Fuel technology

Control of nitrogen oxides

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AIR pollution arising from the emission of nitrogen oxides, NO_x , from combustion taking place in boilers, furnaces and engines, has increasingly been recognized as a problem (see, for example, *Fourth Report from the Environment Committee, Acid Rain*, HMSO, 1985). NO_x has been implicated as a photochemical oxidant and a constituent of acid rain, as well as being a pollutant in its own right. As a consequence, stringent legislation to limit its emission has been introduced or is proposed in the next few years in many parts of the world, but particularly in the United States, Japan and western Europe.

Several methods for controlling NO_x emissions have been developed (for example, *Control Technology for Nitrogen Oxide Emissions from Stationary Sources*, OECD, 1983). Most of these have some unsatisfactory aspects, however, and there is a constant search for new control technologies. Elsewhere in this issue R.A. Perry and D.L. Siebers (*Nature* **324**, 657; 1986) propose such a new technique. This method, developed at the Sandia National Laboratories, Livermore, California, is based on adding isocyanuric acid to hot exhaust gases, the acid being produced from the thermal decomposition of non-toxic cyanuric acid above 330 °C

Because this new control method has some attractive features it is worthwhile looking at it in the context of the control strategies that are currently available. The engineering aspects of the control strategies available for both NO_x and SO_2 are under investigation by the Fellowship of Engineering in the United Kingdom and its results will be published next year.

The major sources of NO_x are stationary combustion sources, such as boilers and furnaces, and motor vehicles, although some NO_x is emitted from chemical processing plants. The primary pollutant produced is NO , although some NO_2 and N_2O can be formed, and the NO reacts in the air to form a mixture of NO and NO_2 (NO_x). First, thermal NO is formed in combustion chambers from the oxidation of N_2 by the oxygen present in the 'excess air' needed to carry combustion to completion. Second, NO is formed from fuel-nitrogen compounds present in coal or to a smaller extent in oil, but not in natural gas. Third, NO can be formed in fuel-rich flames where hydrocarbon radicals react with nitrogen; this source, which is normally small, is termed 'prompt- NO '.

Various NO_x control technologies have been directed at combustion chamber modifications or a flue-gas treatment

called denitrification. The combustion chamber modifications involve techniques to reduce the flame temperature and/or to reduce the amount of oxygen available for primary combustion. In engines this can be achieved by lean-burn techniques or stratified combustion chambers. In boilers and furnaces it can be achieved by low NO_x burners that depend on carefully controlled mixing of fuel and air, by flue-gas recirculation, or by low-temperature combustion techniques such as fluidized bed combustion or catalytic combustion.

The NO_x regulations currently proposed are so strict that in the case of both engines and stationary combustion units it is becoming increasingly difficult to obtain the low concentrations of NO_x required by combustion modifications alone. Consequently, interest has centred on flue-gas denitrification for supplementing or replacing combustion control methods.

The methods available depend on the application and particularly whether the gases are clean or dust-laden. The most attractive methods involve: (1) heterogeneous catalytic destruction usually based on precious metal catalysts and involving the reaction $2 \text{NO} \rightarrow \text{N}_2 + \text{O}_2$; (2) ammonia injection, called thermal NO_x , based mainly on the reaction $\text{NH}_3 + \text{NO} \rightarrow \text{N}_2 + \text{H}_2\text{O}$ and so on; (3) a catalytic version of the ammonia process usually called selective catalytic reduction; and (4) injecting methane or similar hydrocarbons to 'reburn' NO by reactions such as $\text{CH}_4 + \text{NO} \rightarrow \text{HCN} + \text{CO} + \text{N}_2$. The first of these methods needs a cleanish gas,

such as engine exhaust or the flue gases from natural gas combustion, but needs controlled oxygen (air) addition. The other two need controlled ammonia or methane injection and controlled flue-gas temperatures and are really suitable only for large stationary plants. The applicability of many of these methods is limited where extensive heat recovery is required and the platinum-based catalysts, which operate down to 350 °C, look particularly attractive, if deactivation does not occur.

The new technique of Perry and Siebers therefore looks an attractive proposition. It provides a means of reducing NO_x levels down to those required by the most stringent regulations by passing the gas over the reactant without having to control the oxygen levels. It will operate over a temperature range of 450 to 900 °C, although at lower temperatures (100–450 °C) it actually produces NO_x itself. It seems clear that the work describes a technique that is a valuable additional NO_x control technology.

Their paper stems from earlier work (Perry, R.A. *J. chem. Phys.* **82**, 5485; 1985) that contains an interesting proposal about the chemistry leading to the formation of N_2O in some flames containing fuel-nitrogen. Although it has been known for several years that N_2O is formed during the combustion of organonitriles or nitrates (see, for example Gray, P. & Williams, A. *Nature* **188**, 56; 1960) it is a surprise that it can be formed in significant amounts as a result of the combustion of coal. The new work is therefore particularly interesting in that it proposes a control technology linked with these chemical routes and offers additional control mechanisms for future development. □

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JANE Few and Barry Madore, in a survey published in a recent issue of the *Monthly Notices of the Royal Astronomical Society* (222, 673–682; 1986), identify two sub-types of ring galaxies. On the left is a P-type ring galaxy showing the crisp, knotty structure of the ring itself, the displaced nucleus and companion galaxies. On the right is an O-type galaxy, showing the smooth structure of the ring and the centrally located nucleus. These data support the idea that P-type galaxies were formed from disk galaxies by the direct head-on collision with a companion and that O-type galaxies formed in isolation. □