Potential Effects on Air Quality of Introducing Cogeneration Plant Into A Sydney Location

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Abstract Over the past few years in Australia, there has been a significant demand for new Cogeneration plant for electrical and thermal power production. State law usually requires the submissions of an environmental impact assessment for the proposed plant. An assessment will include a determination of the effects of gaseous emissions such as nitrogen oxides (NO_x) and reactive organic compounds (ROC) from the proposed plants on local and regional air quality. The CSIRO, Division of Coal and Energy Technology has developed the Integrated Empirical Rate Reactive Plume Model (IER-RPM) to assess changes to photochemical smog in urban air downwind of a plant. The technique has two distinctive features: firstly, it enables the dispersion of NO_x emissions to be treated independently of their chemical reaction process and secondly, data from ambient air monitoring stations can be used as a basis for the chemical modelling. Applied to a dispersing, photochemically reacting plume containing (NO_x) and ROCs, the model can predict nitrogen dioxide and ozone concentrations at ground level along the plume centreline. This paper outlines work undertaken to investigate the likely impact on photochemical smog formation due to NO_x emissions from a proposed plant in a Sydney suburb. Modelling case studies have been carried out to determine the likely changes in nitrogen dioxide and ozone concentrations that occur with the installation of the plant.

Introduction

Nitrogen oxides (NO_x) emissions are the major pollutant of concern that are emitted by a gas fired cogeneration plant. Reactive organic compounds (ROCs) from the cogeneration plant are relatively low. The main pollutant emissions from a cogeneration plant can be subject to photochemical transformation producing secondary air pollutants that are of possible concern to local and regional air quality. The chimney plumes mix with the surrounding air and under certain conditions the emitted NO_x give rise to increased ground level concentrations of nitrogen dioxide (NO_2) and increases or decreases in the concentration of ozone (O_3).
Potentially both NO_2 and O_3 can be air pollutants and there are regulatory guidelines for acceptable ambient concentrations for these compounds.

The Integrated Empirical Rate Reactive Plume Model (IER-RPM) is described below which simplifies the treatment of the interaction of dispersion and photochemical reaction processes. The model is applicable to the case of NO_x plumes emitted into the atmosphere of urban regions where photochemical smog is of concern and it gives predictions for NO_2 and O_3 concentrations at ground level along the plume centreline for NO_x plumes that disperse and photochemically react in urban air.

This paper gives an evaluation of the downwind NO_2 and O_3 concentrations expected to arise from nitrogen oxides (NO_x) emitted from a power plant located in a Sydney region.

Outline of the Integrated Empirical Rate Reactive Plume Model

The CSIRO has developed a description of photochemical smog production which facilitates the prediction of NO_2 and O_3 formation due to nitrogen oxides plume photochemically reacting and dispersing in urban air. The approach is called the Integrated Empirical Rate Reactive Plume model (IER-RPM) model [Azzi, M. et al. 1993) and is derived from the established IER (Johnson, G.M., 1983) chemistry of the smog forming process.

The IER model consists of a set of functional relationships which were derived from the chemical interpretation of an extensive set of outdoor smog chamber data (Johnson, G.M., 1983). These smog chamber experiments were performed using smog precursor concentrations similar to those commonly existing in urban air and generally the chamber data conform well with the values predicted by conventional chemical kinetic models (Hess, G.D. et al. 1992).

The IER model defines the smog production (SP) as the concentration of NO consumed by photochemical processes plus the concentration of O_3 produced. It provides an alternative concept of smog description by treating smog produced (SP) as a function of the cumulative exposure of the reactants to sunlight rather than a function of time. From this representation it was shown there are two regimes for photochemical smog. Firstly the "light-limited" regime where smog produced increases approximately linearly with respect to the cumulative sunlight. This is followed by the "NO_x-limited" regime where the concentration of NO and NO_2 decrease to zero and smog produced reaches its maximum.

The IER technique is combined with a conventional Gaussian plume dispersion model to give the IER-RPM.

The IER-RPM is suitable for predicting NO_2 and O_3 concentrations at ground level along the plume centreline as a function of distance and time downwind of the NO_x sources. It takes account of the following processes.

- Dispersion of the emitted NO_x plume,
- Photochemical reactions of the ambient air into which the plume is dispersed,
- reactions due to the presence of the plume NO_x,
- dispersion of the smog products formed by the reactions of the plume NO_x,
- photostationary state distribution of the smog products between O_3, NO_2 and other oxidised nitrogen species.

The model has two distinctive features; the dispersion of the NO_x emissions is treated separately from the chemical reaction process and the data from ambient air monitoring stations can be used as a basis for the chemical modelling.

The IER-reactive plume model is illustrated by an example where the model was used to evaluate the effects to be expected from nitrogen oxides emitted from the chimneys of a 150MW gas turbine cogeneration and associated paper recycling plant that was proposed for Smithfield.

Illustration of the IER-Reactive Plume Modelling Technique

Smithfield is a suburb at the geographic centre of Sydney. The region downwind of Smithfield periodically experiences episodes of photochemical smog and the Smithfield district was categorised as a location where high photochemical smog episodes can be generated during summer days (MAQS, 1996). The effects of the NO_x plume from the 150MW cogeneration plant proposed for Smithfield were assessed for meteorological and ambient air conditions corresponding to those when photochemical smog has been observed in the region (Johnson, G.M. and Azzi, M. 1994).

For the purposed of the current evaluation, Hyde and Young (Hyde, R. and Young, M. 1994) refined the meteorological specifications relevant to this case and applied the Ausplume dispersion model to predict the ground level plume centreline 1 hour average NO_x concentrations to be expected for the plume from the proposed plant (assuming no chemical reactions occurred in the plume).

Ambient NO, NO_x and O_3 concentrations for the selected day were available from a monitoring station downwind from Smithfield, at Campbelltown, and were provided by the NSW Environmental Protection Authority. Sunlight Intensity and ambient temperature data was available from Mascot airport.

Total NO_x emissions at full load are expected to be 24.89 g/s (expressed as mass equivalent NO_2). The photochemical model calculations were carried out to give NO_2 and O_3 concentrations to be expected at ground level along the plume centreline. The potential impacts of the NO_x emissions on air quality for up to 30km downwind were predicted.

Ambient air data from the relevant downwind air monitoring station (Campbelltown) are listed in raw form and processed into IER parameters. In the table $[NO_x]^0_{ambient}$ denotes the cumulative emissions of NO_x that are required for the ambient air to have the observed O_3, NO and NO_x concentrations; and "Extent" is the indicator of the progress of photochemical smog formation towards the NO_x-limited regime.
When "Extent" has a value of less than 1 then SP formation is in the light-limited regime and according to the IER model, during this regime SP is independent of the NO_x concentration. When Extent has the value 1 then smog production is in the NO_x-limited regime and then additional emissions of NO_x may cause an increase in smog production.

The results for this example are given in Table 1.
The predicted effect of the plume NO_x on O_3 and NO_2 concentrations at the ground level plume centreline and up to 30km downwind from the plant is obtained by comparison of the concentrations listed in Table 1 for (ambient+plume) with the corresponding values given for the observed composition of the ambient air. Figure 1 facilitates comparison of the ambient and (ambient + plume) ozone concentrations predicted by the model.

The ambient air of the selected case has a high ozone concentration. Therefore the selected case has the greatest potential for NO_x emissions from the plant to impact on the ozone concentration for downwind areas. This case can reasonably be taken to represent something approaching worst case conditions for the ambient air.

The NO_x plume is predicted to increase ground level O_3 concentration at the plume centreline by about 10 ppb in a localised area about 4km downwind with the O_3 increment then decreasing to about 6 ppb at 8km downwind, and to about 2 ppb O_3 at 30km downwind. It should be noted that at short distances from the stack (up to ~ 1.5km) the reactive plume model predicts a decrease in the O_3 concentration.

Conclusion

The IER-reactive plume model enables the effects of NO_x plumes on urban photochemical smog to be made on the basis of ambient air quality monitoring data. The technique was used to evaluate the effects of NO_x emissions on downwind nitrogen dioxide and ozone concentrations for the proposed Smithfield Cogeneration plant. For the considered case, the predicted results show that the greatest effect of the NO_x emissions from the proposed plant on downwind ozone was estimated to be maximum at a distance of 4km from the plant.

Acknowledgments

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References

Azzi, M., Johnson, G.M., Hyde, R., and Young, M. - Predicting the chemistry of NO_x plumes for urban regions. In " Proceedings International Congress on Modelling and simulation", Eds M. McAleer and A. Jakeman. 6-10 December 1993, Perth, Australia. Vol. 1, 287-292 , (1993).

Johnson, G.M. - An Empirical model of photochemical smog formation. In "Proceedings Seventh World Congress on Air Quality"' 16-20 May 1983, Paris, Vol. 1, 25-32, (1983).

Hess, G.D., Carnovale, M.E., Cope, M.E. and Johnson, G.M. - An evaluation of some photochemical smog reaction mechanisms. Parts I, II and III, Atmos. Env. 26A, 625-659, (1992).

Metropolitan Air quality Study - Air Chemistry Task. NSWEPA, (1996).

Johnson, G.M. and Azzi, M. - Evaluation of the effects on atmospheric nitrogen dioxide and ozone concentrations for proposed industrial and cogeneration development at Smithfield, NSW: Photochemical reactions of the chimney plumes, In appendix E to Environmental impact Statement: proposed Smithfield site expansion for Pratt Industries and the Smithfield Power Partnership. Dames & Moore (1994).

Hyde, R. and Young, M. - Photochemical smog investigation, 150MW gas turbine cogeneration plant, Smithfield. In appendix E to Environmental impact Statement: proposed Smithfield site expansion for Pratt Industries and the Smithfield Power Partnership. Dames & Moore (1994).

Table 1. Summary of IER-reactive plume modelling for the selected case. Time of NO_x emissions: 1300h.

Meteorological Conditions:								
N gradient wind. Wind speed = 2m/s Stability Class: A. Mixing height: 500m								
Plume Characteristics for Ground Level, Plume Centreline:								
Elapsed plume age (hh:mn)	13:03	13:04	13:06	13:11	13:22	13:44	14:29	15:47
Distance downwind km	0.6	0.8	1.0	2.0	4.0	8.0	16.0	30.0
$[NO_x]_{plume}$ ppb	10.8	10.2	9.5	6.0	3.4	1.8	1.0	0.5
Ambient Air Composition:								
$[NO_2]_{ambient}$ ppb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
$[O_3]_{ambient}$ ppb	124.1	124.9	126.4	132.7	142.0	145.2	156.1	142.0
$[NO_x]^0_{ambient}$ ppb	38.8	39.0	39.5	41.5	44.4	45.4	48.8	44.4
$[SP]_{ambient}$ ppb	159.0	160.0	162.0	170.0	182.0	186.0	200.0	182.0
$Extent_{ambient}$	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Predicted Concentrations for Plume plus Ambient Air at ground level on Plume Centreline								
$[NO_2]_{ambient+plume}$ ppb	8.3	7.8	7.1	3.4	0.0	0.0	0.0	0.0
$[O_3]_{ambient+plume}$ ppb	120.4	121.5	124.2	136.5	152.9	150.9	159.3	143.7

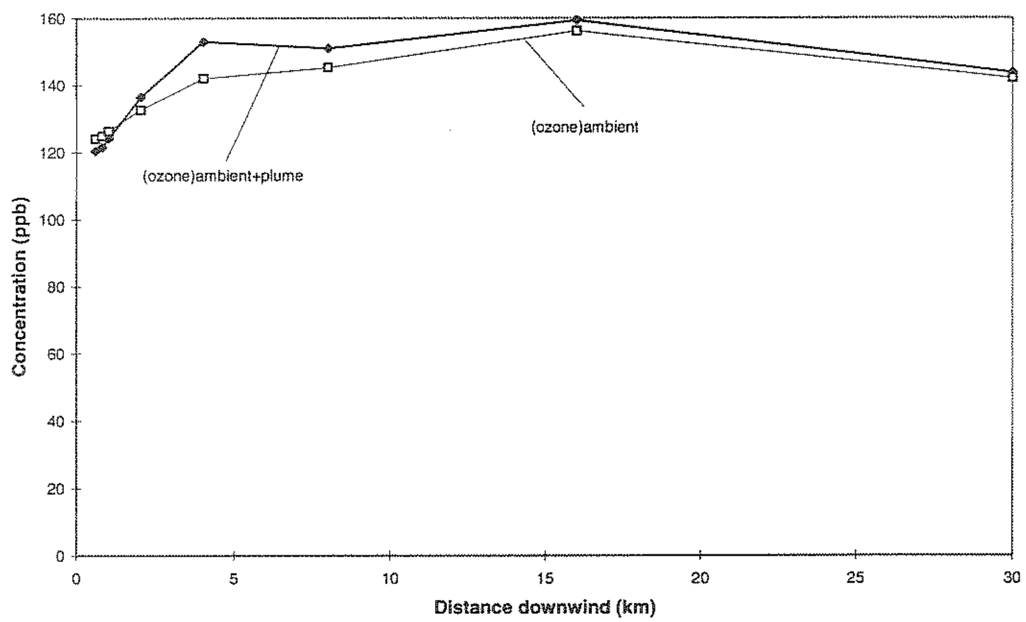

Figure 1.Effects of NO_x emissions on ozone concentrations predicted for the plume centreline at ground level.