Toxic Substances Research Initiative

TSRI # 41 - HEALTH EFFECTS STUDY WITH ENHANCED CHARACTERIZATION OF URBAN AIR POLLUTANT MIX

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Project Length:
3 Years

Why Project Was Undertaken: Breathable particles in air have been associated with illness and premature death in cities on high pollution days. Air quality standards have been set based on concentrations and size of breathable particles (PM_{10}; $PM_{2.5}$). The effects of breathable particles in air may be related to their specific chemical content or they may act together with chemicals in the air. There has been little research into the specific chemical content of particles in air pollution.

How Project Was Conducted: In this study, the sources, formation and chemical content of breathable particles in air and the co-occurrence of other air pollutants was investigated. Air samples were collected daily from sites in Toronto and Vancouver over 2-3 years. Chemical content and particle size were determined. Data were also collected on the presence of other air pollutants present in the form of gases (co-pollutants). A small number of samples were analyzed to determine whether the content of specific indicator chemicals in air particles could help find their pollution source (vehicle exhaust, cooking, wood burning etc.). Specific chemicals of breathable particles produced by different types of sources were identified. Similarly, a small number of samples were collected to assess if semi-volatile organic compounds (i.e., chemicals that may evaporate from the particle and are thus often not measured properly) are an important contributor to the mass of breathable particles.

What Was Found and Conclusions: This study produced a database of breathable particle concentrations and co-pollutant concentrations in city air that has been and will be useful in studying health effects in Toronto and Vancouver over the same time period. The study also produced valuable data on the chemical content of air particles that has been and will be useful in understanding whether the chemical content of particles is associated with health effects. Information on the sources of particle air pollution gained in this study may be helpful in creating pollution-reduction plans for cities, understanding how the chemical content of particles differs in different areas, and understanding how health effects may be related to specific sources. More research is needed to improve ways to detect chemicals attached to particles in air.

Executive Summary

Airborne particulate matter (PM) has been one of the air quality issues of greatest concern for at least the past 5-10 years. This is a result of evidence showing that PM is associated with serious human health effects. The regulatory community has responded to this evidence by setting a new air quality standard focussing on particles smaller than 2.5 µm in diameter ($PM_{2.5}$ or fine particles). The standard is based upon the relatively simple measurement of PM mass below 2.5 :m and does not reflect the complex chemical and physical characteristics of the particles. Hundreds, if not thousands, of different chemicals have been found on particles in a variety of urban and rural locations. A better understanding of how fine particles actually induce adverse health responses, which is likely linked to their chemical and physical characteristics, is needed in order to minimize their impact on health and the environment. More knowledge on their characteristics is also needed for development of effective strategies for reducing $PM_{2.5}$.

A three-year Toxic Substances Research Initiative study was undertaken to advance Canadian knowledge on the possible relationship between $PM_{2.5}$ composition and co-pollutants (e.g., NO_2, O_3) and health effects and on the behaviour of $PM_{2.5}$ in Canadian cities. The main objectives of this study were to obtain new information on the sources, formation and chemical make-up of $PM_{2.5}$ and the critical components of the air pollution mix responsible for health effects. Field measurement studies in Toronto and Vancouver were designed to meet these objectives and to provide the data to test the hypothesis that the organic fraction of $PM_{2.5}$ is a critical component with respect to cardio-respiratory disease.

The SHEMP study was lead by the Air Quality Research Branch of the Meteorological Service of Canada (MSC). The main collaborators were the Environmental Technology Centre of the Environmental Protection Service and the Chemistry Department of the University of Toronto. The breadth of the study also necessitated that many other organizations provide support, such as the Greater Vancouver Regional District, the Pacific Environmental Science Centre and the Ontario Ministry of the Environment. The first step in SHEMP was the selection of multi-year measurement locations in Toronto and Vancouver. These were selected through analysis of past measurements and consultation with local experts. The first set of measurements were collected in August 1999 to test the proposed sampling equipment and then the multi-year sites began operation in February 2000. At each of these sites, daily collection of filter samples were undertaken to measure $PM_{2.5}$ mass and the major chemical components of $PM_{2.5}$. This included inorganic ions such as sulphate, nitrate and ammonium, selected water soluble organic compounds such as low molecular weight dicarboxylic acids, total organic and elemental carbon and about seven trace metal (e.g., iron, lead, aluminium, manganese). Instrumentation for hourly measurement of $PM_{2.5}$ or PM_{10}, ozone, nitrogen oxides, coefficient of haze, carbon monoxide and sulphur dioxide were also being operated. Field intensives, focussing specific $PM_{2.5}$-related issues were conducted in Toronto in March and August 2000 and in July 2001, and in Vancouver in August 2001.

The multi-year daily measurements in Toronto and Vancouver support previous estimates of the importance of the carbonaceous fraction of $PM_{2.5}$. It is responsible for 40% of the total mass in Toronto and 60% in Vancouver. Although the percentage is smaller in Toronto, the actual air concentration is higher because $PM_{2.5}$ is significantly higher in Toronto and because the inorganics (e.g., sulphate) are much higher in Toronto. The organic carbon component of the carbonaceous fraction is dominant while the elemental carbon component is responsible for about 25-30% of the carbon fraction. Although organics are higher in Toronto, the elemental carbon is similar between the two cities. This suggests that traffic, such as diesel, has a similar impact on $PM_{2.5}$ in both cities and that the elemental carbon may be mostly of local origin. Given the clear importance of the carbon fraction, the underlying health-based hypothesis of SHEMP appears to be well-founded. Some aspects of this hypothesis are now being tested as part of the human clinical studies project of TSRI (Silverman #204, 271). The SHEMP data will be critical for examining more closely the relative strength of associations between the carbon components on $PM_{2.5}$ versus other $PM_{2.5}$ components and vs. gaseous air pollutants. Success on this issue depends on the length of the time series available. Consequently, a third year of daily measurements is being funded by Environment Canada and the epidemiological study with Health Canada will start when this is complete. Thus, a key target audience for SHEMP is the epidemiologists at Health Canada. The data will provide a significant leap forward in terms of the $PM_{2.5}$-related data available for health research and risk assessment.

A variety of sources are contributing the $PM_{2.5}$. In Toronto, the main sources were regional (power plants) and local (transportation) NOx emissions, coal combustion, wood combustion, secondary organic aerosols and motor vehicles. Together these sources are estimated to be responsible for 87% of the $PM_{2.5}$. The source apportionment for Vancouver is more ambiguous due to lower levels and because the samples were not subject to as sensitive of an analytical

procedure. Motor vehicles were the most important source due to emissions of organic carbon and NOx emissions. The second most important source was wood combustion + secondary organic carbon (from human activities and biogenic emissions). Identification of $PM_{2.5}$ sources provides useful information for decision-makers in government and industry tasked with lowering emissions. Day to day variations in the source contributions, as opposed to chemical constituents, can also be included in the health studies. This approach has the potential to associate health effects directly with certain sources, which may prove useful for designing $PM_{2.5}$ control strategies that most benefit the health of Canadians and for generating new hypotheses for detailed health effect studies.

The SHEMP measurements have revealed the complexity of the organic fraction of $PM_{2.5}$. This complexity is due to the semi-volatile nature of some organic compounds and our ability to specifically identify <70% of the compounds present. Particle-phase semi-volatile carbon was found in Toronto to vary significantly from day to night, and found in both cities to lead to uncertainty in the traditional measurement methods for organic carbon. This knowledge is being used to improve national $PM_{2.5}$ speciation monitoring, to improve methods for measuring motor vehicle emissions and to develop more realistic air quality models. This new knowledge also needs to be taken into consideration in assessing the health effects of $PM_{2.5}$ and the representativeness of the present filter-based $PM_{2.5}$ time series. All of the new knowledge described above has already been conveyed to numerous federal and provincial groups via formal presentations and to the scientific community through publication in recognized journals.

Publications

Publications in scientific journals

Published Articles

Dabek-Zlotorzynska, E., McGrath, M. 2000. Determination of low-molecular weight carboxylic acids in ambient air and vehicle emissions: a review. Fresenius. Jour. Anal Chem., 367, 507-518.

Tan P., Evans, G., Tsai, J., Owega, S., Fila, M., Malpica, O., Jervis, R., Brook, J. "On- line and Chemical Composition of Toronto Wintertime Particulate Matter". Environ. Sci. and Technol. 36(14): 3512-3518, 2002.

Sharma, S., Brook, J.R., Cachier, H., Chow, J., Gaudenzi, A., Lu, G. 2002. Light absorption and thermal measurements of black carbon in different regions of Canada. J GEOPHYS RES-ATMOS, 107 (D24): 4771-4771

Tsai, J., Evans, G., Jervis, R., Owega, S., Tan, P., Malpica, O., Fila, M. 2004. Chemical Composition and Source Apportionment of Toronto Summertime Urban Fine Aerosol ($PM_{2.5}$). J RADIOANAL NUCL CH, 259 (1): 193-197.