Volatile organic pollution in highly populated areas in South Africa

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Abstract

Ambient hydrocarbon air pollution levels at both industrial and non-industrial sites in South Africa were determined over a period of six months. The study also incorporated comparisons between ambient pollution levels in electrified and semi- or non-electrified areas. Passive samplers and evacuated canisters were used during these surveys to capture the sample, while gas chromatography/mass spectrometry was used for the analysis of 40 volatile hydrocarbon compounds. Benzene levels found at both semi-electrified residential and industrial sites emphasized the need to identify all possible sources of hazardous hydrocarbon air pollutants and to determine their influence on ambient air quality.
Keywords: ambient air quality, hazardous air pollutants, residential coal burning, benzene, South Africa.

1 Introduction

Legislation and monitoring initiatives have historically been focusing on primary and secondary inorganic pollutants such as sulphur dioxide (SO_2), ozone (O_3) and the oxides of nitrogen (NO_X). Initiatives to address and quantify hydrocarbon air pollution in South Africa were sporadic and in most instances badly coordinated. Concerns about the impact of hydrocarbon emissions were

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raised during the late nineties and research investigations have become more focused. It became imperative that the situation be addressed in more detail and that contingency plans be put in place, which would enable informed decisions to be made with regard to hydrocarbon emissions and impact.

The Vaal Triangle, 50 km south of Johannesburg in South Africa, has developed as a major industrial, mining and residential metropolis over the last century. This was primarily due to the availability of water and the presence of large coal reserves. As a result of using low-grade coal as the primary energy source in the region, major regional air pollution impacts have occurred. These detrimental impacts have prompted an investigation into the status of hazardous air pollutants in selected South African cities.

2 Approach

2.1 Introduction

The following criteria were considered in selecting the appropriate technique for sampling and analysis:

- The technique must be validated and internationally accepted;
- The technique must be easily understood and managed;
- The necessary infrastructure to support the initiative must be available;
- The necessary skilled manpower must be available;
- The technique must be cost effective;
- The technique must improve current knowledge;
- The technique must be transferable.

During an assessment of these criteria a decision was made to adopt the United States Environmental Protection Agency's (USEPA) methods TO-14A, TO-15 and TO-17 and passive sampling as the accepted sampling and analytical procedures. These methods would allow for flexibility in the field with both short to medium term, as well as grab sampling made possible. A total of 40 hazardous species can be analysed by using the USEPA canister and tube methods, while benzene, toluene, ethyl benzene and xylene (BTEX) are detected using passive samplers. These methods would also allow for public participation, as limited training would be needed for sampling by unskilled people. The advantage of having such a system is that the public can be issued with a canister, which can be filled with ambient air when high concentrations of hazardous air pollutant species are suspected to be present in any given area.

2.2 Sample positioning, monitoring and analysis

During the assessment program, certain aspects with regard to the position, the time or duration of sampling, as well as the laboratory availability and competency was addressed before proceeding. The following aspects were addressed:

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- The prevailing meteorological conditions.
- Availability of infrastructure at sampling site.
- Distance from source(s).
- Strength and height of source(s).
- Possible areas of high impact.
- Residential versus industrial areas.
- Transport practices for samples.
- Characteristic of pollutants sampled.
- Time lapse from sampling to analysis.
- Competency of laboratory.
- Clear instructions to laboratory.

The long-term strategy was to use existing ambient hydrocarbon pollution information for the area and to focus on areas with the highest probability of experiencing hydrocarbon pollution. Care was taken to include electrified and semi-electrified residential areas, as well as industrial sites. Eight sampling sites were chosen for the greater Vaal Triangle Area, while four samples were taken at Potchefstroom, as a benchmark, since Potchefstroom does not have large heavy industrial activities. A laboratory and field blank were also taken during every sampling exercise. Sampling duration for the canister samples was 8 hours, while the passive samplers were exposed for 30 days. Canister samples were taken and analysed on a weekly basis. Pre-concentration of the samples was carried out before introducing the gas sample into the GC-MS.

2.3 Impact assessments

Numerous tools to determine the impact of pollution exist. These include Life Cycle Assessments (LCAs), Environmental Impact Assessments (EIA), Strategic Impact Assessments (SEA) and Environmental Health Risk Assessment to name only a few.

Based on the possible presence of hazardous air pollutants, a decision was made to undertake an environmental health risk assessment in the Vaal Triangle. Due to the lack of South African data on background benzene concentrations, a decision was made to compare results gathered in the Vaal Triangle with non-chemical industrial sites. Potchefstroom was selected as benchmark due to the lack of such industries. The margin of exposure (MOE) approach was adopted to compare human exposure to benzene at the different sites.

The MOE is defined as the lethal exposure dose resulting in 10 percent of population mortality (LED10) or other point of departure divided by the actual or projected environmental exposure of interest. The point of departure is the dose-response point that marks the beginning of a low-dose extrapolation. This point is often the upper bound on an observed incidence or on an estimated incidence from a dose-response model Rinsky et al [1].

In the case of benzene, based on observations from Rinsky et al [2] the USEPA "is fairly confident that exposure to benzene increases the risk of leukemia at the level of 40 ppm-years of cumulative exposure". Below 40 ppm-years, the shape

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of the dose-response curve cannot be determined on the basis of current epidemiological data. Benzene exposure at 40 ppm-years of occupational exposure would be equivalent to a lifetime (76 years) environmental exposure of 120 ppb. Hence, 120 ppb would be a reasonable point of departure (POD) below which the shape of the dose-response curve is uncertain IRIS [3]. Comparison of ambient benzene concentrations with the POD puts ambient concentrations and the associated cancer risk to exposed populations in perspective. It is clear from this approach that as the MOE figure increases the risk decreases and vice versa. Studies undertaken for a vast amount of scenarios, including rush hour traffic, indicated that the general American citizen's life time exposure to benzene is 4.7 ppb or a MOE of 26. Comparing South African exposure levels (MOEs) with the average American citizen's exposure to benzene may shed some light on the severity of exposure at any given site.

3 Health risk assessment

3.1 Introduction

Hazardous volatile organic pollutant surveys have been conducted during November 2001 to April 2002 in the Vaal Triangle and Potchefstroom (control site). Although more than 40 different hazardous compounds were analysed for during any given sampling period, only a few were detected. The risk assessment mainly focused on benzene due to the greater probability of having a health effect on the community when present. Toluene, xylene and ethyl benzene also formed part of the assessment.

3.2 Terms of reference

For this study, the following criteria for exposure to BTEX compounds was used.

- Due to its carcinogenic effect, exposure to benzene is interpreted in terms of chronic exposure. Benzene levels below 10 $\mu g/m^3$, averaged for long-term exposure, would correspond to typical urban and suburban concentrations, and would be acceptable in the general residential context. The World Health Organisation (WHO) has listed average background levels of benzene between 5 and 20 $\mu g/m^3$ (1.5 to 6.4 ppb) WHO [4].

- Toluene levels below 200 mg/m^3 are unlikely to lead to adverse health effects or even subjective complaints. Subjective observation of fatigue, headache and sleepiness may occur on short-term exposure. Because environmental sampling was conducted over integrated periods of a day or longer, averaged data below 200 mg/m^3 may contain short-term peaks above this value. It is useful in this instance to refer to toluene levels that are considered as normal background, and use those as guidance for ambient air. The WHO referred to toluene background in the range 5 to 150 $\mu g/m^3$ WHO [4].

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Concentrations at the lower end of his range should therefore be acceptable in the general residential context.

- Ethyl benzene and xylenes occur as background in the concentration range 1 to 100 µg/m^3 WHO [5]. The average ambient air concentration for ethyl benzene allowed by the WHO air quality guidelines is 22 mg/m^3 averaged over a week. USEPA has set a reference concentration for chronic exposure at 1 mg/m^3 USEPA [6]. For the combined xylene isomers WHO has set a guideline concentration of 4.8 mg/m^3, averaged over 24 hours.

4 Results

4.1 Vaal Triangle monitoring survey

The data collected at 8 sites over 8-hour averaging periods for toluene, ethyl benzene, and xylenes was within the range of background concentrations. These pollutants are therefore not considered to have a significant impact on health and are therefore not included in the following discussions.

Table 1: Summary of benzene levels obtained in the Vaal Triangle with the corresponding Margins of Exposure (MOEs).

Site	Monthly average concentration (ppb)	Margins of Exposure (MOEs)
Electrified Residential	1.9	63
Electrified Residential	1.5	80
Electrified Residential	2.4	50
Semi-Electrified Residential	5.6	21
Non-electrified Residential	1.9	63
Industrial	4.7	26
Industrial	11.3	11
Industrial	3.9	31
United State Average	4.7	26

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The corresponding data collected over a monthly averaging period for benzene is summarised in Table 1. These values are given in parts per billion (micro mole /mole).

Conversion to µg/m3 is done according to the equation

$$\mu g/m^3 = ppb \times MW/24.45 \quad (1)$$

where: MW is the molecular weight of benzene, i.e. 78, and 24.45 is the molar gas volume at 25 ºC, assuming ideal gas behaviour. If converted to µg/m3 according to Equation (1) above, concentrations in residential areas are similar to suburban concentrations elsewhere in the world. The industrial area showed higher concentrations, but as this is in the industrial complex it does not form part of a community exposure assessment but rather becomes important for occupational health assessments.

4.2 Potchefstroom monitoring survey

The main aim of the Potchefstroom surveys was to benchmark the Vaal Triangle against a urban site where petrochemical industries play a limited if any role in benzene ambient concentrations. Table 2 indicates average results obtained at electrified and non-electrified residential areas in Potchefstroom, as well as the specific margin of exposure (MOE) for each of the control sites.

Table 2: Summary of benzene levels obtained at Potchefstroom with the corresponding Margins of Exposure (MOEs).

Type	Average monthly concentration (ppb)	Margins of Exposure (MOEs)
Electrified residential	0.3	400
Electrified residential	0.3	400
Semi-electrified residential	0.4	300
Non-electrified residential	0.4	300
United States average	4.7	26

5 Discussions

Short-term exposure to toluene, ethyl benzene and xylenes in the Vaal Triangle area, as reflected by the measured 8-hour averaged ambient air concentrations, were lower than concentrations that would be associated with adverse health effects.

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Table 3: Major sources of VOC emissions in South Africa.

Emission source	% of total VOC release
Road transport	33
Other mobile sources and machinery	3
Commercial & residential combustion	3
Industrial combustion	0.5
Public power generation	0.5
Refinery, chemical production processes	6
Distribution of fossil fuel	6
Waste treatment and disposal	1
Solvent use	25
Agriculture	4
Natural sources	18
Total	100

Although still based on limited data, significant trends in monthly averaged ambient air concentrations of benzene are observed in the Vaal Triangle. Results clearly indicate that although benzene was present in close proximity of the industries, the pollution impact region remains small. This was clear from the low levels of benzene experienced in the residential areas, with the exception of a single semi-electrified site (5.6 ppb). This site experienced average benzene concentration levels higher than the observed American citizen exposure level of 4.7 ppb, but remained below the WHO observed exposure level of 6.4 ppb. In comparison to the monthly averages, daily benzene levels exceeded the United States OSHA (TLV) guideline of 10 ppb on twelve occasions, demonstrating a 90% conformance. If industrial exceedances, not governed by these guidelines, are ignored a conformance of 96% is obtained. The South African, British and German guideline of 50 ppb was only exceeded twice over a period of 6 months resulting in a conformance of 98.5%. All Vaal Triangle residential benzene exceedances were observed at the semi-electrified area previously mentioned.

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This specific area is currently the focus of research, due to the presence of a large amount of possible benzene sources including a taxi fleet, a filling station, heavy traffic loads and chemical industry.

The remaining 36 species analysed for during the two surveys did not exceed any national or international guideline as the concentration were found to be extremely low

The control site (Potchefstroom) clearly indicated much lower ambient concentration than the Vaal Triangle (100% conformance to guidelines), emphasising the need to quantify and determine all possible sources of benzene in the Vaal Triangle. Table 3 indicates possible sources of volatile organic pollutants, including benzene and toluene (Harmse [7]). From this table the complexity of determining the contribution of different sources becomes clear.

6 Conclusion

Researchers should strive to differentiate between various sources of hazardous air pollutants and how they are dispersed into the environment. Several emissions sources contribute to benzene levels in ambient air. It should be important to identify such sources and take them into account in assessing their impact. Research into source apportionment and related health impacts is currently being undertaken.

Emission inventories forms part of this initiative, as well as transformation and dispersion modelling currently being developed for hazardous volatile organic pollutants. In conclusion, it is clear that health impacts can only be addressed through mitigation, cleaner production technologies and cleaner fuels.

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