Power Flame Incorporated

MEETING LOW NOx PERFORMANCE REQUIREMENTS WITH THE POWER FLAME NOVAâ SYSTEM

· White Paper ·

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1. General Background

For a number of years the Federal Government has had concerns that relate to the negative environmental and health impact that results from the emission of NOx into the atmosphere. As a result of these concerns the 1990 Federal Clean Air Act Amendments have directed that each state develop a "State Implementation Plan" (SIP) which will meet and then maintain "National Ambient Air Quality Standards (NAAQS)". These Standards include the monitoring and control of NOx emissions.

An increasing number of states are becoming actively engaged in developing regulations that will exceed the Federal requirements. In California the "South Coast Air Quality Management District" (SCAQMD) regulates air emissions in the four (4) counties around Los Angeles and the "Bay Area Air Quality Management District" (BAAQMD) regulates air emissions in all or part of the nine (9) counties surrounding the San Francisco Bay Area. These AQMD's are aggressively implementing NOx emissions limitations that are designed to meet the NAAQS in accordance with requirements set forth in the 1990 Clean Air Act Amendments.

To achieve the Air Quality Standards mandated by the Federal EPA, the California AQMD's have set very stringent NOx emission limits based upon the "lowest achievable emission rate" (LAER) or "best achievable control technology" (BACT). BACT takes into consideration proven technologies that provide significant NOx reductions at reasonable costs. LAER is based strictly upon the lowest NOx reductions that can be achieved irrespective of the cost or proven nature of the technology. In general, BACT has been adopted by the SCAQMB and BAAQMD. It is likely that other states considered "non-attainment" areas by the Federal EPA will adopt similar rules based upon BACT. Texas has already adopted the SCAQMD rules for the counties around Houston and Dallas-Fort Worth. New Jersey and other northeastern states are considering adopting similar rules.

Power Flame has produced hundreds of low NOx, NOVA® burner installations in a wide range of boiler applications. All those applied to the California market have been successfully subjected to stringent on site testing and approvals by State certified independent air emissions testing firms. The Patented NOVA concept as well as variations of the NOVA have been effectively applied to a growing number of states where farsighted Consulting Engineers have written specifications for low NOx results similar to those required in California.

The purpose of this presentation is to provide a general overview of the NOx subject and the various technological approaches that are being employed to deal with the reduction and control of NOx emissions. While some very general information is provided on NOx as relates to fuel oils, we will essentially limit this presentation to NOx and its reduction and control in relation to standard, natural and LP gases.

2. <u>NOx Emission Sources</u>

NOx emission sources can be divided into two (2) main categories - mobile and stationary. Mobile includes on the road type equipment, cars, trucks, buses - as well as others such as planes, trains, etc. It is estimated (in the SCAQMD area) that the mobile sources represent about 70% of all NOx emissions. The other 30% is divided equally between space and water heating from residential and commercial sources - and space and water heating, plus processing in industrial facilities. These percentage estimates will vary with specific areas being considered, but in all cases the mobile sources represent, by far, the greatest source of NOx emission. Power Flame's concern relates to the commercial/ industrial stationary sources.

3. <u>NOx - Definition/Hazards</u>

Oxides of Nitrogen (NOx) is the collective term used in referring to Nitric Oxide (NO) and Nitrogen Dioxide (NO_2). NO is the predominant form produced in the combustion process, which then combines with oxygen in the atmosphere to eventually produce NO_2. NO_2 is also formed directly via the combustion process, but generally represents a small fraction of the total NOx produced.

Some of the specific environmental and health concerns related to NOx emissions include:

> Contributing to the formation of "PM_{10}" which is suspended particulate matter less than 10 microns in size - which is known to effect the human respiratory system.
>
> Photochemical smog is a term used to represent the process of smog formation. NO_2 formed in the atmosphere from NO and O_2 reacts “photochemically”, or in the presence of sunlight, to form ground-level ozone (O_3). Reactive hydrocarbons (RHC’s) in turn react chemically with the ozone to produce smog. Photochemical smog is classified as a health hazard and can affect the respiratory system.

4. <u>The Formation of NOx</u>

NOx is produced from the nitrogen present in the combustion air and in the fuel being burned. The generation of NOx is in large part governed through chemical kinetics, and results from high flame temperatures in the presence of oxygen over a period of time commonly referred to as resident time.

a. <u>Thermal NOx</u> - Results when the Nitrogen and Oxygen in the air combine at the elevated temperatures of the combustion process. (Combustion air consists of approximately 21% Oxygen and 79% Nitrogen). The well known Zeldovich Mechanisms describe thermal NOx formation.

b. <u>Fuel Bound NOx</u> - Is the result of Nitrogen chemically bound in the fuel hydrocarbon chain combining with the burner air at the elevated temperature present in the combustion process. Fuel Bound Nitrogen has a higher propensity to form NOx, and, of course, is difficult to eliminate from the fuel.

c. <u>Prompt NOx</u> - Prompt NOx is formed in the early, low temperature and fuel-rich stages of combustion. Hydrocarbon fragments can react with nitrogen to form fixed nitrogen species such and CN, NH_3, HCN, H_2CN, etc. These, in turn, can be oxidized in the leaner zones of the flame forming NO. While prompt-NOx is usually a relatively smart part of the total NOx produced, it can be a significant portion of the total amount for low-ppm NOx systems, such as with sub 12 and sub 9 ppm burners.

- Natural or LP Gas contains no Fuel Bound Nitrogen and is therefore the fuel of choice for NOx reduction.
- Liquid Fuels (No.2 through No.6 fuel oil) contain high levels of Fuel Bound Nitrogen and are therefore far more difficult candidates for NOx reduction.

Special low fuel-bound nitrogen Liquid Fuels are now available, however, they are extremely expensive. As a result, they are currently being used only as backup fuels for hospitals and similar critical applications.

5. <u>Combustion Chamber Design and NOx</u>

The generation of NOx relates directly to peak flame temperatures, furnace geometry and furnace heat release characteristics, as well as the heat absorbing (and reflecting) characteristics of the chamber surfaces. In general, the larger the combustion chamber volume (for a given BTU input) the lower the NOx emission rate. This relationship may be demonstrated by simply reducing the firing rate in a given chamber. A combustion chamber with its floor and sidewalls made of refractory material (such as firebrick) will typically generate higher NOx emissions than a cool walled chamber, such as wet-base furnace walls incorporated in water-tube boilers. This is due to higher radiation of heat back into the flame from refractory wall furnace designs, than with water-walled designs which will transfer more heat out of the flame.

For typical nozzle mix burner designs, a longer and sometimes luminous flame pattern will generate lower NOx levels than with a more turbulent, short and bushy flame pattern. This is due to higher flame emissivities and lower peak flame temperatures with the elongated, more luminous flame pattern.

6. NOx Measurements

The major form of NOx generated in the combustion process is NO. NO_2 formed in the combustion process is normally a small % of the total NOx formed. However, it can be a significant portion of the total NOx formed at lean low-fire conditions and with very low NOx systems. Combustion instrumentation must accommodate both NO and NO_2 measurements. This equipment is readily available today.

Instrumentation used to measure NOx generally reads out in parts-per-million by volume dry-basis (ppmvd), commonly referred to in its shortened version as ppm.

Because the level of excess air in the flue gases can greatly effect the NOx readings and because it is impossible to have all equipment operating at the exact same excess air levels, the controlling agencies have chosen a standard flue gas oxygen level to which all readings are required to be corrected. For most burner applications that level is 3% O_2. Since the majority of NOx emission levels will be recorded at some flue gas oxygen level other than 3% there is a simple formula to correct to the 3% level.

$$\text{NOx ppmvd (3\%)} = \frac{\text{NOx ppmvd (X\%)} * 17.9}{(20.9 - X\%)}$$

(Also see the NOx Correction Curve in the NOVA Manual)

While many of the Air Quality Management Districts make their rulings in ppm or will accept ppm in permitting forms, there are some that will not. Quite often the requirements are given in pounds of NOx per million BTU fired.

Lbs NOx/MM Btu

As a rule of thumb, 829 ppm of NOx is the equivalent of 1 pound of NOx per million BTU fired for natural gas, and 812 ppm of NOx is equivalent to 1 pound NOx per million BTU fired for commercial propane gas. Therefore, a requirement for a maximum NOx level of 0.036 Lbs/MM BTU for natural gas is:

$$(829)\ (0.036\ \text{Lbs/MM Btu}) = 30\ \text{ppmvd NOx}$$

To convert from ppm NOx (corrected to 3% O_2) to lbs./MMBTU for natural gas:

$$\text{NOx lbs./MMBTU (3\% } O_2\text{)} = \frac{\text{NOx ppm (3\% } O_2\text{)}}{829}$$

NOx values for commercial propane is handled similarly, using the conversion factor of 812 in the above formula (in lieu of 829 for natural gas).

7. How Do We Reduce NOx Formation

In general, the reduction of NOx in the combustion process involves three methods, i.e., the reduction of the peak flame temperatures which drive the chemical kinetics, controlling stoichiometry (the amount of oxygen present during these critical reactions), and reduction of nitrogen in the fuel (which generally pertains to fuel oils). Burners can be classified as diffusion flame (nozzle-mix) type, premix, or a hybrid of both types.

A. Low Excess Air Operation – Nozzle Mix Type Burners

Low excess air operation, while it generally results in a higher flame temperature, does reduce the amount of free oxygen and nitrogen available for the formation of NOx. For every percentage point of reduction of the flue gas oxygen level, the NOx level is generally reduced by 2 to 8 ppm of NOx. The Power Flame Vector burner employs this technology.

B. Staged Air Burners

Early low NOx burners utilized staging of combustion air. This design allowed enough air at the burner nozzle to maintain a stable flame (fuel-rich primary zone) and reduce peak flame temperatures while channeling the remaining air into the flame zone downstream. Inert products of combustion from the first stage quench the second stage, further reducing flame temperature and NOx. The result was burners which reduced NOx approximately 25 to 35%.

C. Internal Recirculation Burners

These burners employ an arrangement whereby the products of combustion in the furnace area are recirculated back into a fuel rich primary flame zone and a fuel lean secondary flame zone. This combination provides lower flame temperatures and reduced NOx levels.

D. Staged Fuel (Secondary Combustion) Burners

The Power Flame NOVA staged fuel low NOx burner uses staging of the fuel rather than the air. Staged fuel burners use a first stage high in excess air (resulting in lower peak flame temperatures in this zone), while the secondary flame zone operates at lower oxygen concentrations which retards NOx formation. NOx emissions are further reduced by the quenching effect of inert products of combustion from the first stage which lower second stage flame temperatures. The result is a burner which reduces NOx by 30 to 50%. The NOVA burner has been able to meet strict air pollution requirements in many applications having relatively low baseline NOx levels with only the use of staged combustion.

E. Flue Gas Recirculation (FGR)

This well known method uses cooled flue gases from the boiler stack as a source of dilution gas. They are very low in oxygen content and are composed of inert compounds like nitrogen, water vapor and carbon dioxide which is an excellent heat sink. These inerts reduce the peak flame temperature in the burner and reduce the NOx formation. Flue gas recirculation can reduce NOx emissions up to 80%, depending on heat exchanger/furnace design and baseline NOx levels. For special applications, FGR can be combined with other NOx strategies, such as staged fuel firing, for additional NOx reduction. Flue gas is recirculated (transported) back to the combustion process by either the forced or induced recirculation method.

F. Forced Flue Gas Recirculation

A dedicated high temperature forced flue gas recirculation blower recirculates a controlled volume of flue gases to the NOVA low NOx head adapter assembly. Flue gases enter the combustion zone through an annular space surrounding the burner head and main flame.

G. Forced Flue Gas Recirculation Combined With Staged Fuel Firing

The NOVA adapter is capable of introducing both staged fuel and FGR into the combustion zone. Many of these effective NOx reduction systems have met tough air pollution requirements on challenging applications.

H. Induced Flue Gas Recirculation

The burner mounted combustion air blower induces a flow of recirculated flue gas which is mixed with the combustion air within the burner. Flue gas enters the burner through an FGR adapter, which prevents recirculation during purge periods and controls the volume of flue gas flow during burner operation. Sub 30 ppm NOx operation is easily achieved in most applications and sub 20 ppm NOx levels is achievable in favorable furnace designs. Power Flame offers an entire series of Induced FGR low NOx burners, including the LNIJ, LNIC, LNIAC, and LNIV burners, ranging from 700 MBH to 63,000 MBH input.

Since the combustion air fan delivers both the necessary air for combustion and the recirculated flue gases, additional fan capacity must be planned and in some instances, burner model size may increase for a given application. In general, Induced Flue Gas Recirculation (IFGR) is a very cost effective and proven method for reducing NOx to sub 30 ppm levels. The addition of flue gas recirculation piping to deliver the FGR to the burner needs to be considered in the total installation cost of this low NOx burner system.

I. Steam Injection

The injection of steam is used to lower the flame temperature in the same manner as recirculated flue gas. The operating cost is usually higher than flue gas recirculation, but does not require the addition of a fan. The introduction of water into the flue gas makes the results slightly less dramatic due to the dry basis reporting methods. Other potential drawbacks to steam injection relate to its negative impact on boiler efficiency, erosion of refractory surfaces, and unavailability with hot water boilers.

J. Full Premix Burner (Non-Surface Type)

Premix low NOx burners reduce NOx emissions by controlling the fuel air mix and temperature in each combustion zone. The premix strategy alone can achieve as much as 90% NOx reduction. Generally, NOx levels are reduced with increased oxygen (O_2) operating levels. Typically, stack O_2 levels in the 4 to 5 -1/2% range will produce sub 30 ppm NOx (corrected to 3% O_2) levels. With O_2 in the 5-1/2 to 6-1/2% range, sub 20 ppm NOx levels can be achieved. Sub 12 ppm and sub 9 ppm NOx levels can be achieved with even higher excess air levels, in the 7-1/2 to 9% range. The Power Flame NOVA Premix series natural gas and propane burners are sized for inputs ranging to 2,200 MBH, and utilize a high swirl number, high spin diffuser.

The NOVA Premix burner does not require any external flue gas piping, and utilizes normal (unfiltered) boiler room combustion air. Burner maximum sizes are generally limited due to increased pressure drop requirements across the burner head and relatively large diffuser openings (for premix technology) to ensure no flash-back conditions.

Similar NOx reductions can be obtained if the premix strategy is combined with flue gas recirculation. This approach will reduce the higher excess air levels normally required with the full premix strategy allowing for more efficient operation.

K. Full Premix Surface Combustion Burners

These are surface burning, radiant type burners usually constructed of metal, ceramic or fiber surfaces and utilize a premix gas/air arrangement. The flame burns at relatively low temperatures and results in very low NOx levels. The NOVA Plus Series offer sub 12 and sub 9 ppm performance ranging from 2,000 MBH to 14,700 MBH input.

The matrix element combustion head has many relatively small openings to produce the surface burn effect and to prevent flashback. Subsequently, these burners require an intake air filter to ensure removal of contaminants in the combustion air.

L. Selective Catalytic Reduction (SCR)

This is a very expensive add-on system which uses a catalytic bed to cause the NOx to react back to nitrogen and water. These systems also require the injection of ammonia or synthetic urea in a tightly controlled temperature zone. This strategy is most often used on very large systems requiring major NOx reductions. Reduction levels of up to 95% can be achieved with SCR. However, there have been problems associated with SCR systems entailing “ammonia slip” into the atmosphere.

8. NOx Compliance Requirements

NOx compliance requirements should be obtained from your state or local air quality regulatory agency.

9. Developing the Power Flame "NOVA" Technology

The original NOVA design concept incorporated the use of both Staged Fuel (Secondary Combustion) and Flue Gas Recirculation, with a forced flue gas recirculation blower. This system is available for Model "C" and "HP" burners through 25,200,000 BTU/HR.

As a result of continuing R&D activities on the NOVA Staged Fuel design, we have achieved significant NOx reduction with Staged Fuel only on many applications. This represented a positive step toward NOVA NOx emissions control system simplification and cost reduction, by eliminating the forced FGR blower and its installation cost.

Further R&D development included the NOVA Induced FGR (IFGR) NOx emissions control system. The IFGR strategy makes use of the burner combustion air blower to also induce a flow of recirculated flue gas. The Induced FGR system provides excellent NOx reduction at low cost for a wide variety of applications. This system is available for Model "J", "C" and Vector burners, through 63,000,000 BTU/HR. Power Flame's NOx reductions are in excess of 70% on gas and 40% on oil.

Power Flame R&D advanced NOx reduction technology by developing the NOVA Premix (NPM) series natural gas and propane low NOx burners, ranging from 700 MBH to 2,200 MBH input. Original Equipment Manufacturers are currently certifying their equipment (up to 2,000 MBH) for sub 30 ppm NOx operation under California's Pre-certification program. Once a package is pre-certified, individual unit source testing is not required.

More recently, Power Flame has introduced its NOVA Plus Series of straight gas, low NOx burners incorporating premix technology and special alloyed steel matrix-type combustion heads. Burner Model inputs ranges from 2,000 MBH to 14,700 MBH. These units are Underwriter's Laboratories Listed.

10. Conclusion

To date, California has expended great effort enacting regulations relating to Air Emission Standards and compliance enforcement. As a result, Power Flame and other burner manufacturers have, at considerable cost, developed burner systems to meet the California standards. Because of the Federal Clean Air Act Amendments of 1990, each state has been required to submit a "State Implementation Plan" (SIP) to meet the National "Ambient Air Quality Standards" -- and that plan must be put into effect.

NOx legislation across the country is beginning to create an accelerated market demand for low NOx burners. Our representative sales organization should now begin to encourage specifying engineers to specify the NOVA low NOx burner - on the basis that this places his customer one step ahead of the legislation that is sure to effect him in the near future.

Since the original NOVA design is based on using a standard "J", "C", "HP" or Vector burner and then adding specific low NOx components in modular groups to develop the operational low NOx burner, it also lends itself to a "future low NOx configuration", i.e., buy the basic burner now and simply install the additional NOVA low NOx equipment when required in the future. Consultants may prefer this approach rather than specifying low NOx burners at the outset.

Power Flame is a Proven Performer in low NOx technology. The experience gained from hundreds of successful installations can provide specific direction (Staged Fuel, IFGR or Premix) for a wide range of heat exchanger applications. The Power Flame Engineering Department is prepared to specifically evaluate and guide your direction for low NOx equipment selection that will serve both your current and future requirements.

Power Flame continues to create new and unique methods to attack the low NOx issue. Induced FGR systems have been successfully applied to a vast number of specific installations. Our current series of Premix burners produce exceptional low NOx results without the aid of FGR. As technology continues to improve, Power Flame is on the leading edge of those developments.

We look forward to working with you on this new and expanding market opportunity.

GLOSSARY OF ACRONYMS
NOx REGULATIONS AND EMISSIONS CONTROL

APCD Air Pollution Control District
A local air quality agency regulation pollution.

AQCR Air Quality Control Region
One of the ten EPA regional offices throughout the U.S..

AQMD Air Quality Management District
A local or regional air quality agency regulating pollution.

ARB Air Resources Board
Air pollution control agency - usually at state level.

BACT Best Available Control Technology
The most stringent of the most effective emissions control device or technique, the most stringent emissions limitation, or any control device or technique determined to be technologically feasible and cost effective by the permitting authority.

BARCT Best Available Retrofit Control Technology
An emissions limitation developed for retrofitting existing equipment, based on BACT principles.

CARB California Air Resources Board
California state air pollution control agency.

CEM Continuous Emission Monitoring
Required in many local districts and by NSPS for certain applications (usually for larger inputs and/or fuels having higher emissions levels).

CFR Code of Federal Regulations
Rules published in the Federal Register by the departments and agencies of the Federal Government.

EPA Environmental Protection Agency
Federal agency responsible for pollution control.

FGR Flue Gas Recirculation
A NOx emission control technique - involving the return of portion of flue gases to the combustion zone.

LAER Lowest Achievable Emission Rate
Most stringent emission limitation contained in any SIP or achieved in practice for a given class of equipment.

MACT	Maximum Available Control Technology Emission standard requiring the maximum degree of emission reduction that has been demonstrated achievable.
NAAQS	National Ambient Air Quality Standards EPA established air quality standards for ambient outdoor emission level.
NOx	Nitrogen Oxides NOx emissions means the sum of nitric oxide (NO) and nitrogen dioxide (NO_2) in the flue gas, expressed as nitrogen dioxide (NO_2).
NSPS	New Source Performance Standard EPA established regulations for emissions from equipment, including boilers. Many state regulations are more stringent than the NSPS.
NSR	New Source Review A review performed during the permitting process for a new major installation in a nonattainment area.
PM10	Particulate Matter Smaller Than 10 Microns NOx plays a major role in creation of PM10, which can penetrate the human respiratory system, causing significant health effects.
PPM (or PPMV)	Parts Per Million - By Volume A volumetric measurement of stack emissions constituents.
RACT	Reasonable Available Control Technology A set of recommended levels of emission controls applicable to specific sources or categories located in nonattainment areas.
SCAQMD	South Coast Air Quality Management District Air pollution control agency for the Los Angeles, CA area. Emission regulations enacted by SCAQMD generally set the trends for other local regulations throughout the U.S..
SCR	Selective Catalytic Reduction A NOx control method in which ammonia or urea is injected into the exhaust gases in the presence of a catalyst.
SIP	State Implementation Plan An EPA approved emission control plan to attain or maintain NAAQS.
SNCR	Selective Non-Catalytic Reduction A NOx control method where ammonia or urea is injected into 1600• F (approximate) exhaust gases.
VOC	Volatile Organic Compound Certain organic compounds which would be emitted during use, processing, etc.. VOC's are precursors to low level ozone and smog.