atomizing steam to appropriate levels
Coking of oil tip when firing oil in combination with gas burners to either fuel	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 firing rate; dedicate individual burners to either fuel
	Incorrect oil gun position	Place tip in location as per burner drawing. If this fails, readjust burner tip +/- 0.5 inches (13 mm) until coking ceases
Erratic flame	Lack of combustion air	Adjust air damper or register
	Plugged burner gun	Clean burner gun
	Worn burner gun	Replace gun
	High rate of gas firing while firing a low rate of oil	Reduce gas rate; dedicate burners to either fuel
	Damaged burner block	Repair burner block
Excess smoke at stack (evidence of incomplete combustion)	Insufficient atomizing steam	Increase atomizing steam
	Low excess air	Increase excess air
	Moisture in atomizing steam	Requires knockout drum or increase in superheat; alter steam at steam source

SECTION 10—MAINTENANCE

10.1 Shipping

All burner and pilot tips should be wrapped to keep them clean during shipment.

10.2 Burner Parts Inspection

10.2.1 Burner parts shall be inspected to confirm that they conform with the vendor drawings and data sheets (see 10.2.2 through 10.2.6).

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

10.2.3 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.

10.2.4 Gas risers should be straight and bent only where specified by burner drawing.

10.2.5 All orifices should be free of deposits.

10.2.6 Primary air orifices shall be of the specified size.

10.3 Installation and Initial Setup

Burners should be installed in accordance with burner manufacturer'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 results in lopsided flames due to zones of high excess air and zones of low excess air. The following tolerances are permissible:

a. Burner tile diameter: ±¼ inches.
b. Burner tile concentricity (out of roundness): ±⅛ inches.
c. Tip port angles: ±4 degrees.
d. Bolting dimensions: ±⅛ inches.
e. Gas tip locations: Horizontal, ±¼ inches, Vertical, ±¼ inches.

10.4 Post-Installation Checkout

10.4.1 Air registers and dampers should be checked for freedom of movement.

10.4.2 Primary air inspirating devices should be tested for full movement.

10.5 Maintenance Program

10.5.1 GENERAL

A routine burner maintenance program for proper burner operation should be scheduled. The items in 10.5.2 through 10.5.9 should be included in a routine maintenance program.

10.5.2 VISUAL INSPECTION

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

10.5.3 CHECK BURNERS WITH ORIGINAL DESIGN

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

a. Fuel pressure.
b. Fuel characteristics (heating value, composition, viscosity, sulfur content, and so on).
c. Gas tip and oil guns (orifice size, drilling angle, and tip and gun position).
d. Burner size.
e. Turndown.

Replacement either of burner tip or gun or of complete burner should be considered if the original burner cannot be operated satisfactorily.

10.5.4 BURNER CLEANING

Users should establish their own cleaning schedules based upon their experience; however, the following should be noted:

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

10.5.5 BURNER BLOCK

The burner block should be inspected. Cracks and spalled sections shall 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 having at least the same temperature rating. Burner blocks requiring extensive repair should be replaced.

10.5.6 AIR REGULATING DEVICES

Air dampers and registers should be operable at all times.

10.5.7 REMOVAL OF 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.

Gas tips and oil guns should be removed on shutdown burners. No metallic burner components should be exposed to the hot flue gas. Burner tiles may be left in place.

Burners may be removed from the outside when the heater is in operation. Burner openings should be covered with carbon steel plate insulated from the heat of the furnace.

Burners may be blanked from the inside of heater after shutdown.

10.5.8 BURNER REPLACEMENT OF MODIFICATION

Burners should be replaced or modified if the burners 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.

The burner manufacturer should be consulted when burner replacement or modification is required.

10.5.9 SPARE PARTS

The number of spare parts depends on burner design, fuel, plant location and operation, and maintenance experiences. It is recommended that 10 percent of all tips, oil guns, and burner tiles as a minimum should be purchased as spares.

SECTION 11—TESTING

11.1 Scope

This procedure covers the requirements and procedures for testing a single burner in a test furnace.

Burner testing is intended to verify thermal and environmental performance of a production burner. The testing is used to determine the burner's satisfactory operating range and flame characteristics.

Waste gas firing and noise test requirements are not included in this procedure.

One production burner of each type and size should be tested to verify burner performance. Tests are recommended for each specified operating mode, for example, natural or forced draft, preheated air, fuel type, and so forth.

11.2 Test Requirements

11.2.1 GENERAL

The owner shall provide information concerning proposed burner installation, site conditions, and intended operation.

The test arrangement and burner orientation, where possible, shall be similar to that proposed for the actual installation.

A description of test facilities, proposed test procedures, and a piping and instrument diagram shall be provided for owner review and approval prior to testing.

Acceptable test point data shall have at least two successive data sets indicating that both operation and analyzer sampling are stable. Measured data fluctuations shall have cycled at least twice to determine the limits of the fluctuations.

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 owner and vendor.

11.2.2 RECOMMENDED TEST SEQUENCE

The following list shows the recommended sequence for testing. The extent of the testing shall be specified by the owner.

a. Damper/register leakage tests.
b. Pilot stability tests.
c. Single fuel burner tests.
d. Simultaneous testing of both fuels on combination burners (if required).

11.2.3 BURNER MECHANICAL DESIGN

The number, size, and orientation of fuel orifices and the number and location of fuel tips shall be recorded for each test. Dimensions used in the successful tests shall be reported along with the burner performance.

11.3 Test Fuels

11.3.1 GENERAL

The fuels used for burner and pilot testing shall be mutually agreed to between burner vendor and owner prior to testing.

11.3.2 BLENDED GAS FUELS

On-site blending of a gas fuel requires measurement of each gas component. Acceptable flow measurement devices include rotometers and orifice meters. The use of other measurement devices must be agreed to by the end user. Fuel may be blended to the heating value or specific gravity as specified or as mutually agreed to with the owner. Hydrogen, water, and diluent content of the gas shall be in the same volumetric proportion as in the specified actual service fuel gas if those proportions significantly impact burner performance.

11.3.3 LIQUID FUEL CONDITIONS

Liquid fuel viscosity shall be maintained by temperature control. When atomizing media is required, (a) atomizing media temperature and (b) mass ratio of atomizing media to fuel shall be maintained. The ratio of atomizing media to fuel shall be plotted for the full range of burner heat release.

Atomizing media shall be representative of anticipated operation. When steam is required, the steam shall be within the burner manufacturer's recommended temperature and pressure range.

11.3.4 FUEL ORIFICE CAPACITY CURVES

The burner manufacturer shall provide capacity curves (fuel pressure vs. heat release) for each test fuel. The range of burner operation is that range between the lean and rich stability limits. Capacity curves shall additionally be provided for the primary fuel stage of staged-fuel burners if the burner can be used with the primary stage alone.

11.4 Air Supply

11.4.1 GENERAL

Process heaters may be either natural draft, forced draft, or induced draft. In addition, the oxygen for combustion may be supplied as air, turbine exhaust gas, or a mixture of air and recirculated flue gas.

11.4.2 PREHEATED AIR

Preheated air can be provided by either direct or indirect heating. Indirect air heating is necessary to determine burner emissions.

11.4.3 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 the test furnace, duct burner, or a direct fired air heater.

11.4.4 FLUE GAS RECIRCULATION

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

11.4.5 DAMPER AND REGISTER LEAKAGE TEST

When specified, damper and register leakage tests may be performed in accordance with AMCA Standard 500 or with another method mutually agreed to by the owner and vendor. The owner shall specify the acceptable damper/register leakage rate.

11.5 Pilot and Ignitors

11.5.1 GENERAL

The pilot and/or ignitor system for the test shall be the same as that proposed for the actual burner installation. Should the pilot or ignitor demonstrate unreliable operation, it shall be modified or exchanged until reliability is proven. The pilot shall be continuously operated during the main burner testing unless interruptible pilot operation is specified.

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

11.5.2 PILOTS

Prior to main burner testing, the pilot shall be proven stable for each of the following conditions:

a. Damper/register slowly moved from the fully closed position to the fully opened position in a *cold* firebox while operating under all specified (natural, balanced, forced) draft conditions.
b. Damper/register quickly and fully opened and closed while operating under all specified (natural, balanced, forced) draft conditions.
c. Pilot fuel instantaneously reduced from design load to 25 percent of design load without changing the air flow.

The pilot must have sufficient liberation to reliably ignite the main burner fuel for all anticipated light-off conditions. Minimum pilot liberation is specified in 7.2.6.

11.5.3 IGNITORS

The ignitor shall be proven to reliably ignite the pilot, or main flame if so intended, under normal light-off conditions. The pilot ignitor shall be proven with the damper/register closed and with it open (see 11.5.2.a).

11.6 Main Burner Test

11.6.1 GENERAL

The main burner shall be tested for thermal and emission performance for each fuel and operating condition specified. The owner shall specify the number of test points and required tests for each point.

Recommended burner test points are illustrated in Figure 17. Nine test points are recommended to define the burner operating range, thermal performance, and for those test points specified, the emissions. Data Sheet B-1 (Appendix B) is a typical data sheet for collecting this data.

The heater design excess air may be greater than the burner design excess air for multiple burner systems. This is due to the possibility of unequal distribution of air and fuel to each burner. The owner and burner vendor shall agree upon the burner design excess air prior to testing.

11.6.2 TEST POINTS

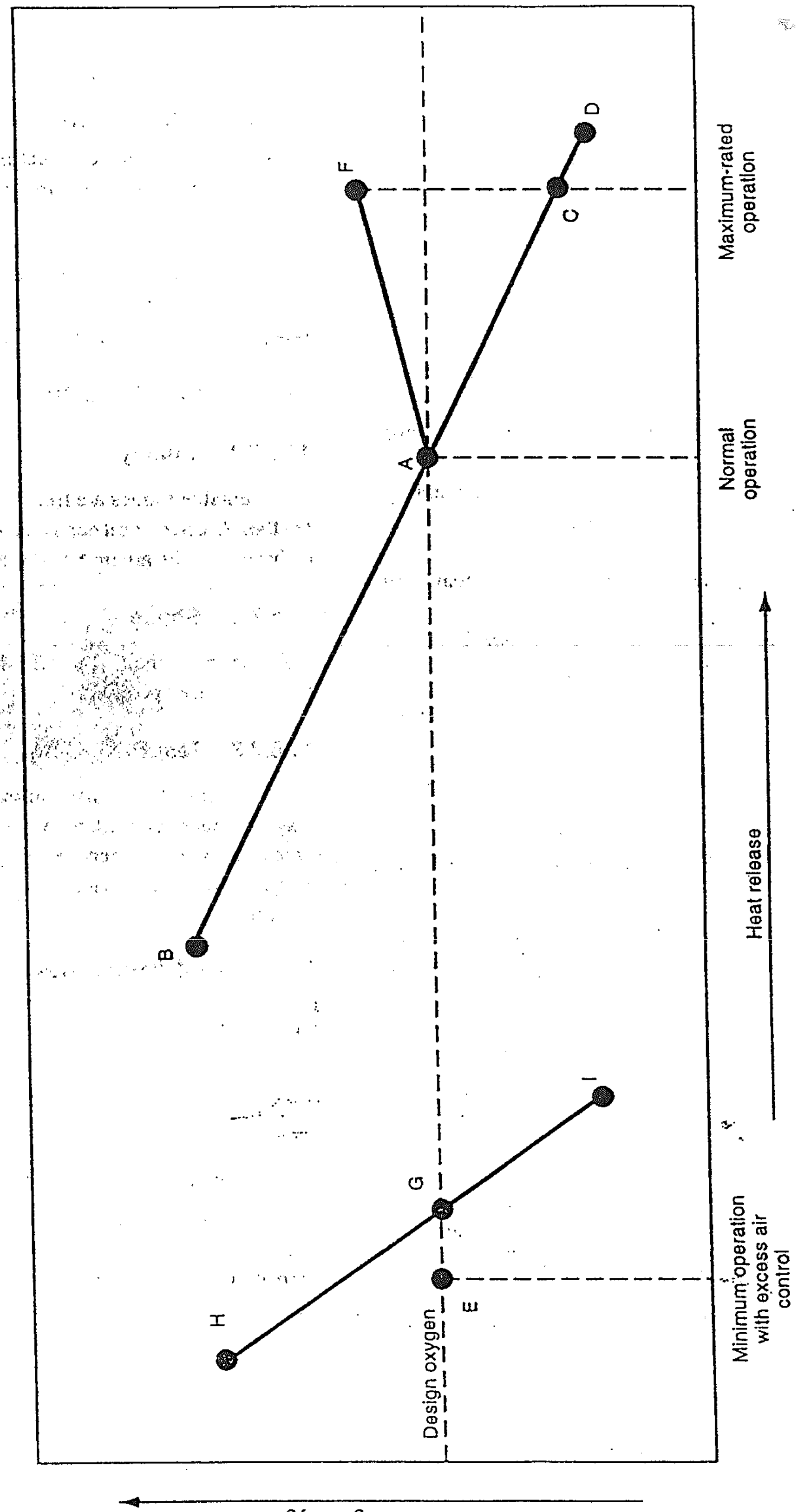
The following is a description of the nine test points. The test points are displayed in Figure 17. Points G, H, and I are for testing of the primary stage of a staged-fuel burner when required:

a. Point A—normal firing rate at design excess air.
b. Point B—maximum turndown firing rate; air register set in the same position as in Point A above.
c. Point C—maximum rated firing rate; air register set in the same position as in Point A above.
d. Point D—maximum firing rate at a CO limit (100–200 ppmvd); air register set in the same position as in Point A above.
e. Point E—minimum firing rate; air register adjusted to give design excess air.
f. Point F—maximum rated firing rate; air register 100 percent open.
g. Point G—normal primary stage firing rate; air register adjusted to give design excess air.
h. Point H—minimum primary stage firing rate; air register set in the same position as in Point G above.
i. Point I—maximum primary stage firing rate; air register set in the same position as in Point G above.

11.6.3 COMBUSTION INSTABILITY

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

a. Pulsation or vibration of burner flame, burner, or furnace.
b. Uncontrollable fluctuations in the flame shape.



Note: See 11.6.2 for an explanation of the test points signified by capital letters.

Figure 17—Burner Performance Test Points

c. Significant combustibles in the flue gas, in other words, over 2000 ppmvd CO or over 0.5 percent unburned combustibles.
d. Flashback into the venturi of premix burners.
e. Loss of flame.

11.6.4 RECOMMENDED TEST PROCEDURE

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 is recommended to minimize the time to collect test data:

a. Establish conditions for the normal operating point (test point A, Figure 17). The oxygen content of the test furnace flue gas shall be no greater than that quoted for normal operation.
b. Vary the fuel rate without changing other burner settings to determine test point data for test points B, C, and D, Figure 17:
   1. Increase the fuel rate to maximum *design* heat input (test point C, Figure 17).
   2. Increase the fuel rate to determine fuel rich CO limits (test point D, Figure 17).

   CAUTION: The burner may become unstable before the CO limit is reached.

   3. Decrease fuel rate to determine fuel lean CO limits (test point B, Figure 17).

   CAUTION: The burner may become unstable before the CO limit is reached.

c. Open fully the damper/register openings, then increase the fuel rate to verify air capacity at the maximum fuel rate (test point F, Figure 17).
d. Adjust the fuel rate and damper/register position to determine minimum heat input CO limits (test point E, Figure 17).

CAUTION: The burner may become unstable before the CO limit is reached.

Additional testing may be required to simulate start-up conditions for staged air or staged fuel burners. This additional testing is desired to determine minimum fuel input (maximum turndown) performance. Test points G through I (line H-G-I), Figure 17, shall be conducted with the primary air or the primary fuel stage (if the burner can be used with the primary stage alone). The recommended test sequence is test points G, H, and I, Figure 17. Only the fuel shall be varied.

Special test procedures should be developed and agreed to by the owner and the burner and heater manufacturers for more complicated burner systems.

11.6.5 MINIMUM BURNER TEST SCOPE

Recommended minimum burner testing should include at least four operating points. These test points are the quoted minimum, normal, and maximum heat release test points B, A, F, and D, Figure 17, respectively.

11.6.6 COMBINATION FIRING

When gas and oil combination burner test firing is specified, test the burner using the procedures in 11.6.4 for each gas and oil fuel separately. If simultaneous firing is specified, the burner shall 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 owner at the normal and minimum heat release rate (test points A and B, Figure 17).

11.6.7 VISIBLE FLAME CHARACTERISTICS

11.6.7.1 Quality

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

11.6.7.2 Shape

Flame shape should be uniform and proportioned properly for the service specified.

11.6.7.3 Test Recording

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

11.7 Test Instrumentation

11.7.1 GENERAL

Flow, temperature and pressure elements, gas analyzers, and other instrumentation are required to conduct a burner test. Typical instrumentation is shown in Figure 18.

11.7.2 FLUE GAS ANALYZERS

Continuous emission analyzers should be used. 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.

11.8 Required Measurements

11.8.1 Fuel gas requires measurement of the following:

a. Temperature.

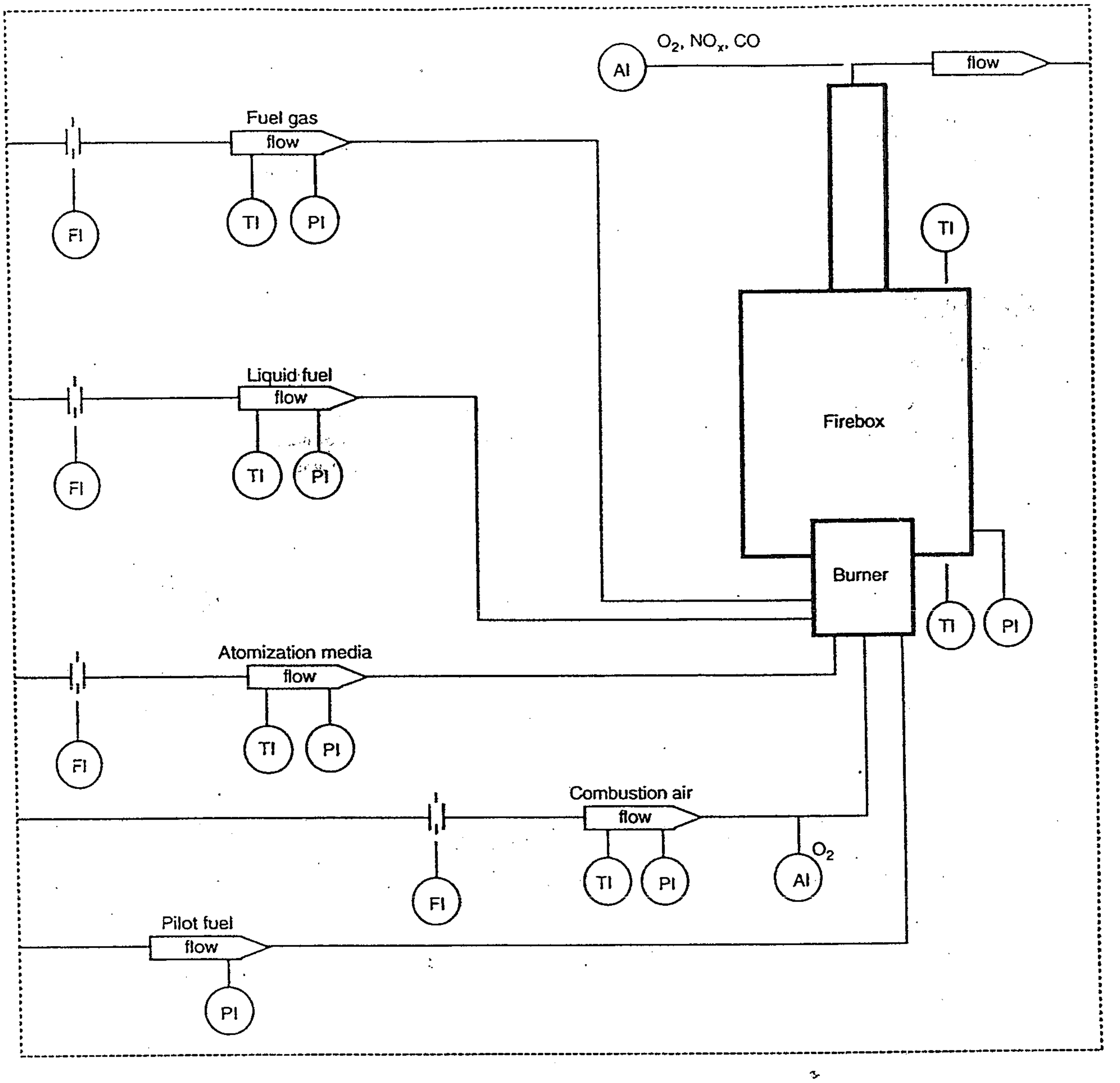


Figure 18—Typical Burner Test Setup

b. Flow.
c. Pressure.

11.8.2 Liquid fuel requires measurement of the following:

a. Temperature.
b. Flow.
c. Pressure.

11.8.3 Atomizing media requires measurement of the following:

a. Temperature.
b. Flow.
c. Pressure.

11.8.4 Combustion air (air, turbine exhaust gas, air/flue gas mixture, and the like) requires measurement of the following:

a. Temperature.
b. Oxygen concentration.
c. Pressure (forced draft systems).

11.8.5 Furnaces require measurements of the following:

a. Draft.
b. Temperature exiting radiant section.
c. Floor temperature.

11.8.6 Flue gas requires measurement of the following:

a. O_2 (percent).
b. NO_x (ppmvd).
c. CO (ppmvd).

11.8.7 Typical burner test data sheets are shown in Appendix B.

Additional measurements when required shall be specified by the owner.

APPENDIX A—BURNER DATA SHEETS

Data Sheet A-1—General Information Data Sheet

Owner				
Plant name				
Plant location				
Furnace service				
Furnace ID designation				
Burner manufacturer				
Date burner manufactured				
Owner reference number				
Burner manufacturer reference number				
Model number				
Type of fuel				
Fuel description				
Type of burner				
Location in furnace				
Number				
Firing orientation				
Model number				
Type of fuel				
Fuel description				
Type of burner				
Location in furnace				
Number				
Firing orientation				
Model number				
Type of fuel				
Fuel description				
Type of burner				
Location in furnace				
Number				
Firing orientation				

Data Sheet A-2—Fuel Data Sheet

Type of fuel (oil, gas, etc.)				
Fuel description				
Design excess oxygen rate, percent				
Fuel temperature at burner, °F				
Max. fuel pressure available at burner, psig				
Max. turndown required				

Data Sheet A-3—Liquid Fuel Properties Data Sheet

Fuel description				
Lower heating value, btu/lb				
Higher heating value, btu/lb				
Specific gravity at 60°F or °API				
ASTM distillation method no.				
(Specify D86 or D1160)				
Initial boiling point, °F				
50% point, °F				
End point, °F				
UOP "K"				
H/C ratio (by weight)				
Viscosity @________°F, SSU				
Viscosity @________°F, SSU				
Total salts, ppm				
Vanadium, ppm				
Sodium, ppm				
Potassium, ppm				
Fixed nitrogen, ppm				
Sulfur, % by weight				
Ash, % by weight				
Water, % by weight				
Atomizing medium				
Available atomizing medium pressure from header, psig				

Data Sheet A-4—Gaseous Fuel Properties Data Sheet

Fuel description				
Lower heating value, Btu/scf				
Minimum				
Normal				
Maximum				
Fuel composition, % by volume				
H_2				
C_1				
C_2				
C_3				
iC_4				
nC_4				
iC_5				
nC_5				
nC_6				
$=C_2$				
$=C_3$				
$=nC_4$				
$=iC_4$				
N_2				
O_2				
CO				
CO_2				
NH_3				
H_2S				
H_2O				
amines				
chlorides				
TOTAL				
Molecular weight				
Steam pressure at burner, psig				

Data Sheet A-5—Heat Release Data Sheet

Type of fuel (oil, gas, etc.)				
Fuel description				
Oxygen source				
Oxygen source temperature, °F				
Forced or natural draft operation				
Min. heat release, MM Btu/hr				
Draft at burner, in. H_2O				
Excess oxygen, %				
Fuel pressure at burner tip, psig				
Flame diameter, ft				
Flame length, ft				
Design heat release, MM Btu/hr				
Draft at burner, in. H_2O				
Excess oxygen, %				
Fuel pressure at burner tip, psig				
Flame diameter, ft				
Flame length, ft				
Max. heat release, MM Btu/hr				
Draft at burner, in. H_2O				
Excess oxygen, %				
Fuel pressure at burner tip, psig				
Flame diameter, ft				
Flame length, ft				
Flame stability limits:				
Min. fuel pressure at burner, psig				
Max. fuel pressure at burner, psig				
Reference capacity curve drawing number				

Data Sheet A-6—Mechanical Information—Gas Firing Data Sheet

Model number				
Type				
Location				
Primary gas tip				
Part number				
Number per burner				
Material				
Drillings				
Ignition drilling dimensions, in.				
Number				
Orientation				
Angle, degrees				
Main fuel drilling diameter, in.				
Number				
Orientation				
Angle				
Primary gas riser				
Part number				
Number per burner				
Material				
Diameter, in.				
Schedule				
Primary gas manifold				
Part number				
Number per burner				
Material				
Diameter, in.				
Schedule				
Connection				
Secondary gas tip				
Part number				
Number per burner				
Material, in.				
Drillings				
Ignition drilling dimensions, in.				
Number				
Orientation				
Angle, degrees				
Main fuel drilling diameter, in.				
Number				
Orientation				
Angle				
Secondary gas riser				
Part number				
Number per burner				
Material				
Diameter, in.				
Schedule				

Data Sheet A-6—Mechanical Information—Gas Firing Data Sheet (Continued)

Model number				
Type				
Location				
Secondary gas manifold				
Part number				
Number per burner				
Material				
Diameter, in.				
Schedule				
Connection				
Flame holder assembly				
Number per burner				
Material				
Thickness, in.				
Fittings				
Type				
Number per burner				
Size				
Material				
Type				
Number per burner				
Size				
Material				
Type				
Number per burner				
Size				
Material				
Valves				
Location				
Number				
Type				
Size				
Material				
Location				
Number				
Type				
Size				
Material				
Miscellaneous				
Description				
Type				
Number per burner				
Material				
Size				

Data Sheet A-6—Mechanical Information—Gas Firing Data Sheet (Continued)

Model number				
Type				
Location				
Burner tile				
Number of pieces per burner				
Material				
Shape				
Type of mortar				
Expansion joint location				
Expansion joint width, in.				
Expansion joint packing				
Heat cure schedule				

Data Sheet A-6—Mechanical Information—Gas Firing Data Sheet (Continued)

Model number				
Type				
Location				
Venturi assembly				
Type				
Material				
Orifice size, in.				
Type of mortar				
Register assembly				
Type of closure				
Fixed section material				
Thickness, in.				
Rotating section material				
Thickness, in.				
Mechanism				
Muffler assembly				
Type				
Sound attenuation material				
Thickness, in.				
Lining retention mode				
Anchoring				
Shell material				
Thickness, in.				
Windbox assembly				
Material				
Thickness, in.				
Lining				
Thickness, in.				
Lining retention mode				
Anchoring				
Thickness, in.				
Windbox damper				
Type				
Material				
Thickness, in.				
Shaft diameter, in.				
Thickness, in.				
Bearing type				
Material				
Location of operator				
Type				
Mounting detail				
Cutout dimensions, ft				
Bolt circle or bolting dimensions, ft				
Number of bolts per burner				
Bolt size				
Bolt material				

Data Sheet A-7—Mechanical Information—Oil Firing Data Sheet

Model number				
Type				
Location				
Tip				
Part number				
Number per burner				
Material				
Drilling				
Screwed				
Welded				
Position in oil tile				
Atomization				
Steam				
Pressure, psig				
Differential pressure (steam-oil), psi				
Air				
Pressure, psig				
Differential pressure (air-oil), psi				
Mechanical				
Type				
Tile				
Part number				
Size/diameter, in.				
Material				
Number of pieces				
Guide tube				
Diameter, in.				
Length, in.				
Material				
Connection				
Clevis				
Other				
Air register				
Type				
Material				
Thickness, in.				

Data Sheet A-8—Pilot Data Sheet

Model number				
Type				
Location				
Model number of pilot				
Type of pilot				
Number per burner				
Heat release, MM Btu/hr				
Fuel type				
Fuel description				
Fuel pressure at pilot, psig				
Flame stability limits:				
Min. fuel pressure at pilot, psig				
Max. fuel pressure at pilot, psig				
Venturi type				
Size				
Material				
Orifice size, in.				
Type of ignition				
Muffler assembly				
Type				
Sound attenuation material				
Thickness, in.				
Lining retention mode				
Anchoring				
Shell material				
Thickness, in.				

Data Sheet A-9—Emissions Data Sheet

Model number				
Type				
Location				
NO_x at maximum heat release				
Firebox temperature, °F				
ppm at 3% excess oxygen (dry basis, LHV)				
ppm at 3% excess oxygen (dry basis, HHV)				
lb/MM Btu released (LHV)				
lb/MM Btu released (HHV)				
NO_x at normal heat release				
Firebox temperature, °F				
ppm at 3% excess oxygen (dry basis, LHV)				
ppm at 3% excess oxygen (dry basis, HHV)				
lb/MM Btu released (LHV)				
lb/MM Btu released (HHV)				
NO_x at minimum heat release				
Firebox temperature, °F				
ppm at 3% excess oxygen (dry basis, LHV)				
ppm at 3% excess oxygen (dry basis, HHV)				
lb/MM Btu released (LHV)				
lb/MM Btu released (HHV)				
NO_x guarantee point				
Maximum				
Normal				
Minimum				

Data Sheet A-9—Emissions Data Sheet (Continued)

Model number				
Type				
Location				
CO at maximum heat release				
Firebox temperature, °F				
Excess oxygen, %				
CO, ppm				
CO at normal heat release				
Firebox temperature, °F				
Excess oxygen, %				
CO, ppm				
CO at minimum heat release				
Firebox temperature, °F				
Excess oxygen, %				
CO, ppm				
CO guarantee point, ppm				
Maximum				
Normal				
Minimum				

APPENDIX B—BURNER TEST DATA SHEETS

Data Sheet B-1—Burner Test Data Sheet (for API Publication 535, Figure 17)

Job No.		Burner		Tips		Pilot		Ignitor	
Client		Mfg.		No. Tips		Mfg.		Mfg.	
Test No.		Type		Holes/Tip		Type		Type	
Date		Model		Hole Dia.		Model		Model	
Test Engr.		Size				Size		Size	

		Burner Performance Test Points								
	Design Pt.	A	B	C	D	E	F	G	H	I
Main Burner										
Heat release (LHV), MM Btu/hr										
Gas Fuel Type										
Fuel pressure, psig										
Fuel temperature, °F										
Fuel flow, scfh										
LHV, Btu/scfh										
Specific gravity										
Liquid Fuel Type										
Fuel pressure, psig										
Fuel temperature, °F										
Fuel flow, gpm										
Atomizing Media										
Atomizing media type										
Media pressure, psig										
Media temperature, °F										
Media flow, lb/hr										
Combustion Air										
(air, turbine exhaust, etc.)										
Temperature, °F										
Pressure, inches H_2O										
O_2 conc. (wet/dry), mole %										
Pilot										
Heat release (LHV), MM Btu/hr										
Fuel type										
Fuel pressure, psig										
Dampers/Registers										
Position										
Test Furnace										
Bridgewall temperature (°F)										
Floor temperature (°F)										
Draft, inches H_2O										
Flue Gas										
O_2 conc. (wet /dry), mole %										
CO, ppmvd										
NO_x, ppmvd										
Flame Characteristics										
Color										
Length, ft										
Diameter, ft										
Miscellaneous										

Data Sheet B-2—Burner Test Fuel Gas Specifications

Job No.	
Client	
Test No.	
Date	
Test Engr.	

Fuel Composition	Design Fuel, Volume %	Test Fuel, Volume %
Hydrogen		
Methane		
Ethane		
Ethylene		
Propane		
Propylene		
Butane		
Pentane		
Hexane		
Nitrogen		
Water		
Carbon monoxide		
Carbon dioxide		
Hydrogen sulfide		
Sulfur		
Sulfur dioxide		
Ammonia		
Other		
Total	100.00	100.00

Fuel Conditions	Design	Test Fuel
Molecular weight		
Specific gravity		
Lower heating value, Btu/scf		
Maximum pressure, psig		
Temperature, °F		

Data Sheet B-3—Burner Test Liquid Fuel Specifications

Job No.	
Client	
Test No.	
Date	
Test Engr.	

Fuel Composition	Design	Test Fuel
Fuel description		
Lower heating value, Btu/lb		
Higher heating value, Btu/lb		
Specific gravity at 60°C or °API		
H/C ratio (by weight)		
Viscosity @____°F, SSU		
Viscosity @____°F, SSU		
Fixed nitrogen, ppm		
Sulfur, % by weight		
Ash, % by weight		
Water, % by weight		
Fuel pressure, psig		
Atomizing medium		
Available atomizing medium pressure from header, psig		