Environmental Monitoring
Rocket Science Applied to Air Pollution in the Developing World

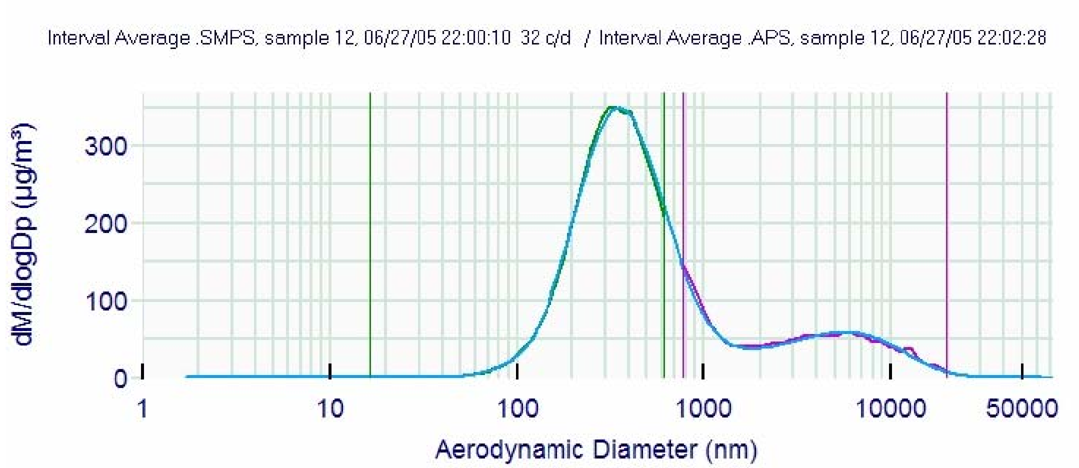
Application Note ENV-001

Three–wheeled utility taxis like theses burn up to 10 percent oil and contribute to the airborne pollution in Jakarta, Indonesia

When Scott Fruin and I took aerosol measurement instruments onto the freeways and roadways of Los Angeles in our electric Toyota RAV4, we thought we were seeing terrible air quality conditions from the trucks and cars around us. Well, this summer we learned what terrible air quality really is!

The US Agency for International Development, through agreements with the US Asian Environment Project, sponsored a study with the University of Indonesia to document the nature of personal exposures to traffic-related pollutants in Jakarta. They hoped to provide hard data to motivate local governmental agencies to proceed with effective plans to improve air quality in Jakarta. The pollutants of concern were $PM_{2.5}$ and carbon monoxide. I was approached for advice regarding how to measure these pollutants, and after a few minutes of Q and A, it became clear to me that the investigators needed more than advice. They needed Scott and me to actually be on site to oversee the efforts. We also recommended adding ultrafine particles (UFP) to the pollutants of concern as a marker of combustion. Our decision opened doors to a very challenging and rewarding air monitoring project.

Jakarta has some similarities to Los Angeles. It has an ocean on one side and is ringed by mountains that limit the flow of pollutants out of the city. It has approximately 15 million residents. Many of these people spend 2 to 4 hours commuting to and from work in bumper-to-bumper traffic. Cars in Jakarta, unlike those in L.A., still have some lead in their gas tanks, and they have no catalysts and few emission controls. Some cars, and most trucks and buses, burn diesel fuels that sometimes exceed 1500 ppm sulfur. There are also many two-cycle motorcycles and 1965-era, three-wheeled utility taxis that burn up to 10% oil. All of these factors would lead one to expect high pollution levels. But in Jakarta, only the most rudimentary air monitoring has been performed on a sporadic basis, and no data was available for $PM_{2.5}$ or UFP.



Merged data from two instruments, collected over a two-hour period (10 p.m. to midnight on June 26, 2005) in a residential area of Jakarta. It shows three minute average mass values from the APS™ and SMPS™ spectrometers overlaid. The curve fit performed by the Data Merge software has a goodness of fit of 0.0025 and is almost indistinguishable from the actual data. The estimated $PM_{2.5}$ mass is 219.9µg/m^3. A density of 1.6 was assumed to get this close match. The values closely match what was observed by a reference BAM. The data shows a remarkable amount of mass is in particles smaller than 0.9 or 1 µm. Particle counts during this period were approximately 100K/cm^3—also very high.

We attempted to build upon the limited scale of the personal monitoring project to assure its success, as well as gather air quality data in community air and near roadways. Local and national environmental agencies cooperated by helping find and secure sites for us. The personal exposure study employed:

- Model 3007 Hand-held Condensation Particle Counters (CPCs)
- DUSTTRAK™ Aerosol Monitors
- Q-TRAK™ Plus Indoor Air Quality (CO/CO_2) Monitors

"Rocket science" extensions included:

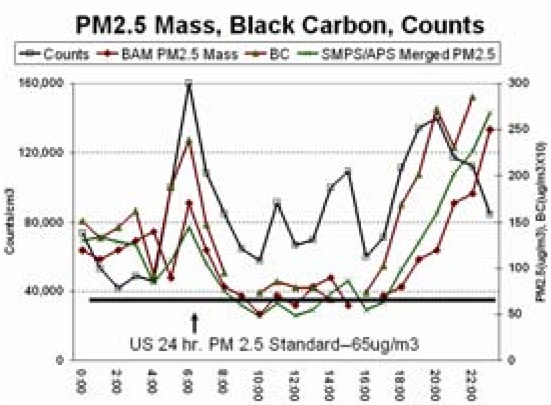
- Model 3034 Scanning Mobility Particle Sizer™ (SMPS™) spectrometer
- Model 3321 Aerodynamic Particle Sizer® (APS™) spectrometer
- Model 3785 Water-based CPC
- Beta-attenuation and black-carbon monitors (BAM)

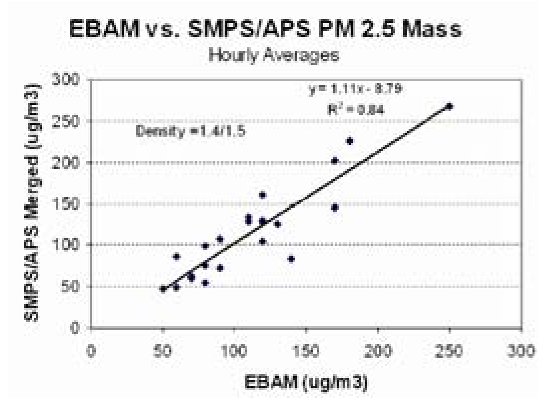
All instruments provided data time resolution of five minutes or less.

Getting these monitors to Jakarta was a trying experience, and measuring the pollution under rugged field conditions pushed the operational limits of the monitors and the investigators. We encountered temperatures approaching 35°C, humidity above 80%, and occasional torrential rainstorms. The temperature and humidity were within the stated limits of most of the instruments, but in reality, these conditions pushed them to their limits. We also encountered UFP counts that briefly exceeded one million counts/cm^3 when on roadways and one-hour averages in excess of 160,000 counts in community air. These levels exceeded the operating range of the Hand-held CPCs and forced us to employ a simple diluter system to keep values below 100,000.

This aerosol view shows the high level of pollutants in the air of Jakarta.

The combination of instruments gave us a clear picture of sources of PM in the community air and allowed for calibration of the DUSTTRAK™ monitors and Hand-held CPCs. The measured factors show the daily pattern of traffic and suggest that nighttime inversions and/or winds intensify its impacts. Furthermore, it appears that PM (UFP, black carbon, and $PM_{2.5}$) has both local and regional sources.





Scatter plot of BAM data (R^2 of 0.84) and merged SMPS/APS data. It shows the role of combustion especially from cars, trucks and buses.

Diurnal pattern of $PM_{2.5}$ mass by BAM, merged SMPS/APS, black carbon mass, and particle counts. The merged data agreed well with the reference method all day long.

Data from the SMPS™ and APS™ spectrometers were imported into and evaluated with TSI Data Merge Software. We were amazed and heartened by the results of these evaluations. Hourly average $PM_{2.5}$ mass calculated by the software corresponded to within approximately 11% of that reported by the beta attenuation monitor (a commonly deployed reference method for ambient $PM_{2.5}$). Additionally, it gave a clear picture of the size distribution of PM mass over the range of 10 nm to 10 µm. Most of the mass was shown to be in particles smaller than 1 µm aerodynamic diameter. This finding points regulators to the importance of controlling primary carbon emissions from diesels, as well as secondary reaction products from vehicle emissions. It should also point them away from misguided controls they might place on fugitive dust.

So how do the values measured in Jakarta correspond to Los Angeles? They dwarf them! UFP counts at the community site were 5 to 10 times what are seen in urban Los Angeles, while $PM_{2.5}$ mass was approximately 10 to 15 times that of LA. Carbon levels alone approached total $PM_{2.5}$ mass seen in LA and carbon monoxide levels exceeded 20 times greater.

I see these levels as very sobering. People in Jakarta are clearly being harmed by the air they breathe and effective control measures are essential to reduce this harm! Even more sobering to me was a realization that this is what Los Angeles could have been if state and local air regulators had not fought for effective control measures on vehicles and stationary sources of pollution.

The researchers posing with some of their test instruments

Jakarta's large volume of motorized vehicles, many of which have little or no pollution controls, contribute to carbon monoxide levels that are 20 times greater than those measured in Los Angeles.

The three-wheeled taxis were not used as monitoring platforms, but they made a handy mode of transport. The researchers used cars and traditional taxis to measure inside the traffic flow.

Data from this research was presented at the Asian Aerosol Conference in Mumbai, India, December 2005. Use of these advanced techniques in future research will give the developing world the data needed to make informed decisions about this growing problem and to develop effective controls.

Dane Westerdahl, University of California at Los Angeles graduate student, performed this research while on summer break during June and July 2005. He was joined in Jakarta by Scott Fruin, who was on vacation from of the California Air Resources Board, and Julian Marshall of the University of British Columbia.

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