ETEC

The Theory of Cost-Effective NOx Reduction

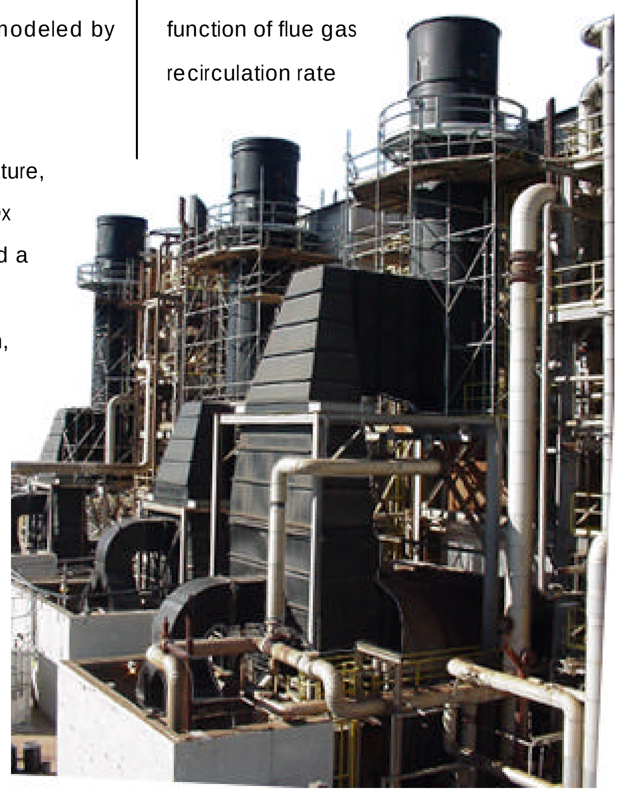
A Business Report

NOx is one of the primary air pollutants emitted from combustion processes and environmental regulations are the only driver forcing industry to install NOx control systems. In the Houston Galveston area alone, there is over 6,000 point sources that would need to be controlled to comply with the new State Implementation Plan adopted by the TNRCC. Many in the industry are in the process of evaluating control techniques to comply with the new regulations. Before evaluating NOx control strategies, it is important to establish the present baseline emission levels and to understand the NOx formation mechanism.

Most of the NOx formed during combustion of gas and light oil is from high temperature oxidation (or "fixation") of atmospheric nitrogen and is referred to as Thermal NOx. NO is the major constituent of thermal NOx and its formation can be modeled by the Zeldovich equation:

$$[NO] = k_1 \cdot \exp(-k_2/T) \cdot [N_2] \cdot [O_2]^{1/2} \cdot t$$

where, [ ] = mole fraction, k's = constants, T = temperature, and t = residence time. The equation indicates that NOx formation is an exponential function of temperature and a square root function of oxygen concentration. Thus, by manipulating the temperature or oxygen concentration, the formation of thermal NOx can be controlled. Systems manipulating the oxygen concentration are referred to as stoichiometry-based combustion control techniques (e.g. Low NOx Burners or LNBs) and those reducing the temperature are referred to as dilution-based combustion control techniques (e.g. Flue Gas Recirculation or FGR). LNBs control NOx emissions by providing air staging to create an initial, fuel-rich zone (partial combustion zone) followed by an air-rich zone to complete the combustion process. Some burner designs incorporate fuel staging that results in lower levels of NOx. Since NOx formation is a square root function of oxygen concentration, the reduction capability of stoichiometry-based technologies is limited. According to the theory, NOx formation should increase with oxygen concentration or with the amount of excess air. In practice, however, increasing the amount of air lowers NOx formation due to reduction in flame temperature. Typical reduction in NOx as a function of actual air to theoretical air ratio is shown in Figure 1. For comparison, typical NOx reduction as a function of flue gas recirculation rate



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is shown in Figure 2.

Reduction in NOx due to fuel staging or varying the oxygen levels can be as high as 40%. NOx reduction due to dilution with flue gas can be as high as 80%. Newer LNB designs such as ULNBs attempt to capture the concept of dilution by incorporating internal recirculation to obtain lower levels of NOx. Unfortunately, to obtain the desired levels of internal recirculation, higher fuel gas pressure and a larger burner throat are required. In retrofit applications, larger burners result in a need to rebuild furnace floor. Rebuilding furnace floor is both expensive and time consuming; and, increases the LNB installation cost exponentially! Performance of ULNBs is also very sensitive to several factors including hydrogen in fuel gas, air preheat, particulates, liquid droplets and air leakage. Fuel gas containing hydrogen, air leakage into the furnace and air pre-heat result in increasing NOx emissions from ULNB. Changing the fuel gas system to remove hydrogen, particulates and droplets from fuel gas and sealing the furnace to ensure no air leakage also increases the cost of installing ULNB significantly. Eliminating air pre-heat for ULNB application not only increases installation costs, but also increases operating costs in terms of additional fuel cost. ***Most combustion experts agree that once the air pre-heater is removed, the unit never returns to the original operation!*** Furthermore, at reduced loads, the internal recirculation rate is reduced due to lower fuel flow. This results in limiting the turndown ratio of the newer burner designs.

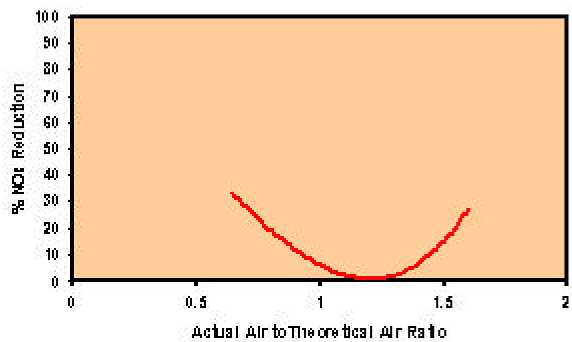


Figure 1. NOx Reduction as a function of Actual Air to Theoretical Air Ratio.

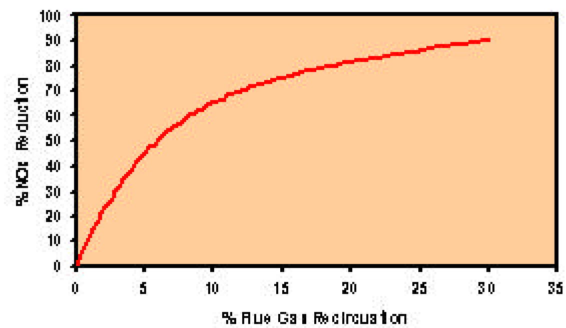
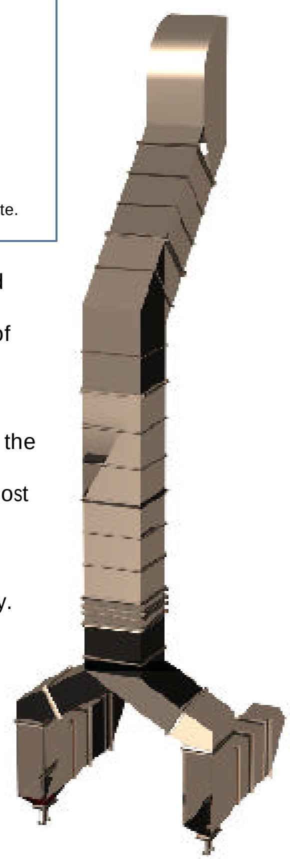


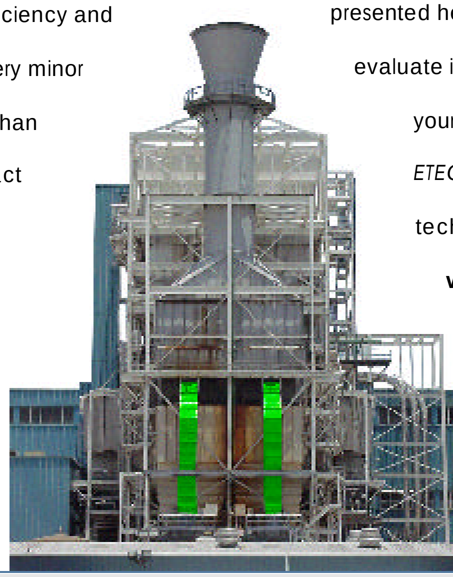
Figure 2. NOx Reduction as a function of Flue Gas Recirculation Rate.

To avoid limitations of the newer burner design but to capture the concept of lower NOx reduction, some burner vendors offer external FGR along with LNB, but for a cost equivalent to that of SCR! Since the total installed cost of burner systems is an order of magnitude higher than FGR; and, since most of the NOx reduction in the newer burners is due to FGR, the most cost-effective alternative is the proven standalone FGR technology.



In a typical FGR application, about 5 to 25 % of the flue gases is recycled back to the combustion zone resulting in NOx reduction as high as 80%.

Thus, NOx levels that can be achieved with newer burners can also be achieved by external FGR- at a significantly lower cost and without limiting the turndown capability of the unit. Elimination of air pre-heater operation to reduce NOx is not necessary with FGR. Major cost of traditional FGR technology is due to an additional hot gas fan requirement to transport the flue gas. To reduce the cost even further, *ETEC* has developed a very cost-effective technology that eliminates the need for a separate FGR fan and windbox mixing devices. *ETEC*'s proprietary Induced FGR technology (IFGR) is based on utilizing the existing forced draft fan to induce flue gas into the combustion air at the fan inlet. FDF capacity required for IFGR is equivalent to operating the fan with extra 1 to 4 % O_2 in flue. IFGR technology (patent pending) reduces NOx emissions by as much as 80%, and typically improves the combustion efficiency and performance. IFGR technology requires very minor modifications and can be installed in less than a week. IFGR has relatively little or no impact on performance and operation. For fan limited units, *ETEC* offers several low cost debottlenecking options to accommodate IFGR flow. For operators of natural draft units planning on installing SCR technology, *ETEC* provides a modified IFGR technology called Slip Stream FGR technology (patent pending), where a slipstream from downstream of SCR fan is recirculated back into the flame zone to obtain high levels of NOx reduction. A combination of *ETEC*'s FGR based systems with post-combustion SCR technology is more cost-effective compared to application of only SCR technology (see Chemical Engineering, Feb 2001). This is because when SCR is used in combination with *ETEC*'s FGR systems, the costs associated with catalyst and ammonia-handling systems are significantly reduced due to lower NOx concentration. In certain situations, reduction in ammonia usage alone payback *ETEC* Technology cost in less than 6 months. BCCA estimates about $ 8 billion will be spent in the Houston-Galveston area to comply with the rules. We believe that the approach presented here can reduce the costs by more than 35%! To evaluate if IFGR or Slip-Stream FGR technology is suitable for your needs, or if you need additional information on *ETEC*, IFGR, Slip-Stream FGR and other NOx reduction technologies, please:



visit us at http://www.eteclp.com or contact us at (281) 807-7007 or by e-mail at: info@eteclp.com.

About *Entropy Technology & Environmental Consultants* (*ETEC*):

ETEC has pioneered advancements in Flue Gas Recirculation and offers turnkey installation for its IFGR and Slip Stream FGR Technologies. *ETEC* engineers have designed/installed over 30 FGR based systems. *ETEC* specializes in providing technical consulting services in the energy and environmental fields. *ETEC* engineers have experience in working with over 80 clients including, Reliant Energy, Entergy, LCRA, ExxonMobil, Lyondell-Citgo Refinery, BASF, etc.