Considerations in Source $PM_{2.5}$ Measurement Methodology Development for Industrial Combustion Emissions

S. Win Lee, I. He and B. Young
CANMET Energy Technology Centre
Natural Resources Canada
Ottawa, Canada. K1A 1M1
E-mail:SWLee@nrcan.gc.ca. Telephone: (613) 996-3873; Fax (613) 992-9335

An ongoing research program at Natural Resources Canada uses dilution sampling to capture and characterize source fine particulate matter (PM) in a receptor-comparable manner. An automatic control and monitoring program allows for diluting flue gas with clean air and maintains ambient-like conditions of relative humidity and temperature in a dilution tunnel. The sampling system is capable of providing tunnel relative humidity levels of 20-70% and temperatures of 20-40°C range. Size-resolved fractions of $PM_{2.5}$, PM_{10} and total particulates are collected through cyclone and filter packs, followed by comprehensive analysis for size distribution, acids, carbons and trace metals. A prototype fine PM measurement system has been developed and applied to provide initial source PM emission profiles for pilot-scale boilers firing with petroleum distillate oils, residual oils and pulverized coal blends. These source profiles are fundamental to the understanding of combustion generated PM characteristics and are needed in source and receptor regional air-quality modeling and source apportionment. The research, which is being co-sponsored by Ontario Power Generation, TtransAlta Corporation and Environment Canada, will also examine the effects of fuel properties and combustion system configuration on PM and possible particulate control strategies for the electric power generation sector. At present, the development of a new source PM measurement system designed for field application is near completion. This summary addresses challenges specific to this development being carried out as part of the ongoing research program.

CANMET experienced several significant technical challenges during this development work. The critical issues to be considered include the following. (a) design and construction of a dilution system that allows for realistic simulation of ambient PM, (b) system operation under isokinetic sampling and computer controlled monitoring, process control and data acquisition, (c) development of an analytical scheme for detailed PM characterization, (d) user friendliness and suitability for field applications and (e) integrity of the results.

The scarcity and inaccuracy of currently available information on source-receptor relationships of fine PM are of major concern. Meaningful information on the relationships between ambient $PM_{2.5}$ and contributing emission sources can only be obtained if the source emissions are measured and characterized under a receptor-comparable manner. Traditional source emission inventories are considered inadequate for use in source apportionment modeling since the measurement techniques do not allow for natural atmospheric transformation of stack emissions. Source dilution of stack gases in an inert dilution apparatus under controlled environment provides a good compromise since near ambient temperatures and relative humidity inside the dilution tunnel are simulated to allow for condensation and formation of secondary particles.

In designing a dilution sampler, sufficient supply of clean diluent and allowance of adequate residence time are of critical consideration to ensure close simulation of atmospheric transformation processes. However, these two requirements obviously compromise each other and a suitable concession is required in the design. CANMET has modified a commercially available dilution system for PM sampling on a small residential oil-fired boiler with success. A relatively low velocity of the flue gas allows withdrawal of small volumes that do not demand large quantities of dilution air. However, the unit restricts the use of stack velocities higher than 5 m/s. A new system has been designed and constructed for a maximum of 80 times dilution and one minute residence time. Another important criterion is the inertness of the internal surfaces of the sampler. Premature nucleation and condensation of aerosols can easily occur, before reaching collection filters, on surfaces that are not clean or inert. A highly cross-linked Teflon coating was selected for surface coating and the resistance of the unit to acidic species of SO_2 and NO_2 was evaluated with acceptable results. Other design considerations necessitate careful planning to avoid particle settling and system leakage during sampling.

In the operation domain, stack gas extraction is performed under isokinetic sampling regime and is maintained by a number of on-line process control equipment and special computer software. The complexity in process control to balance and maintain consistent flows of the flue gas, diluent and PM sample withdrawal, while maintaining the desired relative humidity and temperatures demands a careful design plan. The main difficulty is in measuring and controlling gas flow rates that are orders of magnitude apart. A CO_2 tracer technique was developed and incorporated by installing a three-level multichannel CO_2 analyzer on line. This has provided highly reproducible filterable PM mass data although typical samples are in the 0.5-1.5 milligram range.

Characterization of the source PM fractions require similar analytical procedures applied to ambient PM analysis. The overall sampling protocol has to be optimized to accommodate acquisition of multiple samples that require different sampling times and different filter media, necessitated by the analytical techniques. As in most of the ambient PM analysis procedures, size distribution is examined on the PM collected on 47 mm filters by scanning electron microscopy in the protocol, while acidic species, trace elements and carbons are determined using ionic chromatography, X-ray fluorescence spectroscopy and thermal/optical reflectance technique, respectively.

User friendliness of the sampling protocol is highly desired. The unit at this stage demands skilled scientific personnel. A trial field demonstration is planned to examine its field suitability. Additional modifications will be implemented to further simplify the equipment for plant operators. To accommodate portability, field ruggedness and the ease of assembly and cleaning, the equipment is constructed using several Teflon coated, lightweight aluminum modular pieces.

Validation of this new method remains a key area to be explored. The integrity of the experimental results are assessed by performing replicate analysis and by determining acid and filterable PM concentrations on system components after each sampling. Initial inadequacies in system design contributed to significant particle losses. These include static charge accumulation on the coated surfaces and filter packs and premature condensation of aerosols on the tunnel surfaces and deposition of particles on the sampling probe. Most of the problem areas showed significant improvements after several design modifications and the unit is being further optimized for PM measurement on a coal-fired boiler. Final method validation will be performed using reference standard procedures.