Spectrum

New factory not a recipe for smog

The construction of an $85 million float-glass plant in Sydney will go ahead, after CSIRO research indicated that nitrogen oxides released by the plant — 1200 tonnes a year — would not add to the city's photochemical smog problem.

Paradoxically, the glassworks' emissions will actually cause a slight decrease in ozone levels nearby, according to a model of smog behaviour by CSIRO scientist Mr Graham Johnson, which he submitted to a Commission of Inquiry set up to investigate the proposed Pilkington–ACI development.

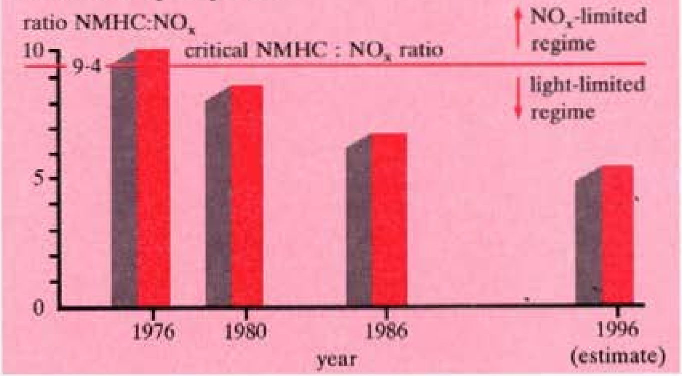
The site for the plant — Ingleburn, in Sydney's south-west — is in a region where the city's highest smog levels are recorded. At full production of 2500 tonnes of glass a week, the plant (which resembles one the company operates at Dandenong, Vic.) will emit 1·6% of all the nitrogen oxides discharged into the Sydney basin.

The nitrogen oxides in the stack gas will comprise 95% nitric oxide (NO) and 5% nitrogen dioxide (NO_2). They come from heating air to the high temperatures needed to melt the raw materials — sand, limestone, dolomite, soda ash, and sodium sulfate.

In the furnace, plate glass is made by drawing a continuous sheet of glass from the melt, which floats on a bath of molten tin. This high-quality plate glass is much in demand for glazing shop and office windows.

The oxides of nitrogen (NO_x), in particular NO_2, are toxic, and the National Health and Medical Research Council (NHMRC) has specified a maximum ground-level concentration of 16 parts per

A trend in Sydney's air



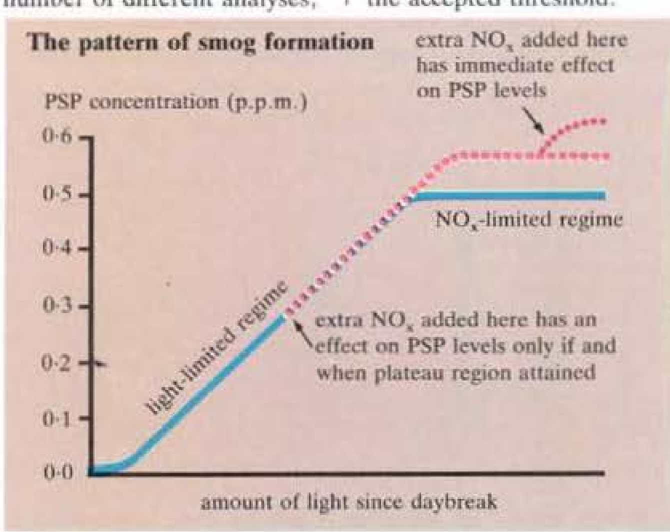
As Sydney reduces its emissions of non-methane hydrocarbons (NMHC), the ratio of NMHC : NO_x falls. With the ratio now well below 9·4, production of photochemical smog is now limited by the amount of sunlight. Adding NO_x cannot increase smog levels.

The CSIRO smog chambers (two transparent boxes that can be moved between full sun and full shade) provided the understanding of smog chemistry that allowed the new factory's effect on smog to be predicted.

hundred million. The NHMRC recommends that this level, measured as a 1-hour average, should not be exceeded more than once per month.

Because of complex terrain in the Campbelltown valley near Ingleburn, the resulting meteorological conditions — including the coming and going of inversion layers that stop pollutants rising out of harm's way — are irregular. Nevertheless, on the basis of a number of different analyses, the State Pollution Control Commission (SPCC) in its submission to the Inquiry concluded that the NO_x levels in the area (which are relatively low to begin with) will not go above the NHMRC limit no matter what the meteorological conditions.

A 75-m-high chimney should ensure that, even when the plant is producing tinted glass and NO_x emissions are highest, ground-level concentrations remain below the accepted threshold.



The amount of primary smog product (PSP) increases linearly until the smog reaction runs out of NO_x. The impact of adding extra NO_x depends on whether the smoggy air is in the light-limited phase or the NO_x-limited one.

A more difficult consideration is the effect on ozone levels. SPCC figures show that 44% of all daily maximum ozone levels it recorded (above a 6 p.p.h.m. threshold) from 1982/83 to 1985/86 occurred in the Campbelltown area. During the summer of 1986/87 the region experienced ozone concentrations above 12 p.p.h.m. (the NHMRC standard) on 3 days, whereas only two monitoring stations outside the region recorded levels above this threshold, and then only on 1 day.

The mechanisms leading to photochemical smog, of which ozone is the most significant component, are complex. The essential ingredients (precursors) are non-methane hydrocarbons (NMHC) and NO_x, but the outcome of their reaction depends on the initial concentrations, temperature, amount of sunshine, meteorological factors, and time spent together.

It's difficult to predict the result of changing NO_x levels, for example, because of an almost paradoxical relation of ozone and nitric oxide. A trace of nitric oxide is essential for smog reactions to proceed, yet nitric oxide and ozone rapidly react to annihilate each other.

When a fresh emission of nitric oxide is made to an air parcel containing ozone, the initial effect is for ozone to be consumed. Yet, at a later stage in the reaction when ozone production is inhibited through lack of nitric oxide, additional NO_x emission can cause ozone production to resume.

Studies over the past decade by Mr Johnson and his colleagues at the CSIRO Division of Fossil Fuels have unravelled what is going on. Using a pair of transparent 'smog chambers', they have acquired a much clearer understanding of smog chemistry, and this makes it relatively easy to predict what the effect of additional sources of precursors will be.

The key to simplifying the description is to use the right variable. Instead of focusing on the concentration of ozone, Mr Johnson replaces it with a new variable called PSP (Primary Smog Product) concentration. PSP represents the amount of oxygen consumed by smog reactions, and equals the sum of the nitric oxide consumed plus the ozone produced.

The advantage of using it as a measure of smog activity is that the entire smog-forming process can then be described using only two main variables: the PSP concentration and the amount of light to which the air has been exposed.

Furthermore, if PSP is plotted against accumulated sunshine, two phases of smog formation are observed. The first, the light-limited regime, sees PSP increase linearly with the quantity of hydrocarbons in the air and the amount of light since daybreak. Provided there is sufficient sunlight, a second phase, the NO_x-limited regime, occurs. This is where PSP production ceases and the ozone concentration reaches a plateau.

The existence of the plateau reflects the fact that there is a maximum PSP, or smog density, that a given set of precursors can produce. And Mr Johnson's smog-chamber experiments demonstrated that this maximum smog level depends only on the amount of nitrogen oxides emitted into the air.

When air has a low NMHC : NO_x ratio the smog reactions proceed for a long time and at a rate as fast as the available light (and temperature and hydrocarbons) will permit (it is in the light-limited regime). Conversely, a high ratio means that the reactions are soon constrained by the availability of NO_x (it is in the NO_x-limited regime).

Now we can see that the impact of fresh nitric oxide emissions depends on the prevailing regime. For light-limited air parcels, extra nitric oxide only reduces the ozone concentrations. But for air parcels that are NO_x-limited (or would be so by the end of the day), the initial lowering of ozone is followed by resumed PSP production, which, in time, can produce higher ozone concentrations.

It boils down to determining if and when the transition from light-limited to NO_x-limited regime occurs. Mr Johnson's smog-chamber experiments have provided the necessary mathematical tool — a set of formulas he calls the Integrated Empirical Rate (I.E.R.) model — to do just this.

In its submission, the SPCC applied the I.E.R. model to the range of conditions found in the Sydney basin. It concluded that, provided the NMHC : NO_x ratio of the air remained below a critical value of 9·4, then the maximum concentration of ozone would always be limited by the amount of sunlight. Even in summer the NO_x-limited regime would not be reached before the end of the day.

In 1976, Sydney had a NMHC : NO_x ratio of 10, but as a result of its hydrocarbon-control program the value has been steadily decreasing, and is currently about 6·9. By 1996, with further emission controls, the ratio is expected to be about 5·6.

With Sydney's air pollution firmly in the light-limited regime, the outcome of the float-glass plant adding extra NO_x to the air is a decrease in ozone levels, not an increase.

Andrew Bell

A model for predicting ozone concentrations. G.M. Johnson. *Proceedings of the Seventh World Clean Air Congress, Sydney, 1986.*

As much as we know about Sydney's smog. A. Bell. *Ecos* No. 34, 3–10.