CONTROL OF INDUSTRIAL ENGINE AND GAS TURBINE EXHAUST EMISSIONS TO MEET PRESENT AND FUTURE CLEAN AIR REGULATIONS

by

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ABSTRACT

Increasingly stringent regulations by the EPA and state air quality agencies in the U.S., as well as new regulations by Environment Canada, are making the reduction of exhaust emissions from industrial engines and gas turbines ever more important for their operators. Not only are these regulations getting increasingly strict with time, but there will be both substantial fines and possible criminal penalties for non-compliance in the future.

This presentation describes how harmful exhaust emissions are formed during the combustion process, what the current regulations are in various areas of North America and where they are probably headed in the foreseeable future. It then discusses possible emission reduction strategies in two broad categories, combustion modification and post-combustion treatment, using catalytic converters.

The three types of catalyst substrates are discussed, with the advantages and disadvantages of each, as well as the relative advantages and disadvantages of the four possible catalyst locations.

HOW ENGINE EXHAUST EMISSIONS ARE FORMED

When combustion takes place in a confined space under pressure, such as in the combustion chamber of a reciprocating engine or gas turbine, the resulting pressure and temperature cause some reactions which create compounds that have been judged to be harmful to the environment.

Under high temperature, high pressure combustion (Fig.1) some of the nitrogen in the air combines with oxygen and creates oxides of nitrogen, principally NO and NO₂, which are commonly referred to as NOₓ. Also, some of the carbon in the hydrocarbons does not completely oxidize and forms carbon monoxide (CO). In addition, some of the fuel does not completely oxidize and carries through in an unburned state. These unburned hydrocarbons are sometimes referred to as volatile organic compounds (VOC), reactive organic gasses (ROG), or non-methane hydrocarbons (NMHC) by various regulatory agencies. They all mean essentially the same thing and, for simplicity, will be referred to in this presentation as CₓHᵧ.

It has been determined that NOₓ assists in the formation of ozone, which is toxic, as is CO, and CₓHᵧ is a factor in the creation of smog. As a result, the Environmental Protection Agency (EPA) and Environment Canada have mandated that all three of these exhaust emissions must be reduced if we are to enjoy an improved environment.

EMISSIONS REGULATIONS

In the Clean Air Act Amendments of 1990, the United States was divided into attainment areas and non-attainment areas by the EPA. The emission requirements are stricter in the the non-attainment areas. These regulations are rather complicated and vary from state to state, but, in general, in the attainment areas exhaust emissions are required to meet the following values for engines of 500 horsepower and above: NOₓ 2.0 gms/bhp/hr CO 3.0 gms/bhp/hr CₓHᵧ 1.0 gms/bhp/hr
In the non-attainment areas, the levels are the same except that they apply to engines of 150 horsepower and above.

In the South Coast Air Quality Management District (SCAQMD) of southern California, the requirements are somewhat stricter, and apply to engines of ISO horsepower and above, as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>NOx</th>
<th>CO</th>
<th>CxHy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>0.30 gms/bhp/hr</td>
<td>0.50 gms/bhp/hr</td>
<td>0.60 gms/bhp/hr</td>
</tr>
<tr>
<td>1995</td>
<td>0.15 gms/bhp/hr</td>
<td>0.50 gms/bhp/hr</td>
<td>0.30 gms/bhp/hr</td>
</tr>
</tbody>
</table>

In 1995 the SCAQMD reduced the allowable NOx and CxHy values to half those previously allowed.

Some jurisdictions limit tons per year, rather than grams per horsepower hour. There has been a trend in the heavily populated northeastern portion of the United States to tighten the restrictions to somewhat more stringent than the rest of the country.

Environment Canada issued a guideline in 1994 calling for the following exhaust emissions for gas engines of 600kW or greater:

- NOx 6.0 gms/kW/hr
- CO 3.5 gms/kW/hr
- CxHy 2.0 gms/kW/hr

The regulations for gas turbines are a moving target at present, due to the rapid advances being made in NOx control by the turbine manufacturers. These technologies will be covered later in this presentation. Environment Canada has an innovative approach in this area in that they have a higher allowance for turbines that have waste heat recovery, to account for the fact that this saves the pollution from additional fuel being burned elsewhere.

It is evident that as various governmental bodies become more environmentally aware, there are going to be increasing restrictions on exhaust emissions. It is important for an engine or turbine operator to look ahead and select a reduction scheme that not only meets present requirements, but is capable of being upgraded to meet more stringent future regulations.

EMISSIONS REDUCTION STRATEGIES

Reduction of exhaust emissions falls into one of two basic categories, the first being internal modifications to reduce the formation of emissions during the combustion process and the second is post-combustion treatment, which involves the use of catalytic converters in the exhaust. Following is a listing of the various types of gas and diesel engines, as well as gas turbines, and the applicable reduction strategies for each.

RICH BURN (STOICHIOMETRIC) GAS ENGINES Non Selective (Three Way) Catalytic Converters.

The basic and most widely used catalytic converter technology is the three way catalytic converter, which simultaneously reduces NOx, CO, and CxHy. A three way catalytic converter requires that the air/fuel ratio be slightly rich of stoichiometric, where the quantity of CO and NOx are equal. The CO acts as a reducing agent for the NOx in the following reaction:

\[
\text{NO}_x + \text{CO} \rightarrow \text{N}_2 + \text{CO}_2
\]

The small amount of oxygen remaining in the exhaust oxidizes the CxHy in the following reaction:

\[
\text{CxHy} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}
\]

\(\text{N}_2, \text{CO}_2\) and H\(_2\text{O}\) are all non-toxic. This is a very simple and cost effective emission reduction strategy and is used on all automotive gasoline, propane and CNG fueled engines being built today.

Two Stage Catalytic Converters.

In southern California, and other critical areas, the emission reduction requirements are somewhat more stringent than can be met with a standard three way catalytic converter. In these instances a two stage catalytic converter is employed, in which a larger first catalyst is used, for a more thorough conversion of the NOx, producing the following reaction:

\[
\text{NO}_x + \text{CO} \rightarrow \text{N}_2 + \text{CO}_2 + \text{CO} \text{(excess)}
\]

Air is sometimes introduced down stream of this catalyst to provide a leaner mixture going into a second oxidation catalyst producing the following reaction:

\[
\text{CO} + \text{CxHy} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O}
\]

Because of the two catalysts required, this is more expensive than a three way catalytic converter, but will produce emissions reductions that meet all current and foreseeable future requirements. Also, it’s possible to design a catalytic converter to initially employ a three way catalyst, with space available for the later addition of a second catalyst, should it be necessary to meet a somewhat stricter emission requirement in the future.
Air/Fuel Ratio Controller

Exhaust emission control of rich burn gas engines is dependent on an engine air/fuel ratio that maintains equal quantities of NOx and CO (Fig.1). Under steady state operating conditions the engine can be adjusted to the proper air/fuel ratio manually, however as conditions change the air/fuel ratio deviates from the manual set point. This can be caused by a change in the fuel composition, engine load, speed or ambient air temperature. A normal carburetor cannot hold a constant air/fuel ratio under these changing conditions. For this reason, best conversion efficiency can only be achieved with an automatic air/fuel ratio controller.

Air/fuel ratio controllers are driven by an oxygen sensor installed in the exhaust stream of the engine, upstream of the catalyst. This sensor sends an electrical signal to a computer in the controller. This signal varies from 0 millivolts at full lean to 1,000 millivolts at full rich, with the ideal set point for a three way catalytic converter being somewhere in the neighborhood of 700 to 800 millivolts, as determined by exhaust gas analysis. The computer then either varies the fuel flow or pressure to the carburetor, or adds trim fuel, to maintain the proper air/fuel ratio.

TWO-CYCLE AND LEAN BURN FOUR-CYCLE GAS ENGINES

In general, gas engines that run with an extremely lean air/fuel ratio produce lower emissions than engines that run at a stoichiometric mixture, in which the fuel and air are theoretically correct for complete combustion (Fig.1). This is true for both lean burn four-cycle gas engines and two-cycle gas engines, which cannot be run stoichiometrically and always have some excess oxygen in the exhaust due to the scavenging air required. The additional air in lean operation causes more thorough combustion of the fuel, thereby reducing the levels of CO and CxHy in the exhaust, up to a point. The cooler combustion also reduces the formation of NOx as well, but as the mixture becomes very lean, the CO and CxHy begin to increase again, due to the cooler combustion. In order to reach the low emissions produced by these engines, the excess air causes the air/fuel ratio to exceed the lean ignition limit by a normal spark plug and it has to be ignited by some other means. There are several strategies for doing this, as follows:

1. The cylinder head can be manufactured with a pre-chamber combustor, which contains the spark plug. Additional fuel is introduced into this chamber to enrich the mixture to near stoichiometric. The spark plug then ignites this richer mixture, sending a flame into the combustion chamber to ignite the lean mixture there.

2. There are after market pre-chambers available that are designed to screw into the existing spark plug hole, to save the expense of purchasing new heads when converting an older engine to lean burn.

3. Ignition systems have recently been introduced which produce multiple sparks over several degrees of crank angle to improve the ignition of lean mixtures.

4. "Plasma" ignition systems have recently come on the market which produce a hot, long duration, arc at the electrodes for improved ignition of lean mixtures.

Excess Air for Lean Burn Engines

In addition to more reliable ignition for lean mixtures, lean burn engines also require substantially more air than rich burn (stoichiometric) engines. There are several strategies for providing this additional air, as follows:

1. New Engines - All new lean burn engines are turbocharged and are designed with high capacity turbochargers which provide excess air over and above normal requirements. In addition, these engines are generally built with the pre-chamber ignition system described above, as well as more sophisticated engine controls to maintain the air/fuel ratio and ignition timing at optimum for lowest emission levels. For this reason, lean burn engines are generally somewhat more expensive than their rich burn counterparts of the same horsepower.
2. **Retrofit of Turbocharged Engines** - When an older turbocharged rich bum engine is converted to lean bum operation it occasionally is possible to modify the existing turbocharger for higher capacity, but in most cases it is necessary to replace the existing turbocharger with a new higher efficiency, higher capacity unit. In addition the turbocharger after cooler must be replaced with a higher capacity unit and additional cooling water flow has to be provided to adequately cool the higher volume of air. Also it is imperative that the ignition system be improved by one of the methods described above. Of course the engine must still have very sophisticated engine controls. These retrofits can be very expensive.

3. **Retrofit of Naturally Aspirated Engines** - In an effort to retrofit naturally aspirated gas engines to some form of lean bum operation, a number of different schemes have been tried with varying degrees of success, as follows:

a. **Deration** - In cases where the full original design power of the engine is not required, it is sometimes possible to lean the air/fuel ratio by readjusting the carburetor, or inducting air downstream of the throttle valve, so that the engine burns less fuel with the same amount of air it was originally designed for. This can derate the engine 35% or more. It is generally necessary to improve the ignition somewhat to prevent misfiring at this lighter load, which can be expensive.

b. **Turbocharging** - the deration described above can sometimes be avoided by turbocharging a naturally aspirated engine during the conversion to lean bum operation. Not only is the new turbocharger rather expensive, but it generally is necessary to cool the air between the turbocharger and the engine, which involves not only the additional expense of an after cooler but the additional cooling water capacity involved. In some cases it also is necessary to replace the existing water cooled exhaust manifold with an insulated exhaust manifold, to provide more heat energy to the turbocharger, in addition to the added expense of more powerful ignition and better engine controls.

Many of the above lean bum combustion schemes will reduce NOx emissions to the 2.0 gms/hp/hr required in most of the United States and Canada and some will even go lower than that, however none of them will come anywhere close to meeting either the 0.15 gms/hp/hr required currently in Southern California or the stricter standards being proposed for the northeastern United States. Since requirements are beginning to tighten up, anyone contemplating new lean bum engines or a lean bum conversion on their existing engines needs to seriously consider whether the results achieved will meet the probable stricter future requirements in their area.

**Oxidation Catalysts**

As was noted earlier, the reduction of NOx emissions during lean bum combustion is often accompanied by increases in the formulation of CO and CxHy due to the cooler combustion (Fig.1). The levels of the CO and CxHy can be reduced by the installation of an oxidation catalyst in the exhaust to oxidize these pollutants into carbon dioxide and water. This reaction is the same as was explained above in the two stage catalytic reduction for rich bum engines.

**Selective Catalytic Reduction (SCR)**

In an oxygen rich exhaust, such as is produced by a lean bum four cycle engine or two cycle engine, it is not currently possible to significantly reduce NOx with a catalyst alone. In this situation the NOx can be reduced by introducing ammonia (NH3) in some form into the exhaust upstream of an SCR catalyst. A reaction between the NOx and NH3 takes place in the catalyst producing the following reaction:

\[ \text{NOx} + \text{NH3} \rightarrow \text{N}_2 + \text{H}_2\text{O} \]

In a premium SCR system, the addition of an oxidation catalyst downstream will cause the CO and CxHy to react with the excess oxygen to produce the following reaction:

\[ \text{C}_x\text{H}_y + \text{CO} + \text{O}_2 \rightarrow \text{CO}_2 + \text{H}_2\text{O} \]

This currently is the only effective way to reduce these three emissions in an oxygen rich exhaust. At present three different methods are being used to introduce ammonia into the exhaust stream:

1. The most cost effective way to provide ammonia in the exhaust is by the injection of anhydrous ammonia. Even though farmers have been handling anydrous ammonia and injecting it directly into their fields as fertilizer for many years, with a good safety record, many engine operators feel that there is a potential for problems should this pressurized gas escape into the atmosphere and are reluctant to use it. It has been classified as a toxic gas by OSHA and there might be some potential liability problems in this area.

2. Most of the problems associated with anhydrous ammonia can be overcome by the use of aqueous ammo-
nia, which is a solution of 25%-30% anhydrous ammonia into mineral free water. This water needs to be of very good quality to avoid depositing mineral scale on the catalyst when the water evaporates in the exhaust. This aqueous ammonia, also called ammonium hydroxide, can be purchased premixed from several suppliers in North America and is available delivered from their tank trucks. This solution can be stored at atmospheric pressure in closed tanks, which are arranged to prevent escape of any fumes into the atmosphere. This arrangement is being successfully employed at a number of installations in North America. The net ammonia delivered to the exhaust with this scheme is more expensive than with anhydrous ammonia, due to the expense of mixing and transporting the ammonia water solution.

3. The safest, and many people feel the most satisfactory, system is the injection of a solution of urea and water into the exhaust. Urea (ammonium nitrate) is a commonly and widely used fertilizer readily available all over the world. It is crystalline in form and granular, similar to rock salt. It is available in plastic or paper bags sized for handling by one person. It is non-toxic and is even used as a feed supplement for cattle and other livestock. It can be either purchased in its granular form and mixed by the user at the jobsite with demineralized water, or is available from several suppliers around North America as a premixed solution delivered in liquid form to the users storage tank. In either case, there is no vapor pressure problem or irritating fumes associated with the solution. Depending on the concentration, there can be some crystallization problems at very low temperatures, which can be solved either by heating the storage tank during these low temperature periods or using some additives that are available to retard this crystallization.

When the aqueous urea solution is injected into the engine exhaust the water is vaporized and the urea is transformed into ammonia by the exhaust heat. The resulting ammonia then reacts with the NOx as described previously. The net ammonia delivered to the exhaust is more expensive than with either aqueous ammonia or anhydrous ammonia, but most operators feel that the added safety is worth the additional cost.

In all of the above schemes, either a variable speed pump or a fixed volume pump with a variable bypass valve can be used to regulate the flow to the exhaust system. However, if the engine load is not excessive, ammonia is injected into the system. Excessive flow not only wastes ammonia but causes "ammonia slip" thereby introducing another toxic substance into the atmosphere. This can be prevented with proper controls.

**DIESEL ENGINES**

Unlike four cycle gas engines, diesel engines operate with an open throttle and, in the case of a naturally aspirated diesel, the air flow is strictly a function of the speed of the engine. In turbocharged diesels there is additional air that is a function of the exhaust energy available to the turbocharger. The power output of the engine is controlled by the amount of diesel fuel injected on each power stroke. Because of this, the exhaust of a diesel is always oxygen rich, even at full load, and it is impossible to operate a diesel at the stoichiometric point. For this reason a three way catalytic converter will not work on a diesel engine and the methods employed to reduce exhaust emissions are similar to those used on a lean burn four cycle or two cycle gas engine, both of which also have an oxygen rich exhaust. Some of the techniques for doing this are as follows.

**Combustion Modification**

In modern diesels the formation of NOx during the combustion process can be reduced by varying the fuel injection timing, injection pressure and injection duration to lower the combustion temperature and minimize the combining of nitrogen and oxygen in the air to form NOx. In some instances exhaust gas recirculation is also employed to reduce NOx formation. This reduced combustion temperature also increases the level of CO and CxHy in the exhaust.

**Oxidation Catalysts**

As is the case with lean burn gas engines, the CO and CxHy in diesel exhaust can be significantly reduced by employing an oxidation catalyst to complete the combustion process of these two emissions, using the excess air already present in the exhaust. Depending on the exhaust temperature available, it is not uncommon to get a 95 to 99 percent reduction in CO and 80 to 85 percent reduction in CxHy with an oxidation catalyst.

Another benefit of an oxidation catalyst in diesel exhaust is that both the diesel odor and visible smoke are significantly reduced to make the diesel engine more acceptable to the nearby community. The odor normally associated with diesel engines comes from the CxHy in the exhaust and, by significantly reducing these elements, the diesel odor that many people find objectionable is significantly reduced as well. Also the reaction between CO and CxHy in the catalyst is exothermic. This high temperature causes the black soot particles in the exhaust to either completely incinerate or further oxidize into
white particles, causing the exhaust to become very translucent, in fact essentially transparent.

The initial puff of smoke at start-up only lasts for a few seconds with an oxidation catalyst in place, and even this brief time can be reduced by electrically pre-heating the catalyst prior to start-up.

The use of an oxidation catalyst in conjunction with residential or hospital grade silencing has made many diesel engines much more acceptable in densely populated areas.

Selective Catalytic Reduction (SCR)
In cases where the NOx reduction by combustion modification is not adequate for the local air quality agency, the NOx can be further reduced by SCR, employing the use of ammonia injection, as described in the section on lean burn gas engines.

CATALYST SUBSTRATES
The catalyst in a catalytic converter consists of precious metals coated onto a substrate, which supports the catalyst and provides a flow path for the exhaust gas. These precious metals cause the necessary catalytic reactions. Several different substrates have evolved over the years.

In early converters the catalyst was in the form of ceramic beads containing the precious metals, which were then packed into a basket through which the exhaust gas flowed and contacted the catalyst. The disadvantage of this scheme was that pulsation in the exhaust caused the beads to rub against each other, reducing the volume of catalyst by abrasion.

This problem was solved by substituting a ceramic honeycomb structure for the beads. The catalyst was then coated onto the surface of this honeycomb. The disadvantage of using this substrate on industrial engines is that the pulsating flow in the exhaust causes fatigue cracking in the catalyst module. Also, ceramic substrates are very vulnerable to destruction by engine backfire.

To overcome this problem, some catalytic converter manufacturers are now using metal substrates. In a metallic substrate a foil of stainless steel is crimped to prevent its nesting, then either wound into a roll, or folded back and forth, to form a catalyst module which allows axial flow of the exhaust gas. The catalyst is coated onto the metal foil. These metallic substrates have proven to be more durable in operation on industrial engines, due to their better resilience and greater strength.

LOCATION OF CATALYST
There are four possible locations for the catalyst in a reciprocating engine exhaust (Fig 2). The advantages and disadvantages of each are as follows:

1. Catalytic Converters With No Exhaust Silencer - (Fig. 2a) This arrangement has the advantage of minimal exhaust back pressure to the engine, but the sound attenuation within the catalytic converter is also minimal and not adequate for most applications. The catalyst is also subject to damage by exhaust pulsation or backfires.

2. Catalytic Converter Located Upstream of the Exhaust Silencer - (Fig. 2b) This arrangement has the advantage of providing maximum exhaust temperature at the catalyst, which provides good catalytic conversion. In
general, the higher the temperature, the better the catalyst operates, up to a point. The disadvantage of this arrangement is that it subjects the catalyst to full pulsation of the engine exhaust, which can cause fatigue damage and eventual deterioration of the catalyst module, as well as possible backfire damage.

3. Catalytic Converter Located Downstream of the Exhaust Silencer - (Fig. 2c) This arrangement has the advantage of protecting the catalyst module from exhaust pulsation and backfire damage. It has the disadvantage that a lot of heat is radiated from the exhaust silencer, resulting in the exhaust temperature being reduced to a point where the catalyst is less effective.

4. Catalyst Located Within the Exhaust Silencer - (Fig. 2d) This is the optimum location. The first reactive chamber of the silencer greatly reduces the exhaust pulsation, for minimal fatigue damage to the catalyst module, and provides good backfire protection, yet the exhaust is still very hot at this point and will give a good catalytic reaction. This has the further advantage that the exhaust gas is flow conditioned by the first chamber so that not only is there less pulsation in the exhaust, but the exhaust is distributed more evenly across the entire face of the catalyst for maximum catalytic reduction. This arrangement can be designed for a lower total pressure drop than a separate converter and silencer in series, resulting in less exhaust back pressure to the engine for cooler, more economical engine operation.

GAS TURBINES

All gas turbines have an oxygen rich exhaust, due to the large quantities of dilution air that must flow through the turbine in order to keep the temperature to the first stage turbine blades at a low enough level to prevent failure of the blades. For this reason, the exhaust emission reduction schemes are similar to those used in lean burn gas engines and diesel engines. Some of these techniques are as follows:

Combustion Modification

The preferred and most cost effective way to reduce NO\textsubscript{x} in gas turbine exhaust is to reduce its formation in the first place. In the earlier days of gas turbines, combustion in the burner cans, or combustors, took place as a near stoichiometric combustion in the center of the can, which gave very good flame stability, with the necessary dilution air being added after the combustion took place. This gave a very hot flame in the center of the can, which generated large amounts of NO\textsubscript{x} due to the high temperature. The key to lowering the formation of NO\textsubscript{x} was to lower this temperature of combustion. The combustion modification schemes fall into one of two categories, as follows:

1. Water or Steam Injection - The earliest attempts to accomplish this was to add either high quality deionized water or steam to the combustion air as it entered the combustor. The presence of this water or steam lowered the combustion temperature and reduced the formation of NO\textsubscript{x}. This scheme was satisfactory in combined cycle plants where the exhaust heat was being used to generate steam for a steam turbine, as the high quality injection water had to be produced for the steam boiler anyway and it was not that difficult or expensive to produce additional deionized water for the gas turbine as well. This was not as satisfactory in pure mechanical drive turbines, as the deionized water or steam had to be made from scratch at a significant expense. Also water is scarce and expensive in many parts of the world. The quality of this water is critical because the presence of any minerals in the water will result in deposits in the combustors and on the turbine blades.

2. Dry Low NO\textsubscript{x} Combustors - Because of the problems above, most gas turbine manufactures are now concentrating their development efforts on the design of dry low NO\textsubscript{x} combustors, which do not require water or steam. In a dry low NO\textsubscript{x} combustor the fuel and most of the air are premixed as they enter the combustor to provide a very lean homogeneous mixture. The flame stability of such a lean mixture would normally be very poor, however this is overcome by a very small, near stoichiometric, pilot flame in the center of the combustor to maintain flame stability. Of course some NO\textsubscript{x} is formed in this pilot flame but this pilot fuel is held to the bare minimum, generally somewhat less than 5% of the total, so that the overall mixture generates very low NO\textsubscript{x}. Additional dilution air is added near the exit of the combustor to reduce the exit temperature to the necessary level for the first stage turbine blades. The key to making this scheme work is very careful control of the air/fuel ratio and mixing under a wide range of operating conditions to prevent flame out.

Dry low NO\textsubscript{x} combustors generally have been able to obtain lower NO\textsubscript{x} levels with gaseous fuel than with liquid fuel, due to the fact that it is easier to get a homogeneous mixture between gas and air than with liquids. Even sub micron size liquid particles have a high combustion temperature in the vicinity of the particle, which encourages NO\textsubscript{x} formation. Most base load turbines run on gaseous fuels anyway, with liquid fueling available as a standby in case of
interruption of the gas supply.

**Oxidation Catalysts**

In some cases the combustion modification used to control NOx formation does not adequately control the formation of CO and CxHy due to the lower combustion temperature. In this instance an oxidation catalyst can be added to the exhaust system to reduce these emissions as well, similar to the technology used on lean burn gas engines and diesel engines. These oxidation catalysts will also reduce the exhaust odor in the case of liquid fueled turbines.

**Selective Catalytic Reduction (SCR)**

In instances where combustion modification will not adequately reduce the NOx emissions in a gas turbine, SCR can be used to further reduce NOx levels, as described previously.

**CONCLUSION**

Hopefully this information will assist engine and turbine operators in choosing the exhaust emissions scheme best suited for their particular situation. It is important to keep in mind that the historic trend of emissions regulations have been for them to get increasingly strict as time goes by. Because of this, it is important that the operator select an emission control system that will not only meet the current requirements, but also have the capability of being upgraded to meet stricter requirements which seem to be inevitable in the future.